James J. Gibson's Strategy for Perceiving: Ask Not What's Inside Your Head, but What Your Head's Inside of

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INTRODUCTION

For many years James Gibson has been impressed with the precision of visually guided behavior. In 1938 he published a study of automobile driving (Gibson & Crooks, 1938); during World War II he studied visual components of aviation, particularly the activity of landing airplanes. The priority that these studies reflect, and which seems to have been developing with increasing explicitness as Gibson's ideas have developed, is to treat perception as a biologically adaptive activity first and as a study of "interesting phenomena" much later—if at all. On Gibson's view, even though it is surely true that all perceptual phenomena, and particularly curiosities such as illusions, can tell us something important about how visual systems work, curiosities are probably the last things we want to worry about in our theories. First, theories should do justice to the everyday perceptual accomplishments that contribute to the survival of the species. The problem of guiding ourselves (cf. Gibson, 1958; Turvey, this volume), as well as cars and airplanes is primarily a problem of veridical perception. These are cases where perception seems to be in close touch with the environment. Yet the traditional theories of space perception available to Gibson when he was faced with the practical problem of understanding airplane landings and visually guided locomotion had little to say about such cases. Therefore he gradually struck out on his own.

THE FIRST VERSION OF GIBSON'S PROGRAM: PERCEPTUAL PSYCHOPHYSICS

New Conceptions of the Stimulus

By 1950 Gibson thought that the need was for what Troland called a psychophysics of perception (cf. Lombardo, 1973, for an extensive discussion of the history and development of Gibson's ideas, including his relation to Troland). It was believed at the time that the "givens" in the light to the eye could not support perceptual phenomena, but only elementary experiences such as sensations. Organized percepts were thought to be constructed by adding order and meaning to the sensations which elementary stimuli were capable of evoking directly. Gibson reopened the case for thinking of perception as being a function of stimulation by offering new conceptions of the stimulus. Even though it seemed clear that perception could not be a direct function of the variables of stimulation such as frequency and intensity of light (those variables ordinarily controlled in psychophysical experiments), there was no reason to believe that perceptual experiences could not be supported by any of a wide variety of other patterns of variation in light. The best known candidates for being alternative, "higher order," variables of stimulation relevant to perception were the gradients of texture and texture flow that Gibson discussed in *The Perception of the Visual World* (1950). These were shown to specify surface extent and surface slant (Purdy, 1958) as well as the path traveled by a moving observer (Gibson, Olum, & Rosenblatt, 1955).

The new insight Gibson provided in these examples was that the stimulus for perception is just as much a problem for research and theory as are the mechanisms of perception. In fact once the appropriate description of stimulation becomes a scientific problem, one might well presume that it is logically and strategically prior to any detailed proposals about processing (Mace, 1975). That is certainly the major thrust of current linguistics and psycholinguistics (Chomsky, 1972). By specifying the accomplishments of a system first, one can gradually limit the class of plausible mechanisms for perception to those that satisfy the job description. For example, Gibson has argued that just as units of structure can be sought at many levels of analysis in the light, so perceptual mechanisms functioning as units might be analyzed at corresponding levels of analysis. Thus, as he has often argued, even though light may be a stimulus for a rod or a cone, patterns like gradients are stimuli for organs such as eye-brain systems. He has never worked out a detailed theory of the detection of a particular variable of stimulation, but he has not been mute on the matter of processing either. His suggestion that the functional organization of perceptual systems must be analyzed with respect to corresponding levels of stimulus patterning is a serious constraint that more detailed theories must consider (Gibson, 1966). Surely imposing constraints to be satisfied by possible mechanisms is a key part of any effort to understand what mechanisms are actually at work.

Environmental Constraints on Stimuli Surfaces

The perceptual psychophysics that Gibson proposed was actually more than merely an attempt to specify constraints on processing models. In addition to arguing for perception as a function of stimulation he argued that much stimulation is a function of the environment—and, therefore, that it is possible to view perception as a function of the environment. Theories built within a program like this would not slight the facts of biological adaptation and useful perceptual activity. By considering the environment and its structure as part of perceptual theory the scientific task of understanding perception does not necessarily become easier, but the task looks more like the investigation of natural law and less like the contemplation of miracles.

Surprisingly it is not uncommon for perceptual psychologists to ignore or downplay the important role that environment-dependent stimulus mapping relations play in Gibson's theory, applauding him only for recognizing the role of "higher order" variables in stimulation (Garner, 1970; Hochberg, 1974). Apparently researchers who are willing to investigate stimulus structure do not recognize a need for principled limitations on the stimulus variables sought. The psychophysical task *is* simplified inasmuch as one would limit the patterns used in experiments to those which might correspond to selected environmental properties. Otherwise Gibson's insight that "higher-order" variables of stimulation could function as stimuli for perception would have opened a Pandora's box of possibilities. Researchers could wander aimlessly through long lists of patterns searching for those to which observers responded in experiments constrained only by their imaginations and the existing body of literature, possessing a selection strategy based solely on luck and tenacity.

The environmental features that have occupied Gibson most are surfaces, especially the ground. He has maintained that what organisms see when perceiving the arrangement of the world is never "space" per se as presented in traditional theories, but surfaces and their interrelations. To say that one sees a vast expanse of space, or depth, receding far into the distance is wrong to Gibson. The experience should really be described in terms of the extended surface seen, since a person can only see an expanse of distance when presented an appropriate texture gradient indicating a ground surface extending to a horizon. By contrast, Gibson has pointed out that a person looking at patterns which ought to be specific to pure space, such as a *Ganzfeld,* give rise to little if any experience of space. He said,

> Spaces are determined by their surfaces. . . . A space *is* a surface; at least an environmental space always has a floor or a ground. . . . In general, a space is an unbounded surface. . . . The biggest space we are capable of seeing is the surface of the terrain. . . .

> The sky, paradoxically, presents scarcely any stimulation for space perception although it is what psychologists have been tempted to call space [Gibson, 1959, p. 478].

The transitive relation of the physically extended ground to optical texture gradients to the *perceived* extended ground was the paradigmatic instance of stimulation as a function of the environment and perception as a function of stimulation, hence perception as a function of the environment.

Through the 1950s, Gibson held to the idea that his "ground" theory of perception could be considered a basically psychophysical program. Since that time, however, Gibson has discovered his system developing beyond anything that could properly be called psychophysics. His is now a radical position in the literal sense of proposing to reformulate drastically the foundations of perceptual theory.

THE REVISED VERSION OF GIBSON'S PROGRAM: AN ECOLOGICAL APPROACH TO PERCEPTION

Gibson's psychophysical approach to perception marked a significant departure from mainstream thinking on how to frame and answer questions about perception. Few others had entertained the possibility of studying stimulus structure with the aim of finding correspondences between stimulus and percept, and of concentrating on biologically significant percepts. However, there was much in Gibson's early vision which was far more traditional than the ecological approach he is now developing. Succinctly put, the psychophysical program was basically a stimulus–response psychology. It was new in that it took the stimulus as well as stimulus–response relations as objects of investigation, but traditional in considering perception to be a set of responses to presented stimuli (albeit "higher order" stimuli).

What is important to realize now is that Gibson does not presently hold a stimulus–response view in any commonly understood sense, even though he continues to maintain that perception of the environment is direct as opposed to being mediated by nonpercpetual stages of psychological processing (e.g., memory, inference, or imagination). To do this is what requires his current approach to be so radical—radical in the sense that he claims that a direct theory of perception is both plausible and necessary.

His current approach is also radical in the sense that, first, it requires developing a theory of what there is to be perceived as an integral part of a theory of how perceptual processing could possibly occur and, secondly, it requires a theory of how processing actually does occur. Gibson makes it clear in his current theory that one can only have direct perception if the environmental and organismic components of perceptual theory are compatible. Presumably they will be compatible only if one develops each component of the theory with an eye to the other. For Gibson, one cannot realistically expect to synthesize a general theory of perception from patching together a theory of the physical world constructed by physicists who are primarily interested in the imperceptible microstructure of matter with a theory of optics developed for lens makers, astronomers, and microscopists with a theory of image recording developed for painters and geometers with a theory of neural functioning developed for communication engineers so as to yield a unified theory of adaptive perception for ecologically minded psychologists.

Thus Gibson himself has done a great deal of work on the question of what there is to be perceived in the environment and in energy structures (for example, an optical array where vision is under discussion) as well as sketching out new ideas of how to catalogue perceptual systems in ways that mesh with his analyses of what there is to be perceived. Each of these components, the *what* and the *how*, must be considered an integral part of the same perceptual theory for Gibson. (For a detailed discussion of this point see Shaw & McIntyre, 1974.) If they do not fit together, then the structure falls and direct perception becomes untenable.

Over the last 10–15 years Gibson has tried to develop enough theory in each of these realms to demonstrate that direct perception is indeed plausible even if hordes of difficult details remain to be worked out. The research and theory that form the content of Gibson's program such as his analysis of the optic array, stimulus information, and the functional organization of perceptual systems are what Gibson most often points to as radical features of his work. These will be treated soon.

The remainder of this chapter will first describe the key concepts currently holding the system together and then will examine the multiple underpinnings which make direct perception plausible by discussing five different ways one could hold an indirect theory of perception.

MOTION PERSPECTIVE AS A CASE AGAINST PERCEPTUAL PSYCHOPHYSICS

The concepts that Gibson developed which decisively distinguish his ecological approach from his psychophysical approach may be illustrated by referring to his paper on motion perspective (Gibson *et al.,* 1955). This paper presents a formalization of principles Gibson had discovered from his work on aircraft landing, the full implications of which, however, were not pursued until after this paper.

Essentially the Gibson *et al.* (1955) analysis of what they called motion perspective was a generalization of earlier analyses of motion parallax by Helmholtz. In motion parallax the rate of optical flow of points in a stable environment relative to a moving point of observation is inversely proportional to the distance of the environmental points from the observer. The farther away the points, the slower they translate in the visual field. However, this is an analysis of that portion of the visual field parallel to the path of locomotion. Gibson noted that there is, in fact, texture flow all around the moving point of observation. Gibson *et al.* (1955) formalized the case of rectilinear motion over an extended surface showing that motion parallax was a special case of their motion perspective.

There are three items of special interest in their analysis. The first is the observation that the equations for texture "motion" not only specify relative distances of stable environment points, but that the path of locomotion of the moving point is reciprocally specified. That is, the same global transformation of texture can be decomposed into parts that are specific to the environment and to the path of whatever is moving in that environment:

> The fundamental visual perception is that of *approach to a surface.* This percept always has a subjective component as well as an objective component, i.e., it specifies *O*'s position, movement, and direction as much as it specifies the location, slant, and shape of the surface [Gibson *et al.,* 1955, p. 383].

A second important feature is that significant parameter values such as the angle of inclination of the approach to the surface and the point of imminent contact remain the same as long as the motion is uniform and the environment stable. They are invariant properties of the optical flow. The third fact to note is that the moving point of observation generates a specific texture flow with its characteristic invariants defined relationally among many samples of points. This suggested to Gibson that the path of locomotion was probably specified everywhere in the flowing texture—which would in turn imply that any eye sensitive to the crucial variables of stimulation could register these variables at different places in the array. On this analysis one could theoretically take various *samples* of the flowing texture and get the same surface and path information.

What all this has in common with the psychophysical program (within which this particular analysis was carried out) is a concern for correspondence between optical texture and environmental conditions with special attention to the optical texture generated by surfaces. What makes it hard to fit into a psychophysics is that none of the traditional interpretations of the concept of a stimulus seem to be involved (see Gibson, 1960, for a survey and discussion of these meanings). Ordinarily the notion of stimulus has indicated something that could be applied or presented to an animal followed by an observable response. But each of the three points mentioned above makes it difficult to view the optical flow as a stimulus that could be presented in the ordinary psychophysical experiment.

First, if one were to test the sensitivity of an organism to the world events potentially available, there are at least two major judgments to be made instead of one—the path of locomotion and the layout of the environment. To say that one stimulus could cause two simultaneous, complementary responses (that is, what Gestaltists have called a "scission" effect) is unlike psychophysics as traditionally practiced. More importantly, such dual specification contained in the changing stimulation to a moving point of observation (that is, a locomoting observer) indicates that a very special kind of analysis is needed to explain how such perceptual processing might occur. Presumably, such an analysis will be in terms of acts of perceptual differentiation into orthogonal components of information—one component specifying invariant environmental properties, another specifying the observer's place in that environment as a creature with a history.

Traditional psychophysics, on the other hand, has typically been rationalized as the study of automatic responses to stimuli (rather than acts) which serve as building blocks for perception. From this viewpoint, however, the observer is but a passive receiver. Under such a view, Gibson argues, a perceiver would not be able to differentiate stimulation into its most useful dimensions. Thus, traditional psychophysics encounters serious difficulty in attempting to explain why the optical motions of an image over the retina is not intrinsically ambiguous with respect to whether the source of the optical motion is due to observer movement or environmental motion. Under this view it is not at all clear that one can explain how passive registration of a stimulation flux will allow the observer to extract the perceptual invariants specifying the stable layout of the world.

Second, Gibson *et al.* (1955) point out that crucial features of both the environment and the path of locomotion are specified by relations which remain invariant in the optical flow of texture. But how might one present an invariant in a psychophysical experiment? One can certainly present displays in which invariant relations are defined, but to regard an invariant relation as a stimulus, in the sense of being a "goad" which elicits behavior (Gibson, 1960), is incompatible with the view that the perceptual system actively separates invariant information from variant information.

The above two points are really the same, in that perceptual processing must decompose the information detected into subjective–objective components as well as variant–invariant components. If one accepts the view that important optical structure is to be found in the decomposition of a total structure such as a flow gradient, then the idea that there can be isolated stimuli which give rise to isolated responses that somehow become percepts (and this must be assumed by psychophysics if it is to be regarded as relevant to perception at all) has to be rejected.

Finally, the idea that texture flow can contain structure without reference to a retinal projection creates a psychophysical puzzle. Ordinarily one would think that an observer who is sampling different segments of an optic array over a long while would be getting different stimuli. Although this is certainly true in some sense, such a view ignores the possibility that the information specifying the path of locomotion and much of the environmental layout (ground plane, horizon, etc.) remain invariant as long as the organism is sampling within the same transforming array.

Major features of the ecological approach information and the optic array. Since the geometry provided by Gibson *et al.* (1955) specifies a great deal about the environmental events generating it, one would think that such "variables of stimulation" would play an important role in perceptual theory. Yet, as the above discussion shows, it is difficult to see what role they might play in traditional views. Over the years, Gibson solved this dilemma by rejecting the notion of stimulus in favor of stimulus *information*. This latter notion captures all the important aspects of the foregoing example. Because many connotations of the term "stimulus" are misleading from Gibson's point of view (Gibson, 1960), he now prefers to avoid all use of the term. Thus "stimulus information" is replaced with phrases such as "information contained in . . ." some specified type of array. This idea of information is a particularly central concept, and thus will be used to organize the full discussion of Gibson's ecological approach.

Whenever environmental events structure light (or any other vehicle of structure if not discussing vision) in a specific fashion, Gibson asserts that the light contains *information* for those events. This use of the term information to indicate structure specific to its sources is a special one. It is not the same as the Shannon and Weaver concept of information as a measure of uncertainty more commonly found in perceptual psychology. By using this term instead of "stimulus," Gibson hoped to avoid the muddles he pointed out in his review of the stimulus concept (Gibson, 1960) and retain the possibilities of direct perception expressed in his psychophysical program. *Information* was also meant to capture the insights illustrated in Gibson, Olum, and Rosenblatt (1955) along with their extensions. Hence, for the reasons already mentioned, perceiving based on the detection of variables of stimulation (information) such as were shown in that analysis could not be thought of as simple responding to physical stimuli.

Information (for vision) is a geometric concept defined over a transforming optic array, the 360° solid angle of variations in ambient light intensity converging on a point of observation from all directions. Animals or humans do not enter the picture except as a scale factor for selecting appropriate environmental features to analyze. Thus Gibson can speak of available information in an optic array. Whether or not a particular observer can detect such information is a logically distinct question, though of course a necessary question for the psychologist.

The optic array is taken as structure *surrounding* a point of observation. The point of observation in the geometric analysis (for which the nodal point of an observer's eye may be substituted in applications) is taken to be *immersed* in this array structured by environmental events. To replace the traditional image of the "stimulus" for vision as a picture that can be presented to an observer by the ambient optic array has a number of consequences. First the structured ambient array is always present and cannot be turned on and off the way stimuli in psychological experiments can be. It makes far more sense to characterize the basic contact of organisms with such an array as one of exploration than as a response. Furthermore it makes no sense to think of an organism's responding to isolated bits of such an array as if they existed in hermetically sealed packages. Rather one would be more likely to view the perceiver's problem as one of decomposition. That is, if a point is immersed in a richly nested structure of optical events, which of these can a particular perceiver separate out to respond to? Finally, the particular optic array of the terrestrial environment which is light above and dark below, in correspondence to sky and earth, provides the foundation for an absolute frame of reference within which all other event structure can be nested. Gibson now argues that this fundamental invariant is perhaps the best place to emphasize that his approach deals with real environmental space, which does have an intrinsic polarity, and not with abstract geometric space, which does not. In doing so he hopes to avoid the regresses and hopeless relativism that are implied in discussions of frames of reference in much perceptual literature.

Since *information* refers to variables that are specific to environmental features, Gibson must determine what these correspondences are. Where there are persistent features of the environment such as the substantiality and rigidity of surfaces to be specified, Gibson would want to find correspondingly persistent features of the ambient array (invariant information). Where there are changes in the environment such as motions, there should be changes in array structure (variant information). One should note carefully that specificity and not intuitive similarity is the basis for correspondence. Gibson does not expect the information for motion to be motion or the information for shape to be forms. Rather, in cases where persistent environmental properties are specified, he says that the information is contained in "timeless and formless invariants." Structures defined in terms of adjacent and successive orders of units are the types of things he has in mind here. Interestingly enough, this all follows from the assumption that the ambient optic array has a nested structure. If the point of observation is surrounded by densely packed structured light, then there are no units to move or to form the basis of shape perception. Every change in the array, whether induced by movements of an observer, by motions of objects, by changes in material composition, or by changes in shape must be regarded as a transformation of the *whole* array. To say that an object in the array moves, in the example of motion, would be to presuppose the appropriate decomposition of the array (in terms of figure ground, phenomenal identity, and so forth) which is, of course, the problem to begin with.

Information for self and the world. A central feature intrinsic to Gibson's sense of information that has already been discussed somewhat is that the same transforming optic array not only can specify change and nonchange generally, but also specifies the movements and postures of the observer and the arrangement and rearrangements of the environment simultaneously. Gibson asserts that *all* information has two poles of specification, a "subjective" aspect and an "objective" aspect, as illustrated in Gibson *et al.* (1955) in particular and more generally in all cases of locomotion through a basically stable environment (Gibson, 1958; Lee, 1974). In such cases he has often suggested that the variants in the array specify subjective movement and the invariants specify the persisting environment, although this is a simplification meant more to stimulate thinking than to provide closure. Gibson calls the structure specific to environmental events exterospecific (as opposed to "exteroceptive" which is associated with specialized receptors) and the structure specific to the organism or point of observation propriospecific. These are aspects into which information can be decomposed regardless of its manifest form (although the focus of this discussion has primarily been on information available in optical form). Gibson maintains that information carried in any manner can contain both propriospecific and exterospecific information. Therefore, he sees no need for classifying sensory organs into those specializing in detecting states of the self and those specializing in detecting states of the world. To dramatize the argument against specialized receptors Gibson discusses "visual kinesthesis" as an example of obtaining propriospecific information from light (1958) and a variety of examples of haptic shape perception to illustrate obtaining exterospecific information from the skin-joint system (e.g., Gibson, 1962).

Generalizing the array concept. Throughout this chapter I am following Gibson's practice of concentrating on examples from light and vision. Nevertheless the principles of Gibson's approach require that the full story of perception be told in more than light and sight. The terrestrial world filled with a variety of events contains many different embodiments of patterned energy. What each of these can specify must be investigated just as carefully as light. Thus one could analyze the specifying potential of vibrations in the air (ecological acoustics), of the gases dissolved in air (ecological olfaction and gustation), or of patterns of deformation of the skin and articular stresses (ecological haptics). One should recognize that these are each quite different embodiments of event structures. Various combinations of them co-occur. Each embodiment has its own strengths and weaknesses in terms of the events it can specify. For instance, chemicals in the air do not seem capable of maintaining the kind of persistent detail that reverberating volumes of light patterns do. Opaque surfaces have somewhat different consequences for structuring acoustic vibrations and light. The same world of events should be regarded as simultaneously structuring each of the possible embodiments of information in a specific fashion, but the different capacities of the patterning media themselves constrain the aspects of the world that can be specified in them.

Facts such as these should in turn have consequences for the possible evolutionary design of perceptual systems by nature and their analysis by researchers. That is, no one perceptual system (that is, sense modality) should be regarded as a privileged purveyor of truth in the Bishop Berkeley tradition. Each should be considered as having access to information about the same set of events simultaneously. But each should also be recognized as potentially having special capabilities, strictly as a consequence of what can be specified in light, sound, smell, and so forth. Possessing multiple channels of sensitivity allows observers to differentiate more available information than they could otherwise. In cases where two or more perceptual systems happen to overlap in the information they are obtaining, one should regard this as redundant information and not as a case of enrichment or integration (where the integration implies combining units that were not previously integrated). Thus a cube which is seen and felt at the same time and is identifiable as a cube through either system, is a cube specified in two ways at the same time on Gibson's view. The invariant information specifying the cube is presumed to be sufficiently abstract so as to be identical for both touch and vision. Some properties, however, may be modality specific. For instance, the temperature of the cube is more likely to be available to touch than to vision, whereas the color of the cube is more likely to be available to vision than to touch.

Thus there is no claim that there are not important distinctions. Yet to the extent that the information of interest is that specifying geometrical shape Gibson would assert that it is the same across modalities. In this way the observer, whether animal or human, was designed to conform with the identities and differences that exist in the world of events rather than as an assemblage of message channels which have no meaning apart from the way they are combined (say, as implied in Bishop Berkeley's idea that vision derives its meaning from touch).

The environment. The actual investigations which fall into the area of perceptual research that Gibson designates as ecological optics have one basic goal in common; they have all sought to characterize the geometric structure underlying the most important properties of the world, such properties as rigidity, nonrigidity, occluding edges, shape and size. It is important to realize that finding variables of an array which are specific to environmental structures depends as much on selecting the appropriate environmental structures as it does on finding the correct "higher order" geometric variables. Gibson's stress on the nature of surfaces played this role in his earlier work. Thus an equally important problem for Gibson's general approach is the attempt to formulate a description of the environment that is compatible with theories of every array (optic array, acoustic array, haptic array, etc.) which can contain information about the environment.

From 1966 on, Gibson has begun his account of perception with a description of environments, where by environment he means a description of the physical world which is relevant to the time and space scale of organisms. His careful environmental description is intended to capture the qualities of the physical world which have made the origin and maintenance of life possible. It is also meant to show that the composition and arrangement of substances, media, and the surfaces of their interfaces structure light (and acoustic vibrations, etc.) in specific ways. Thus a substance that is rigid should interact with light in ways that are different from substances that are nonrigid, and these differences may be specific. If an environment specifically structures an array, it is clear that an organism capable of processing this array's structure would be in contact with that environment.

Ecological optics: The current status of research. It is very important to have the overall coherent view such as Gibson is developing, but no matter how plausible or promising it appears, there is no substitute for detailed investigations. Much of the research conducted by Gibson and his followers has been devoted to working out detailed examples of information. For the most part these emphasize geometric analyses of ecologically significant situations intended to discover possible environmentally structured array specificities. They have not emphasized research on characterization of the environment itself. In this respect this aspect of the overall enterprise which Gibson calls *ecological optics* is a continuation of the program begun as perceptual psychophysics and pursued primarily in the search for "higher order variables of stimulation." The overall approach to perception in terms of ecology that Gibson takes is probably best thought of as a metatheory rather than a theory in the sense of offering specific, falsifiable hypotheses. The overall approach and its subcomponents such as ecological optics should be evaluated in terms of their fruitfulness. No one will ever be able to claim truth or falsity for it. However, the work conducted within a subspecialty such as ecological optics is full of testable and tested hypotheses. Some of the key steps have been taken by the following investigators: Gibson *et al.* (1955) whose work has already been discussed; Purdy (1958), who worked out an analysis of the correspondence between gradients of texture and surface slant; Hay (1966), who showed that the changing pattern or the shadow of an arbitrarily moving rigid plane surface was specific to the shape and slant of that surface; Farber (1972), who extended Hay's work by investigating a special case where the magnified projection of a rigidly rotating plane specified a nonrigid motion; Sedgwick (1973), who showed the power of the terrestrial horizon to specify the size of objects seen against it; Kaplan (1969), who investigated the role of the progressive appearance and disappearance of texture in specifying the occlusion of one *opaque* surface by another; Mace and Shaw (1974), who investigated the role of translatory symmetry in specifying the perception of one surface through another (transparent "depth"); Lee (1974), who provides a mathematical description of the optical flow pattern afforded a moving observer showing the existence of both exterospecific and propriospecific information; John Pittenger who, with Robert Shaw (this volume), showed that the perceived age of faces can be explained in terms of a "remodeling" transformation belonging to a special geometry for nonrigid shapes. Only when specific proposals such as those in these studies can be made is it possible to construct and control stimulus conditions for perceptual experiments to see if particular organisms actually use the available information or not. The studies conducted with the information defined in the above work have generally shown excellent results, but none have established open-and-shut cases. They should be seen as decisive groundbreaking operations opening the way for a great deal of constructive work on many fronts in the future.

FIVE WAYS TO HAVE A THEORY OF INDIRECT PERCEPTION

Throughout most of his career a tenet of Gibson's has been that perception must be *direct* rather than mediated by memory, inference or any other psychological process. It has seemed apparent to him that only a theory of direct perception can do justice to the facts of evolution and adaptive behavior. Yet the construction of such a theory cannot proceed by fiat. As I have tried to show, a coherent theory of direct perception must have a broader scope than merely trying to model the mechanisms of perception. It must recognize that a theory of environments and a theory of the patterns of energy created by environments are just as much a part of a complete theory of perception as are theories of what organisms do. Once it is explicitly recognized that these are all mutually dependent components of perceptual theory, then they can be developed in compatible ways. Only as they are developed in compatible ways can direct perception make sense. I suspect that much of the consistent criticism Gibson has received for holding a direct theory of perception (e.g., Gregory, 1972; Gyr, 1972; Johansson, 1970) stems from not recognizing how thoroughly comprehensive such a theory must be. To further clarify the multiple foundations of Gibson's direct perception, let us examine what theorists seem to have meant by indirect perception. Contrary to the dichotomy implied in the direct–indirect contrast, there seem to be at least five common grounds used to support the claim that perception is indirect. Holding any one of them would be sufficient to make a person an indirect theorist. Consequently, to hold a direct position such as Gibson's requires an alternative to each one.

What Structures Can Count as Stimuli?

Any theory of perception presupposes some set of structures that are detected by the perceptual processes rather than constructed. Early theorists claimed that perception was based on point sensations in a frozen moment of time. Currently more complex entities such as oriented lines are being proposed as directly detectable structures. Since perception results in the experience of events that are spatially unified and exist continuously over time, a theory whose basic structures of stimulation do not have these qualities must interpose compounding or constructive mechanisms to build unified percepts. This integration of substructures is an intervening process thought to be different from the end result of perceiving. Such an approach represents one way that a theory of perception can be indirect. Helmholtz (1925) was quite explicit on this point: "*A direct image* of a portion of space of three dimensions is *not* afforded either by the eye or by the hand. It is only by comparing the images of the two eyes, or by moving the body with respect to the hand, that the idea of solid bodies is obtained [p. 23; italics added]."

Gibson, on the other hand, holds that such a "piecing-together" description of stimulus processing is not necessary because structure in the stimulation itself consists of spatial and temporal relationships. For him, structure is patterned discontinuity in an array. Thus a pattern of regularly appearing or disappearing texture relative to some point in the environment can be thought of as an instance of structure in the optic array defined over time. Such regularities or invariants which are defined only over change are common in mathematics, being at least as old as the derivative, and should not be ignored in descriptions of stimuli available for perception. It is important to realize that Gibson's definition of structure is sufficiently abstract to apply to media other than light, indeed, any medium that can preserve any pattern of discontinuities over time. Since order and change of order are not modality-specific characteristics, Gibson's definition makes it possible to say that the same stimulus structure is equally available to several senses. For example, the adjacent order of the vertices of a cube are an obvious aspect of its physical structure. This physical adjacent order will produce corresponding adjacent orders both in the pressure patterns to a hand that grasps the cube and in the light patterns to an eye that looks at it.

From the viewpoint of Gibson's dynamic approach to stimulus analysis, the observation that organisms perceive events structured over time no longer provides sufficient reason to conclude that perception is an indirect, constructive process which adds a dimension of temporal integration not to be found in raw impinging stimuli. Since dynamic structures may count as stimuli, perceptual processes using them may be referred to as *direct detection processes,* which occur over time because the stimuli being processed are defined over time. Thus, Gibson has overcome one obstacle to a direct theory of perception, or the notion that givens or data are momentary slices in time, by changing what can count as structural givens in stimulation to include regularities of change.

A consideration of current single cell "detector" mechanisms may help to dispel the notion that Gibson's ideas about direct response to complex relationships are abstract speculations that cannot be physically realized.[1] The perceptual apparatus of amphibians and mammals is somehow constructed so that certain central cells respond to relationships that are defined in terms of space (line detectors) and in terms of space–time (motion detectors). Their existence is thoroughly documented. Recently, Gross, Rocha-Miranda, and Bender (1972) have reported "monkey paw" detectors in the inferotemporal cortex of *Macaca mulatta.* None of the investigators in these areas seems to have felt a need to explain the action of such cells by referring to comparisons of current input with stored images or integrating momentary images over time with constructive operations. Detector cells should be considered to be examples of physical systems which are organized ("tuned" in Gibson's terminology) to give specific responses to specific relations in light. These detectors do not, of course, prove the existence of mechanisms that respond directly to the more complex relations that Gibson discusses. However, the single cell work does provide an analogue to Gibson's notion of direct perception of structured events, which in turn makes the idea plausible and shows that it cannot be dismissed on a priori grounds.

Does Information Exist?

As already discussed, stimulation is said to contain information if its structure is specific to the environmental sources of that structure. Only if stimulation contains such specific structure could it specify its sources, and only if it specified its sources could the detection of such structure be said to be direct perception of these sources. The possibility of direct contact with an environment thus depends heavily on the existence of information in Gibson's sense. Indeed, ecological optics, the theoretical and empirical investigation of the information available in light has occupied most of the time of Gibson and his students. If information in Gibson's sense did not exist, then intervening steps in perceptual processing such as hypothesis constructing and testing are necessary. Assuming the idea that the structure of stimulation does not specifically

[1] The observations in this paragraph are primarily those of John B. Pittenger, Department of Psychology, University of Arkansas at Little Rock.

correspond to any of its sources, then, requires that perception be indirect. Gibson has avoided this lure into mediation by developing his concept of information.

The Senses Considered as Perceptual Systems

Traditionally the "senses" have been regarded as separate input channels funneling messages to a central processor which must compare the inputs coming in from each in order to make unitary decisions about the current state of the world. To the extent that perception is a product of putting together these messages from separate channels, perception must be regarded as indirect or constructive. Richard Gregory (1969) has suggested that perception of visual patterns is indirect because "what matters is whether the object is useful, a threat, or food. It is non-optical properties that are important [p. 245]." And later he asserts: "To build a seeing machine, we must provide more than an 'eye' and a computer. It must have limbs, or the equivalent, to discover non-optical properties of objects for its eyes' images to take on significance in terms of objects and not merely patterns [p. 246]." In other words, our skin and body have certain privileges not enjoyed by the visual system—namely that patterns of deformation of the skin created by objects and patterns of muscle movements created, say, by walking toward an object are directly meaningful.

This view goes back at least to Bishop Berkeley and is apparently forced by the assumption of meaningless punctate stimulation for vision. Interestingly enough it is not supported by a shred of empirical evidence or coherent theory. For instance, if one arranges conflicts of information available to various modes of attention, the conflicts are always resolved in favor of vision (e.g., Pick, 1970). Or imagine some of Gibson's favorite key cases, a fish swimming upstream or a bird flying against the wind. How could nonvisual criteria such as effort expended or muscles recruited have any effectiveness for guidance in these cases? Could it really be very convincing to try to account for these kinds of phenomena by saying that somehow organisms learned to trust vision gradually after first not trusting it? How could this work? It is really quite difficult to see why the pupil would always outstrip its teacher in perceptual conflict situations. What would guide such a shift of control?

For Gibson, the difference between meaningful and meaningless stimulation has nothing to do with whether or not stimulation across modalities is integrated. As described above, there is information differentially available to the various sense modalities. Hearing is better than seeing when one is interested in events taking place behind a nearby opaque surface; though seeing is certainly better than hearing in determining the opacity or shape of a surface. Touch is clearly better at perceiving temperature differences. And so it goes. Rather than having these be isolated systems to correlate, however, Gibson would have each of these modes of attention (each of which has the motor resources of the body available to it) sampling the same structured world. When they are sampling the same events, there would rarely be contradictory information—though the information could be richer as suggested in the examples immediately above.

In summary, for Gibson, the senses operating as perceptual systems are all sensitive to information about the entire environment. Each mode of attention has its own special capacity for detecting information but these specialties reflect the nature of the embodiment of world structure as well as the nature of the detecting system.

Affordances

Gibson's concept of affordances, that is, information specifying the adaptive value of objects or events for organisms, is an important result of considering the senses to operate as perceptual systems rather than uncoordinated sensory channels. (See Gibson, this volume.) As indicated above, Gregory and others often seem to give special status to nonoptical stimuli. From Gibson's viewpoint these arguments are seen to rest upon a very narrow set of examples that ignore the important role of visual perception in survival and adaptation. Although it is true that no organism has ever been killed or maimed by a purely optical event, say by just seeing a club swung, successful avoidance of harm may require seeing it swung in time to dodge. Try hiding in a glass phone booth to avoid being seen by a mugger or using a cellophane fig leaf to avoid public embarrassment. Consider the indispensable role of optical information for transparency (e.g., in seeking water), opacity (e.g., in avoiding bumping into objects), coloration (e.g., in selecting ripened fruit) and patterns (e.g., in using camouflage to avoid predators) before accepting Gregory's or Bishop Berkeley's exclusive appeal to nonoptical properties of stimulation in order to give meaning to visual information. Indeed the felt effects of being caressed, kissed, clubbed or burned derive as much meaning from seeing the initiating source as the proper interpretation of the source depends upon its felt effects. Full meaning of such events arises from the systematic coordination of all sense modalities. This coordination is made possible by the fact that the spectra of energy forms appropriate to each sense modality have a source (the object or event) which possesses a unitary structure as von Hornbostel (1927) so well knew.

Gibson's notion of affordance not only allows one to describe the environment from a point of observation, but does so with respect to a particular observer, taking into account the observer's size, form, and capabilities. Affordances constitute a partitioning of an environment with an organism in mind instead of, say, the more neutral partitioning of the environment of energy flux into observer-independent properties by classical physics.

Some typical examples of affordance descriptions of environmental properties are walk-on-ability, grasp-ability, injury, collision and nutrition. One says that environmental properties *afford* the above activities; for example, a coffee cup at room temperature affords grasping by humans. Although defined relative to an organism, affordance relations exist independent of conscious experience or any subjective states of an organism. A persistent surface which is strong enough to hold the weight of an animal can be said to afford support for it whether the animal is in a state of realizing it or not.

Without this concept one could say that even if Gibson's position on the previous three points were accepted, perception of the world could nevertheless be indirect because an organism detecting Gibson's higher order invariants would still have to make a connection between those invariants and properties of the world which were useful to him. Not only would there be this step, but there might also be a step from a property to what the organism could do with it. For example the animal might have to connect the invariant structure of a perceived pattern with a property such as "hardness" or "opacity" and then from these infer what activities it can perform. The concept of affordance makes the last step unnecessary. It says that "hard" and "opaque" are no longer the descriptions of any properties whose invariants we're seeking. Rather we are seeking optical structure (where vision is concerned) that corresponds to what can be seen through, hidden behind, hammered with, and the like. An affordance partitioning of the world would be very different from one based on "properties" defined with respect to events that do not involve organisms directly.

A full appreciation of what is entailed in an affordance analysis also removes the need for talking about the other "step" in perception, that from computing the input structure to finding the environmental property to which it corresponds—even where the environmental property is expressed in affordance terms. This is the step in Gibson's direct perception theory which is hardest to comprehend and even harder to accept. Johansson (1970) expresses typical reservations. He argues that there must be some kind of code allowing the organism to infer the nature of the world around him from the structure in the light which he detects. A more internal threat to the coherence of the theory of direct perception which I will deal with sneaks in through Gibson's typical examples of affordances. Take "graspability." To say that an organism sees the graspability of an object could imply that it had to make a cross-modal correlation à la Gregory and lead right back to a version of constructive theory.

Both of these possible Trojan horses can be dealt with through a more careful consideration of what a thorough affordance description of an environment would look like. Instead of "senses" Gibson speaks of modes of attention. Let us examine vision as a mode of attention relative to which affordances can be described. By sticking to one mode of attention I hope to avoid raising the issue of cross-modal correlation for at least a little while, since it is something of a red herring.

Imagine an organism in an open field looking to the horizon. The optic array consists of a light upper portion and a darker lower portion, the sky above and the earth below. The gradient of the earth's texture can be thought of as specifying what optical transformations are afforded in this particular optic array for this particular organism with its size, shape, and exploratory capacities. In such a case, all optic array transformations obtainable by displacement would be specified. Suppose there was an indistinct object near the major light–dark transition in the array (the horizon). How might the visual system magnify part of its optic array so as to clarify the indistinctness and to identify the relative permanence in the overall structure? By using its legs, of course!

This type of description can be used to illuminate what Gibson means by perceptual systems as well as affordance structure. For him, vision is a system capable of actively exploring the environment precisely because it is a subsystem of a more complex system, the human body; as a subsystem evolution has attuned vision to work in a well integrated fashion with other subsystems (for example, the motor system). In this sense it is the whole organism which "sees" and thus which can use its legs to carry out visual investigations of the environment. The whole body can be mobilized in the interests of visual exploration and, for Gibson, counts just as much as a part of the visual system (when being used for visual exploratory purposes) as the eyeball itself. From this point of view, it is to be expected that so-called motor sections of the nervous system should be involved in perceiving. It should also be expected that careful consideration of the motor nervous system would ultimately equivocate on the very existence of a firm distinction between the motor and sensory aspects of the nervous system when considered with respect to perceiving. (See Turvey, Chapter 9, this volume.)

When Gregory said it was nonoptical properties of the world that really mattered, he did not consider whether or not there might be specific optical correlates for the events he had in mind. Expanding stimulus patterns which specify looming objects, for example, could again be considered from the optical viewpoint as well as from the point of view of mechanical contact with the skin. Thus one could say with justification equal to Gregory's that a symmetrically expanding pattern which fills the entire visual field is one to be avoided. Surely it makes at least as much sense to say that the *optical* event which specifies collision should be avoided as to say that the *tactile* events corresponding to collision are what the organism is avoiding (in the cases where it actually does avoid the potentially injurious event). Indeed, there is evidence that animals will attempt to avoid optical looming, as if experiencing the imminence of an impending collision, although no tactile stimulation is possible (Schiff, Caviness, & Gibson, 1962). Information for occluding surfaces, supporting surfaces and open vistas is information for possible paths open to the visual system for clarifying the optical structure of the environment. Thus, a very rich partitioning of the whole environment can be referred to an affordance analysis of vision alone (or any other mode of attention).

Second-Hand Perceiving

A fifth sense of indirect perception is a literal one which Gibson himself has often discussed—seeing at second hand, as in pictures. When one looks at a photograph or a representational painting or a movie, one is looking at a segment of someone else's optic array. Though sharing some similarities with a natural optic array, these displays are not the same as a full optic array, and, therefore, cannot be explored in the same ways. They do not contain all of the same information and, consequently, should be analyzed separately. This is not to say Gibson is not interested in such forms of indirect perception. In fact he has written often about the problem of perceiving pictures (e.g., Gibson, 1971) and certainly has no prejudice against the study of indirect perception when it is construed as the perception of someone else's view. Obviously interest in this problem in no way compromises his belief in the notion of direct perception.

On the other hand, the belief that the retinal image is the stimulus for vision would indeed make perception indirect. If what is really perceived were the retinal image projected from the world rather than aspects of the world itself, then perception would be second hand, and hence indirect; moreover, under this view seeing a picture would be an account of how one normally sees the world instead of being just an account of a very special case of seeing, as Gibson would have it. Gibson's objections to the idea that we see the world by means of retinal images are numerous. Here are five:

1. An observer for the image is implied and this observer's perception must be explained. Such homunculus explanations lead to infinite regresses.

2. No theory is provided to explain what aspects in the organization of the image are sufficient to account for visual perception. All an image can account for is the fact that some organization from the world is faithfully mapped on to physiological structures. Since this organization, whatever it might be, must be further mapped throughout the nervous system, all that is asserted is a causal chain. There seems to be no compelling reason to claim that the "ultimate perceiver" of the nervous system is in any more direct contact with the retinal image than with the patterns in the environment. Thus, the so-called "mind–body" problem raises its ugly head.

3. One gets into hopeless muddles with respect to problems of orientation. The image is often referred to as upside down or left-right reversed. But such judgments must be made with respect to some frame of reference. The ultimate frame of reference of earth and sky cannot change in normal perceiving. They cannot be upside down. Yet when considered as a picture in the head which is upright in the world the image is upside down. Many theorists have taken this to indicate that the world should be perceived as upside down. That is part of the retinal image-as-stimulus assumption. However it assumes that the observer is well-oriented in order to notice that the image is inverted. Although Gibson does not claim to have a fully articulated theory of what happens in optical inversion experiments, he is nevertheless quite sure that reference to the retinal image is not helpful (compare Gibson, 1964, for a discussion of Kohler's prism studies):

4. There are organisms such as the horseshoe crab which functionally perceive and appear to be sensitive to much the same information that is detected

by other organisms (Schiff *et al.*, 1962), but they have no retinal images because they have no retinas.

5. One never supposes that there are auditory or haptic images which are the real objects of perception. One does not say that the skin is in indirect contact with substances it touches. Gibson sees no reason why variant and invariant information and their detection should not be thought of as examples of the same types of decomposition process in each mode of attention. (An excellent philosophical argument against claims that images are the direct objects of perception may be found in Austin, 1962.)

Above are five different ways that an indirect theory of perception might be held. There are surely more. However, these points illustrate that Gibson's view that perception is direct apprehension of many important aspects of the environment is a reasonable alternative to the indirect view which is fraught with logical weaknesses. On the other hand a proponent of any of the indirect positions bears the considerably heavier burden of showing how such a view is compatible with both evolution and adaptive behavior.

CONCLUSIONS

In my opinion, the fruitfulness of Gibson's research project is well established. Insofar as it has been based upon a direct theory of perception this provides a strong argument that such a theory is both logically consistent and empirically sound. However, though thoroughly sketched now, the approach is far from complete. It should be recognized that what Gibson said of his psychophysical theory in 1959 is also true of his current ecological theory:

> The theory offered is immature in the sense that the program of investigations called for has only begun. It is also immature in that its potential scope seems to be wider than the scope of the problems to which it has been applied.
>
> . . . The theory has been extraordinarily fruitful in suggesting to the author hypotheses for experiments and in opening up new ways of experimenting on old problems. The important question is whether it will serve the same function for others [Gibson, 1959, p. 499].

A full appreciation of Gibson's theory requires a careful review of over a quarter of a century of work. Nothing less suffices to give a clear picture of the breadth and depth of his thinking about the most difficult problems in the theory of knowledge that psychology must face. His work is truly a significant exercise in experimental epistemology. There can be no doubt, however, that many of his views are quite radical, strikingly so if we look at Koffka's statement of the problems of perception. He asked "Why do things look as they do?" After rejecting as utterly ridiculous the answer "because they are what they are," and as reasonable but wrong "because the proximal stimuli are what they are," Koffka settled on an answer appealing to organized brain processes set up by proximal stimuli. In his psychophysical program, Gibson showed that by reconceiving the stimulus structure one could make a good case for the second of Koffka's answers. One might say "things look as they do because the proximal stimuli are what they are—we just looked at the wrong proximal stimuli." But now, with his ecological program, reconceptualizing the physical environment as well as the stimulus, Gibson is suggesting that what was utterly ridiculous might be true. We may be able to change Koffka's question to the stronger "why do things look as they *are*?" and seriously answer "because they are what they are."

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