LETTERS TO J. J. GIBSON

BY U. T. PLACE

DECEMBER 1955 - JANUARY 1956

WITH GLOSSES BY JJ.G.

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PERCEPTION AS A FUNCTION OF STIMULATION

BY J. J. GIBSON

WITH GLOSSES BY U.T.P.

Institute of Experimental Psychology,

Oxford, December 1955

Dear Professor Gibson,

At the close of our conversation after your class on Wednesday evening, you indicated your dissent from my statement that we can only describe our experience by reference to the physical state of affairs which is normally the case when we have an experience of that kind. May I be permitted to anticipate what I suggest from your published work would be your objections to my thesis and put my case before you in writing, as I usually find I can express myself more effectively in this way.

You agreed with me when I said that `red' is a property of lights *and* objects, but I fancy that your interpretation of my statement was different from my own. I meant that `redness' is a real physical property of lights and objects in the physical environment [JJG's gloss reads: "It is that by virtue of the *differential reflectivity* of the surfaces, i.e. *red* is specific to a surface"]. You, I fancy, would want to say that it is a property not of physical objects and phenomena, but of phenomenal objects in the visual world [JJG's gloss reads: "No"]. I think the visual world, except as a name for those aspects of the physical world which we can discriminate visually [JJG's gloss reads: "It's simply a name for perception"], is a myth. It is part of the homunculus theory which you deplore [JJG's gloss reads: "It is that, too"]. It is the television screen in the brain which the homunculus looks at before deciding what to do or say.

A crucial case is the red after-image. You, I suspect, would want to say that in this case we see a phenomenal surface which is literally red. [JJG's gloss reads: "No. We see a colour patch in the visual *field*, *not* a surface"] I would disagree, there is only a physical surface which *looks* red, i.e., we are having the sort of experience we have when we look at a patch of red light projected onto a surface [JJG's gloss reads: "How about closed eyes?"]

The view I suspect you of holding has some awkward consequences. Firstly where is this surface with its red patch. It is clearly not in the physical environment, but equally clearly it is not in the brain. There is nothing in the brain which could get red when the after image starts and cease being red when it fades [JJG's gloss reads: "Why not?"]. Brain processes just aren't the sort of things to which colour concepts apply. If therefore there really is something red, that something must exist outside the physical world

known to science. [JJG's gloss reads: "an ancient paradox"] Perhaps you don't find this conclusion embarrassing. Many people don't; but you say in your book (p.1) that the view we get when we look at things "is in every detail a nervous process". [JJG's gloss reads: "Redness is an abstraction"]

Another difficulty is this; if "it looks as if there is a red patch on the card though in fact there isn't" means "the card in my visual world, unlike the corresponding card in the physical world, has a red patch on it", does "This house looks at least 200 years old, although in fact it isn't," mean "The house in my visual world, unlike the corresponding house in the physical world, is at least 200 years old"? If not, why not? If so, then what on earth does it mean to say that I have got a 200 year old house in my private visual world?

In ordinary English which is after all the language spoken and understood by the naive subject in a psychological experiment, to say "It looks as if there were a red patch of light on the card", is, I should have thought, the only obvious and natural way of describing what happens when the subject has what in the technical language of psychology is known as `a red after image', and this, I would suggest, means simply that the subject is having the sort of visual experience he usually has when confronted with a red patch of light projected onto a surface like the one in question. Similarly a house which looks 200 years old is one that gives him the sort of visual experience that 200 year old houses usually give.

Of course to say that there is nothing red at all in the after-image situation, appears extremely paradoxical at first sight. One feels like objecting "but dammit! You can see the redness right there in front of you." The trouble here, I think, is that, having learnt to identify redness by means of the special type of experience we get when we look at red things in daylight illumination, we tend to think of `red' as the name for the experience by which we identify redness; whereas in fact redness is a property of physical objects, not a property of experiences or of `phenomenal' objects.

Colour, of course, is a specially difficult case. The physicists tell us that redness does not correspond to any simple characteristic of the physical stimulus, and that our classification of things in terms of red, yellow, green, blue, etc., is based on the peculiarities of our visual receptor system and does not correspond to any distinctive features of the physical stimulus. This, however, does not alter the fact that the word `red' as used in ordinary English is the name of a property of physical objects and light sources. It is if you like the property of giving rise in normal daylight illumination to a characteristic type of visual

experience; but the word `red' refers to the property of objects whereby they excite that experience, not to the experience itself. It is poppies, hot pokers and pillar boxes that are red and they don't stop *being* red when the light goes out, though they may cease to *look* red. Incidentally the history of colour as the evil demon of perception theory is interesting. It goes back at least to Locke who classified it along with smells and tastes as a `secondary quality', a quality aroused by the object in the mind of the beholder as distinct from primary qualities like shape and size which belonged to the object itself. As you point out in your book, it was the only quality which could be attributed to Wundt's visual sensations.

There is, however, another and more fundamental mistake underlying the belief both in sensations and a phenomenal world of objects. I have described it in a paper which is coming out in the February number of the *British Journal of Psychology* as

> "the mistaken assumption that because our ability to describe things in our environment depends on our consciousness of them, our descriptions of things are primarily descriptions of our conscious experience and only secondarily, indirectly and inferentially descriptions of the objects and events in our environments. It is assumed that because we recognize things in our environment by their look, sound, smell, taste and feel, we begin by describing their phenomenal properties, i.e. the properties of the looks, sounds, smells, tastes and feels which they produce in us, and infer their real properties from their phenomenal properties. In fact, the reverse is the case. We begin by learning to recognize the real properties of things in our environment. We learn to recognize them, of course, by their look, sound, smell, taste and feel; but this does not mean that we have to learn to describe the look, sound, smell, taste and feel of things before we can describe the things themselves. Indeed, it is only after we have learnt to describe the things in our environment that we can learn to describe our consciousness of them. We describe our conscious experience not in terms of the mythological `phenomenal properties' which are supposed to inhere in the mythological `objects' in the mythological `phenomenal field', but by reference to the actual physical properties of the concrete physical objects, events and processes which normally, though not perhaps in the present

instance, give rise to the sort of conscious experience which we are trying to describe." (Place 1956, p.49)

I would submit that the view I am putting forward is the logical conclusion to which your own view leads. You reject the homunculus in the skull story and Helmholtz's doctrine of unconscious inference and yet both these doctrines follow logically from the doctrine of an interior visual world which you appear to accept. You say in your book (p.8) that "the stimulus variable within the retinal image to which a property of visual space corresponds need only be a correlate of that property, not a copy of it." You also indicated in class that you reject the Gestalt theory of isomorphism in so far as it implies that in order for perception to be veridical an accurate reproduction of the stimulus environment must be constructed in the cortex from the input arriving at the cortex from the retina. Why not take the final step and recognise that the various elements of visual experience are correlates, but not copies, of the corresponding properties of the stimulus environment? Unless you take this further step, so it seems to me, stages F and G in the diagram on p.18 of your book will never lose their nebulous character, since you will never find anything in the physical world which has the properties you ascribe to them.

Yours sincerely

Ullin T. Place

Institute of Experimental Psychology,

Oxford, 10th January 1956

Dear Professor Gibson,

As I understand it from our conversation last month your view of the `visual world' may be formulated as follows:

The concept of the `visual world' and the descriptions which are given of it are a shorthand device for describing the responses, verbal or otherwise, which an organism [JJG's gloss reads: "a `naive' organism"] makes to a stimulation [JJG's gloss reads: "to `ordinal' stimulation (i.e. focussable light) not to retinal images"] impinging on its visual receptor system. On this descriptive system these responses are characterised in terms of the state of affairs in the physical environment which would have to be the case [JJG's gloss reads: "and which ordinarly *are* the case"] for the response in question to be `appropriate' or `adapted' to the actual situation confronting the organism.

This is undoubtedly a logically defensible use of the term, but I very much doubt whether, if applied consistently, it would allow you to say all the things you say about the `visual world' in your book. In particular I find it difficult to see what can be meant by the term `visual field' if you adopt this definition of `visual world' [JJG's gloss reads: "I mean visual *sense-data*"].

The concept of the `visual field', I take it, is introduced in order to explain what it is that we are describing when we adopt a sophisticated attitude and describe what we see in fixed monocular regard as if framed by the outlines of the nose and eyebrows and the rather indeterminate limits of visual discrimination in other directions. [JJG's gloss reads: "Yes, very roughly."]

Such descriptions, I should have thought, are responses appropriate to the environment which would be the case if the light waves impinging on the eye were reflected from a surface at a uniform though indeterminate distance from the eye. [JJG's gloss reads: "This is *not* an environment, in any sensible meaning of that term."] If so they are, on the above definition, descriptions of the individual's visual world at the time when this peculiar attitude is adopted. [JJG's gloss reads: "?".] In other words the visual field is a special type of visual field, not a separate category which can be contrasted with the visual world. On this interpretation you would not be able to speak as you do as if the visual world were somehow a compound of a number of

visual fields. [JJG's gloss reads: "Speaking thus was a mistake I now regret. The visual field is simply an artifact of human picture-perception."]

I would submit that your use of the term `visual world' in your book is not consistent with the above definition, that you can only say what you want to and do say about it by treating it as if it were a kind of internal television screen [JJG's gloss reads: "this must be avoided, we agree."], and that your introduction of the terms `visual world' and `visual field' in your theoretical analysis of visual perception is both unnecessary and misleading.

Rather than trying to defend the view that your use ofthese terms is not consistent with your definition by quoting chapter and verse, let me try to show how the main argument of your book could be introduced without using these terms at all. What follows is an introduction to the psychology of visual perception from a purely behaviorist point of view, which to my mind would provide an ideal starting point from which to develop the main argument of your book:

The Psychology of Perception

The psychology of perception may be defined as the study of those features of its environment which an organism can discriminate by virtue of the stimulation impinging on its receptor organs [JJG's gloss reads: "Good. But one must define stimulation."], the stimulus conditions under which such discriminations are possible, and the stimulus conditions under which discrimination breaks down.

The Meaning of Discrimination

To discriminate a featre of the environment is to make a response which is specific to the feature in question in the sense that it is made when and only when the distinctive pattern of stimulation characteristic of the feature in question impinges on the appropriate receptor organ. [JJG's gloss reads: "Good".]]

In studying the perceptual capacities of human subjects, the ability to apply a descriptive epithet appropriate [JJG's gloss reads: "specific"] to the environmental feature in question is usually taken as evidence of discrimination. Animals do not possess this complex repertoire of verbal habits which enable the human adult to make an immediate discrimination of some kind when presented with almost any stimulus. It is

therefore necessary in most cases to train animal to perform some simple movement or some other type of response in such a way that the response is elicited when and only when the environmental feature in question is presented to it. If the animal can learn to restrict its responses in this way, we conclude that it can discriminate the feature in question. [JJG's gloss reads: "Correct".]

It should be noted that, in the case of animals, a failure to learn does not necessarily imply a failure to discriminate, since we know that learning can often be impeded by other factors. Consequently it is often extremely difficult to demonstrate conclusively that an animal cannot discriminate a particular feature of its environment. [JJG's gloss reads: "Correct".]

In the case of human subjects failure to discriminate is shown either by a failure to respond or, more frequently, by the use of the `wrong' descriptive epithet, i.e. one that is inappropriate [JJG's gloss reads: "unspecific"] to the actual situation presented to him. A misdescription of this kind indicates a failure to discriminate between the stimulus situation presented to the subject and the type of stimulus situation where the epithet used would be appropriate. (N.B. It would be in talking about these `misdescriptions', as I have called them, that you would use the concept of the `visual world' as defined above. A case where the subject says, "It looks round, two feet away, etc., although I know it can't be", would count as a misdescription in this sense.) [JJG's gloss reads: "This sounds like nonsense to me."]

Misdescriptions and failures to respond can, of course, merely be an indication of an inadequate vocabulary, mistaken use of words or a failure to understand the instructions; but with proper instructions and subjects of reasonable intelligence and education, such factors can usually be neglected.

Features of the Environment which are discriminated by Eye

The features [JJG's gloss reads: "You mean *substances* not *features* don't you? Substances have *many* discriminable features"] of the environment which can be discriminated by eye are basically of three types:

1. light sources,
2. gases liquids and solids which transmit some but not all the light impinging on them and therefore `transparent' [JJG's gloss reads: "You can't be glib about *this* problem. It's difficult"],
3. gases, liquids and solids which absorb and/or reflect the light impinging on them.

Any light source, any concentration of gaseous, liquid or solid substance which transmits, reflects or absorbs light may be said to constitute a `visual object' [JJG's gloss reads: "No. A gas which transmits light without refraction or reflections is invisible."]. The principal features of a visual object which a human subject can detect by eye are the brightness of a light source, the degree of transparency-opacity of a transparent object, the albedo (reflecting capacity) of an opaque object, the level of illumination in different parts of the environment, crude differences in the wave length of light generated by a light source (the colour of light sources), crude differences in the differential reflecting and transmitting capacity of opaque and transparent objects (the colour of objects as distinct from the colour of lights), the size and shape of objects, the texture of surfaces, the distance and position of objects relative to one another and to the observer, the movement of objects and their velocity and direction of a movement. [JJG's gloss reads: "Your list constitutes a set of *problems*, not definitions."]

Before we can understand the conditions under which a particular environment feature is discriminated, we need to understand the stimulus conditions under which we are able to discriminate differences in these general features of visual objects, such as brightness, colour, size, shape, texture, position and movement, since it is differences of this kind which provide the basis for our discrimination of all those myriads of features of our environment which we can discriminate by eye. The psychology of visual perception is, therefore, primarily concerned with the conditions under which these basic discriminations are made. (N.B. This section may be described as a brief survey of the `visual world' in the sense of those features of the physical environment which can be discriminated by eye. Your description of the `visual world' in your book is, I suggest, primarily a description of the visual world in this sense, rather than in the sense defined earlier on.)

The phenomenon of constancy

Differences in the albedo, colour, size, shape, texture, position and movement of transparent and opaque objects can only be detected by eye when the objects in question are adequately illuminated, that is when light of a certain intensity is reflected or transmitted by them onto the eye. Nevertheless, although there are levels of illumination below which such features are no longer discriminated, within the range of illumination

conditions where discrimination of detail is possible changes in illumination do not materially affect the discriminations which a subject makes in spite of considerable changes both in the pattern and in the absolute intensity of the light reaching the eye from the environmental feature in question [JJG's gloss reads: "and why do you think this *is*?"]. Similarly discrimination of such features as the size, shape, relative distance and velocity of objects is maintained in spite of vast changes in the pattern of stimulation which is projected from the object onto the retina of the eye which result from changes in its distance from and orientation with respect to the observer [JJG's gloss reads: "True. But how can this be so?"]. Such changes in the conditions of illumination , distance and orientation with respect to the observer are, of course, discriminated as such; but the marked changes in the pattern of stimulation which they imply do not normally affect the organism's capacity to discriminate those features of the environment which are independent of the observer and the conditions of illumination [JJG's gloss reads: "a paradox"].

Under normal circumstances an organism will only respond to those aspects [JJG's gloss reads: "?"] of the stimulus impinging on the eye which correspond to identities [JJG's gloss reads: "?"] and differences [JJG's gloss reads: "?"] in the physical constitution of its environment, and will ignore those which merely reflect the particular conditions under which observation takes place [JJG's gloss reads: "?"]. Thus a penny will be discriminated as a round object in spite of the considerable changes in the pattern of stimulation projected from it onto the retina which occur with alterations in its orientation with respect to the eye, and its similarity, when viewed at a slant, to an elliptical object viewed full face by virtue of a similarity in the cross-section of the light rays passing to the eye will be ignored. [JJG's gloss reads: "???"]

How far this tendency is a product of the innate constitution of the organism and how far it is a product of learning is open to dispute [JJG's gloss reads: "In short, this theory has no proper explanation of constancy"]; but its biological utility is obvious.

Visual Discrimination of the Artist Type

Although the discriminations which it normally makes are of features of the environment which are independent of the special conditions under which they are observed, it is possible for the human organism, at least, to learn to discriminate differences in the pattern of stimulation impinging on the eye corresponding

to differences in the conditions of observation [JJG's gloss reads: "`` *conditions of observation*' - *vague*"] rather than to differences in the actual constitution of the environment. [JJG's gloss reads: "The question is, what proximal stimuli *do* correspond to the actual constitution of the environment?"]

The ability to make discriminations of this kind only becomes important in the normal course of events when the problem arises of making an accurate representation of a tri-dimensional scene on a two-dimensional surface. In any course in drawing or painting one is taught to ignore the discriminations of the shape size and colour of objects that we `habitually' make. One learns to pay attention to the shape as projected instead of `thinking in terms of' the tri-dimensional shape or its conventional representation, the elevation. One learns to `see' distance in terms of perspective, the `smallness' of large objects far away, the `whiteness' of the highlights on a shiny black object. [JJG's gloss reads: "i.e. to see the visual *field*"]

In the past the ability to make discriminations of this specialised kind in which objects are differentiated according to the pattern of light and shade and the size and shape of the images projected from them onto the retina has been studied by psychologists far more extensively than is warranted by the actual importance of such discriminations in the individual's adaptation to his environment. There have been two main reasons for this interest, one valid reason and one whose validity is extremely doubtful.

The valid reason for studying these `artist-type' discriminations, as we may call them, is that when made by a skilled observer they seem to correspond very closely with the pattern of stimulation impinging on the retina [JJG's gloss reads: "seem to, but do not. This was the mistake of my book."]. Direct observations of the retinal image by existing methods tell us comparatively little, and although the pattern of stimulation can be inferred from our knowledge of the optics of the light stimulus, this is an extremely cumbersome method of determining the pattern of stimulation at any given moment. Consequently, although they are not strictly speaking observations of the retinal image itself, these artist-type discriminations do provide a very convenient method of assessing the main characteristics of the retinal image at any given moment [JJG's gloss reads: "No."]. Since it is the pattern of stimulation on the retina or, more precisely, the combination of the patterns of stimulation on the two retinas to which the organism is responding when it makes its visual discriminations, this information can be extremely useful in helping us to understand how the more normal and biologically more useful discriminations are made.

(N.B. The concept of the `artist-type visual discrimination' corresponds to your concept of the `visual field'. In this section I have tried to bring out the contrast between the `visual field' in this sense and the `visual world' in the sense of the features of the environment we normally discriminate, and the sense in which knowledge about the `visual field' helps us to understand the `visual world'.)

The Doctrine of Unconscious Inference

The second and less valid reason for studying what I have called the `artist-type' of visual discrimination was the assumption that these discriminations are somehow more basic and fundamental than the discriminations of shape, size, colour and distance that we ordinarily make. It was thought that we begin by noting the shapes, sizes and colours which the artist notices and then learn to infer from these `apparent' shapes, sizes and colours the `real' shapes, sizes and colours of the objects themselves. As we do not normally make any conscious inferences of this kind, it was assumed that some sort of `unconscious inference' must occur. [JJG's gloss reads: "Good"]

In view of the difficulty which most children experience in learning to make these discriminations when required to do so by their preceptors in the visual arts, it is perhaps difficult to understnad why so improbable a hypothesis should ever have been seriously entertained. It must be remembered, however, that when psychologists first started to think about these problems a great deal of work had already been done by physicists, on the nature of the light stimulus, and by anatomists and physiologists, on the mechanism of the eye, and that this information provided the jumping off point for psychological research in this field.

The physicists had shown that light is a physical energy which varies only in intensity and wave length; while the anatomists and physiologists had shown that the eye is like a camera with a photosensitive surface (the retina) onto which a two-dimensional pattern of light is reflected in the environment.

It seemed to follow from this that the basic discriminations made by the visual apparatus and hence by the organism must be of differences in the intensity and wave length of the light projected from different points in the visual field (not in your sense), and the distribution of these differences over the surface of the

retina. In fact the basic discriminations, in the sense of the ones the organism normally and naturally makes, are between features of the environment corresponding to certain rather complex relationships within the pattern of stimulation on the retina [JJG's gloss reads: "of the focussable light entering the eyes"].

There is, of course, a sense in which the discrimination of intensity wave length and their bi-dimensional distribution is more basic [JJG's gloss reads: "I now doubt this"] than the discriminations we ordinarly make of the shape, size and colour of objects in that differences in intensity, wave length and bi-dimensional distribution must be `detected' by the visual apparatus before the organism can respond, as it normally does, to the more complex relationships between them which correspond to similarities and differences in the stimulus environment; but the word `before' here should be taken to refer only to priority in the sequence of events between the impingement of light energy on the retina and the resulting response. It should not be taken to imply priority in an ontogenetic or phylogenetic sense. Nor should differentiation or `detection' by the eye be confused with discrimination by the organism.

(N.B. In this section I have tried to state what I take to be the essence of your theoretical position `vis a vis' earlier work in the field. The historical story is, of course, grossly oversimplified. At this point the stage is set for a discussion of the stimulus conditions which provide the basis for our normal discriminations of distance shape and size in a three dimensional environment along the lines of your book.) [JJG's gloss reads: "You seem to agree with everything except the "field *vs* world" distinction. That admittedly needs clarification. But it is necessary, I am sure, for the explanation of constancy."]

I would very much like to hear your comments on this effort, if you can manage to wade through it.

Yours sincerely

U.T. Place

Institute of Experimental Psychology,

Oxford, 27/1/56

Dear Prof. Gibson,

Thank you for your pencilled comments on my last screed. It would appear from these, that apart from the question of how `experience' comes into the picture, a problem which I deliberately left out in my letter, there is no substantial disagreement between us.

The only remarks which you make which seem to call for comment concern the problem of constancy. You seem to think that there is something that I have failed to explain and that your `visual world' and `visual field' concepts are required to do this.

In this connection I should like to begin by saying that I do not regard my previous letter as presenting a `theory' in any proper sense of the world. A theory is either a set of presumptive scientific laws designed to coordinate an existing body of empirical facts and to predict new ones or a hypothesis as to the particular application of known or presumed laws and principles in a given case. I have not tried to formulate any laws or principles, nor have I put forward any hypotheses. I have not tried to give an explanation, in the scientific sense, of anything. I have merely tried to present the problems in the field of visual perception as clearly and simply as possible, and in such a way as to avoid generating pseudo-problems, like the traditional problem of constancy, which arise when the real problems are badly stated.

The problem of constancy as traditionally discussed is a pseudo-problem because it is based on the mistaken assumption that the only sort of discriminations which can be made on the basis of the stimulation impinging on the retina are discriminations of the `artist', `picture' or `visual field' type.

As I see it there are only two genuine empirical problems tangled up with this ghastly conceptual muddle. The first is the problem with which you deal so admirably in your book of defining the `proximal stimuli' to which the organism is responding when it discriminates the albedo, size, shape, distance and velocity of objects under varying conditions of stimulation. The only other psychological question, as distinct from the physiological questions about the underlying neurological processes, is why the organism discriminates these rather complex aspects of the stimulus more readily than it discriminates, in so far as it ever does, the relative size, shape and intensity of different parts of the stimulus itself.

Unfortunately at this point in my last letter I made some rather misleading remarks as to the type of answer to be given to this latter question. I pointed out the obvious fact that `constancy' discriminations are biologically useful, whereas the `retinal image' discriminations of the artist are not; but I also raised the further problem of whether our tendency to make the former type of discrimination more readily than the latter is due to an innate predisposition or to learning.

I must emphasise that in talking about learning here I was not talking about `learning to perceive' in the sense used by some writers who suppose that we start with a `visual field' type of discrimination and have to learn somehow to modify our visual experience in the direction of constancy or have to learn to make the correct unconscious inference. This is pure mythology.

Nor was I intending to overlook the obvious fact that all the human discriminations we investigate are learned in the sense that we have to learn to use words correctly. In many cases, however, this verbal learning is clearly superimposed on earlier discriminations involving other types of response, such as the basic locomotor and manipulatory adjustments. Most of these discriminations, no doubt, are also learned; but there are some responses such as reaching out for a near object which seem to imply some degree of distance and size discrimination which may well be innate. There is certainly nothing intrinsically improbable in such an assumption, since there are many innate reactions of animals which involve constancy discriminations. Many organisms for example have innate escape reactions triggered off by moving objects larger than themselves, but not so far as one can gather by objects projecting a retinal image of any particular size.

It may be of course that in the case of the human organism the question of which stimuli shall trigger off which responses is entirely decided by learning. Even so it is still possible that the innate constitution of the organism might be such that `gradients of stimulus generalisation', to use Hull's phrase, develop more readily along dimensions of the stimulus, such as those which you have described, than they do along simple dimensions of more or less uniform patches of retinal stimulation.

In other words, all I am asking when I ask how far constancy is learned and how far it is an innate tendency, is how far the difficulty most of us experience in learning to discriminate objects according to their retinal projections can be accounted for by the incubus of past learning which has been exclusively of the

constancy type and which conflicts with the super-imposed picture perception habits. That is certainly part of the explanation; but the possibility of an innate predisposition towards constancy-type discriminations cannot be ruled out, and I see no reason why there should be any need to prejudge this issue which can be safely left to future research without seriously affecting any important theoretical issue.

If you think there are any other empirical issues in the constancy problem, I should be very interested to know what you think they are and how the `visual world' and `visual field' concepts would help.

Yours sincerely

U.T. Place

PERCEPTION AS A FUNCTION OF STIMULATION

James J. Gibson

Cornell University

Theories of perceiving have generally taken it for granted that the process is not directly dependent on the stimulation of receptors but only indirectly dependent. [UTP's gloss reads: "Perceiving is an achievement not a process."] Perception is supposed to be based on sensation. The latter depends on stimulation, to be sure, but the former involves some additional process the nature of which must be discovered. The theory to be outlined, however, assumes that perception [UTP's gloss reads: "i.e. discrimination?"] can be explained as a direct function of stimulation when the stimulus is analysed with sufficient care. The proposal is to dispense entirely with the concept of sensation, using the term only to refer to a rare and sophisticated kind of experience instead of an elementary one, and relegating it to the status of a psychological curiosity.

This approach is not, then, a theory of perception in the ordinary meaning of that world. Existing theories of perception are concerned with how sensations or sense-data get converted into percepts. The formulas have been various: interpretation of the data by the mind, supplementation of the data by memory, or organization of the data by the brain. In the present theory all such formulas are superfluous since no process of conversion is assumed. Not only the qualities of things but also their very thingness itself is taken to be discoverable in stiumulation, [UTP's gloss reads: "a confusing way of putting it."] and the assumption extends to places and events in space and time. They are all supposed to be, in the rejected terminology, "sensed". This basic assumption can be tested by psychophysical experiments. [UTP's gloss reads: "?"] The theory incorporates, then, certain aspects of both perceiving and sensing in the older meanings of the terms; it is concerned with the facts of perception on the one hand the methodology of sensation on the other but rejects the theoretical distinction between them.

Classical psychophysics has accumulated the most solid body of scientific facts in the whole of psychology by studying the dependence of so-called sensory experience on stimulus variables. The commonest psychophysical method is to show that differences in experience (as evidenced by judgements)

correspond to differences in stimulation. In order to do so, the experimenter must have previously built a device to isolate and control a variable of stimulus-energy in which he is interested. The essence of the experiment is that a judgement of "greater" is always given when the experimenter sufficiently varies the energy in one way and a judgement of "less" when he varies it the other way. The output is specific to the input, within limits which are investigated. The success of the psychophysical procedure has been so great that the specialists in it like to claim that they are scaling or even measuring experience (20). The correspondences obtained, whether or not mathematical functions can be written to express them, have yielded a mass of evidence for physiological theory on the ways in which the neural process is specific to the stimulus, and consequently sensory physiology nowadays goes hand in hand with traditional psychophysics.

The contemporary workers in this tradition tend to cultivate their own garden of so-called sensory problems and shy away from the perceptual problems. If they are physiologists they are apt to say the perception is "mental" and not their business. If they are psychologists they are apt to feel distrust for difficult speculations about *gestalten*. But surely this shyness is a mistake. The possessors of a good method in science ought to try it on any problem where it can be used. The psychophysical experiment can be extended, for example, to the investigation of visual space-perception if devices can be built for the control and systematic variation for the stimulus conditions which arouse it (13). Whether these are to be called cues for depth or stimuli for depth is not so important as is the trying out of the experiment. Presumably no one doubts that a psychophysics of perception would be desirable if it could be achieved.

Over and above the argument for extended psychophysical experiments, however, there is the possiblity of a general psychophysical *theory* of experience. The central idea of such a theory would be this: *for every aspect or property of the phenomenal world,* [UTP's gloss reads: "The phenomenal world is a myth and so are its properties. If you say `For every aspect or feature of the environment which we can discriminate..' O.K."] *however subtle, there exists some variable of the energy flux at receptors, however complex, with which the aspect or property is in psychophysical correspondence.* This says that there are not only stimuli for colours and sounds and tastes, but also for objects and places and events, and for meanings and values and abstract things. [UTP's gloss reads: "???"] It implies that when no stimulus for a

quality or kind of experience is known, one should be sought. It is a bold hypothesis, not to say a grandiose one. Nevertheless it is worth examining for its presuppostions and implications.

In the first place, it assumes that the phenomenal world can be resolved into phenomenal dimensions, aspects, or properties. It coes not admit that exepreince is composed of irreducible units, forms, or figure-ground impressions. [UTP's gloss reads: "We can say nothing about what experience is composed of except perhaps that it is composed of patterns of neural activity."] It asserts that awareness is fundamentally discriminative and that the difference between any one experience and any other is a transitional difference, not an absolute one. These dimensions are not taken to be those of the "sensory solids" of analytic introspection, however, for these depended on a doctrine. They are the dimensions of everyday experience and since this is enormously variable, they are vastly greater in number. [UTP's gloss reads: "I do not see that we can speak of `dimensions of experience'. All you need here surely is the notion of parameters of response"'.]

In the second place, it assumes that there exist in the flux of energy surrounding us variables of stimulation of high order as well as those of low order. The latter are mostly the ones which psychophysical experimenters have learned to isolate and control but this is no reason for doubting that the former exist, nor that they might be brought under experimental control with the exercise of ingenuity. Light, heat, sound, and force vary not only in such ways as frequency intensity, direction, and the like but also with respect to serial order and succession. The energy flow at the surface of an organism can be measured as the amount at a fixed point, and sensory physiologists have done so, but the differences, rations, rates, gradients, and derivatives of this flow are the variables in which the psychologist is interested. They are the stimuli for the activity of the whole organism as distinguisehd from that of a cell. These higher order variables are the ones that correspond to the physical properties of objects and events in the environment, or at least to the properties that are important for an animal's behavior. They explain why it is that stimuli at the sense organs can specify objects beyond the sense organs.

Many or most of these high order variables in the surrounding sea of energy are not responded to by a given individual or by the individual at a given moment. An animal may not react because its species does not possess the necessary receptor mechanism, or because it has not learned to discriminate the

variable in question, or because it is responding instead to some other variation of evergy. The way to find out whether an animal is equipped to react specifically to an energy charge, or can be trained to react specifically, or can be "set" to react specifically is to perform a discrimination experiment. In the case of man, this can be a psychophysical experiment. [UTP's gloss reads: "I should have thought that the precise relationship between human and animal psychophysical experiments requires more detailed discussion."]

The psychophysical theory of perceptual experience does not assume, it should be noted, an innate repertory of sensory responses to a fixed list of energy variables. It asserts that the energy variables around us are far richer and more complex than we have imagined and the the ability to discriminate these variables increases first with the maturation of the nervous system and later with the progress of learning. They are capable of becoming stimuli insofar as an individual develops the ability to make differential reactions to them, that is, to perceive them. The phenomenal world [UTP's gloss reads: "I don't like this ?"] of one individual, consequently, may be quite different from that of another individual, and it may be different for the same individual on different occasions. But the physical environment is the same for all, and the differences in perceptual reactions are differences in what the individual is responding *TO*. They are not differences in the process of constructing or organizing a world out of meaningless sensations. The process of perception is one of discriminating and selecting and abstracting a world, not one of building it.

The psychophysical theory of perception, as was suggested at the outset, proposes to dispense with the concept of sensation or, more exactly, to dispense with the *distinction* between sensation and perception. This proposal involves difficulties of terminology for which the reader should make allowances. Terms like "sensing" and "the senses" cannot be abandoned without substitutes, which are not easy to invent. What should be dispensed with, in the last analysis, is the persistent notion that sensory impressions [UTP's gloss reads: "All impressions are surely impressions of something. What are sensory impressions impressions of?"] are prerequisite to, or the basis of, other impressions. Sensations are the symptoms not the cause of perception. They are the products of introspection and, not only this, the products of a doctrinal kind of introspection that expects to find them at the core of every perception. Introspection is a very useful guide to the study of why things look, sound, and feel as they do, and is the usual preliminary to a good psychophysical experiment, but a cultivated naivete about what the world *does* look, sound, and feel like is

a better guide than the fixed expectations of a premature structuralism. The danger of structuralism is that a list of modes, attributes, and qualities gets written down in accordance with supposedly known variables of stimulation. This results in a tendency thereafter to find just these elements in experience and not to look for new variables of stimulation in the environment.

The theory of sensation and the practice of analytic introspection were necessary perhaps for the development of our knowledge of sense-physiology to its present stage, which is impressive. But they are nothing but a hindrance to the development of what might be called perceptual physiology, that is, the physiology of the afferent side of the total behavior process. An adequate theory of behavior depends on the latter kind of knowledge. They physiology of the receptor-cell is beginning to be understood; what is needed is information about the physiology of the receptor-mosaic and the higher-order processes within it. We need a molar instead of a molecular physiology to go with a molar psychophysics.

A Psychophysics of the Visual World

The psychophysical theory of perception has been applied, as yet, only to vision (3). Its claims extend to the whole of phenomenal experience and it tends toward a break down of the classical sense-modalities, but our concern here will be primarily with experiments about visual phenomena. To what extent can it be shown that visual perception is a function of optical stimulation?

The question actually is whether the visual world (perception) is a function of stimulation instead of merely the visual field (sensation). The visual world is an experience [UTP's gloss reads: "No."] characterized by a ground and other surfaces, receding, frontal, or slanting, not by patches of colour as such. It includes edges, gaps and depth-shapes, or objects, which possess constancy of colour, size, and shape. It includes the point-of-view itself as one pole of the experience, and impressions of a changing point of view when the observer moves. It includes such phenomena as the motions and rotations of visibly rigid objects and the elastic or fluid deformations of non-rigid objects like faces or the surface of the ocean. It includes the perception of events, living things, and human artifacts like pictures and symbols. Its properties and

qualities largely remain to be described and classified, and the above list should only arouse the visual investigator to look for himself.

The Optical Array and the Theory of Gradients.

The stimulus condition for determinate vision is light reflected (or occasionally radiated) from substances through clear air, that is, the focussable light from the objects of the environment to any point in the environment where an animal may place its eyes. The projective capacity of the light to the point in question is analysed by talking about rays, but the ray of light is not the elementary stimulus for vision as sometimes has been imagined. This array of rays converges to the point from all directions, although animals like ourselves can pick up less than half of the total sphere at any one moment. We explore the total array by turning our eyes and head. We also sample the family of all possible arrays by moving from one to another point of view. As a matter of fact we are normally never limited to the stimulation provided by the single array to a motionless point; we have two eyes and we pick up two arrays at the same time, converging to different points a short distance apart. These facts might be expressed by saying that the incoming optical ray-sheaf is dual and fluid, rather than single and static (13, pp.1-2).

The higher order variables of optical stimulation on which perception is said to depend should all be discoverable in the patterning of the single ray-sheaf, the duality of the patterning at the same moment, and the transformation of its patterning over time. The duality factor can be referred to as *disparity* and the transformation as *motion parallax*. The momentary pattern of the single ray-sheaf is projected as the momentary retinal image[1] and this consists of transitions of luminous energy between areas of relative light and dark. We may speak of this condition, for convenience, as *optical texture*. Textured images are necessary for any impression more definite than filmy or fog-like colour in a void. If one wears diffusing

[1] It may come as a surprise that the stimulus for vision is here defined as external to the eye. Traditionally, the retinal image is taken to be the stimulus, or at least the "proximal" stimulus, but this assumption is made by investigators preoccupied with the visual sensation, or the visual *field*. They are thus tempted to assume that the retinal image is a "picture" which is "transmitted" to the brain (as if that could do the brain any good). The investigator of the visual world should face that fact that projection on the retinas is dual and fluidly changing; he may then find that it specifies, although it does not replicate, the external environment. Actually it then does not make much difference whether the stimulus is defined as focussable light (outside) or focussed light (inside).

plastic hemispheres over the eyes (half ping-pong balls) the experience can be described as "nothingness" in the sense that "thing quality" has disappeared from the perception (9,14).

An important variable of optical texture is its *density*, or the frequency of transitions. This may be either the overall density or the density at a certain region along one or another meridian or the array. There is also the ratio of the horizontal to the vertical density in a certain region, and perhaps other variables which may be found significant. Finally, there is the *gradient of density* over the array, for example an overall increase in density upward. Such an increase is produced by a terrain or ground surface in the optical array given to a terrestrial animal.

It should be noted that under natural conditions the gradient of texture density in each single projection is accompanied by two coincident gradients, one of the degree of successive incongruence of the elements in each projection (the gradient of parallactic motion) and the other the degree of simultaneous incongruence of the elements of the dual projection (the gradient of disparity).

The Apparent Recession and other Spatial Properties of Phenomenal Surfaces.

Granting that a surface in perception [UTP's gloss reads: "I don't like this sort of talk."] is produced by retinal images which are textured, the recession or increasing distance of the surface should be produced by the triple gradient defined above. There is psychophysical evidence for this hypothesis (2,13). Moreover, the specific distance of any point or object on the surface would be given by the degree of density, disparity, and motility of that point in the array relative to the gradient. The distance from "here to there", in short, is probably produced by the difference with respect to these variables between the image of the nose in the field of view (the visual "here") and the image of the object (which is "there"). It would seem that the stimulus variables for the perception of distance [UTP's gloss reads: "This is better."] in the visual world have been literally under our nose all the time.

The length of a *stretch* of distance along the ground from "there to there", at whatever distance the stretch may lie, may be given by some such variable as the number of transitions or texture elements in the stretch. This would make possible objective judgements of such distance stretches at different distances, and these are, in fact, possible (19). The same reasoning should apply to stretches of "width" along the

ground at different distances as well as to stretches of "depth", that is, to the frontal as well as the longitudinal dimension of a receding surface. The surface should possess a phenomenally constant scale, or in other worlds, constancy of size aong both dimensions.

The property of the "optical slant" of a delimited surface such as the face of an object, that is, its apparent departure from the frontal plane or angle to the line of sight, should be given by the degree of "one way compression" of the texture (the ratio of vertical to horizontal density) along with concomitant degrees of skew of the texture as regards both disparity and motility (3, p.173). This implies that constancy of shape of the elements or structure of the texture is a necessary corollary of slant-perception. The direction in which a surface slants or recedes is given by the direction in which the density of its texture increases and in which the supplementary gradients run.

The Phenomenal Edges of Surfaces and Objects.

An edge in the visual world seems to be characterized by an *abrupt* increase in distance as compared to the *gradual* increase in distance of a receding surface. The quality and amount of this depth at an edge should depend respectively on a stepwise discontinuity in the gradients, and on the degree of increasing density, disparity, and motility of the texture at the step. Exploratory experiments suggest that it does.

An edge should be distinguished from a margin, which is given by a simple discontinuity of luminous intensity in the array and which induces no clear depth impression. An edge, especially if "closed", is what makes the surface of an object appear in front of the surface of the ground or background. This reminds one of the figure-ground phenomenon. But an edge with depth may also surround a hole, window, gap, or interspace, in which case the surface inside the edge appears *behind* the surface outside the edge. Such a phenomeon has what could only be called a "frontground". The conclusion of gestalt theorists, therefore, that a textureless closed contour necessarily yields a figure-on-ground experience is incorrect, and the inferences that the differences between figure and ground are a "field phenomenon", and that a form constitutes a prototype for visual perception are both equally dubious. The gestalt theorists could not wholly rid themselves of the old doctrine that two-dimensional form is primitive and sensory while three-dimensional depth is secondary and perceptual. If depth is given in stimulation, however, it does not have

to be derived from sensory organization. A phenomenal object involves impressions of edges and sufaces, not of tracings on paper (4).

The Experimental Production of a Phenomenal Surface.

[UTP's gloss reads: "This use of phenomenal is O.K."]

An observer can be made to see a substantial surface where no substantial surface exists by manipulating the array of light to his eyes, that is by artifically producing the stimulus conditions necessary for the perception. An optical device for this purpose has been constructed (13). It is called a "pseudo-tunnel", since the perception it induces is that of looking into a long cylindrical space or room. It is a "place", not an "object". Physically it consists of circular apertures or edges cut in sheets of smooth material hung behind one another, of alternating low and high reflectance, which are uniformly illuminated. The number and frequency of the sheets in the series can be varied. Optically it yeilds an array to each eye consisting of either concentric or skewed circular margins, that is, abrupt alternating transitions of intensity. Perceptually it yields a solid and substantial tunnel when the transitions are sufficiently frequent. As their frequency decreases the perception becomes less solid or substantial. The walls of the tunnel then lose the quality which Katz, speaking of colour, called visual "hardness" or "inpenetrability" (15). When the transitions are wholly eliminated (by substituting sheets of the *same* reflectance) the experience is that of fog filling the nearest aperture.

The solid phenomenal tunnel appearing when the overall texture of the array is dense consists of a surface which recedes from the periphery of the field of view to the center; it slants inward. It appears thus because the density of the array increases from the periphery to the center and because (if both eyes are open and the head is mobile) there is a decreasing crossed disparity and decreasing crossed displacement of the texture from the periphery to the center. When an observer peers through the holes in the sheets the tree gradients are mutually congruent. The perspective of the light and dark rings is in geometrical agreement with the perspective of binocular parallax and that of head-movement parallax. In these circumstances the depth and distance of this synthetic visual space is compelling. Two thirds of the

observers report that the walls of the tunnel seem parallel even when asked if they seem to converge, that is, the far diameter appears as large as the near diameter (13, p.8).

Constancy of the Size of Objects and Constancy of the Dimensions of Spaces.

It is generally recognized that the problem of the size constancy of objects in perception is somehow related to the problem of space perception, but the question is precisely how? This question might be clarified by examining the physical distinction between *things* and *space*. We are concerned with things of visible magnitude, and we also concerned with *spaces*, not with space as such. Things (like books, students, trees, and cows) are seen in spaces (like rooms, corridors, gardens, and fields). Spaces are determined by their surfaces, and so are things. A thing is physically bounded by its surface but a space *is* a surface [UTP's gloss reads: "No."], or at least it always has a floor or ground and things either rest on it or come to rest on it. In general, a space is an unbounded surface. The surface of a thing may be detached from the surface of the surrounding space, but some things are more separable from the ground than others; a cow in a field is detachable from it but a hillock in the field is less so. A thing usually intercepts a small angle of the optic array; a space is what fills the whole array. The biggest space we are capable of seeing is the surface of the terrain (we can only imagine the spherical surface of the planet) in which case half of the optical array represents the sky. The sky, paradoxically, presents scarcely any stimulation for space perception although it is what we are tempted to call space, for reasons discoverable in the history of scientific thought. [UTP's gloss reads: "Space, surely, is the gap between surfaces into and through which one is free to move. The distinction you want is between the surfaces which define a space and the surfaces which define `thing' or `material object'."]

Once this distinction is clear it is possible to realize that the difference between a thing and a space is not absolute. A thing is normally a part of a space, and a space is a collection of more or less adjacent things. A surface itself is a collction of adjacent elements of texture, which look like things on close inspection. A thing therefore is located in a space relative to other adjacent structures. Consequently a phenomenal thing is located in a phenomenal space relative to adjacent structures in the optical array and relative to the gradients in it.

The investigators of the size constancy of objects have not paid sufficient attention to the spaces in which they set their standard and variable objects. Instead, they have been concerned with the "cues for depth" of the object itself, assuming one must have sensations before one can possibly have a perception. Size constancy is a matter of discriminating the surface which lies between the observer and the object, the edges which separate the object from the surface, and the gradients and steps of stimulation which determine them. The question is why, when we see an object in a space, does it not look smaller when observed from a greater distance in proportion as its retinal image gets smaller? The answer is that when the object is seen as part of its space the *space* of which it is a part does not look denser or more compact or smaller when that part is observed from a greater distance. It certainly does not look smaller in proportion as the retinal image gets denser. The density is the stimulus for increasing distance, or an aspect of it. This is true so long as the observer attends to the space of "world" and is not reminded that he is supposed to have sensations or to see the perspective of the scene. The perspectives of double imagery and of parallactic motion are also usually not seen as such (but then we have not been trained to attend to them as we have to ordinary perspective). With fixed monocular stimulation the size of an object is given by the size of its image relative to the size of the elements of texture or structure at that part of the gradient - a ratio rather than a simple magnitiude, that is, a higher-order variable. Size is perceived relative to the size-scale of the place where the object is seen. [UTP's gloss reads: "I like this sort of talk."] When phenomenal objects are seen of constant size, it is because the phenomenal space in question is seen as possessing constant dimensions. If it is not, the objects are not. [UTP's gloss reads: "But not this."]

An advantage of this theoretical approach is that it can explain the constancy of *shape* of objects with the same hypotheses. It can also account for constancy of *velocity* in the same way. The phenomenal *rigidity* of the world during locomotion (despite the expansion of the visual field ahead follows from the same line of reasoning (12). There is even some promise that constancy of *brightness* and *color* will prove to be consistent with a surface theory of space perception. The arguments will not be extended here.

Some investigators of space perception are convinced that phenomenal space does *not* have constant dimensions at its extremities from the observer. It can certainly be pointed out correctly that the spaces one sees are not like the space of an "empty box without sides" with three dimensions extending to

infinity - the abstract space of Euclidean-Cartesian geometry. It is therefore easy to make the assumption that phenomenal space is non-Euclidean as this term is understood by geometers. This assumption sounds very interesting, the more so since Luneberg adopted and elaborated it in the effort to establish a non-Euclidean metric for binocular visual space (16). The essence of the position seems to be that perceived space is finite while physical space is infinite. It is based (as the writer understands it) on two supposed facts about space perception, said to be grounded on experimental results. The first is that perceived distance reaches a limit asymptotically as physical distance increases without limit. The second is that perceived size approaches zero as physical distance increases without limit. It is true, of course, that the visual field has a horizon. For an unlimited textured surface (a plane, for the sake of simplicity) the horizon is the point in the gradient of the optical array where density becomes infinite - the "vanishing point" of classical perspective. It is also true that the optic apparatus is limited by an acuity threshold below which any increase of density of the array becomes indiscriminable. But is it a fact that the visual *world* has a horizon? [UTP's gloss reads: "I don't know what this question means."] Does the naive uncritical experience of trying to make out something in the distance involve seeing the horizon? The writer doubts it, and the reader should look or himself in order to decide the question.

It seems to me that perceived size does *not* vanish and perceived distance does *not* reach a maximum as one looks into the distances. Instead, they both tend to become indefinite or indeterminable, which is a different matter. By analogy, when a letter of an acuity chart becomes too small to read, it is because the separation of its parts has become imperceptible, not perceptibly zero. It can be argued, then, that the limits of phenomenal size and distance on which the Luneberg theory is based are not facts at all. Phenomenal size depends on a variable of ratio in the retinal image, not a variable of "retinal size", and phenomenal distance depends on a density variable, not on "cues" or sensations.

The Experience of the Point of View in a Space.

Every perception or judgement in the so-called third dimension involves, as one pole, the impression of the point of view or "here". A report that the variable object is more distant than the standard is convertible into the report that "I am more distant from the variable object than I am from the standard". The theory of

sensory cues neglects this fact. The theory of stimulus gradients, however, find it implicit in the gradients themselves. The bottom of the dual and fluid projection for a space like the terrain (or the periphery of the projection for a space like a room or tunnel) is unique with respect to density, disparity, and parallactic motion. The nose is a prominent feature of the bottom of the optical array; it projects as the largest structure in the field of view (the minimum of density), as the maximum of crossed retinal disparity, and as the maximum of crossed parallactic motion. According to the present theory it should arouse the maximum possible impression of nearness or, what is the same thing, the zero of distance away (3, p.228). Not only a visual space but also the lcoation of oneself in that space is determined by optical stimulation.

A point of view has not only position in a space but also direction in a space. This also is given in stimulation. A surface at the point of fixation has a quality which has been termed optical slant. It is definable as the apparent inclination of the surface to the plane perpenticular to the line of sight (8). But it is equally definable as the apparent angle at which I am looking at the surface. It is given by the slope, or rate of change, of density of texture at the center of the incoming projection, or by the degree of one-way compression of the texture at that point (the density variable being normally correlated with the other two variables). The direction of the gaze-line in space is given by optical stimulation, whether or not it is also given postural sitmulation. In short, we are sensitive to the particular sample of the total optical array which our eyes at the moemt are picking up. Since we do sample the total spherical array by exploratory eye movements and head movements - we look around - we are able to survey the whole of a new environment in a few seconds, and to orient ourselves in it.

The perception of the whole of an environment, including where the observer is and where things are, is not achieved in a single eye-fixation. It depends on stimulation over time and seemingly on stimulation which *changes* with time. Nevertheless what the observer is responding to are the *properties of stimulation which are invariant over time*. He ordinarily pays no attention to the properties which change with time when he is attending to space. These invariants, or high-order variables, are the basis for our perception of the world as boundless, permanent, concurrent, and as "public" rather than "private" (3, p.160-162).

The Perception of Moving Objects and of One's Own Locomotion in a Rigid Space.

How we perceive motion in an environment or space has always been puzzling if, as seemed obvious, we have nothing to go on except simple sensations. Actually, if successive series are a fact of stimulation as well as adjacent series, the phenomenal qualities of motion may find their explanation in the resulting variables of high order, and there will be no need to suppose that motion depends on inference or intellectual processes. It will, howeve, be necessary to discover how a man discriminates, or comes to discriminate, the variables.

A great deal of confusion has resulted from the seemingly simple assumption that the stimulus for motion is the motion of a retinal image across the retina. This leads into a theoretical morass when eye-movements have to be taken into account. A really simpler assumption, because more general, is that the stimulus is some transformation or change of pattern in the optic array to the eye. The array is not only fluid as a whole when the observer changes position; it also includes changes of parts relative to the whole when external objects move relative to their surroundings. This array is what stimulates the eye (there are two, of couse, each being a perspective transformation of the other) and the retinal image is simply that part of the sheaf which stimulates the retina in a given position of the eye. The mathematical types of motions and transformations in this array are in a very neat correspondence with types of physical events, as the writer has pointed out (5) and if these are chosen as variables of stimulation a psychophysics of motion perception is practicable.

A whole class of changes in the retinal image, it should be realized, are produced by responses of the individual as distinguished from events of the environment. At one extreme the maximizing of the definition of the image and a considerable alteration of the luminous intensity of the image are produced respectively by the accommodation response and the pupillary response. A variety of transpositions and rotations of the total image relative to the retina are produced by the exploratory movements of the eyes. At another extreme a set of transformation of the total image are produced by the set of locomotor responses of the individual (3, ch.7). They involve gradients of velocity, and can be described by the term motion perspective (12). All these modes of stimulation are response-produced or, in a currently fashionable terminology, they are "feedback" stimuli. Only the last mentioned, however, has ever been supposed to

have the status of yielding a kind of visual sensation, presumably because only this is easily introspectable. It has been called a cue, a sign, or an indicator of space, and the liklihood that it is a stimulus for the visual impression of locomotion or change of the point of view has gone unrecognized. Presumably all these kinds of stimulation, whether or not conscious, do not have the function of yielding sensations but of guiding or controlling the responses which produce them.

The impression of locomotion through an environment is unquestionably visual, over and above the contribution of the classical proprioceptors. And now one can understand better the phenomenal fact that the environment seems stable and rigid during locomotion rather than moving and elastic. If motion perspective is a stimulus for moving ahead in the third dimension it cannot be a stimulus for an expanding visual picture in two dimensions, or at least it cannot be both at the same time. The phenomenal rigidity of surfaces and objects in perception and their constancy of size and shape as the observer moves in space is the obverse of the fact that he senses that movement. Both aspects of the total perception are given by the same stimulation, the one by its invariant properties in time and the other by its variation in time.

Phenomenal rigidity of a textured surface (along with other properties like substantiality, continuity, and Katz's surface-color) is preserved under all perspective transformations of the proximal stimulus, but it seems to be *not* perserved under *non-perspective* transformations of the stimulus (7). These, in contrast, seem to yield the perception of deformation or elastic movement, that is, of non rigidity. The eye seems to be sensitive to different specific *kinds* of transformation. The perception of elastic movement is important since it is the kind of movement characteristic of animate creatures or biological objects.

The Perception of Events, Living Things, and Human Artifacts.

A psychophysics of the visual world, in order to be complete, would have to include some account of the perception of events such as cause-and-effect sequences, some explanation of how we perceive other organisms including the behavior and traits of persons, and above all some reference to the apprehension of written symbols, including pictures and images, which compose so large a part of the human world as compared to that of other species. The question is whether these more abstract features of the visual world are specified by still higher high-order variables of stimulation than any yet considered. If a perceptual

psychophysics is possible, how about a psychophysics so global as to encompass meaning? This is clearly not an issue to be settled in a few paragraphs but perhaps the suggestion of an answer can be given.

If simple motions in the environment can be mathematically specified in the optical stimulus, so can complex motions. The events or happenings of the environment are complex motions. They are projected as transformations in the array, and if we knew the transformations we should know the potential stimuli for the perception of the events. They may prove to be not so impossibly complex as might be supposed. Michotte has already discovered regularities in the stimulus conditions for the perception of causation by manipulating only simple variables of motion, and he has shown that the resulting impressions are immediate, which implies that events are directly apprehended from the stimulation projected to the eye (17). [UTP's gloss reads: "No. For the perception of `pushing' perhaps. To say A causes B is to say `if A had not occurred, B would not have occurred.' Whether or not this is so in a given case can only be determined by experiment. Causation as such gives rise to no characteristic stimulation, though certain kinds of causation, e.g. pushing, do. It is with them that Michotte is concerned."[2]]

The perception of persons has been said to be a matter of apprehending "physiognomic" and "dynamic" qualities. What these may be in the visual mode we do not know, but one thing is certain: the visible responses of human individuals from which we mostly judge their intentions, habits, personality and character are all complex deformations of the surfaces of their bodies, the facial surface being especially important, and they are given to the observer as complex deformations in the optical stimulus. The ability to communicate by pantomime, even when it is mediated by a motion picture, is proof of this. Little is known about the significant variables of such deformations but there is nothing in principle to prevent an experimental attack on the problem. A valuable method will be the psychophysical procedure of using artificial stimulation, with control of the variables. All that is required is ingenuity in choosing variables and constructing devices to control them.

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[2] [Added 1990] I am fascinated to find that I have been committed to the counterfactual theory of causation at least since 1956, some time before the appearance of J. L. Mackie (1962) `Counterfactuals and Causal Laws', in R. J. Butler, Ed., *Analytical Philosophy*, Oxford, Blackwell, pp. 66-80.

The perception of human artifacts is perhaps the most complex of all kinds of perception. Like the perception of speech-sounds, it involves the psychology of communication between persons, and the problem takes on aspects of this higher order of stimulus-response relations. Words, pictures, or symbols are far removed from the natural events of the physical environment. They are said to be mere tokens or substitutes for other events not "present to the senses". Nevertheless it should not be forgotten that they *are* concrete sources of optical stimulation (usually tracings on a paper surface). And, what is more important, they are *specific to* the natural objects or events said to be "absent" (6). If they were not specific they would not be symbols, i.e. would not signify anything.

The perception of artifacts, then, is genuinely mediated or indirect perception, and the symbols are genuinely indicators, clues, or cues to something else. The perception is said to be based wholly on associative learning. (It is interesting to realize that the classical theory of sense data conceived them to be analogous to human artifacts, as if the communicating and interpreting of a message were the only way the process of sensation and perception could be understood.) Nevertheless the fact of specific correspondence between a set of different symbols and a set of different percepts (or responses) makes this kind of perception fundamentally like the kind studied in the psychophysical experiment. [UTP's gloss reads: "This sounds rather muddled."]

In what sense can it be said that there exist *stimuli* for, say, the letters of the alphabet? There are stimuli in the obvious sense that deposits of something like ink must differentially reflect an array of light from a surface like paper. But there are stimuli for letters in another sense - that the variables of linear shape in the array specify discriminable differences between each letter and every other letter. After learning to discriminate them, there come to be 28 responses to 28 specific patterns. And after learning to "read", there may exist 28,000 specific responses to 28,000 letter-combinations. The variables which specify the higher order shapes of words are of very high order indeed, but they certainly exist, and it is probably to these that the reader specifically responds. Investigators of the process have long since concluded that a child does *not* learn to read by associating the separate letters in various combinations. There exist not only letter-forms but phrase-forms. And if so why do there not also exist sentence-forms, and paragraph-forms, and even book-forms? The process of learning to read can legitimately be conceived as one of

discriminating and abstracting the variables of stimulation in a pyramiding order. As we shall see, the process of learning to perceive in general can be thought of in the same way.

The Effect of Past Stimulation on Responses to Present Stimulation

Empiricism is the belief that knowledge of the world comes through the sense organs, not from within, together with the additional hypothesis made necessary by the seeming unreliability of the senses that knowledge of the world comes from past experience. The psychophysical theory of perception makes no assumption about an influence of past experience on perception. Does this omission make the theory inconsistent with empiricism, and guilty of an ativistic taint? Surely not. The emphasis on stimulation makes it an even more radical empiricism than is customary in theories of perception. If a postulate about the effect of past experience on present experience is not necessary to explain the latter it would be unparsimonious to make it. Moreover the precise nature of such an effect, despite its commonsense plausibility, is a troublesome problem which no one has ever really solved. The problem of past experience, however, is interesting if not relevant and it should be faced.

The most radical solution to the past experience problem is to assert that "past" and "present" are subjective terms - that time is simply a protensive or sequential attribute of experience and that likewise sequential order is a dimension of stimulation. We are not only surrounded by an array of energy; we are also immersed in a flow of energy. Stimulation includes variables of temporal change, and these may reach high orders of long duration. We can apprehend events over longer temporal spaces as we learn to discriminate these variables of higher order. Consequently the only problem of so-called past experience is how to develop a psychophysics of the perception of "times", by analogy with the perception of "spaces". There is simply a third sequential dimension in the two-dimensional optical array which corresponds to the fourth dimension of three-dimensional physics. In this solution to the problem memory evaporates so far as explanation is concerned, and "memories" are reduced to the status of a psychological curiosity, like "sensations". This is the most satisfactory theoretical position. The only trouble with it is that traditional modes of thought are violated, and that the position itself is undeveloped.

With greater orthodoxy and in more familiar terms the question can be put in this form: what is the effect of past stimulation, direct or indirect, on responses to present stimulation? Since the words "past" and "present" have subjective connotations, one can ask what is the effect of previous stimulation on response to subsequent stimulation? There can be no doubt that there *is* an effect of earlier stimulation on the perception (or judgement or response) induced by later stimulation. The effect is to alter it, as compared with what the perception would have been in the absence of the previous stimulation or in the presence of a *different* previous stimulation. Just this is what a properly controlled learning or transfer experiment demonstrates. The usual answer to the question is that the effect is indirect: a trace or memory of the previous stimulation persists and somehow interacts with the direct effect of the subsequent stimulation to alter the response.

This answer to the question has been termed the "enrichment theory" of perceptual learning (10). There is at least one serious objection to it, for it has an awkward implication. It says that as memories accumulate with time perception is in a progressively decreasing correspondence with present stimulation. Perception becomes more assumptive, more inferential, more imaginary and therefore more subjective as learning progresses. It means that we get less and less in touch with the environment with practice in perceiving the environment. This seems to contradict what we know about learning. There is a great deal of evidence to show that the effect of practice on perception is to make it more precise. Discrimination tends to improve on repetition, as measured by decreases in the variable errors and the constant errors of the psychophysical experiment (1). It is therefore likely as well as reasonable that we get more and more in touch with the environment as a result of previous experience. Presumably we do so by learning to respond specifically to variables of the environment not previously responded to, that is, variables of higher order. The effect of previous stimulation on the perception of subsequent stimulation is to make it more finely discriminative.

The latter position has been termed the "differentiation theory" of perceptual learning (10, 11, 18). It admits an influence of the past on the present in experience or behavior but it dispenses with the notion of traces or memories as the explanation of this influence. It also dispenses with the theory of association. It says that an organism can learn in time to respond appropriately to the permanent properties of its

environment even when these are subtle and intricate. It can respond to [UTP's gloss reads: "To understand or appreciate something is to respond to *it* not to its meaning or value."] the meanings, values, or valences of things insofar as they are unique to the objects, and inasmuch as each thing is discriminated from other things. But it does not *necessarily* have to remember or recall or associate in order thus to respond appropriately, as the enrichment theory assumes. It may simply discriminate, abstract, and identify the meanings which are implicit in the subtle properties of stimulation.

The differentiation theory of perceptual development, it should be noted, has to assume that the permanent properties of the environment *are* implicit in the sea of surrounding environmental energy. In the case of the projective properties of light, which an animal samples with every fixation of its eyes, this assumption has already been discussed. The total environment is implicit in the potential optical stimuli which an organism may get, or learn to get, not in the momentary array at a given instant of time. The difficulty with the past experience theory of perceptual development arises when one tries to define what is meant by *present* experience. Presumably by "present" not theorist has ever meant an instantaneous cross section, but a certain duration or span of temporal experience. What span shall be chosen - a second, six seconds, an hour, or a week? in the face of this difficulty the more radical theoretical approach of sequential psychophysics, mentioned earlier, seems desirable.

The organism learns to respond appropriately not only to the "permanent properties" of the environment, but also to its lawful changes, movements, events, and the directions of events. Within the transformations of proximal stimulation it distinguishes between those aspects of it which are invariant over time and those not invariant over time, as suggested earlier. The latter specify the changes of things in the physical world and the former specify the unchanging things. If the concept of stimulation is taken broadly enough it can encompass not only perception but cognition, knowledge [UTP's gloss reads: "No. This is on the response side."], and thought [UTP's gloss reads: "Perhaps - `pure stimulus act'"] as well.

To the extent that the energies at the surface of the organism consist of a vast potential of stimuli which it may react to in lesser or greater degree, the problems of maturation, learning, attention, and habit formation, like the problem of perception, can all be formulated as the investigation of what the organism is specifically responding *to*. Development is a matter of the increase in the specificity of responses to stimuli,

not a matter of the connection of "old" responses to "new" stimuli, or of the connection of "new" responses to "old" stimuli. Instead, behavior becomes differentiated, with repetition. At the level of neural physiology it is probably not that new connections are formed between receptors and muscles but that the nervous system itself becomes progressively more differentiated.

This theory of the specific correspondence of the qualities of perception to variables of stimulation is intended as an alternative to the theory that perception is supplemented by memory. It does not deny the existence of memory in some sense of that term; it only asserts that the process of remembering, recalling, recollecting, or the "reinstatement of past experience" is not a process which contributes to the development of perception. [UTP's gloss reads: "One must, however, remember the names of things and what to do with them."] Remembering or reminiscing is a *symptom* of learning, not the *cause* of it. No one will deny that a man *can* remember, recall, recollect, etc. He often does. But it need not be assumed that he has to mix memories with sensations in order to have perceptions, meanings, cognitions, or knowledge of the world in which he lives.

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