The Problem of Event Perception

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(Preliminary draft, not yet for publication)

The first difficulty in formulating the problem of the perception of events is to decide what is to be meant by an event. After that we can go on to study the activity of an observer in perceiving one, and distinguishing it from others. For this, we have to analyze the stimulus information that is available to an observer, formulate hypotheses about the process of perception, and finally test them with experiments that provide stimulus information.

The defining of an event for purposes of studying perception involves several questions about which psychologists have not been clear. First, we are surely concerned with physical events in some sense of the term, not mental events. Only the former are relevant to perception. But are we concerned with all physical events including those on the cosmic and the atomic scales or only those on the terrestrial scale? Next, we must surely include behavioral events, but where do we stop? Should we exclude events in the nervous system and the brain? The locomotor acts of animals are events for perception, very significant events, but then we must ask whether an act of locomotion by the observer himself to be counted as an event for perception? It is obviously different from an act of locomotion by another animal. Finally, we must try to get clear about the relation

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of *motions* and events so as to decide whether or not events are composed of motions.

Physical Events and Ecological Events

We are concerned with the problem of perception, not with the much larger and more difficult problem of scientific knowledge. Human adults can know about astronomical events, chemical events, and even atomic events but what they perceive directly is terrestrial events. Animals do not have scientific knowledge and children have to be taught it. What we all share is the ability to detect objects of moderate size and events of moderate duration--those that occur in seconds, not microseconds or eons. Knowledge of ecological events by the child precedes knowledge of physical events in general by the adult. What happens in atomic lattices, test tubes, and the universe is, to say the very least, *harder to see* than what happens in the environment of animals.

To put the matter radically, physics cannot go from a universe of atoms to a world of surfaces without a conceptual leap that physicists avoid thinking about, but that biological scientists cannot afford to neglect. The consequences of this neglect will be evident later.

The evolution of perceptual systems sets limits to what animals can apprehend directly. These systems incorporate receptors that have to be stimulated. The perceiving of ecological events depends on stimulus information obtained through eyes, ears, and fingers that are directly affected by ambient light, sound, and contact, whereas the knowing of "physical" events depends on information at an entirely different level, obtained indirectly with instruments or by experiment, and still more indirectly by means of pictures and language. We are concerned with ecological events.

Behavioral Events and Physiological Events

Animals and men perceive the behavior of other animals and other men, what we loosely call their "movements," but not the muscle-contractions, and certainly not the nerve-impulses, that underlie the behaviors. The movements of limbs, the deformations of the body, and the transients of vocalization are observable without the mediation of instruments. These have been called "molar" as against "molecular" behavior; they are activities of an organism at the ecological level of size and duration, measured in centimeters and seconds, not in microns or miles and not in microseconds or years. Animate movements include changes of posture, orienting responses, manipulations, "expressive" movements, and movements of the animal from place to place, that is, locomotions.

Is a behavioral act of the observing animal to be considered an event for perception, for example, his own locomotion? He is certainly aware of this kind of molar behavior by virtue of all the kinds of sensitivity called proprioceptive, but is it an event for perception? This question has led to endless debate in psychology and philosophy over "private" perception, so called, vs "public" perception. Confusion can be avoided, I suggest, if we discard the orthodox idea that proprioception is one of the senses and acknowledge that it is an accompaniment of perception--of all perception (Gibson, 1966, Ch. 2). I take the word to mean "awareness of self."

The fact is that movements of the observer himself have to be allowed for in order to understand his perception of the environment. At a minimum, even without gross responses, a perceiver has to orient his trunk, head, and eyes, making a series of adjustments and maintaining the posture of these body-parts, in order to see the world at all. Otherwise he is asleep. Hence one cannot be aware of the stream of events in the world without having at least some awareness of the stream of events in the body.

In the event of locomotion men and animals do see their own displacements in the environment as well as the displacements of objects and other animals, although it is surely a special kind of seeing. The two kinds of displacement are never confused--or almost never. The distinguishing of objective motion and subjective movement (Gibson, 1954) is an old puzzle for the theory of perception but the solution may prove to be simpler than has been supposed.

The Relation between Motions and Events

Since Newton discovered the laws of motion and laid the foundation for mechanics, physics has concentrated our attention on the motions of rigid bodies, translations and rotations along or around any of the axes of space. This analysis worked beautifully for falling bodies and machines with rigid parts and, what was most impressive, the science of mechanics could be extended up to the celestial and down to the atomic scale. The perceptionist, however, confines himself to mechanical events on the intermediate scale. But he cannot limit his concern to these only for he must also consider biological events, which are in general fluid or visco-elastic motions of surfaces. When a substance flows, stretches, contracts, bends, turns, twists, writhes, or in general deforms the ecological occurrence is usually significant and needs to be perceived. But mechanics or kinetics does not work so well in this case.

Whenever it can, physics reduces non-rigid motions to the component rigid motions of particles because of the powerful mathematics that can be applied to the latter. When events can be reduced to motions and motions can be analyzed into quantities of space and time proofs are possible. We are told that "anything that exists exists in some quantity," and the perceptionist is urged to quantify the stimuli he takes into the laboratory so as to fulfill the requirements of scientific method. Most psychologists have dutifully tried to do so, including the writer. But I am now convinced that this analytic reduction is hopelessly inadequate to define an ecological event. It does away with the features of an event that enable it to be perceived.

The necessary characteristic of an event, I propose, is that it has a beginning and an end. But this is not necessarily characteristic of a motion. The term motion is ambiguous; it can refer either to a displacement that starts and stops or to the amount of displacement per unit of time. The former is a fact, the latter an abstraction. One is an event but the other is only a velocity. Since uniform velocity does not occur in nature (uniform "motion" as Newton put it) we postulate instantaneous velocity, ds/dt, for purposes of analysis, and then go on to postulate second and third derivatives, and so on. If we need to analyze the rotary motion or spin of a body we do the same thing using units of angle instead of units of displacement. The beginning and the end of the displacement (or turn) have vanished from the analysis. Calculus fails to describe the beginning and the end of the occurrence. In differential geometry the structure of the event disappears.

Perceptionists have tried to determine the threshold for perception of velocity, the barely noticeable speed of an object or a moving belt (Spigel, 1965; Gibson, 1968). The efforts have failed. Observers can see a displacement or an occlusion but when they try to see a pure velocity an event or a series of events takes its place. There will be more of this later. If I am right there is no threshold for detection of velocity, or of any derivative of motion inasmuch as beginnings and ends, transients, events, have to exist for any perception to be possible.

The flow of liquid or viscous substances, as I understand it, is never perfectly uniform and continuous. Events arise like shearing, overtaking, deforming, and vortex formation. The ideal but nonexistent river whose parts all move with the same velocity throughout all time is nevertheless the metaphor we use when we refer to the "flow of time."

Space and Time; Environment and Events

It should have been clear long ago that there is no such thing as the perception of space but only the perception of environmental layout. Similarly there is no such thing as the perception of time but only of events. Physics and mathematics begin with empty space, three reference axes, the dimension of time, and bodies that move. Biology and psychology, on the other hand, must begin with an environment, a medium, and surfaces (solid, viscous, liquid) that undergo change. We are tempted to think of the medium, air, as being space but this misleads us. Part of an environment is transparent and part of it is opaque whereas geometrical space is everywhere transparent; its lines and planes do not hide anything that lies behind them, as edges and surfaces do.

Physics geometrizes the world, for mathematical reasons that have been suggested. Biology and psychology, however, cannot do so without losing hold of their basic concept of the terrestrial environment. Mathematical physics goes so far as to geometrize the already pure dimension of time itself, in the interests of understanding the universe. But this would be a compounded mistake for biological science since it would leave us with nothing whatever to be perceived--neither environment nor changes of the environment. This tendency in physics has been deplored by Whitrow (1961) in a book called The Natural Philosophy of Time.

The notion of environment implies some solid portion that is persistent, the "permanent" terrestrial layout, and some portion that is not, the changing layout. The medium, where animals can move about, is filled with illumination (to say nothing of sounds and odors). There are loci in the medium at which an animal could be positioned, and these loci are rather different from the points of geometrical space. They are potential points of observation, with a specific optic array at each point. The set of all these loci constitute the possible paths of locomotion for a single observer and also the positions that could be taken simultaneously by a host of observers (Gibson, 1966, p. 192). This is why the concept of environment is neither "subjective" nor "objective"; it implies the surroundings of any single observer and those of all observers, without contradiction. The possibility of locomotion by observers must be assumed. This is the heart of ecological optics as distinguished from physical optics (Gibson, 1966, Ch. 10) and this is the basis for an explanation of how an animal sees his own locomotion in a stable environment and distinguishes it from the displacements of objects and the locomotions of other animals.

An environment as thus defined is distinguished from a chaoc, where there is no stable surface of support and where either clouds of matter continually deform, or bodies in space move in random fashion. Animals could not live in a chaos.

A Classification of Ecological Events

Having decided what is to be meant by an event, a tentative classification is possible. If an event is something with a beginning and an end it can be repeated; an occurrence can recur. A sequence of events then exists. A very familiar kind of sequence is of identical events, such as the swings of a pendulum, the revolutions of a crank, or the oscillations of a floating cork. A sequence has a frequency and a frequency, unlike a velocity, can be perceived. Moreover it can be perceived directly; the segregated events do not have to be counted by the observer. For this direct perception, the frequency cannot be too high or too low. The rate of occurrence of "steps" when a man strolls, walks, or runs is visible (also audible) and this, not his speed, is what we perceive. In order to perceive speed one would have to sense units of abstract time (like seconds) and units of abstract distance (like centimeters) and then compute it. One would have to perceive "space" and "time." But there are no natural units of space except the components of a surface and no natural units of time except events.

In the laboratory experiments on the perception of velocity mentioned above, using a moving belt behind a window (the "waterfall" apparatus) or an object rotating in front of a surface, what the observer detects, whether he knows it or not, is frequency--the frequency with which the parts of one surface hide and reveal the parts of the other surface. And when we judge the "speed" of an automobile we are probably detecting the frequency with which its edges occlude the trees or bushes of the background, or the squares of pavement (Gibson, Kaplan, Reynolds, and Wheeler, 1969). I am suggesting that the visual system contains nothing analogous to a speedometer but that it might have something like a tachometer without a scale.

The events of a sequence need not all be identical, of course, like oscillations or waves or cycles. At another extreme the events of a sequence may be all different, as when an experimenter presents an observer with a series of nonsense syllables to be "remembered," or a series of unrelated pictures. Metronome beats or light flashes are cases of pure repetition and nonsense items are cases of no repetition but neither is characteristic of natural sequences. Environmental sequences commonly have cycles imbedded in longer cycles, that is, <u>nested</u> events.

Consider the events in speech or music or pantomime or ballet (or in the sexual courting behavior of animals, for that matter). There are some different events and some similar events in the sequence. There will be shorter events that make up longer events and these making up still longer events. All are units of a sort, in the way that syllables, words, phrases, sentences, and discourses are units. Units are nested within other units. And the remarkable fact is that both the superordinate and the subordinate events can be perceived.

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Note that in a structured sequence of this sort there is no fixed frequency, for beginnings and endings depend on the duration of the event we select for attention. The number of discrete events <u>cannot be counted</u>. Hence a numerical "span" of apprehension or memory is not to be expected.

Can a continuing process like the flow of a river be treated as a sequence of events? A perfectly uniform stream does not exist, I argued, and even if it did it could not be perceived. A real river has different velocities in different parts with vortices that begin and end, and with ripples and bubbles that come and go. Deformations are perceived although velocities are not. A deformation is probably an event (although I am not sure of this. But I think that a deformation must have an end.).

The behaviors of animals are visco-elastic events, as was suggested, with beginnings and ends, although they occur in nested sequences. An example of a unitary event is the "expressive movement" of the human face, as in smiling or frowning. The overall shape of this surface, or surface layout, is composed of subordinate shapes, called features (forehead, eyes, nose, mouth). There is a deformation of the overall shape and of the component features, consisting of a departure from the normal layout and a return to the resting state. The specific event of smiling or frowning has meaning by virtue of the fact that it is imbedded in a particular sequence, a longer event that constitutes a course of action. As we have already argued, the psychologist cannot afford to reduce the facial expression to muscle-contractions.

In contrast to these biological events are the mechanical events of the environment. There are the rigid motions of levers, wheels, cranks, slides, rollers, rockers, pendulums, gears, pinions, escapements, screws, hinges, pistons (and sometimes the non-rigid motions of springs). Each of these so-called motions is an event. When the parts of a complex machine are assembled there will be a nested hierarchy of parts, with sub-assemblies, and when the machine is running there will be a nested hierarchy of synchronous events. (Note that this latter is quite different from the nested hierarchy of sequential events found in the behavior of animals, and in speech, music, and the theater. The machine does not exhibit sequential nesting; it does the same thing over and over in a repetitive way.) The combination of subordinate synchronous motions into a superordinate motion when a complex machine is running is the basis, I think, for what Johansson has called "configurations in event perception (1950)."

Finally, a class of events should be mentioned that might be called changes of state as contrasted with changes of shape, layout, or position. When a substance undergoes evaporation, sublimation, diffusion, vaporization, crumbling, or breaking, a surface is destroyed and when there is condensation, crystallization, or biological growth a surface comes into existence. At the particle level, to be sure, nothing is destroyed and nothing is created. But at the ecological level objects can and do go out of and come into existence (Gibson, Kaplan, Reynolds, and Wheeler, 1969).

This kind of ecological event must be sharply distinguished from the kind when objects go out of sight and come into sight but have permanent existence. We tend to confuse them because we use the loose terms <u>appearance</u> and <u>disappearance</u> for both. But to use these terms is to confuse the objects of the world with the projection by light of the objects in the world. A fixed object that is concealed at one point of observation is revealed at another. An observer who moves so as to get the object in sight does not see a <u>new</u> object but only a newly <u>revealed</u> object. Locomotor occlusion and its inverse are thus a kind of optical event but not a physical or material event. I call it an optical transition. The transition involves self-reference as well as object reference, like the going out of sight of one wall of a room and the coming into sight of another when an observer turns his head. There can also be occlusion without locomotion or head-turning, of course, when one object goes behind another (Michotte <u>et al</u>., 1964). The displacement of the object is then a true ecological event and the occlusion is an optical transition. In short ecological <u>events</u> must not be confused with the optical <u>transitions</u> in an ambient array. The events may be <u>specified by</u> the transitions but they are by no means the same kind of thing. We have long confused them because of a false analogy between physical "motions" and optical "motions," and paid for the mistake with wasted efforts.

The Optical Information for Event Perception

The next step is to ask what changes of the ambient optic array correspond to ecological events? These changes constitute the available information for perceiving events. It should be kept in mind that an optic array at a fixed point of observation consists of units like bits of optical texture, projected forms, and superordinate forms, in a nested hierarchy. All these components of an ambient array will be called "units" even though they may vary in angular size. They are the projections of the adjacent facets, faces, and surfaces of the environmental layout to a point of observation. (The void of empty space, the blue sky, does not provide any optic array.) It is taken for granted that a changeless optic array, one with a "frozen" structure, arises from and specifies a stationary point of observation in a world without events, a fixed observer in a fixed layout. When we speak of a changing optic array we must refer both to the persistence of its component units and to the possible lack of persistence of these units. (Astronomical motions thus do not provide a changing optic array.)

The general hypothesis is that ecological events are specified by disturbances in the optic array. A change, mathematically speaking, can be either of two kinds, that which preserves one-to-one mapping of elements and that which does not; a disturbance here refers to the latter kind. It is a change that entails loss or gain of some of the adjacent units in an array, that is, a disturbance in the persistence units. This is to be distinguished from a disturbance in the adjacent order of persisting units, which will be discussed later.

This hypothesis is quite different from previous hypotheses about change in the optic array. It does not refer to the motion of units (certainly not to the motions of stimulating light-points) nor even to the relative displacements of units in the array. It does not even appeal to the transformations of units considered as forms or point-sets, since all these changes imply one-to-one sequential correspondence of elements. It says that neither "optical motions and transformations (Gibson, 1957)" nor "continuous transformations" of any sort (Gibson, 1968) are adequate to describe the information for event perception. It is simply not the case that each unit of a stationary array goes into a corresponding unit of a subsequent array except in a special limiting case. Unhappily, then, neither the axioms and postulates of projective and perspective geometry nor the powerful mathematics of analytic geometry are sufficient for our purposes.

The general hypothesis of "disturbances" in the optic array has a number of underlying assumptions which I will try to make explicit.

1. It is assumed that the environment is not a chaos but has a relatively permanent layout in large part. The ambient array from a chaos would have no persistence of its component units or mapping of successive arrays. It would resemble what we call scintillation.

2. It is assumed that the surfaces of the layout are never wholly transparent, and that the layout is never wholly "open" but always more or less "cluttered." The ideal example of an

open layout is a flat terrain with no occluding edges out to the horizon, and this is the limiting case analyzed by Gibson, Olum, and Rosenblatt (1955) in which continuous gradients of optical flow occur during locomotion. Another example of the limiting case is a closed bare room, without apertures or furniture. All faces and facets of the layout are then projected to all points of observation. But in actual cluttered layouts there exist what we call "objects," protuberances or detached bodies, that occlude some parts of the layout at some points of observation. The world in general is full of occluding edges. This means, parenthetically, that my attempt to explain the perception of surface layout in terms of continuous optical gradients (texture-density, flow, disparity) is incomplete (Gibson, 1950). What needs explanation is the perception of cluttered as well as open layout.

3. It is assumed that all terrestrial displacements of objects, all visco-elastic events, all mechanical events, and all changes of existence, in fact all the events listed in the previous section including subjective movement and locomotion occur with reference to the permanent cluttered layout, especially the background surface, and therefore entail change of occlusion. When an object is displaced it occludes the background and when it turns it occludes its own back. When it goes behind a part of the layout its surface is occluded by the "frontground" and when it comes from behind this optical transition is reversed. The approach of an object progressively covers the wall behind

it and its recession uncovers it. Animal behaviors and deformations of shape are not different in this respect from rigid displacements. The mechanical displacements of levers, wheels, pendulums, and crankshafts involve the displacements of occluding edges. The evaporation of a puddle, the dematerialization of a solid, and the fading of a smoke-ring reveal whatever was behind it previously. Even the hand-movements of the observer himself, and his locomotion over the ground by walking, driving, or flying involve progressive change of occlusion at a moving edge. Finally, turning the head, that closest of events to the self, uncovers one part of the ambient array while covering up another.

This third assumption is the one most likely to evoke disagreement. The objection might be made that it certainly does not hold for events in the cloudless sky, or in the night sky, or in complete darkness, where no textured background exists. The reply is that the empty sky and empty darkness constitute the limiting case of a non-layout, and the optically limiting case of a non-array. Only when a bird flying overhead occludes at least part of itself during flight do we perceive an event. Moving spots of light in utter darkness do not represent an event, in our sense, for the spots do not constitute an optic array. They constitute only optical atoms in an optical void, by analogy with material atoms in the void. Such optical transitions are not the prototype of optical information as we have assumed but only an impoverishment of it. The carryover from physics is inappropriate. The fallacy is to assume (as I once did) that "an optical motion is a projection in two dimensions of a physical motion in three dimensions" (Gibson, 1957,

p. 289; see also Johansson, 1964). The fact is that ecological events cannot be projected in one-to-one fashion.

What do Disturbances Specify?

A disturbance in the optic array, i.e., a disturbance in the persistence of its units, may be either a progressive gain or loss of units on one side of a contour or a substitution of different units. The former specifies coming into sight or going out of sight at an occluding edge, change of occlusion, and is so perceived (Gibson, Kaplan, Reynolds and Wheeler, 1969). The latter probably specifies change of existence, although this has not yet been verified by experiment. At any rate, increments or decrements of optical texture are distinguishable from substitution of one texture for another; this corresponds to the fact that occlusion-change in the array means something radically different from existence-change in the world.

The new hypothesis for event perception does not affect the rule that a changeless ambient array specifies a wholly motionless observer in a world wholly without events. But animals are never motionless except when asleep (or when trying to avoid notice by a predator). It is still true that, for the limiting case of the "open" layout, continuous gradients of optical flow specify locomotion of the observer in a stable environment, the direction of this locomotion, the imminence of collision, and other useful matters. The centrifugal flow of the array decreases to zero at the center of magnification (or minification) and also decreases to zero at the horizon of the earth (Gibson, Olum, and Rosenblatt, 1955). The units of the array "vanish" at the horizon, along with the transforming of these units; they "open up" ahead and "close in" behind as we fly over the earth. Thus, even in this idealized layout, there is something analogous to gain and loss of the units of the optic array, and therefore a violation of pure mathematical correspondence.

Note that disturbances in the optic array of the gain-or-loss type are precisely the same in an otherwise frozen array as they are in an otherwise flowing array. Hence the detecting of occluding edges when an object is displaced, with deletion at the leading edge and accretion at the trailing edge, is as much possible for a moving observer as for a stationary observer. But the detecting of <u>fixed</u> occluding edges by a stationary observer is much more difficult than for a moving observer. This is why an observer standing still in a thick woods, cannot distinguish "what belongs to one tree and what to another....But the moment he begins to move forward, everything disentangles itself...as if he were looking at a good stereoscopic view of it (Helmholtz, 1925, p. 296)." The information for occlusion in a frozen array is impoverished. And the information in a flowing array is not due to "motion parallax," as Helmholtz thought, but to optical accretion/deletion.

Disturbance in the Adjacent Order of Persisting Units

So far we have considered only a disturbance in the <u>persistence</u> of the adjacent units of an optic array. We now consider a less common disturbance in the <u>adjacent order</u> of persisting units, of what is next to what, of arrangement. (Perhaps this is a problem in topology but I cannot find it treated; topology has not yet been applied to the optic arry.) Each unit of a person's frozen array corresponds to itself in a subsequent frozen array but there has been a disruption of adjacency.

One kind of disruption occurs in the changing array from a *semi-transparent* surface or substance as distinguished from an *opaque* surface. Water or glass or swirling mist yield the perception of one thing behind another, but without opaque occlusion. Gibson *et al*. (1959) displayed an array with two sets of interspersed units. When frozen, it provided the information for an opaque surface, but when one set of units was displaced relative to the other it seemed to specify one transparent surface in front of another--at least that is what was perceived. The adjacent order of units in the frozen texture had been destroyed; more exactly it had been partially permuted. To quote, "It was a peculiar sort of permutation, to be sure, for each of the two sets of elements retained an adjacent order, but the disruption of order as between these sets broke the original continuity. And this produced the perception of different surfaces with separation between (p. 46)." Presumably, if there had been a *complete* permutation of the original array nothing but a chaos would have been visible. The fact that one can drive a car on a rainy night, with an optic array coming from multiple moving reflections and changing blurs on the glass windshield, and nevertheless see the road instead of a chaos bears witness to the mathematical wisdom of the ocular system.

Another kind of optical disruption without gain or loss of optical units comes from one opaque surface sliding across an adjacent opaque surface at a crack, without any occluding edge. Adjacent order is preserved in both parts of the array except at the linear (or circular) rupture. I do not know how to describe this optical transition in mathematical terms. There need be no contrast contour in the array--only the break in adjacency. It is probably a limiting case since all but ideal cracks in a surface layout will entail some change of occlusion.

The Process of Event Perception

With some idea of what the information is for event perception we can begin to study the process of perception. If the foregoing analysis is right, or even partly right, the process is not at all what we have supposed it to be. We have assumed, first, that it is based on retinal sensations of motion; second, that it entails an organizing of the pattern of retinal motions, and, third, that there has to be a special process of cancelling out the "reafferent" sensory inputs caused by eye-movements. Along with these we have also assumed, fourth, a picture transmitted to the brain at each moment of time, a sort of physiological image by analogy with the image of the photographic camera and a sequence of images in time by analogy with the motion picture camera. The latter assumption is actually not consistent with the former but efforts have been made to reconcile them.

I have already argued that whatever gives rise to the perception of motion it is not retinal motion (Gibson, 1968). That is, it cannot be "the successive stimulation of adjacent retinal loci (Spigel, 1965, p. 2)." I have here argued that it cannot even be optical motion considered as displacement of optical units, and still further that the ecological source of optical change is not physical motion in the Newtonian sense.

The second assumption fails equally when the structure of the ambient light is taken to be the basis of perception instead of the retinal image. There is no pattern of retinal displacements and not even a pattern of light-point displacements in the ecological optic array.

The third assumption is gratuitous if there is no necessity of cancelling out the sensory inputs caused by eye and head- movements--if they are taken to be simply the invariant accompaniments of sampling the ambient array, to be part of the flow of self-awareness coming from the exploratory visual system. The retinal image displacement hypothesis arises from a misconception of the way the eye works (Gibson, 1968, p. 338).

The fourth assumption, based on the motion picture analogy, is perhaps the most misleading of all. Despite a belief in irreducible sensations of motion we are tempted to believe in a sequence of discrete pictures each sensed or perceived for itself. We then try to reconcile them with such hypotheses as the "persistence of vision," or "apparent" motion due to neural short-circuiting, or "traces" of past stimuli that link them with the present stimulus. We are hopelessly confounded by the distinction between "present" experience and "past" experience although no one has ever been able to say what a "present" experience is. More generally, we contrast perception with memory and assert that perception depends on memory. But the explanation of storage and retrieval are becoming more and more elaborate.

I have already argued that the perception of sequences does not depend upon memory in the sense of storage and retrieval of traces (Gibson, 1966a). Surely the perception of an event as described here does not depend on recall or recollection. A unitary event is a unit of experience. But what about a sequence of nested events of considerable duration? If they constitute a single event, it seems to me, it is perceived. Consider the two extreme cases of pure event-repetition and no event-repetition. I think that only in the latter case, exemplified by nonsense figures (or nonsense syllables) does storage-and-retrieval memory enter into consideration. Only then is there a "span" of short-term memory and a "transfer" to long-term memory. At the other extreme, the repetitive set of brief events, the whole episode surely does not involve memory. No one would claim that an immediate recurrence, end-to-beginning, requires recognition in the sense of comparing this percept with the trace of the past percept and noting the match. The sequence and its frequency are directly grasped. ? ?

All the above only goes to show that the process of event perception is not what we have supposed it to be. But it is prerequisite to a fresh start on the problem. We have to conceive of stimulus information for ecological events, not stimuli. We have to think of a kind of stimulus information that is unaltered by eye-movements or head-movements, or even locomotor movements--a kind that is invariant under these changes. We have to take into account the fact of occlusion and dis-occlusion as specified by the optical transitions in an array at a moving point of observation and at a stationary point of observation. It is helpful but not sufficient to think of mathematical transformations of the optic array. A promising hypothesis is that the information for events is to be found in perturbations of the structure of the array, and two kinds called disturbances and disruptions have been defined.

These can occur in a sequential nesting of units for a changing array, and they can also occur in a synchronous nesting of units for the ambient array (things happen in sequence and they also happen at the same time). We cannot hope to establish a psychophysics for the perception of events, physics being of no help, but only a kind of psycho-optics, and this must be a novel kind of optics that considers the environment, not a branch of physics that considers only radiant energy.

References

Gibson, J. J. The perception of the visual world. Boston: Houghton Mifflin, 1950.

Gibson, J. J. The visual perception of objective motion and subjective movement. Psychol. Rev., 1954, 61, 304-314.

Gibson, J. J. Optical motions and transformations as stimuli for visual perception. Psychol. Rev., 1957, 64, 288-295.

Gibson, J. J. The senses considered as perceptual systems. Boston: Houghton Mifflin, 1966.

Gibson, J. J. The problem of temporal order in stimulation and perception. J. Psychol., 1966, 62, 141-149. (a)

Gibson, J. J. What gives rise to the perception of motion? Psychol. Rev., 1968, 75, 335-346.

Gibson, J. J., Gibson, E. J., Smith, O., & Flock, H. R. Motion parallax as a determinant of perceived depth. J. exp. Psychol., 1959, 58, 40-51.

Gibson, J. J., Kaplan, G. A., Reynolds, H. N., & Wheeler, K. The change from visible to invisible: A study of optical transitions. Percept. & Psychophys., 1969, 5, 113-116.

Gibson, J. J., Olum, P., & Rosenblatt, F. Parallax and perspective during aircraft landings. Amer. J. Psychol., 1955, 68, 372-385.

Helmholtz, H. Physiological optics. Vol. 3 (J.P.C. Southall, ed.) Optical Society of America, 1925.

Johansson, G. Configurations in event perception. Uppsala: Almkvist and Wiksell, 1950.

Johansson, G. Perception of motion and changing form. Scan. J. Psychol., 1964, 5, 181-208.

Michotte, A., Thinès, G., & Crabbé, G. Les complements amodaux des structures perceptives. Studia Psychologica, Louvain: Publ. Univ. de Louvain, 1964.

Spigel, I. M. Readings in the study of visually perceived movement. New York: Harper and Row, 1965.

Whitrow, The natural philosophy of time. 1966.

The Environment to be Perceived

Part I of

AN ECOLOGICAL APPROACH TO VISUAL PERCEPTION

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Part I

The Environment to be Perceived

In this book, "environment" will refer to the surroundings of those organisms that perceive and behave, that is to say, animals. The surroundings of plants, organisms that lack sense organs and muscles, are important for biology but not for the study of perception and behavior. We shall treat the vegetation of the world as animals do, as if it were lumped together with the inorganic minerals of the world, with the physical, chemical, and geological environment. Plants in general are not "animate"; they do not move about, they do not seem to be sensitive to stimuli, and they have seldom been thought to have souls. In these respects they are like the objects of physics, chemistry, and geology.

The world can be described at different levels and one can choose which level to begin with. Biology begins with the division between the non-living and the living. But psychology begins with the division between the inanimate and the animate, and this is where we choose to begin. Then the animals themselves can be divided up in different ways. Zoology classifies them by heredity and anatomy, by phylum, class, order, genus, and species but one can also classify them by their way of life and mode of locomotion, as predatory or preyed upon, terrestrial or aquatic, crawling or walking, flying or non-flying, arboreal or ground living, and quadripeds or bipeds. The animal is suited to its habitat, as ecologists put it, and the habitat is suited to the animal.

The environment consists of the <u>surroundings</u> of animals. Let us observe that, in one sense of that term, the surroundings of an individual animal are the same as the surroundings of all animals but that in another sense the surroundings of a stationary animal at a fixed location are not the same as those of any other individual. These different meanings of the term can be troublesome and cause confusion. The apparent contradiction can be resolved, however, and the meanings reconciled but let us defer the problem until later. For the present it is enough to note that the surroundings of any animal include other animals as well as the plants and the non-living things. The former are just as much parts of its environment as the inanimate parts. For any animal needs to distinguish not only the substances and objects of its material environment but also the other animals and the differences between them. It cannot afford to confuse prey with predator, own-species with another species, or male with female.

The Mutuality of Animal and Environment

The fact is worth remembering because it is often neglected that the words animal and environment make an inseparable pair. Each term implies the other. No animal could exist without an environment surrounding it. Equally, although not so obvious, an environment implies an animal (or at least an organism) to be surrounded. This means that the surface of the earth, millions of years ago before life developed on it, was not an environment properly speaking. The earth was a physical reality, a part of the universe, and the subject matter of geology. It was a potential environment, prerequisite to the evolution of life on this planet. We might agree to call it a world but it was not an environment.

The mutuality of animal and environment is not implied by physics and the physical sciences. The basic concepts of space, time, matter, and energy do not lead naturally to the organism-environment concept, or the species-habitat concept. Instead they seem to lead to the idea of an animal as only an extremely complex object of the physical world. The animal is thought of as a highly organized part of the physical world. I do not suggest that this way of thinking about the animal is false but it neglects the fact that the animal-object is surrounded on all sides in a special way, that an environment is ambient for a living object in a different way from the way that a set of physical objects is ambient for a given object.

The term "physical environment" is therefore misleading, and will be avoided in this book, since it may be taken to suggest that physics describes all that we need to know about the environment of an animal.

Every animal is, in some degree at least, a perceiver and a behaver. It is sentient and animate, to use old-fashioned terms. It is a perceiver of the environment and a behavior in the environment. But this is not to say that it perceives the world of physics and behaves in the space and time of physics.

The Difference between the Animal Environment
and the Physical World

The world of physics encompasses everything from atoms through terrestrial objects to galaxies. These things exist at different levels of size which go to almost unimaginable extremes. The physical world of atoms and their "ultimate particles" is measured at the level of millionths of a millimeter and less. The astronomical world of stars and galaxies is measured at the level of light years and more. Neither of these extremes is an environment, nor could either possibly be an environment. The size level at which the environment exists is the intermediate one that is measured in millimeters and meters. The ordinary familiar things of the earth are of this size--actually a narrow band of sizes relative to the far extremes. The sizes of animals, similarly, are limited to the intermediate terrestrial scale. The smallest animal is an appreciable fraction of a millimeter and the largest is only a few meters in size.

The masses of animals, likewise, are measured within the range of milligrams to kilograms, not at the extremes of the scale, and this is for good physiological reasons. A cell must have a minimum of substances in order to permit biochemical reactions; a living animal cannot exceed a maximum of cells if they are all to be nourished and if the animal is to be mobile.

Physical reality has structure at all levels of metric size from atoms to galaxies, from the smallest to the largest, but the structure is by no means the same at these different levels. The patterns, shapes, and arrangements are different. Within the intermediate band of terrestrial sizes the environment of animals and men is itself structured at various levels of size. At the level of kilometers the earth is shaped by mountains and hills. At the level of meters it is formed by boulders and cliffs and canyons, and also by trees. It is still more finely structured at the level of millimeters by pebbles and crystals and particles of soil, and also by leaves and grass-blades and plant cells. All these things are structural units of the terrestrial environment, what we loosely call the "forms" or "shapes" of our familiar world.

Now, with respect to these units, there is an essential point of theory to be emphasized. The smaller units are imbedded in the larger units by what I will call "nesting." For example, canyons are nested within mountains; trees are nested within canyons; leaves are nested within trees, and cells are nested within leaves. There are forms within forms both up and down the scale of size. Units are nested within larger units. Things are components of other things in a hierarchy, with the proviso that this hierarchy is not categorical but full of transitions and overlaps. Hence for the terrestrial environment there is no special proper unit in terms of which it can be analyzed once and for all. There are no atomic units of the world considered as an environment. The unit you choose for describing the environment depends on the level of the environment you choose to describe.

The size levels of the world emphasized by modern physics, the atomic and the cosmic, are inappropriate for the psychologist. We are concerned here with things at the ecological level, with the habitat of animals and men. And this is because we all behave with respect to things we can look at and feel, or smell and taste, and events we can listen to. The sense organs of animals, the perceptual systems (Gibson, 1966), are not capable of detecting atoms or galaxies. Within their limits, however, these perceptual systems are still capable of detecting a certain range of things and events. A man can see a mountain if it is far enough away and a grain of sand if it is close enough. That fact is sufficiently wonderful in itself to deserve study, and it is one of the facts that this book will try to explain.

The explanation of how we human observers, at least some of us, can <u>visualize</u> an atom or a galaxy even if we cannot <u>see</u> one will not be attempted, at least not at this stage of the inquiry. It is not so much a problem of perception as it is a problem in the psychology of scientific apprehension. Any such attempt would be extremely ambitious, perhaps even presumptuous. The first problem is how we can perceive the environment--how we apprehend the same things that our human ancestors did before they learned about atoms and galaxies. We are concerned with direct perception, not so much with the indirect perception got by using microscopes and telescopes or by photographs and pictures, and still less with the kind of apprehension got by speech and writing. These higher-order modes of apprehension will only be considered in Part IV of this book, at the end.

The Time Scale of the Environment. Events.

Another difference between the environment to be described and the world of physics is in the temporal scale of the processes and events we choose to consider. The duration of processes at the level of the universe may be measured in millions of years and the duration of processes at the level of the atom may be measured in millionths of a second. But the duration of processes in the environment is measured only in years and seconds. The various life-spans of the animals themselves fall within this range. The changes that are perceived, those on which acts of behavior depend, are neither extremely slow nor extremely rapid. The human observer cannot perceive the erosion of a mountain but he can detect the fall of a rock. He can notice the displacement of a chair in his room but not the shift of an electron in an atom.

The same thing holds for frequencies as for durations. The very slow cycles of the world are imperceptible and so are the very rapid cycles. But at the level of a mechanical clock each motion of the pendulum can be seen and each click of the escapement can be heard. The rate of change, the transition, is within the limits of perceptibility.

In this book, emphasis will be placed on events, cycles, and changes at the terrestrial level of the physical world. The changes we shall study are those that occur in the environment. These transitions and only these provide what the physiologists and psychologists call <u>stimuli</u>--the stimuli that elicit responses, that is, the effective stimuli. The concept of the stimulus in psychology is vague and slippery but it seems to be agreed that without change there is no effective stimulation (Gibson, 1960). I shall talk about changes, events, and sequences of events but not about time as such. The flow of abstract empty time, however useful this concept may be to the physicist, has no reality for an animal. We do not perceive time but processes, changes, sequences, or so I shall assume. The human awareness of clock-time, socialized time, is another matter.

Just as physical reality has structure at all levels of metric size so it has structure at all levels of metric duration. Terrestrial processes occur at the intermediate level of duration. They are the natural units of sequential structure. And once more it is important to realize that smaller units are nested within larger units. There are events within events, as there are forms within forms, up to the yearly shift of the path of the sun across the sky and down to the breaking of a twig. And hence there are no elementary units of temporal structure. You can describe the stimuli for an observer at various levels of nested events.

The natural units of the terrestrial environment and the natural units of terrestrial events should not be confused with the <u>metrical</u> units of space and time. The latter are arbitrary and conventional. The former are unitary in one sense of the term and the latter are unitary in a quite different sense.

Permanence and Change of the Layout

Space and time will not often be referred to in this book but a great deal will be said about permanence and change. Consider the shape of the terrestrial environment, or what may be called its layout. It will be assumed that the layout of the environment is both permanent in some respects and changing in some respects. A living room, for example, is relatively permanent with respect to the layout of floor, walls, and ceiling but every now and then the arrangement of the furniture in the room gets changed. The shape of a growing child is relatively permanent for some of its features and changing for others. An observer can recognize the same room on different occasions while perceiving the change of arrangement, or the same child at different ages while noticing the change. The permanence underlies the change.

Permanence is relative, of course, that is, it depends on whether you mean persistence over a day, a year, or a millenium. Almost nothing is forever permanent. So it is better to speak of persistence under change. The "permanent objects" of the world which are of so much concern to psychologists and philosophers are actually objects that persist for a long time without disintegrating.

The abstract notion of invariance and variance in mathematics is similar to what is meant by persistence and change in the environment. There are variants and invariants in any transformation, constants and variables. Some properties are conserved and others not conserved. The same words are not used by all writers (e.g., Piaget, 1969) but there is a

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common core of meaning in all such pairs of terms. The point to be noted is that for persistence and change, for invariant and variant, each term of the pair is reciprocal to the other.

The persistence of the geometrical layout of the environment depends in part on the kind of substance composing it and its rigidity or resistance to deformation. A solid substance is not readily changed in shape. A semi-solid substance is more easily changed in shape. A liquid substance takes on whatever may be the shape of its solid container. The upper surface of a liquid substance tends to the ideal shape of a plane perpendicular to gravity but this is easily disturbed, as when waves form. When we speak of the permanent environment, therefore, we refer mainly to the solid substances. The liquids of the world, the streams and oceans, are only permanent in a special way, and as for the gaseous matter of the world, the air, it is seldom thought of as the environment at all. I will argue that the air is actually a <u>medium</u>, not an environment, for terrestrial animals.

When a solid substance with a constant shape melts, as a block of ice melts, we say that the object has ceased to exist. We are then speaking ecologically, not physically, for there is physical conservation of matter and mass despite the change from solid to liquid. The same would be true if a shaped object disintegrates, changing from solid to granular. The object does not persist but the matter does. Ecology calls this a non-persistence, a destruction of the object, whereas physics calls it a mere change of state. Both assertions are correct but the former is more relevant to the behavior of animals and children. Physics can be taken to imply something even more radical, that when a liquid mass has evaporated and the substance has been wholly dispersed in the air, or when an object has been consumed by fire, nothing has really gone out of existence. But this is an error. Even if matter cannot be annihilated a resistant light-reflecting surface can, and this is what counts for perception.

Going out of existence, cessation or destruction, is a kind of environmental event and one that is extremely important. When something is burned up, or dissolved, or shattered, it disappears. But it disappears in special ways that have recently been investigated at Cornell (Gibson, 1968). It does not disappear in the way that a thing becomes hidden, or that it goes around a corner. Instead the form of the object may be optically dispersed or dissipated, in the manner of smoke. The visual basis of this kind of perception will be further considered in Part II on ecological optics.

The environment normally manifests some things that persist and some that do not, some features that are invariant and some that are variant. This suggests a sort of theoretical test. What about an environment that was wholly invariant, unchanging in all parts, and motionless? It would be "frozen," that is, completely rigid. Obviously this would no longer be an environment for animals and in fact there would no longer be either animals or plants. What about the other extreme, an environment that was changing in all parts and was wholly variant? It would consist only of swirling clouds of matter, completely non-rigid. This would be a chaos and would also no longer be an environment for organisms. In both extreme cases there would be space, time, matter, and energy but there would be no habitat.

The Medium

For describing the environment of animals precisely, we need the concept of medium. Let us begin by noting that our planet consists mainly of earth, water and air, that is, of a solid, a liquid, and a gas. The earth forms a substratum; the water is formed by it into oceans, lakes, and streams; and the formless gasses of the air make a layer of atmosphere above the earth and water. The interface between any two of these three states of matter, solid, liquid and gas, constitutes a surface. Technically, in chemistry, a surface is a "phase boundary." The earth-water interface at the bottom of a lake is one such, the water-air interface at the top is another, and the earth-air interface is a third--the most important of all surfaces for terrestrial animals. This is the <u>ground</u>. It is the ground of their perception and behavior, both literally and figuratively. It is their surface of support.

One of the characteristics of a gas or liquid as contrasted with a solid is the fact that a detached solid body can move through it without resistance but not through another solid. Air is "insubstantial" and so is water, more or less. It thus affords locomotion to an animate body. A gas or liquid is a <u>medium</u> for animal locomotion. Air is a better medium for locomotion than water because it offers less resistance. It does not require the streamlined anatomy needed by a fish for rapid movements.

Another characteristic of a gas or liquid medium is that it is generally transparent, transmitting light, whereas a solid is generally opaque, absorbing or reflecting light. A medium thus affords vision. The way in which it does so will be described in Part II. For the present it is sufficient to observe that a terrestrial medium is a region in which light not only is transmitted but also <u>reverberates</u>, that is, bounces back and forth at enromous velocity and reaches a sort of steady state. The light has to be continually replenished from a source of illumination since some of it is absorbed by the substances of the environment, but the reverberating flux of light brings about the condition that we call steady illumination. Illumination "fills" the medium in the sense that there is ambient light at any point, that is, light coming to the point from all directions. Ambient light, as we shall see, is not to be confused with radiant light.

A third characteristic of air or water is the fact that it transmits vibrations or pressure waves outward from a mechanical event, a source of sound-waves. It thus affords what we call vaguely hearing the "sound"; more precisely it permits listening to the vibratory event. The solid earth also transmits pressure waves, to be sure, but we do not ordinarily call them "sound waves" unless we are thinking in terms of physics. In physics a medium is any substance, including solids, that transmits waves.

A fourth characteristic is the fact that a medium of air or water allows of rapid chemical diffusion whereas the earth does not. Specifically it permits molecules of a foreign substance to diffuse or dissolve outward from a source whenever it is volatile or soluble. In this way the medium affords "smelling" of the source, by which I mean detecting of the substance at a distance.

Let us next observe that animal locomotion is not usually aimless but is guided or controlled. It is always guided by light if the animal can see, it is guided by sound if the animal can hear, and it is guided by odor if the animal can smell. Because of light the animal can see things, because of sound it can hear things, because of diffusion it can smell things. The medium thus mediates an <u>outward flow of information</u> from things that reflect light, vibrate, or are volatile. It is by detecting this information that the animal guides and controls locomotion.

If we understand the notion of "medium," I suggest, we come to a new way of thinking about perception and behavior. The medium in which animals can move about (or in which objects can be moved about) is at the same time the medium for light, sound, and odor coming from sources in the environment. An enclosed medium can be filled with light, with sound, and even with odor. Any point in the medium is a possible point of observation for any observer who can look, listen, or sniff. And these points of observation are continuously connected in lines, or paths of possible locomotion. Instead of the points and lines of physical space, then, we have points of observation and lines of locomotion. As the observer moves from point to point the optical information, the acoustic information, and the chemical information change accordingly. Each potential point of observation in the medium is unique in this respect. The notion of a medium, therefore, is not the same as the concept of physical space inasmuch as the points therein are not unique but equivalent.

All these facts about moving bodies and about the transmission of light, sound, and odor in a medium can be derived from physics, mechanics, optics, acoustics, and chemistry but they are facts of higher order which have never been made explicit by those sciences. The science of the environment has its own facts.

A very important characteristic of a medium, it should now be noted, is that it contains oxygen and permits breathing. The principles of respiration are the same in the water as in the air; oxygen is absorbed and carbon dioxide is emitted after the burning of fuel in the tissues. This ceaseless chemical exchange of substance is truly the "flame of life." The animal must breathe, whether by gills or by lungs. It must breathe all the time and everywhere it goes. Thus the medium needs to be relatively constant and relatively homogeneous.

Both the water and the air do tend to be unchanging. The amount of oxygen in the air has not departed much from 21% in countless ages, and the amount of dissolved oxygen in the water tends to be xx% at the surface. Animals have been able to rely on these invariants and this is why evolution could proceed. Similarly both the water and the air tend to be homogenous, that is, the same in one region as in any other. From place to place the composition of water and air does not change much, and temporary gradients that may arise are dissipated by currents and wind. There are no sharp transitions in a medium, no boundaries between one volume and another, that is to say, no surfaces. This homogeneity is crucial. It is what permits light waves and sound waves to travel in perfect circles outward from a source and, indeed, it is what makes a chemical emanation from a source "foreign" to the medium itself.

Finally, a sixth characteristic of a medium is that it has an intrinsic polarity of up and down. Gravity pulls downward, not upward. Radiant light comes from above, not below, from the sky, not the substratum, and this is as true in the water as in the atmosphere. Because of gravity water pressure and air pressure increase downward and decrease upward. The medium is not isotropic, as the physicist says, along this dimension. Hence it is that a medium has one absolute axis of reference, the vertical axis. The two horizontal axes of reference are more or less artibrary but not the vertical axis. This fact reveals another difference between medium and space, for in space all three reference axes are arbitrary and can be chosen at will.

To sum up, the characteristics of an environmental medium are that it affords respiration or breathing, it permits locomotion, and it can be filled with illumination so as to permit vision. It also allows of detecting vibrations and of detecting diffusing emanations. The medium is homogeneous. Finally, the medium has an absolute axis of reference, up-and-down. All these offerings of nature, these possibilities or opportunities, these affordances as I will call them, are invariant. They have been strikingly constant throughout the whole evolution of animal life.

Events in the Atmosphere

The atmospheric medium, unlike the underwater medium, is subject to certain kinds of change that we call "weather." Sometimes there are drops or droplets of water in the air, rain or fog. Annually, in some latitudes of the earth, the air becomes cold and the water turns to ice. Occasionally the air currents flow strongly as in storms and hurricanes. Rain, wind, snow, and cold, the latter increasing toward the poles of the earth, prevent the air from being perfectly homogeneous, uniform, and unchanging. The changes are rarely so extreme as to kill off the animals but they do necessitate various kinds of adaptation and all sorts of behavioral adjustments such as hibernation, migration, shelter-building, and clothes-wearing.

Substances

Consider next the environment that does not freely transmit light, sound, or odor and that does not permit the motion of bodies and the locomotion of animals. Matter in the solid or semisolid state is said to be substantial whereas matter in the gaseous state is insubstantial and matter in the liquid state is in between these extremes. Substances in this meaning of the term are more or less rigid. That is, they are more or less resistant to deformation, more or less impenetrable by solid bodies, and more or less permanent in shape. They are generally opaque to light. And the substantial part of the environment is heterogeneous unlike the medium which tends to be homogeneous.

The substances of the environment differ in chemical composition. As everybody knows, there are a limited set of chemical elements, about 90, and a much larger set of chemical compounds. More important for our purposes is the fact that there is an unlimited set of <u>mixtures</u> of elements and compounds, some being homogeneous mixtures and some not. The latter may be called aggregates. The air is a homogeneous mixture of oxygen and nitrogen with carbon dioxide; the water is a homogeneous mixture of H_2O with dissolved oxygen and salts. But the earth together with the "furniture" of the earth is a heterogeneous aggregate of different substances.

Rock, soil, sand, mud, clay, oil, tar, wood, minerals, metal, and above all, the various tissues of plants and animals are examples of environmental substances. Each of these has a more or less specific composition but almost none is a chemical compound, a pure chemical of the sort that is found on the shelves of chemistry laboratories. A few substances like clay are "amorphous," that is, lacking in structural components but most of them are geometrical aggregates, that is, they are made of crystals and clumps, of cells and organs, of structures within structures. These substances rather than chemicals are what is important for animals. It is these they have to distinguish in order to live.

What a substance is composed of can be analyzed at various levels.

There is the compounding of chemical elements but there is also the mixing of compounds and the complex aggregating of mixtures. When we talk about the composition of a substance, what it is "made of," we must keep in mind the level of analysis that is appropriate to the problem being considered.

It is obvious why animals need to distinguish among the different substances of the environment. They have different biochemical, physiological, and behavioral effects on the animal. Some are nutritive, some are non-nutritive, and some are toxic. And it is very useful for a hungry animal to be able to distinguish the edible from the unedible substances at a distance, by vision or smell, instead of only by contact sensitivity, by taste or touch.

Substances differ in all sorts of ways. They differ in hardness or rigidity. They differ in viscosity, which is technically defined as resistance to flow. They differ in density, defined as mass per unit volume. They differ in cohesiveness or strength, that is, resistance to breaking. They differ in elasticity, or the tendency to regain the previous shape after deformation. They differ in plasticity, or the tendency to hold the subsequent shape after deformation. Presumably all these properties of substances are explainable by the microphysical forces of attraction among molecules but they do not have to be analyzed at this level in order to be facts. Flint and clay were distinguishable substances for our primitive tool-making ancestors long before men understood chemistry. So were wood, bone, and fiber.

Substances considered as compounds differ in their susceptibility to chemical reactions, in their degree of solubility in water, in their degree of volatility in air, and thus in their chemical stability or resistance to chemical transformation. And they also differ, as will be emphasized later, in the degree to which they absorb light; a substance like coal for example absorbs most of the light falling on it whereas a substance like snow absorbs very little of the light falling on it.

The substances of the environment change, of course, both structurally and chemically. Some solids dissolve and their surfaces cease to exist. Leaves shrivel, and plants decompose. Animals decay and return their substances to the environment. Metal rusts and even the hardest rock eventually disintegrates into soil. The cycles of such changes are studied in ecology. Their causes at the molecular level of analysis are chemical and physical; they are governed by chemical reactions of the sort that chemists isolate and control in test tubes, and by microphysical forces. But these changes also occur at a molar level and then they are environmental events, not simply physico-chemical events. Large-scale chemical reactions are visible. The event we call combustion or fire is large-scale rapid oxidation. This is of enormous importance to animals and they look out for it. But other forms of oxidation are too small or too slow to observe, for example the rusting of iron.

A great many substances of the environment, of course, do not change either structurally or chemically and the non-change is even more important than the change. It is chiefly on this account that the environment is persistent or permanent. But also, even when substances change, they are often restored by processes of growth, compensation, and restitution so that an equilibrium or steady state arises and there is invariance despite change--an invariance of higher order than mere physico-chemical persistence.

The Status of Water in this Description--Medium or Substance?

It is now time to make a decision as to how we are to consider water. It is the medium for aquatic animals, not a substance, but it is a substance for terrestrial animals, not the medium. It is insubstantial when taken with reference to the aquatic environment but substantial when taken with reference to the terrestrial environment. I suggest that this fact does not invalidate the distinction but only makes it depend on the kind of animal being considered. The animal and its environment, remember, are reciprocal terms. The medium of water and that of air have much in common, but they are sufficiently different to make it necessary hereafter to concentrate on the environment of terrestrial animals like ourselves. For us, water falls into the category of substance, not medium.

The underwater medium is bounded both above and below, by a surface of water-to-air and a surface of water-to-mud. The atmospheric medium is bounded only below, by a surface of air-to-earth (or air-to-water) and it has no definite upper boundary. The fish is buoyed up by its medium and needs no surface of support. Our kind of animal must hold itself up off the ground with effort, working to maintain posture and equilibrium. The fish is cradled in the water and is never in any danger of falling down or falling off. We are always in such danger. The fish need never make contact with the bottom. But we cannot for long avoid contact with the earth, and only upon the earth can we come to rest, even birds. All animals, in the water, on the ground, or in the air, must orient to gravity in order to behave which is to say they must keep "right side up" (Gibson, 1966, Ch. 4) but this basic orienting activity is different in the fish, the quadriped, and the bird.

There are some animals, to be sure, that can get about in both water and air, the amphibians. They live an interesting life and the study of how they can perceive in either environment is a problem very much worth study. The interface between air and water is not the barrier that it is for us. Men can temporarily wear aqualungs, but not for long. We are terrestrial animals. And so hereafter I will concentrate on the terrestrial environment of animals like ourselves.

To summarize what has been said about substances, they differ in both chemical and physical composition. They are compounded and aggregated in extremely complicated ways and thus do not tend toward homogeneity, as the medium does. They are structured in a hierarchy of nested units. And these different components have very different possibilities for the behavior of animals, for eating, for resisting locomotion, for manipulation, and for manufacture.

Surfaces and What They Afford

For describing the environment, we have now established the triad of medium, substances, and surfaces, allowing for both permanence and change. The medium is separated from the substances of the environment by surfaces. Insofar as substances persist, their surfaces persist. All surfaces have a certain layout, and the layout also tends to persist. The persistence of the layout depends on the resistance of the substance to change. If a substance is changed into the gaseous state it is no longer substantial and the surface together with its layout ceases to exist. These statements provide a new way of describing the environment.

This description is superior for our purposes to the accepted description in terms of space, time, and matter, then going on to bodies, forms, and motions. It is novel, but only in the sense that it has never been explicitly stated. Everything in the above paragraph has long been known implicitly by practical men--the surveyors of the earth, the builders, and the designers of the environment. It is tacit knowledge (Polyani). This description is superior because it is appropriate to the study of the perception and behavior of animals and men as a function of what the environment affords, that is, to psychology.

The above description omits the reverberating flux of light in the medium and is therefore incomplete. The way in which light is absorbed and reflected at surfaces must also be considered, and the way this action depends on the composition of the substances. At the atomic level of size, matter and light energy interact; at the ecological level of size surfaces soak up or throw back the illumination falling upon them. Substances are substantial with respect to light as much as they are substantial with respect to force. They resist the penetration of light as they resist the penetration of a moving body. And substances differ among themselves in the former respect as much as they do in the latter.

In our concern with surfaces and their purely geometrical layout we must not forget that the air is filled with sunlight during the day and that some illumination almost always remains even during the night. This fact, too, is an invariant of nature. Light comes from the sky and becomes ambient in the air. This is the fact that makes persisting surfaces potentially visible as well as potentially tangible. How they are actually seen by animals with eyes is the problem of this book (although admittedly we are arriving at the problem only by slow stages). A "potentially visible" surface is one that could be looked at from some place in the medium where an animal might be. Nothing is implied about the actual stimulation of an eye, not yet. And no slightest reference is made to sensations of vision.

For the sake of simplicity, no consideration will be given here to luminous surfaces such as very hot bodies that emit light, or to flat surfaces of transparent substances like glass that transmit light with refraction, or to polished flat surfaces like mirrors that reflect light "regularly," or to very fine gratings that diffract light. Emission, transmission, refraction, and diffraction are important but for the present let us bracket these elegant laws of optics so as to concentrate on the ecological optics of rough, mixed, cool, opaque, ordinary surfaces. We are not here concerned with the sun and the stars, with rainbows and sunsets, with reflections and mirages, but chiefly with the ground under the observer's feet. Emission, transmission, refraction, and diffraction refer to radiant energy considered as waves or photons but we are concerned only with illumination.

Why, in the triad of medium, substances, and surfaces, are surfaces so important? It is because the surface is where most of the action is. The surface is where light is reflected or absorbed, not in the interior of the substance. The surface is touched by or touches the animal, not the interior. The surface is where chemical reaction mostly takes place. The surface is where vaporization or diffusion of substances into the medium occurs. And the surface is where vibrations of the substance are transmitted into the medium.

It would be useful to formulate what might be called the ecological laws of surfaces. The following laws are subject to amendment. The list will serve, however, to focus the discussion, and it also provides an outline of what is to follow. They are not independent of one another and must be considered in combination.

1. All persisting substances have surfaces and all surfaces have a layout.

2. Any surface layout has resistance to deformation, depending on the viscosity of the substance.

3. Any surface layout has resistance to disintegration, depending on the cohesion of the substance.

4. Any surface has a characteristic texture, depending on the composition of the substance. It generally has both a layout texture and a pigment texture.

5. Any surface has a characteristic shape, or large-scale layout.

6. A surface may be strongly or weakly illuminated.

7. An illuminated surface may absorb much or little of the illumination falling on it.

8. A surface has a characteristic reflectance, a ratio, depending on the substance.

9. A surface has a characteristic distribution of the reflectance ratios of the different wavelengths of the incident light, depending on the substance. This property is what I will call its "color," in the sense that different distributions constitute different colors.

1. Substances, Surfaces, Layout, and Persistence

The first law merely summarizes what has been emphasized repeatedly about the substantial persisting surfaces of the environment. Combined with the second, it explains why the level terrestrial surface, the ground, offers support for an animal. With support, he can crawl on it, as a lizard or a human infant does, or he can walk or run on it. But the law of layout also applies to surfaces like walls and obstacles that are barriers to locomotion--surfaces with which he will collide unless he stops short. A surface can be laid out parallel to gravity as well as perpendicular to it so that surfaces can surround as well as support him. A surface can even be supported by walls so as to be above him, that is, there can be a roof over his head as well as a floor under his feet. A medium can be more or less enclosed by surfaces and a cave, or burrow, or a house is such an enclosure.

2. Surfaces Resist Deformation

The second law allows for variation in the solidity of surfaces. It says that substances vary in the degree to which they resist deformation, from rigid to plastic to semisolid to liquid. When measured in terms of resistance to flow, this variable is technically called viscosity. The more fluid or flowing the substance the more penetrable the surface, and the more changeable (less permanent) the layout. This law implies that the bog or swamp does not offer support for standing or walking to heavy animals, and still less does the pond or lake.

With respect to obstacles, it implies that the surfaces of flexible substances are yielding or can be pushed aside whereas the surfaces of rigid substances cannot. With respect to fluid substances it implies that fluid surfaces are polymorphic in the extreme; they can be poured, spilled, and splashed and they can be smeared, painted, and dabbled in. The human infant explores these possibilities with great zest; the adult artisan has learned to perceive and take advantage of them.

3. Surfaces Resist Disintegration

The third law allows for variation in the degree to which surfaces are breakable or go to pieces. The surface of a viscoelastic substance will stretch and remain continuous under the application of a force whereas the surface of a rigid substance may be disrupted and become discontinuous. This distinction, incidentally, is fundamental to the branch of mathematics called topology, sometimes called "rubber sheet geometry," in which it is assumed that a plane (actually a surface) can be bent or curved or stretched or compressed but cannot be torn.

The last two laws explain why clay can be pressed into the shape of a pot whereas flint has to be chipped into the shape of an axe. And it explains why the pot or the axe becomes useless when it is broken. It implies that a house of glass is a poor place to live and the person who lives in one should certainly not throw stones.

4. Any Surface has a Characteristic Texture

The fourth law has to do with what I call texture, which might be thought of as the structure of a surface as distinguished from the structure of the substance underlying the surface. It is the relatively fine structure of the environment we are talking about, at the size level around centimeters and millimeters (p. 4). Surfaces of rock, or of plowed soil, or of grass are aggregated of different units, of crystals, clumps, and grass-blades, respectively, but these units are nested within larger units. [Insert photographic illustrations of surface textures, from e.g., Brodatz.]

The texture of a surface arises from two main facts, first, that a natural substance is seldom homogeneous, but is more or less aggregated of different homogeneous substances and, second, that is seldom amorphous but is more or less aggregated of crystals and chunks and pieces of the same stuff. Hence the surface of a natural substance is also neither homogeneous nor amorphous but has a chemical and a physical texture. It is generally both conglomerated and corrugated. It has what I will call a pigment texture and a layout texture. It is generally both speckled and rough.

This says that a perfectly homogeneous and perfectly smooth surface is an abstract limiting case. A polished surface of glass approximates to it but it has to be manufactured. Mirrors are rare in nature.

When the chemical and geometrical units of a surface are relatively small the texture is fine; when they are relatively large the texture is coarse. If the units are sufficiently distinct to be counted the density of the texture can be measured as the number of units in an arbitrary unit of area, a square centimeter or meter. But this is often very hard to do since units of texture are generally nested within one another at different levels of size. The texture of commercial sandpaper can be graded from fine to coarse, but the textures of vegetation cannot. Moreover, the units of texture vary in form, and there are forms within forms, so that the "form" of a texture escapes measurement. The ideal pigment texture of a checkerboard and the ideal layout texture of a tesselated surface are rare.

The laws says that rock, shale, soil, and humus have different textures, and that mud, clay, sand, ice, and snow have different textures. It says that the bark and the leaf and the fruit of a tree are differently textured, and that the surfaces of animals are differently textured, by fur, feathers, or skin. The surfaces of the substances from which primitive men fashioned tools have different textures, flint, clay, wood, bone, and fiber. The surfaces of the artificial environment, plywood, paper, fabric, plaster, brick have different textures. The surfaces with which man is beginning almost to carpet the earth are differently textured, the pavements of concrete, asphalt and other aggregates. The texture in each case specifies what the substance is, what it is made of, its composition. And that in turn specifies what the surface affords the observer for habitation, manipulation, nutrition and, not least, for social interaction.

It is important to understand now the chemical and geometrical determinants of surface texture so as later to be able to understand what I call optical texture, although this conception will not be fully developed until Part II. It is enough to remember now that surfaces are homogeneous only as a limiting case such as the plaster wall behind a stage-setting which looks like the sky from a distance, and that surfaces are smooth only as a limiting case such as a sheet of plate glass and a mirror. Under certain conditions a homogeneous, very smooth, flat, large surface is not visible to a man or animal with ordinary eyesight.

5. A Surface has a Characteristic Shape

The fifth law has to do with the layout of the environment on a scale that is relatively large, its coarse structure or macrostructure. If a surface can be geometrically analyzed into facets, a layout can be analyzed into faces. This terminology is useful inasmuch as it expresses the fact that a flat surface can "face" the source of illumination, or not, and that it can face the point of observation or not. As will become evident, the fact that a flat surface can be more or less inclined to the vertical axis, that it has a measurable slant or slope relative to gravity, is insufficient for the purpose of understanding vision, although it is important for understanding locomotion. Curved surfaces, those that depart from geometrical planarity, can also be treated as faces but, for the present, let us take a surface to mean a flat surface, a face, and a layout of adjoining surfaces to mean a set of faces meeting at dihedral angles, that is, edges and corners.

The law has to do with surface-layout at the size level of environmental enclosures and environmental objects. It asserts that enclosures and objects have characteristic shapes. Enclosures differ in shape as, for example a cave, a tunnel, and a room differ. Objects differ in shape in the ways that the polyhedrons of solid geometry differ (the tetrahedron, pyramid, cube, octahedron, etc.) and in all the ways that the "irregular" polyhedrons differ. These "geometrical solids," so-called, progress toward enormous complexity but they can all be analyzed in terms of three components called faces, edges, and vertices. These have meaning for environmental objects since, for example, the edge is characteristic of a cutting tool and the vertex is characteristic of a piercing tool.

Obviously, differently shaped enclosures afford different possibilities of inhabiting them. And differently shaped solids afford different possibilities for behavior and manipulation. Man, the great manipulator, exploits these latter possibilities to the utmost degree.

6. High and Low Illumination of a Surface

The sixth law says that the light falling on a surface from the medium, the incident light, may be high or low, intense or dim, but that generally there is some illumination. The completely dark room of the vision laboratory, like the deep interior of a cave, is a limiting case.

The amount of light falling on a surface in empty space depends only on the distance of the source and the transmissivity of the medium, but the amount of light falling on an environmental surface depends also on the condition of the atmosphere and the layout of the environment. On earth light comes from the whole sky as well as the sun, and from other reflecting surfaces as well. Illumination, thus, is omnidirectional. Light reverberates between the sky and the earth and between surfaces, but its velocity is so enormous as to become no longer a flux of light but a steady state of illumination. Direct illumination from a source is always mixed with indirect illumination from surfaces. Thus there is ambient light at any point in the air and omnidirectional illumination falling on any surface. But nevertheless there is always a "prevailing" illumination, a direction at which the incident light is strongest.

A surface facing the prevailing illumination will be more highly illuminated than a surface not facing it. This seems to be a general principle relating illumination to surface layout. It means that the different adjacent faces of objects and enclosures will be differently illuminated.

7. High and Low Absorption of Light by a Surface

The seventh law says that, of the illumination falling on a surface, more or less will be absorbed by it depending on the chemical composition of the substance. Certain substances like pure carbon absorb much while others like chalk absorb little. This is why carbon is black and chalk is white.

In theoretical optics there are two alternatives for the absorption of light by a surface, transmission and reflection. In ecological optics, however, transmission can be neglected for most purposes and there is only one alternative, reflection. This is because most surfaces are not transparent like optical glass and pure water, but are opaque. And in any case no substance is perfectly transmitting. Only the medium itself is that. A surface that transmitted all of the light falling on it would not be a surface but the mere ghost of a surface, like the insubstantial fiction of a geometrical plane.

8. High and Low Reflection of Light by a Surface

The eighth law is merely the inverse of the seventh. It says that the amount of light bounced back into the medium instead of being soaked up by the surface is a characteristic of the substance. That is, the ratio of light reflected to light absorbed is a constant for any given compound or any homogeneous mixture. This is essentially the reflectance of a surface.

Coal has a low reflectance (xx%) and snow has a high reflectance (xx%). When substances of this sort are conglomerated the surface will have what I called a pigment texture; it will be "speckled." Granite and marble are substances whose surfaces are mottled or variegated in this way.

9. Differential Spectral Reflection of Light by a Surface

The last law of ecological surfaces goes even farther than the others in bracketing physical optics and bypassing complexities. It asserts that a surface has a characteristic distribution of the reflectance ratios of the different wavelengths of the incident light, and that different distributions constitute different colors. The word color here means hue, or chromatic color as distinguished from achromatic color, the variation of black, gray, and white.

For animals and men the colors of surfaces as defined above are more important than the colors of sunsets, rainbows, and flames as defined in optics. They specify the ripeness or unripeness of fruit and distinguish the leaf from the flower. They help to distinguish feathers and fur and skin, along with the textures of those surfaces. Surface color is inseparably connected with surface texture, for colored objects are apt to be particolored. And the different faces of objects and enclosures are often differently colored as well as always being differently illuminated.

A New Terminology for Surface Layout

The terms I have used in describing the environment and its layout are not quite the same as the terms of geometry. It would be useful to try and define the former as explicitly as possible. Geometry refers to planes and space whereas environmental science refers to surfaces and medium. The intersection of two planes is not the same as the junction of two flat surfaces. Planes and lines are transparent ghosts; surfaces and edges are opaque and substantial. The following terminology is tentative but it expresses a first attempt at an applied geometry of surface layout, a _theory_ of surface layout.

The ground. This term refers, of course, to the surface of the earth. It is, on the average, level, that is to say, perpendicular to the force of gravity. It is the reference surface for all other surfaces. It is also said to be horizontal and this word refers to the _horizon_ of the earth, the optical margin between earth and sky, a fact of ecological optics that has not yet been considered. Note that both gravity and the sky are implied by the ground. A special case of the ground is a floor.

An open environment. This term refers to a layout consisting of the surface of the earth alone. It is a limiting case only realized in a large desert or the open sea. The surface of the earth is usually "cluttered," that is to say not open but partly enclosed. There will be much more of this in Part II.

An enclosure, or enclosed environment. This term refers to a layout of surfaces that surrounds the medium, more or less. A wholly enclosed medium is a limiting case, at the other extreme from an open environment. It is only realized in a windowless cell which does not afford entry or exit. The surfaces of an enclosure all face inward.

A detached object. This term refers to a layout of surfaces that are completely surrounded by the medium. It is the inverse of a complete enclosure. The surfaces of a detached object all face outward, not inward. This is not a limiting case, for it is realized in objects that are moving or are moveable. Animate bodies, animals, are detached objects in this sense however much they may otherwise differ from inanimate bodies.

An attached object. This means a layout of surfaces less than completely surrounded by the medium. The substance of the object is continuous with the substance of another surface, often the ground. The surface layout of the object is not topologically closed as it is for the detached object, and as it also is for the complete enclosure. An attached object may be merely a convexity.

It may be noted that objects are denumerable, they can be counted, whereas a substance is not denumerable and neither is the ground.

Note also, parenthetically, that an organism such as a tree is an attached object in the environment of animals since it is "rooted" in the ground like a house with foundations, but it is a detached object when considered in relation to the environment of plants.

A partial enclosure. This means a layout of surfaces that only partly encloses the medium. It may be only a concavity. But a cave or a hole is is often a habitat.

A hollow object. An attached object that is also a partial enclosure --an object from the outside but an enclosure from the inside, part of the total surface layout facing outward and the other part inward. A snail shell and a hut are hollow objects.

A place. Any stationary location in the medium where an animal or an object can exist. But note that no animal or object can exist at rest except when in contact with a surface of support. A point of observation (p. 19) is a place where a stationary animal can exist but, since animals move about, a moving point of observation is more typical.

A site. A place on the ground, or at least on a surface of support. A hut, a house, and even a bird's nest must have a site.

A sheet. This means an object consisting almost entirely of two parallel surfaces enclosing a relatively small volume of substance. It is not to be confused with a geometrical plane. A sheet may have flat surfaces or curved surfaces, and it may be flexible or freely changeable in shape.

A fissure. This means a layout consisting of two parallel surfaces close together enclosing a small volume of medium.

A stick. An elongated object.

A fiber. An elongated object of small diameter. Not to be confused with a geometrical line.

An edge. The junction of two flat surfaces enclosing a substance. An edge is convex. It is analogous to the apex of a dihedral angle in geometry, the intersection of two planes, but not to be confused with it.

<u>A corner</u>. The junction of two flat surfaces enclosing a <u>medium</u> (in the present terminology). A corner is concave.

<u>A curved convexity</u>. A curved surface tending to enclose a substance.

<u>A curved concavity</u>. A curved surface tending to enclose the medium.

The foregoing terms apply to <u>surface</u> geometry as distinguished from <u>abstract</u> geometry. What are the differences between these two? A surface is substantial; a plane is not. A surface is textured; a plane is not. A surface is never perfectly transparent; a plane is. A surface can be seen; a plane can only be visualized.

Moreover a surface has only one side; a plane has two. A geometrical plane, that is, must be conceived as a very thin sheet in space not as an interface or boundary between a medium and a substance. A surface layout may be either convex or concave; a plane layout convex on one side is necessarily concave on the other. In surface geometry the junction of two flat surfaces is either an edge or a corner; in abstract geometry the intersection of two planes is a line. A surface has the property of facing a source of illumination or a point of observation; a plane does not have this property. In surface geometry an object and an enclosure can be distinguished; in abstract geometry they cannot.

Finally, in abstract geometry the position of a body is specified by coordinates on three chosen axes or dimensions in isotropic space; in surface geometry the position of an object is specified relative to gravity and the ground in a medium having an intrinsic polarity of up and down. Similarly the <u>motion</u> of a body in abstract geometry, a motion governed by Newton's laws, is a change of position along one or more of the dimensions of space or a rotation of the body (spin) on one or more of these axes.

But the motion of an object in surface geometry is always a change of surface layout, a change in the shape of the environment even when the object approximates to a Newtonian rigid body. And since environmental substances are often not rigid their surfaces often undergo deformation and these motions, stretching, squeezing, bending, twisting, flowing, and the like, are not reducible to the motions of classical mechanics.

What the Environment Affords the Animal

The environment of any animal and all animals contains substances, surfaces and their layout, enclosures, objects, terrestrial events, and the other animals. This description is very general; it holds true for insects, birds, mammals, and men. Let us now attempt a more particular description, selecting those surfaces, layouts, objects, and events that are of special concern to animals that behave more or less as we do. The total environment is too vast for description even by the ecologist, and we should select those features of it that are perceptible by animals like ourselves.

1. Terrain Features

The level ground is only rarely an "open" environment, as noted a few pages back. It is usually "cluttered." An open environment affords locomotion in any direction over the ground whereas a cluttered environment affords locomotion only at "openings." These rules refer, of course, to pedestrian animals, not flying animals or climbing animals. Man is a pedestrian, although he is descended from primates who were arboreal, and he has some climbing ability. The general capacity to go through an opening without colliding with the edges is not limited to pedestrians, however. It is a characteristic of all visually controlled locomotion (Gibson, 1958).

A _path_ affords pedestrian locomotion from one site to another, between the terrain features that prevent locomotion. The preventers of locomotion consist of _obstacles_, _barriers_, _water margins_, and _brinks_ (the edges of cliffs). A path must afford _footing_, which is to say that it must be relatively free of rigid foot-sized obstacles.

An obstacle can be defined as an animal-sized object that affords collision and possible injury. A barrier is a more general case, including the face of a cliff, a wall, or a man-made fence. Note parenthetically that a barrier usually prevents looking-through as well as going-through but not always; a sheet of glass and a wire fance are barriers but they can be seen through. A cloud, on the other hand, may prevent looking-through but not going-through. These special cases will be treated later.

A water margin (a margin is not to be confused with an edge in this terminology) prevents pedestrian locomotion; it permits other kinds, but let us postpone consideration of the various affordances of water.

A brink, the edge of a cliff, is a very significant terrain feature. It is a "falling-off place." It affords injury, and therefore needs to be perceived by a pedestrian animal. The edge is dangerous, but the near surface is safe. Thus there is a principle for the control of locomotion that I will call the _edge_ of danger and _gradient_ of danger principle; the closer to the brink the greater the danger. This principle is very general.

A step, or stepping-off place, differs from a brink in size, relative to the size of the animal. It thus affords locomotion. A stairway, a layout of adjacent steps, affords both descent and ascent. Note that a stairway consists of convex edges and concave corners alternating, in the terminology here being employed.

A slope is a terrain feature that may or may not afford pedestrian locomotion depending on its angle from the surface of the level ground and its texture. A ramp with low inclination can be negotiated; a cliff-face with high inclination cannot.

Man has been altering the natural features of the terrain for thousands of years, constructing paths, roads, stairways, and bridges over gorges and streams. Paths, roads, stairways, and bridges facilitate human locomotion and obviate climbing. Man has also been constructing obstacles and barriers to prevent locomotion by his enemies, human or animal. He has built walls, moats, and fences to prevent access to an enclosure, that is, to his camps and fortresses. And then, of course, he had to build doors in the walls, drawbridges over the moats, and gates in the fences to permit his own entry and exit.

2. Shelters

The atmospheric medium, it will be remembered, is neither entirely homogeneous nor wholly invariant. Sometimes there is rain in the air, or hail, or snow. Sometimes the wind blows, and in certain latitudes of the earth the air periodically becomes too cold for warm-blooded animals who will die if they lose more heat to the medium than they gain by oxidizing food. For this reason many animals and all men must have shelters. They often take shelter in caves or holes which are animal-sized partial enclosures. But some animals and all men of recent times build shelters, constructing them in various ways and of various materials. These are generally what I called hollow objects, not simply cavities in the earth. Birds and wasps build nests, for example, especially for sheltering their young. Men build what I will call huts--a generic term for the simplest human artificial shelters.

A hut has a site on the ground, and it is an attached object from the outside. But it also has an inside. Its essential features are, first, a roof which is "get-underneath-able" and thus affords protection from rain and snow and direct sunlight, second, walls which afford protection from wind and prevent the escape of heat and, third, a doorway to afford entry and exit, that is to say, an opening. A hut can be built of sticks, clay, thatch, stones, brick, or of many other more sophisticated substances.

3. Water

The margin between land and water stops the pedestrian. But the animal can wade if the water is shallow, float if his specific gravity is not too high, or skitter over the surface if he is an insect. Some terrestrial animals can swim on the surface of water, as man can after a fashion, and dive under the surface for a short time. But water does not afford respiration to a terrestrial animal with lungs and he is always in danger of drowning.

Considered as a substance instead of a surface or a medium, water is a necessity for terrestrial life, not a danger. Animal tissue consists mainly of solutions in water and the fluids of the body have to be replenished. The animal must drink. Only the intake of fresh water prevents death by dessication, or what we call thirst. So he needs to recognize water when he meets with it.

Water causes the wetting of dry surfaces. It affords bathing and washing, to elephants as well as men. Streams of water can be dammed, by beavers as well as by children and hydraulic engineers. Ditches can be dug and aquaducts built. Pots can be made that contain water, and then it affords pouring and spilling. Water, in short, has many kinds of meaning.

4. Fire

Fire was the fourth of the "elements" which, in the belief of the Greek thinkers, constituted the world. They were the first analyzers of the environment, although their analysis depended on direct observation. They observed earth, air, water, and then fire. In our chemical sophistication we now know that fire is merely a rapid chemical reaction of oxidation but nevertheless we still perceive a fire as such. It is not an object, not a substance, and it has no surface. A fire is a terrestrial event, with a beginning and an end, giving off heat and consuming fuel. Natural fires in the forests or plains were and still are awesome to animals but man, perhaps at the very beginning of the species, learned how to control fire. He learned how to begin it (with a fire-drill for example), how to make it persist (by feeding it fuel), how to conserve it (with a slow match), and how to quench it. The controlling of fire is a unique human habit. Our primitive hunting ancestors became very skilled at it. And as they watched the fire they could see a prime example of persistence with change, of invariance under transformation.

A fire affords warmth, even in the open but especially in a shelter. It provides illumination and, in the form of a torch, can be carried about, even into the depths of a cave. But a fire also affords injury to the skin. Like the brink of a cliff, one cannot get too close. There is a gradient of danger and a limit at which warmth becomes injury. So the controlling of fire entails the control of motor approach to fire and the detecting of the limit.

[Boxed note on the detecting of limits.]

Once this control is learned by the man and the child, fire affords many benefits besides warmth and illumination. It allows of cooking food substances and the boiling of water in pots. It permits the glazing of clay and the reduction of minerals to metals. So fire, like water, has many kinds of meaning, many uses, many values.

5. Objects

The term object in philosophy and psychology is so inclusive as to be almost meaningless. But I have limited its meaning so as to refer only to a persisting substance with a closed or nearly closed surface, a detached or attached object, a so-called "concrete" object not an "abstract" one. In this restricted sense the surface of an object has a characteristic texture, reflectance, color, and layout, that is to say, shape. These are some of the distinguishing features of an object.

An attached object of the appropriate size permits a primate to grasp it, as a monkey grasps a tree branch. (A bird can grasp with its claws in the same way.) Such an object is something to hold on to, and permits climbing. A detached object of the appropriate size to be grasped is even more interesting. It affords carrying, that is, it is portable. If the substance has an appropriate mass-to-volume ratio (density), it affords throwing, that is, it is a missile.

A hollow object like a pot can be used to contain water or wine or grain and to store these substances. An object with a level surface knee-high from the ground can be used to sit on. An elongated object, a stick, if the substance is elastic and flexible, affords bending and thus can be made into a bow for launching arrows. A rigid straight stick, not bent or curved, can be rotated on its long axis without wobbling; it can be used as a fire-drill or as an axle for a wheel. The list of examples could go on without end.

6. Tools

Tools are detached objects of a very special sort. They are graspable, portable, manipulable, and usually rigid. The purposive use of such objects is not entirely confined to man for other animals and other primates take advantage of thorns and rocks and sticks in their behavior but man seems to be the only animal that makes tools

The missile that can be thrown is perhaps the simplest of tools, although when combined with a launching device it can become very complex. The discovery of missiles by man was surely one of the factors that made him a formidable hunter as compared to the animals with teeth and claws. Soon after that discovery, presumably, came the invention of striking tools, edged tools, and pointed tools.

An elongated object, especially if weighted at one end and graspable at the other, affords hitting or hammering. It is a club. A graspable object with a rigid sharp edge affords cutting and scraping. This may be a knife, a hand-axe, or a chopper. A pointed object affords piercing as does a spear, an arrow, an awl, or a needle. These tools may be combined in various ways to make other tools. Once again it may be noted that the user of such a tool must keep within certain limits of manipulation since he himself may be struck or cut or pierced by the object.

When in use, a tool is a sort of extension of the hand, almost an attachment to it or a part of the user's own body, and thus is no longer a part of the environment of the user. But when not in use the tool is simply a detached object of the environment, graspable and portable to be sure, but nevertheless external to the observer. This capacity to attach something to the body suggests that the boundary between the animal and the environment is not fixed at the surface of his skin but can shift. More generally it suggests that the absolute duality of "objective" and "subjective" is false. When we consider the affordances of things we escape this philosophical dichotomy.

Clothing, even more than a tool, is a part of the wearer's body when being worn instead of a part of the environment. Apart from the utility of modulating heat-loss, clothing permits the individual to change the texture and color of his surface, to put on a second skin as it were. When not being worn a body covering is simply a detached object of the environment made of fabric or the skin of a dead animal--a complex, flexible, curved sheet in our terminology. But the article objectively affords wearing, as a tool affords using. And when it is worn it becomes attached to the body and is no longer a part of the environment.

8. Other Animals

Animate objects differ from inanimate objects in a variety of ways but notably in the fact that they move spontaneously. Like all detached objects they can be pushed and displaced by external forces, they can fall when pulled by the force of gravity, in short they can be passively moved, but they also can move actively under the influence of internal forces. They are partly composed of viscoelastic substances as well as rigid skeletons and their movements are always deformations of the surface. Moreover the style of movement, the mode of deformation, is unique for each animal. These special objects differ in size, shape, texture, color, odor, and in the sounds they emit, but above all they differ in the way they move. Their postures change in specific modes while their underlying invariants of shape remain constant. That is to say, animals have characteristic behaviors as well as characteristic anatomies.

Animals are thus by far the most complex objects of perception that the environment presents to an observer. The other animal may be prey or a predator, a potential mate or a rival, adult or young, and own-young or other's young. Moreover it may be temporarily asleep or awake, receptive or unreceptive, hungry or satiated. What the other animal affords is specified by its permanent features and its temporary state --eating or being eaten, copulation or fighting, nurturing or nurturance.

What the other animal affords the observer is not only behavior but also social interaction. As one moves so does the other move, the one sequence of action being suited to the other in a kind of behavioral loop. All social interaction is of this sort, sexual, maternal, competitive, co-operative, social grooming, play, and even human conversation.

9. <u>Human Displays</u>

Finally we come to a very special class of artificial objects, or perhaps devices is a better term, that display optical information. I refer to solid images of several types, pictures of many sorts, and all the surfaces of the environment that bear writing. Some twenty or thirty thousand years ago sculptures and pictures were first made, and some four or five thousand years ago writing was developed and records began to be kept. By now images and records are everywhere. A <u>display</u>, to employ a useful generic term, is a surface that has been shaped or processed so as to exhibit information for more than just the surface itself (Gibson, 1966, pp. 26-28 and 224-244). For example, a surface of clay is only clay, but it may be molded in the shape of a cow or scratched or painted with the profile of a cow or incised with the cuneiform characters that stand for a cow, and then it is more than just a surface of clay.

There will be much more about displays in Part IV, after we have considered the information for visual perception in Part II, and the process of visual perception in Part III. It can be suggested in a preliminary way, however, that images, pictures, and written-on surfaces afford a special kind of perception or knowledge that I call mediated or indirect. It is perception and knowledge at second hand. Moreover, images, pictures, and writing, insofar as the substances shaped and the surfaces treated are permanent, permit the storage of information and the accumulation of information in storehouses, in short, civilization.

The Environment of One Observer and the Environment of All Observers

The essence of an environment is that it <u>surrounds</u> an individual. I argued at the outset that the way in which a physical object is surrounded by the remainder of the physical world is not at all the same as the way in which a living animal is surrounded by an environment. The latter surrounds, or encloses, or is ambient in special ways that I have tried to describe.

The term "surroundings" is nevertheless vague and this vagueness has encouraged confusions of thought. One such is the question of how the surroundings of one single animal can also be the surroundings of all animals. If it is assumed that no two observers can be at the same place at the same time it can be inferred that no two observers ever have the same "surroundings." This seems to be a philosophical puzzle, but it is a false puzzle. One may consider the layout of surrounding surfaces with reference to a stationary point of observation, a center where an individual is standing motionless as if the environment were a set of frozen concentric spheres. Or one may consider the layout of surrounding surfaces with reference to the medium in which the individual can move about, that is, with reference to a _moving_ point of observation along a path which any individual can travel. This is much the more useful way of considering the "surroundings," and it recognizes the fact that animals do in fact move about. The animal that does not move is asleep--or dead.

The available paths of locomotion in a medium constitute the set of all possible points of observation. In the course of time each single animal moves through the same paths of its habitat as do other animals. Although it is true that no two individuals can be at the same place at the same time, any individual can stand in all places and all individuals can stand in the same place at different times. Insofar as the habitat has a persisting substantial layout, therefore, all its inhabitants have an equal opportunity to explore it. In this sense the environment surrounds all observers in the same way that it surrounds a single observer.

The old idea that each observer stands at the center of his world and that each environment is therefore unique gets its main support from a narrow conception of optics and a mistaken theory of visual perception. This, at least, is what I shall try to show in Part II.

Chapter 10

The Discovery of the Occluding Edge

and its Implications for Perception

Chapter 10

The Discovery of the Occluding Edge and its Implications for Perception

The facts of occlusion have already been described in Chapter 5. They are part of ecological optics. But they were not recognized as facts until observations and experiments made them compelling. The experiments described in the last chapter about surfaces, layout, change, and kinesthesis were radical enough but they culminated in the most radical of all, in what I can only call the discovery of the occluding edge. It is radical for the following reason. If it is true that there are places where opaque surfaces are seen one behind another, if it is true that one can perceive a _hidden_ surface, a paradox arises. For we are not allowed to say that a hidden surface is _perceived_; we can only say that it is _remembered_. To be perceived, a thing must be "present to the senses." It must be stimulating receptors. If not, it can only be experienced by means of an _image_; it can be recalled, imagined, conceived, or perhaps known, but not perceived. Such is the accepted doctrine, the theory of sensation-based perception. If an occluded surface is perceived the doctrine is upset.

Kaplan's Experiment

The crucial experiment involved kinetic, not static, displays of information. It was performed by Kaplan (1969). Each display was a motion picture shot of a random texture filling the screen. There was a progressive deletion (or accretion) of the optical structure on one side of a contour with preservation of the structure on the other side. Photographs of a randomly textured paper were taken frame by frame, and successive frames were modified by careful paper-cutting. No contour was ever visible on any single frame, but progressive decrements of the texture were produced on one side of the invisible line by cutting off thin slices of paper in succession. Progressive <u>increments</u> of the texture could be obtained by reversing the film. This particular kind of decrementing or incrementing of structure had not previously been achieved in a visual display.

In effect, a reversible disturbance of structure in a sample of the optic array had been isolated and controlled, a reversible transition. It is called a <u>transition</u>, not a <u>transformation</u>, since elements of structure were lost or gained and one-to-one correspondence was not preserved. What was perceived?

All observers, without exception, saw one surface <u>going behind</u> another (or <u>coming from</u> behind) which was always concealing (or revealing) the first. Deletion always caused the perception of covering and accretion always caused the perception of uncovering. The surface going out of sight was never seen to go out of existence and the surface coming into sight was never seen to come into existence. In short one surface was seen in a legitimate sense <u>behind</u> another <u>at an occluding edge</u>.

When the array was arrested by stopping the film the edge-perception ceased and a wholly continuous surface replaced it; when the optical transition was resumed the edge perception began. The "motion" of the display as such, however, had nothing to do with the occluding edge; what counted was accretion or deletion and whether it was on one side or the other.

These results were striking. There were no uncertainties of judgment, no guessing as in the usual psychophysical experiment. What the observers saw was an edge, a *cut* edge, the edge of a *sheet*, and another surface behind it. But this depended on an array changing in time.

The surface that was being covered was seen to persist *after* being concealed and the surface that was being uncovered was seen to preexist *before* being revealed. The hidden surface could not be described as *remembered* in one case or *expected* in the other. A better description would be that it was perceived retrospectively and prospectively. It is certainly reasonable to describe perception as extending into the past and the future, but note that to do so violates the accepted doctrine that perception is *confined* to the present.

The crucial paper by Kaplan (1969) was published along with a motion picture film called *The change from visible to invisible: a study of optical transitions* (Gibson, 1968) and an article having the same title by Gibson, Kaplan, Reynolds, and Wheeler (1969). A sharp distinction was made between *going out of sight* and *going out of existence* and it was proposed that there is information to specify the two cases. I have described the information in Chapters 5 and 6. The former is a *reversing* transition but the latter is not.

Anticipations of the Occluding Edge

The important result of Kaplan's experiment was not the perceiving of depth at the occluding edge but the perceiving of the persistence of the occluded surface. Depth perception requires no departure from traditional theories but persistence perception is radically inconsistent with them. Only in the experimental work of Michotte had anything like persistence perception ever been hinted at (Michotte, Thines, and Crabbe, 1964). He discovered what he called the "tunnel phenomenon" or the "tunnel effect," the perception of a moving object during the interval between going into a tunnel and coming out of it. He did not ascribe it, however, to progressive deletion and accretion of structure for going in and coming out, but to a tendency for perception to be completed across a gap, in the style of Gestalt theorizing. He did not realize how universal occlusion is during locomotion of the observer. But he was very much aware of the paradox of asserting that an object could be seen during an interval when there was no sensory basis for seeing it. The "screening" or "covering" of an object, he realized, was a fact of visual perception. But he could only suppose that the perception of an object must somehow persist after the sensory input ends; he did not entertain the more radical hypothesis that the persistence of the object is perceived as a fact in its own right. There is a vast difference between the persistence of a percept and the perception of persistence.

It had long been recognized that in pictures, or other displays with a frozen array, the appearance of superposition could be obtained. Likewise the discovery of Rubin that a closed contour or figure in a display involved the appearance of a ground that seemed to extend without interruption behind the figure was well known. But these demonstrations were concerned with the seeing of contours and lines and the perceiving of forms, not with the perceiving of the occluding edges of surfaces in a cluttered terrestrial environment. They showed that what might be called depth-by-superposition, could be induced by a picture but not that an occluded surface is seen to persist.

The occluding edge seems to have escaped notice in both physics and psychology. In truth, it is not a fact of physics nor a fact of psychology as these disciplines have been taught. It depends on the combined fact of a surface layout and a point of observation taken together.

The Theory of Reversible Occlusion

The theory of reversible occlusion was formulated in Chapter 5 on the ambient, optic array in terms of what I called projected and unprojected surfaces. Reversible occlusion was said to be a consequence of the reversibility of locomotions and motions in the medium, and this was contrasted in Chapter 6 with the unreversibility of changes like disintegration, dissolution, and the change from a solid to a liquid or gas. These changes, I said, were not such that the waning of a surface was the temporal inverse of waxing, not such that if a film of one event were run backward it would represent the other (Gibson and Kaushall, 1973).

Then in Chapter 7 on the self the principle of reversible occlusion was extended to the head turning of the observer and the margins of the field of view were compared to the occluding edges of a window. The principle is widely applicable. It would be useful to bring together all this theorizing and to summarize it in a list of propositions.

Terminology. The reader should be reminded again that many pairs of terms can be used to denote what I have called occlusion. In what follows the words hidden and unhidden are chosen to have a general meaning although they have the unwanted flavor of buried treasure. Unprojected and projected are the terms used in Chapter 5. They are all right except for the implication of throwing an image on a screen which gives precisely the wrong emphasis. Covered and uncovered are possible terms, or screened and unscreened, and these were employed by Michotte. There also is concealed and revealed, or undisclosed and disclosed. They all refer to various kinds of occlusion. The most general terms are out-of-sight and in sight, which contrast with out-of-existence and in existence. It should be kept in mind that all these terms refer to reversible transitions, that is, to becoming hidden or unhidden, to going out of sight or coming into sight. But a pair of terms that shoudd not be employed is disappear and appear. Although in common use, these words are ambiguous and promote sloppy thinking about the psychology of perception. The same is true of the words visible and invisible.

There seem to be a number of different ways of going out of sight, some not by occlusion and some by occlusion. The latter always involves an occluding edge with progressive deletion on one side of a contour but the former does not. I can think of three kinds of going out of sight not by occlusion, first, going into the distance by minification of the solid angle to a so-called vanishing point in the sky or on the horizon, second, going out of sight in "the dark" by reduction of illumination and, third, going out of sight by closure or covering of the eyes. Perhaps going out of sight in fog or mist is another kind but it is similar to loss of structure by darkness (Chapter 4). I can also think of three kinds of occlusion, first, at the edge of an opaque covering surface, second, at the edge of the field of view of an observer and, third, at the horizon of the earth for celestial bodies. As for the going out of existence of a surface there seem to be many kinds of destruction, so many that only a list of examples could be given in Chapter 6 on ecological events.

The Case of Locomotion in a Cluttered Environment. Here are ten statements about reversible occlusion taken from Chapters 1 to 5.

1. The substances of the environment differ in the degree to which they persist, some resisting dissolution, disintegration, or vaporization more than others.

2. The surfaces of the environment, similarly, differ in the degree to which they persist, some being transitory and others being relatively permanent. A surface goes out of existence when its substance dissolves, disintegrates, or evaporates.

3. Given an illuminated medium a surface is unhidden at a fixed point of observation if it has a visual solid angle in the ambient optic array at that point. If it does not (but has at another point of observation, it is hidden.

4. For any fixed point of observation the persisting layout of the environment is divided into hidden and unhidden surfaces. Converse-

ly, for every persisting surface the possible points of observation are divided into those at which it is hidden and those at which it is not.

5. A surface that has no visual solid angle at any point of observation is neither hidden nor unhidden. It is out of existence, not out of sight.

6. Any movement of a point of observation that hides previously unhidden surfaces has an opposite movement that reveals them. Thus the hidden and the unhidden interchange.

This is the law of reversible occlusion for locomotion in a cluttered environment. It implies that after a sufficient sequence of reversible locomotions all surfaces will have been both hidden and unhidden.

7. The loci of occlusion. The hidden and unhidden surfaces into which a layout is temporarily divided are separated at occluding edges, there being two sorts, apical and curved. But equally the hidden and unhidden surfaces are joined at occluding edges. Thus to perceive an occluding edge, even a fixed occluding edge at a fixed point of observation, is to perceive both the separation and the junction of surfaces.

The Case of the Motions of Detached Objects. Here are three more statements about reversible occlusion from Chapter 5.

8. For any opaque object the near surface, the temporary "front," hides the far surface, the temporary "back' at a fixed point of observation. The two interchange, however, when the object is rotated. The near surface also hides the background of the object, if present, but when the object is displaced the parts that go behind at one edge come

from behind at the other. These facts can be observed in the film entitled "a study of optical transitions" (Gibson, 1968).

9. For both solidity and superposition, any motion of an object that conceals a surface has a reverse motion that reveals it.

10. To the extent that the objects of the environment have moved around all sides of every object, will have passed back and forth from hidden to unhidden. This holds true over and above the extent to which the observer has moved around.

The Case of Head Turning. Here is the theorem about reversible occlusion when the observer looks around by turning his head. It is now assumed that the point of observation is occupied (Chapter 7).

11. For any fixed posture of the head, surfaces of the surrounding layout are divided into those inside the boundaries of the field of view and those outside the boundaries of the field. But with every turn of the head surfaces come into sight at the leading edge of the field of view and go out of sight at the trailing edge. The observer who looks around can thus see undivided surroundings and see himself in the middle of them.

The Case of Non-Persisting Surfaces. Here is the theorem about the unreversing destruction and creation of surfaces and the unreversing optical transitions that accompany them (Chapter 6).

12. The going out of existence of a surface is not the reverse of its coming into existence, nor is the disturbance of optical structure that specifies one the reverse of the disturbance of structure that specifies the other. Hence the disappearance of a surface by, say, dissolution can be distinguished from its disappearance by

occlusion if the observer has learned to see the difference between the optical transitions. Such evidence as there is suggests that they are usually distinguished (Gibson, Kaplan, Reynolds, & Wheeler, 1969). This is not to say that infants notice the difference, or even that adults always notice the difference. The difference may sometimes be hard to notice, as when a conjuror is playing tricks with one's perception. It is only to say that anyone can learn to see the difference.

The occlusion of a surface can be nullified whereas the destruction of a surface cannot. Occlusion can be cancelled by a movement of the body, head, or limbs in the opposite direction. Destruction can sometimes be remedied but not simply cancelled by an opposite movement. It seems to me that young children must notice the optical transitions that can be thus nullified and those that cannot. How could they fail to pay attention to them? They play peek-a-boo, turn their heads, and watch their hands, all being cases of reversible occlusion, and they also spill the milk, break the glass and knock down the tower of blocks, these being cases that cannot be reversed. But this hypothesis has not been tested with babies, since the only experiments carried out are in the spirit of rationalism promoted by Piaget, which asserts that the child must form a concept of persistence or permanence and emphasizes what the child believes instead of what he sees (e.g. Bower, 1974, Chapter 7).

<u>What is Seen at this Moment from this Position does not Comprise what is Seen</u>

The old approach to perception took the central problem to be how one could see into the distance and never asked how one could see into the past and the future since those were not problems for perception. The past was remembered and the future was imagined. Perception was of the present. But no one could decide how long the present lasted, or what distinguished memory from imagination, or when percepts began to be stored, or which got stored, or any of the other puzzles to which this doctrine led. The new approach to perception, admitting the co-perception of the self to equal status with the perception of the environment, suggests that the latter is timeless and that present-past-future distinctions are only relevant to the awareness of the self.

The environment seen-at-this-moment does not constitute the environment that is seen. Neither does the environment seen-from-this-point constitute the environment that is seen. The seen-now and the seen-from-here specify the self, not the environment. Consider them separately.

What is seen-now is a very restricted sample of the surfaces of the world, limited to those that are inside the boundaries of the field of view at this head posture. It is even limited to that surface which is being fixated at this eye-posture, if by "seen" one means <u>clearly</u> seen. This is at most less than half of the world and perhaps only a detail of that.

What is seen-from-here is at most the optically uncovered surfaces of the world at this point of observation, that is, the near sides of objects, the unhidden portions of the ground, the walls, and the bits that project through windows and doors.

The fact is that, although one can become aware of the seen-now and the seen-from-here if he takes the attitude of introspection, what one perceives is an environment that surrounds one, that is everywhere equally clear, that is in-the-round or solid, and that is all of a piece. This is the experience of what I once called the visual world (Gibson, 1950, Chapter 3). It has vistas that are connected and places that adjoin, with a continuous ground beneath everything, below the clutter, receding into the distance, out to the horizon.

The surface being fixated now at this momentary eye posture is not a depthless patch of color, and the surfaces inside the field of view seen now at this head posture are not a depthless patchwork of colors, for they have the quality that I called <u>slant</u> in the last chapter. The seen-at-this-moment is not quite the same, therefore, as the supposedly flat visual <u>field</u> analogous to the colors laid on a canvas by a painter that the old theory of color sensations asserted. I once believed that you could with training come to see the world as a picture, or almost do so, but I now have doubts about it. That comes close to saying that you can almost see your retinal image, which is a ridiculous assertion.

The seen-from-here, from this fixed point of observation, is not the supposedly flat visual field of tradition either, for it is ambient. But it might justly be called seeing the world in perspective, or noticing the perspectives of things. This means the natural perspective of ancient optics, not the artificial perspective of the Renaissance; it refers to the set of surfaces that create visual solid angles in a frozen ambient optic array. This is a very small sample of the whole world, however, and what we perceive is the world.

Perception over Time from Paths of Observation

It is obvious that a motionless observer sees the world from a single fixed point of observation, and can thus notice the perspectives of things. It is not so obvious but true that an observer who is moving about sees the world at no point of observation and thus, strictly speaking, cannot notice the perspectives of things. The implications are radical. Seeing the world at a travelling point of observation, over a long enough time for a sufficiently extended set of paths, begins to be perceiving the world at all points of observation, as if one could be everywhere at once. To be everywhere at once with nothing hidden is to be all-seeing, like God. Each object is seen from all sides, and each place is seen as connected to its neighbor. The world is not seen in perspective. The underlying invariant structure has emerged from the changing perspective structure as I put it in Chapter 5.

Animals and men do in fact see the environment during locomotion, not just in the pauses between movements. They probably see better when moving than when stationary. The arrested image is only necessary for a photographic camera. An observer who is getting around in the course of daily life sees from what I will call a path of observation. A path does not have to be treated as an infinite set of adjacent points at an infinite set of successive instants; it can be thought of as a unitary movement, an excursion, a trip, or a voyage. A path of observation is the normal case, short paths for short periods of observation and long paths for hours, days and years of observation. The medium can be thought of as not composed of points but of paths.

It sounds very strange to say that one can perceive an object or a whole habitat at no fixed point of observation for it contradicts the picture theory of perception and the retinal image doctrine on which it is based. But it has to be true if it is acknowledged that one can perceive the environment during locomotion. The perception of the environment is understood to accompany the visual proprioception of the locomotion, of course, and the hypothesis of invariant structure underlying the changing perspective structure is required for this to be intelligible. These are unfamiliar notions. But they are not more difficult, surely, than the notion of successing snapshots of the flowing optic array taken by the eye and shown in the dark projection room of the skull.

Implications for the Problem of Orientation

Animals and men are capable of being oriented to the habitat. This state is the opposite of being disoriented or "lost." The rat who can find his way directly to the goal box of a maze is said to be oriented to the goal. If there are many paths to the goal the animal is capable of taking the shortest path. A man, similarly, can learn the way to work, to the postoffice, to the grocery store, and back home again through the passageways of his town. When he can do so in an unfamiliar town he has become oriented in the new habitat. Both animals and men are capable of homing. More generally, they are capable of way-finding. Or in still other terms they can do place-learning. The observer can go to the places in his environment that have affordances for him. If he is a human observer, moreover, he may be able to point to these places, that is, to indicate their direction from here through the walls or other surfaces that hide them.

There are two current explanations of how animals learn to find their way to hidden places, the theory of response chains and the theory of cognitive maps. Neither is adequate. Way-finding is surely not a sequence of turning responses conditioned to stimuli. But neither is it the consulting of an internal map of the maze, for who is the internal perceiver to look at the map? The theory of reversible occlusion can provide a better explanation.

An alley in a maze, a room in a house, a street in a town, and a valley in a countryside each constitutes a place, and a place often constitutes a vista (Gibson, 1966, p. 206). It is a semi-enclosure, a set of unhidden surfaces. A vista is what is seen-from-here, with the proviso that "here" is not a point but an extended region. Vistas are serially connected since at the end of an alley the next alley opens up; at the edge of the doorway the next room opens up; at the corner of the street the next street opens up; at the brow of the hill the next valley opens up. To go from one place to another involves the opening up of the vista ahead and the closing in of the vista behind. In a maze or a cluttered environment there is a choice of vistas. And thus to find the way to a hidden place one needs to see which vista has to be opened up next, or which occluding edge hides the goal. One vista leads to another in a continuous set of reversible transitions.

(Insert illustration similar to Fig. 10.10 from Perceptual Systems)

When the vistas have been linked up by exploratory locomotion the invariant structure of the house, the town, or the whole habitat will be apprehended. The hidden and the unhidden become all one environment. One can then perceive the ground below the clutter, out to the horizon, and at the same time perceive the clutter. One is oriented to his environment. It is not like having a bird's-eye view of the terrain so much as being everywhere at once. The getting of a bird's-eye view is helpful in becoming oriented, and the explorer will look down from a high place if he can. Homing pigeons are better at orientation than we are. But orientation to goals behind the walls, beyond the trees, and over the hill is not just a looking-down-on, and it is certainly not the having of a map, not even a "cognitive" map supposed to exist in the mind instead of on paper. A map is a useful artifact when one is lost but it is a mistake to confuse the artifact with the psychological state which the artifact promotes.

Note that the perception of places and the perception of detached objects are quite different. Places cannot be displaced whereas objects can be and animate objects displace themselves. Places merge into adjacent places whereas objects have boundaries. Orientation to hidden places with their attached objects can be learned once and for all whereas orientation to moveable objects has to be relearned continually. I know where the kitchen sink is, I think I know where the ski boots are stored, and I don't always know where my child is. One can only go to the last known locus of a detached object. Hidden objects can be moved without that event being perceived and the unhappy state of the man whose car keys are seldom where he left them is notorious.

Summary. A theory of orientation to the places of the habitat has been formulated. The perceiving of the world entails the co-perceiving of where one is in the world and of being in the world at that place. This is a neglected fact that is neither subjective nor objective. To the extent that an observer has moved from place to place, from vista to vista, he can stand still in one place and see where he is, which means where he is relative to where he might be. I suggest that this constitutes the state of being oriented.

Implications for the Problem of Public Knowledge.

The hypothesis of reversible optical transformations and occlusions resolves the puzzle of how, although the perspective appearances of the world are different for different observers, they nevertheless perceive the same world. Perspective appearances are not the necessary basis of perception.

It is true that there is a different optic array for each point of observation and that different observers must occupy different points at the same time. But observers move and the same path may be travelled by any observer. If a set of observers move around, the same invariants under optical transformations and occlusions will be available to all. To the extent that the invariants are detected they will all perceive the same world. Each will also be aware that his place in the world is different here and now from that of any other.

Points, of course, are geometrical concepts whereas places are ecological layouts, but the above can also be put geometrically: although at a given instant some points of observation are occupied and the remainder unoccupied, the one set can go into the other.

The theory asserts that an observer can perceive the persisting layout from other places than the one he occupies at rest. This means that he can perceive it from the position of another observer. The common assertion, then, that "I can put myself in your position" has meaning in ecological optics and is not a mere figure of speech. To adopt the point of view of another person is not an advanced achievement of conceptual thought, It means I can perceive surfaces hidden at my point of view but unhidden at yours. This means, I can perceive a surface that is behind another. And if so, we can both perceive the same world.

Implications for Egocentric Awareness

Psychologists often talk about egocentric perception. An egocentric perceiver is supposed to be one who can see the world only from his own point of view, and this habit is sometimes thought to characterize an egocentric person. Egoism is thought to come naturally to man because he is innately aware of his private experiences and does not easily learn to adopt the point of view of another. This line of thinking now seems mistaken. Perception and proprioception are not alternatives or opposing tendencies of experience but complementary experiences.

The sensation-based theories of perception assume that the perspective appearances of the world are all that a newborn infant is given. They are the data for perception. Hence the young child is necessarily egocentric, and cognitive development is a matter of progressing from subjective sensations to objective perceptions. The child's ego includes everything, supposedly, and yet he is confined to the awareness of his fleeting sensations. But there is reason to be suspicious of these speculations. The evidence about the earliest visual experiences of infants does not suggest that they are confined to surfaces seen-now-from here, and the evidence definitely contradicts the doctrine that what they aee is a flat patchwork of color sensations. I suspect that the supposed egocentricity of the young child is a myth.

Implications for Social Psychology

In Chapter 8 on affordances I described how some of the places of an environment are hiding places. That is, they afford the hiding of oneself or of one's property from the sight of other observers. The phenomenon of seeing without being seen illustrates the application of optical occlusion to social psychology. The passage on hiding places in Chapter 8 should be reread.

The perceiving of occluded places and objects does occur and can be shared with other perceivers. To this extent we all perceive the same world. But there is also ignorance of occluded things, and if you hide from me your private property, your hideaway in the hills, your secret mistress, or the birthmark on your buttocks, to this extent you and I do not perceive quite the same world. Public knowledge is possible but so is its reciprocal, private knowledge.

Not only do babies like to play peek-a-boo and children to play hide-and-seek; animals who are preyed upon hide from the predator, and the predator may hide from the prey, in ambush. One observer often wants to spy upon others, to see without being seen. He peers through a peephole or peeks around the occluding edge of a corner. In opposition to this is the striving <u>not</u> to be seen by others, the need for privacy. Burrows, caves, huts, and houses afford not only shelter from wind, cold, and rain but also the state of being out of sight, or out of the "public eye."

The human habit of covering the body with clothing whenever one is in sight of others is a matter of hiding some skin surfaces but not others, depending on the conventions of the culture. To display the usually covered surfaces is improper or immodest. The providing of some information for the layout of these hidden surfaces, however, is the aim of skillful dress-designers. And the careful manipulation of the occluding edges of clothing with progressive revealing of skin is a form of the theatrical art called stripping.

Psych 512
March 1974

A Further Note on the

Perceiving of Hidden and Unhidden Surfaces

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There are still more facts or laws of ecological optics that deal with hidden and unhidden surfaces, and the interchanges between them, beyond those listed in the memo of February, 1974. They also have further implications.

1. To every point of observation in the medium, there corresponds a unique optic array. This is because a surface layout at one place in the world is not duplicated at any other; one "scene" is not repeated elsewhere. This law holds at the ecological but not the atomic level.

2. To every <u>moving</u> point of observation in a medium, there corresponds a uniquely <u>changing</u> optic array, the change being specific to the path of locomotion.

Now consider objects and enclosures, an object such as a table and an enclosure such as a room.

3. To every object or enclosure in the world, there corresponds a unique family of optic arrays at all the points of observation to which the object or enclosure is projected. We express this fact very loosely when we say that there is a family of "perspective appearances" for each object or enclosure.

The family of optic arrays can be registered in sequence by an individual observer who <u>moves around</u> the table or in the room; the family can be registered simultaneously by a crowd of different observers who <u>stand around</u> the table or in the room. (I am assuming that each observer can look around at his point of observation). It follows, since all can move around, that all observers can perceive the same table, and the same room. It is only true that no observer can have the same perspective at the same time as another observer. This law is the basis of consensus.

4. To perceive an object means to perceive its far side as well as its near side, i.e., what it looks like if one walks around it (or if it is turned around). That is, to perceive something is to be aware of it from other points of observation than the stationary point being occupied. I suggest that this is entailed in perceiving.

This is what I meant when I wrote of visualizing as a kind of "apprehending without a fixed point of observation" in Leonardo (1974).

5. An observer who is aware of something from other points of observation than the one now occupied is able to take the point of view of another observer or, as we say, "see" from his point of view. If he can do so, he should be able to describe an object as it appears to another person in the room, since he can perceive that the other person is facing the "far" side of the object, or the "left" side (or whatever). Or he should be able to recognize a photograph of the object taken from the other person's point of view. This is the experiment carried out by Piaget and Inhelder with children in The Child's Conception of Space.

6. There is said to be egocentric perception as well as behavior. The egocentric person is said to be one who sees the world only from his own point of view. But this, it should now be clear, is literally

impossible, since the point of view moves, the structure of the optic array keeps changing, and the appearances fluctuate. If the world can only be perceived from a moving point of observation it is, of necessity, perceived from "other" points of view, which includes those of other persons. In short, there is no such thing as egocentric perception (there is only egocentric <u>proprio</u>ception). The evidence does <u>not</u> suggest that the earliest visual experiences of the child are those of the perspective projections of objects and places; more likely the first percepts are based on what may be called "formless invariants."

7. In short, the assertion that "I can see things from your point of view," or "I can put myself in your position" has an exact meaning in the terms of ecological optics and is not merely a figure of speech. It means <u>I can perceive surfaces that are revealed at your point of view but concealed at mine</u>. It means <u>I can see one thing behind another</u>. And it implies that <u>we both see the same world</u>.

8. The fact that animals and men can be oriented to the environment <u>behind the surfaces that are projected to the momentary point of view</u>, the "hidden" environment, or to the <u>geographical</u> environment (Ryan and Ryan) becomes intelligible in the light of the above facts. The homing of animals and the migration of birds can be explained in this way instead of by the theory of the development of the concept of "object permanence."

May 1979

What is Involved in Surface Perception?

(Preliminary Draft)

James J. Gibson, Cornell University

The theory put forward in The Ecological Approach to Visual Perception begins with the properties of surfaces instead of the traditional qualities of objects: color, form, location, and motion. What properties of a surface are perceivable? The following proposals extend what was said in Chapter 2. I can think of at least nine such surface properties. Most of them have been noticed by phenomenologists, but I assume that they are also real.

Several facts about surfaces as distinguished from objects should be noted. First, a surface is not discrete like a detached object and thus surfaces are not denumerable. Instead, a surface is nested within superordinate surfaces. Second, a surface does not have a location as an object does, a locus in space. Instead, it is part of what I call the environmental layout; it is situated relative to the other surfaces of the habitat underlaid by the ground, the surface of support. A Newtonian body has location relative to the three coordinate axes of mathematical space but these axes are not perceived; they are thought of. Hence the problem of how we perceive space is a false problem, and the unsolved puzzle of how we might perceive locations in space (on the basis of cutaneous or retinal "local signs") is a false puzzle. Third, a surface does not have a color in the sense of that term employed in physical optics, and does not have a form in the sense of that term used in plane geometry.

An object, in this theory, is only a surface that stands out from the rest of the surface layout, the ground, because it is bounded by an occluding edge. This is an ecological fact, to which the figure-ground phenomenon is incidental.

What perceivable properties does a surface have? Here is a partial list: hard to soft, luminous or reflecting, illuminated to shaded, high to low reflectance, uniform to speckled reflectance, smooth to rough texture, opacity to transparency, dull to shiny, and hot to cold. Note that some of these are accessible to both the visual and the haptic system in corroboration, some are accessible only to vision, and the last is accessible only to the skin system.

1. The property of being rigid, viscous, or ~~fluid~~ liquid. This is observable by palpating, prodding, or pounding the surface without seeing it, by seeing the "impact-character" of a collision without feeling it (as has recently been shown by Runeson at Uppsala), or by both together. This distinguishing of regidity-viscosity and firmness-softness, is a good beginning basis for later differentiating the variety of substances in the environment, and babies seem to do so are at an early age (E. Gibson) long before they learn to apply names to them.

2. The property of being radiant or reflecting. A luminous surface emits light; an ordinary surface only reflects illumination. How are they distinguished visually? (e. g., Wallach on the quality of being luminous). If heat accompanies the light the source can also be detected by turning one's skin from side to side.

3. The property of being weakly or strongly illuminated. If any surface in a layout is illuminated all of them are illuminated, and there are ambient optic arrays at all points in the air. But some faces of the layout are relatively lighted "while some are relatively "shaded," and this fact is independent of the amount of light in the air. It depends on the inclination of the surface to the direction of the source, for one thing. How do we see whether a surface is in weak light or in strong light? A surface in weak light during the morning will be in strong light during the afternoon, and *vice versa*. Ratios of luminance among the visual solid angles of the ambient array must have something to do with it. You cannot tell by touching a surface, of course, whether and how much it is illuminated.

4. The property of high to low reflectance of the incident light. The reflectance of a reflecting surface is intrinsic to the substance, i. e., the kind of substance it is. Reflectance is a diagnostic ratio, a fraction. The relative reflectances of all the surfaces in the layout are also invariant. How do we see them despite all the fluctuations of terrestrial and artificial illumination? I suggested in my new book (page 86 ff.) that a persistent structure in an ambient optic array underlies the changing structure caused by the movement of the sun across the sky and the resulting interchange between surfaces that are lighted and shaded. Perhaps in this way one can see both the relative slants of surfaces in the layout and their relative reflectances. They are what persist; shadows fluctuate. The fact is that we can see the convexities and the colors of the surface layout underneath the shadows.

5. The property of having uniform or non-uniform reflectance. The reflectance of a surface may be uniform or the surface may be speckled,

spotted, patterned, pigmented, variegated, or the like. It is not enough merely to say that a surface has an intrinsic "color." A substance is often a conglomerate. The *natural* spotting of a surface characterizes the substance that underlies it, as does its texture (below). But that fact is complicated by the presence in the human habitat of *artificially* spotted flat surfaces like drawing-pads and canvases, walls, screens, and writing paper. The original [redacted] surface can often be recognized. The spots, traces, or deposits are man-made. Apart from what we call *stains* or *dirt* they are said to be *graphic*. And apart from those we call *purely decorative* they *stand for something other than the surface itself*. Hence they may induce a mediated awareness of this "other" along with the direct perception of the surface. These complex facts tend to confuse everybody, and the study of this kind of mediated perception is full of perplexities. But most of the experiments that illustrate Gestalt theory were carried out with man-made tracings on a surface.

6. *The property of being smooth or rough and, if the latter, whether the texture is coarse or fine and, in either case, what form it takes*. This property, especially the form of texture (rippled, pebbled, granular, ridged) is very characteristic of the underlying substance. It can be seen with exactness whenever the illumination has a prevailing direction, or is "glancing," but not so well when it is equal from all directions; then the illumination is said to be "flat." The smoothness, fineness, and roughness of a texture can be detected by rubbing it, as Katz showed (*Systems*, page 126 ff.).

7. *The property of being dull or shiny (lustrous)*. This property is related to its being unpolished or polished (specular). Luster seems

to depend on the presence in the optic array of "highlights" on the surface. The property of being polished can be observed by rubbing the surface with the tips of the fingers. Is this the same as the property of being lustrous?

8. The property of being opaque or transparent. The ordinary substances of the habitat transmit none of the incident light (they reflect some portion and absorb the rest). Their surfaces are opaque. A few natural substances transmit some or much of the light. Their surfaces, if the interface is a flat plane, are said to be transparent, more exactly semi-transparent. There is refraction at the surface, i. e., the rays of rdiation are bent, but if a surface of pure water is unrippled, or if a sheet of clear glass is polished, the visual solid angles of an optic array have essentially the same structure and are not "distorted" by the surface (cf. the research on the wearing of distorting spectacles). I think this is what is meant by saying that the still surface of a pool or the parallel plane surfaces of the glass plate are transparent: one can perceive the essential properties of another surface behind it or, as we say, one can "see through it." Note that a translucent sheet (ground, pebbled, or diffusing) allows the passage of light but disrupts the structure of an array.. An opaque sheet or screen blocks both the light and its structure. The edge of a transparent sheet does not hide or conceal but the edge of a translucent sheet does, as much as the edge of an opaque sheet. There can also be semi-transparent sheets that are only partially concealing or blurring, as some of Metelli's demonstrations seem to suggest.

9. The property of being at a higher or lower temperature than the skin. What we call hot, warm, neutral, cool, or cold "to the touch" is relative temperature. Psychologists have emphasized the sensation, but the useful perception of the state of the substance is what matters (Systems, Ch. 7). It is based on the direction and amount of heat flow into or out of the tissue. You cannot see this; you can only feel it.

Persisting and Non-Persisting Surface Properties

We can now observe that the most persistent properties of a surface are those numbered 4, 5, 6, 7 and 8, reflectance, natural spotting, texture, shininess, and transparency. The most changeable property of a surface is number 3, that of being lighted or shaded. This is because the general illumination in the medium fluctuates with day and night, with white light at noon and red light at sunset with the sun going behind and coming out of a cloud, with the flickering of firelight or torchlight. Also the incident illumination on a surface fluctuates with the change from morning to afternoon, with the dappling of light under the trees in a wind, with the shifts of lighting as one carries a torch at night; and of course with the arbitrary "ons" and "offs" of artificial illumination. So transient is the illumination on a surface that one might even question whether or not it should be considered a "property" of the surface.

A somewhat more persisting property is number 9, the temperature of the surface and its substance. Number one, solidity, is quite stable at the ordinary temperatures of terrestial substances, except for ice which melts at a not unusual level. Number two, being luminous, depends on a very hot substance (apart for the exceptional case of luminescence).

The perception of the properties of the persisting substances of the habitat is necessary if we are to know what they afford, what they are good for. But substances change with aging, fermenting, ripening, cooking, and melting. We can see the change in the surface. Persistence is not permanence. The widely accepted assumption that the child learns to apprehend the "permanence" of objects when he acquires the "object concept" is misleading and unnecessary. The question is this: how do we perceive which properties of a surface are persisting, which are fluctuating, and which are changing irreversibly?

Fluctuation in the Ambient Optic Array

Substances change and surfaces undergo periodic changes of illumination but neither can be seen without a specifying change of some sort in the ambient optic array at a point of observation. Fluctuations of the shadow-structure of an array have not been studied experimentally under controlled conditions; only an unchanging shadow-structure.

For example, you can see the surface of a lamp or a lighting fixture as luminous when it is radiating and non-luminous when it is not, in relation to the other surfaces of the rrom, with a steady-state optic array. If, however, the luminosity fluctuated like the surface of a flame, would not this discrimination be more exact and the perception more vivid?

You can see a shadow cast on a flat surface as a shadow if it has a penumbra, but as a stain on the surface if you eliminate the penumbra with a drawn line (the "ringed" shadow of Hering). Moreover, an artificial penumbra will convert a real stain into a shadow (MacLeod). But the apparent stain with a ring around it will be converted back into a shadow if the latter comes and goes; i. e., fluctuates, according to my observation. Similarly a patch of light that looks like a spot of white will be seen for what it is if it fluctuates.

You can see the convexities and concavities of a non-flat surface (the relief), by means of the stationary pattern of light and shade in the array, but only with some ambiguity. The convexities and concavities reverse if you are able to make the illumination seem to come from the opposite direction. If, however, the light source is actually moved back and forth over the layout so that the lighted and shaded surfaces interchange, and the shadow-structure of the array fluctuates, the relief is no longer ambiguous and does not reverse. So I conclude on the basis of informal motion picture studies.

You can see the dullness or luster of a surface in a fixed array according as highlights are absent or present (cf. Beck on surface color). But it seems to me that the luster becomes more evident when you move the vase (or your head) and thus cause the highlights to shift relative to the texture.

You can see the transparency of a surface with an unchanging optic array, and this can be simulated experimentally, as noted above. But it can also be simulated when some of the interspersed spots of an array have one coherent motion and the remaining spots have another. This change involves permutation of adjacent order. Two separated surfaces are vividly seen, the superposed surface being transparent.

The experiments reported in Chapter 9 of my new book suggest that the optical information for seeing *surfaciness* is density in the array, a variable of *fixed* pattern. But the above experiment on interspersed random textures (chapter 10), and Kaplan's experiment on the gain or loss of texture on one side of a contour (chapter 11), suggest that the information for seeing the *unity* or *coherence* of a surface has to do with *changing* pattern in time, not with fixed pattern. I mean the persisting aspects of the changing pattern. I suggested (p. 179 ff.) that what counts for surface perception is the *preservation* of adjacent order, that is, the *continued non-permutation* of order. Consider that the Brownian movement of spots in a microscope is what specifies a non-surface, a group of particles. Then the continuous unbroken connectedness of a true surface at the ecological level of reality is specified by what I can only call the absence of Brownian movement!

Note that a persistently unchanging pattern of a natural optic array specifies a great deal about the surfaces surrounding an observer. It also specifies that they do not change during the period of observation. A changing pattern of the natural array specifies still more about the surfaces: how they change during the period of observation and how the observer moves. Possible ambiguities are eliminated. The *artificially arrested* pattern of the peculiar optic array coming from a picture is a different matter; you cannot always tell whether the state of a pictured surface is a persisting one or is only the instantaneous cross-section of a changing state.

The Ecological Level of Reality

A surface is the interface between a substance and the medium. The notion of a substance and of degrees of substantiality should not be confused with the physical concept of matter; it is connected with the complicated "states" of matter the gaseous state being wholly insubstantial and the liquid to solid states being increasingly substantial (for terrestrial animals). Continuous substantial surfaces are not real for physics, but they are primary realities for ecology and for the kind of psychology founded on it.

Animals perceive surfaces and their properties, since animal behavior must be controlled by what the surfaces and their substances afford. (They also perceive the <u>layout</u> of surfaces and what the invariants of layout afford, but that is not the main concern of this essay.) There is a need to study the perception of surfaces with a realistic attitude as well as with a phenomenological attitude. The approach advocated is much closer to Gestalt theory than it is to input processing theory ("information" processing, so-called). It is a sort of <u>ecological</u> Gestalt theory.

June, 1979

A Note on
Substances, Surfaces, Places, Objects, Events

James J. Gibson, Cornell University

In _The Ecological Approach to Visual Perception_ I propose that what animals perceive are the substances, surfaces, places, objects, and events of the environment instead of objects in space. What animals discriminate are the meaningful properties of substances, surfaces, etc. instead of the primary and secondary qualities of physical objects. What they move around in is the medium instead of space. What they see is the layout, the dihedrals and curves that surfaces make to one another, instead of depth in space.

Substances vary in substantiality, and a substance is not to be confused with matter. _Surfaces_ are the interfaces between substances and the medium, not geometrical planes. _Places_ are semi-enclosures in a cluttered environment of larger and larger places, not loci relative to a coordinate system. _Objects_ are substances with a topologically closed surface detached from the substratum, not the vague entities of physics or the latter half of the subject-object dichotomy in philosophy. (A substance with a nearly closed surface attached to the ground is also an object. This means that trees, houses, rocks, tools, dogs, and humans are objects, the first two being attached, the last four being mobile without breaking the surface, and the last two being _animate_ and mobile objects.) _Events_ are changes in the environment of any sort, some reversible and some irreversible, not just the rigid motions and rotations of bodies along and around the axes of space.

These realities constitute the environment of animals. They comprise the niche for each species of animal, and the habitat of each individual animal. They are appropriate for the study of what animals perceive, how they behave, how they learn, and what they know, that is, for psychology. The realities of physics (particles, atoms, elements, compounds, the motions of particles and the radiation of energy) are not appropriate for the study of perception and behavior.

Ever since Descartes, human psychology has been held back by the doctrine that what we have to perceive is the "physical" world that is described by physics. I am suggesting that what we have to perceive and cope with is the world considered as the environment.

Note that substances, surfaces, places, and events are nested. They are not denumerable, which is to say they cannot be counted like discrete objects. There is no definite number of them. A surface, for example, can always be incorporated in a superordinate surface. A place is not separated from an adjacent place by a sharp boundary. This seems to imply that they cannot be classified, categorized, or grouped (only discrete objects can be grouped) and that hence the mathematical theory of sets does not apply to them. If true, this is alarming to the psychologist who assumes that, in order to be scientific, he must compute or measure as the physicist is able to do (cf. memo on surface perception, May 1979). But perhaps an ecological psychology would gain in relevance what it lost in mathematical simplicity. Moreover it might be able to solve the problem of meaning and value in a simple way, which metric psychology has been unable to do.

Substances, surfaces, places, objects and events provide utilities and dangers. They have positive and negative affordances. If there is information in the normally obtainable flux of stimulation, as I have tried to show, the invariant meanings can be learned by extracting them instead of constructing them. Thus explanation is much more parsimonious than traditional explanations based on receptors, physical stimuli, sensations, psychophysics, and the epistemological paradox of assuming that one gets knowledge of the world from these inputs because one already has knowledge of the world.

The traditional psychology of stimuli, exteroceptors, proprioceptors, interoceptors, their sensations, and the "specific nerve energies" of these sensations has also not been able to solve the problem of self-awareness. The complexity of the problem is forbidding. But the hypothesis that the body of the observer is specified in the flux of stimulation obtained by a perceptual system (although not by the inputs of a sensory nerve) is actually quite simple, and so is the theory of the facing surfaces viewed now from here. The assumption that both locomotion and stasis of the self relative to the surface layout are specified by change and non-change of the ambient array is elegantly simple.

Substance and surface are taken relative to an observer; they are of no interest to physics. Place is part of the habitat where an observer can stand; the standpoint is something that physics tries to eliminate although, in the last analysis, it fails to do so. An object has affordances for an observer; these supposedly subjective values do not enter into physical science. An event at the terrestrial level as distinguished from an atomic or astronomic event shows its meaning for the observer in the transients and sequential structure; orbits, spins, states, and purely relative velocities do not show their meanings.

Behavior is motivated by substances, surfaces, places, objects, and events. They have valences in the Terminology of Lewin. (It is also motivated by hunger, sex, pain, and the need for shelter, of course, but these two facts are complementary, not discrepant.) A substance that is nutritive invites eating, water invites drinking, pouring, or washing (but not walking on), clay invites molding, and dry wood affords fire-making.

A surface that offers support invites sitting, standing, walking, or running; a surface that is a barrier to locomotion demands a halt; a double surface that is flexible affords wearing; a warm, soft, suitably shaped, animate surface invites caressing.

A place that is enclosed affords getting out of the rain, a place that is hidden and safe affords sleeping, a place where prey is found allows food-getting but a place where predators lurk affords danger; a grocery store also affords food-getting but a six-lane highway with trucks is as bad as a place with saber-toothed tigers.

An object that has a handle can be grasped and used as a tool, an extension of the hand, and the forms of manipulatory behavipr are endless. Every tool has a corresponding action sequence, the perception and the movement running concurrently: hammers, pliers, awls, knives, and so on.

An event like fire affords being warmed and also being burned, so that locomotion and manipulation are adjusted to it. The fire invites approach up to a certain limit and then repels; the limit can be both seen and felt. Behavior of this sort is controlled, but it does not seem to be reducible to definite responses to discrete stimuli. The popular phrase for it is that one perceives the "margin of safety."

According to this formula, behavior consists primarily of acts that take advantage of the existing substances, surfaces, places, objects and events of the environment while avoiding painful encounters with them. Another kind of behavior, most fully developed in our own species, consists of acts that change the substances, surfaces, places, objects, and events of the environment by manipulation and manufacture. Fundamental to both is the kind of behavior that obtains stimulation, orienting and adjusting the perceptual organs so as to extract information about the substances, surfaces, places, objects, and events of the environment.

Metelli (2 copies)

December, 1969

Transparency and Occlusion, or How Bishop Berkeley went Wrong in the First Place

James J. Gibson, Cornell Univ.

In the second paragraph of the New Theory of Vision, 1709, Berkeley wrote, "It is I think agreed by all that distance of itself, and immediately, cannot be seen. For distance being a line directed end-wise to the eye, it projects only one point in the fund of the eye, which point remains invariably the same whether the distance be longer or shorter." This states the problem of the perception of the "third dimension," or "depth perception," as it has been puzzled over for some 250 years.

Now I argued in the Visual World that a kind of distance could be seen, of itself and immediately, that is, distance over the ground, or along a surface. It was specified by a gradient on the retina, not by a point on the retina; different points at different distances thus did not "project only one point in the fund of the eye."

I now wish to argue that Bishop Berkeley's statement of the problem was inadequate in an even more radical way. There is yet another kind of "distance" that can be seen directly, namely transparency, or the seeing of one surface through another. In this case there is an optical superposition of one surface on the other, both objects being seen in the same direction. Both objects are, indeed, projected to the same points on the retina, if the analysis of optical projection in terms of rays and points is accepted. But in terms of a different analysis, the optical information for the perception of transparency gives promise of being formulated (e.g. Metelli).

Moreover, there is a fourth kind of distance other than the abstract and invisible "line directed end-wise to the eye." It is optical _occlusion_, or one surface _behind_ another, the occluding surface being opaque rather than transparent. Our evidence, like that of Michotte, shows that the occluded surface may be perceived immediately in certain circumstances, and we have a theory of what the information is for the perception of an opaque occluding edge.

Where Bishop Berkeley went wrong was in assuming that point-sensations were necessary for perception, that is, the _basis_ of perception. "What we _immediately_ and _properly_ see," he wrote, "are only lights and colors in sundry situations and shades, and degrees of faintness and clearness." These are the spots and patches of color composing the visual field. He added that they "are only in the mind; nor do they suggest aught external, whether distance or magnitude, otherwise than by habitual connection, as words do things." Perhaps it is true that there can only exist one color sensation in the direction of any given light ray. But this should not count against the fact that different objects can in fact be experienced in the same direction-from-here. Nor does it count against the possibility of optical information to specify the existence of more than one surface in the same direction.

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March, 1970

Memo on

The Relation between Hallucination and Perception

James J. Gibson, Cornell University

All discussions of hallucination that I have been able to find assume that it is a false perception which is nevertheless indistinguishable to the perceiver from a true perception. This indistinguishability is sometimes expressed by saying that a hallucination is accompanied by the same "feeling of reality" as is a perception. To the subject it is seemingly a genuine percept.

This assumption rests on a deeper assumption, going back at least to John Locke, asserting that a memory image differs from a sense impression or sense-percept only in being fainter or less vivid. Since the image is supposed to be a trace, replica, or representation of the original impression this is only reasonable. It follows that, as an image becomes less faint or more vivid, for whatever reason, it will become indistinguishable from a sense impression.

The importance of hallucinations for the theory of perception, therefore, is that they seem to confirm this old assumption that in certain circumstances <u>a person cannot tell the difference between an image and a percept</u>. Someone who is hallucinating <u>behaves</u> as if he were perceiving a fact of the environment, not imagining it, and later <u>reports</u> that he was perceiving it so far as he can tell, not imagining it. At least he is sometimes said to give this report. The other evidence bearing on this old assumption is the Perky experiment showing that a faint optical

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image secretly projected on a screen is often not characterized as such when the observer is imagining an object on the screen of the same sort (Perky, 1910). Titchener believed, on grounds of this sort, that an image is easily "confused with" a sensation (Titchener, 1924, p. 198) and he asserted that "in certain pathological states the image may become what is called an hallucination (p. 199)."

This assumption that images, whether of memory, imagination, dreams, or those occurring in hallucinations, are made of the same stuff as percepts can and should be challenged. It is contradicted by the theory of perceptual systems (Gibson, 1966, Ch. 3). An implication of this theory is that a person can always tell the difference between an image and a percept when a perceptual system is active. When the information for perception is obtained by the system, as contrasted with information supposedly imposed on the receptors, a percept should never be confused with an image, since the activities of orienting, exploring, and optimizing will always distinguish the two cases (Gibson, 1966, Ch. 2).

According to this theory, the essential difference between a memory image and a percept is not that of being fainter or weaker or less vivid; the difference is essentially that the image is not explorable, or investigable, or susceptible to increased clarity by sense-organ adjustment. The supposed criterion of faintness or low intensity has always been debatable (e.g. McDougall on Hallucination, 1929) and some thinkers have suggested that livelines or being lifelike is a better indicator of a percept. This suggests to me that the so-called feeling of reality that accompanies a percept is actually a result of the tests for reality that go with active perception. Actually, they are tests for the existence of an external source of stimulation.

It is fair to ask how the theory of perceptual systems would explain the occurrence of hallucinations. It can be argued, first, that under conditions of disease or drugs a passive observer may fail to apply these tests for the existence of an external object, tests that would exhibit the spontaneous images he is experiencing for what they are. One can suppose, second, that some observers tend to believe in the existence of a world that is different from the environment they usually perceive, that they either want to experience it or are fascinated by the possibility, and that hence they are not inclined to apply these tests (Masters and Houston, 1966).

The theory of perceptual systems emphasizes the external loops that permit orientation, exploration, and adjustment, but it also admits the existence of internal loops, more or less contained within the central nervous system. Only in this way could the facts of dreaming be explained. In the waking state the internal loops are driven by the external ones but in sleep they may become active spontaneously, the internal component of the perceptual system running free as it were, like a motor without a load. In the case of daydreams and waking fantasies one can suppose that internal experiencing of a similar sort occurs in parallel with ordinary perceiving, the former being split off from the latter, and the latter being reduced.

There is no doubt but what the brain can generate experience of a sort. What it _cannot_ do is to generate _perceptual_ experience. In a daydream, the brain can seemingly generate imaginings even while the retina-brain-eye-retina system is still registering the surrounding world. But in a night dream the inputs of the optic nerves are missing and ocular adjustments if they occurred would have no effect on the inputs of the optic nerves. Note that, on this theory, the rapid eye-movements that accompany night dreams are frustrated efforts of the perceptual system to explore an ambient optic array that cannot be sampled because the eyes are closed, or that does not even exist because of darkness. Rapid eye movements are a good index of having a dream because ocular exploration is an expression of an effort to perceive. But since there is no feedback from these REMs, since they have no consequences, the dream wanders on uncontrolled.

An observer can _orient_ his head and eyes to some component of an optic array. This is the same as _fixating_ the object, and along with this goes _accommodating_ for it, and _converging_ on it. An observer can _explore_ or _scan_ the optic array. This is to look at its parts in succession by saccadic eye-movements, or to examine a sector of the environment. But an observer _cannot_ orient his head and eyes to an afterimage or a memory image. (Can he do so to an "eidetic" image, or to a hallucination?) An observer surely cannot _accommodate_ and _converge_ on an image of any sort. He cannot _scan_, or _inspect_, or _examine_ a subjective image in the sense that one can apply the fovea of the eye to any detail of an optic array.

A tentative rule seems to emerge from the above considerations: Whenever adjustment of the perceptual organs yields a corresponding change of stimulation there exists an external source of stimulation and one is _perceiving_. Whenever adjustment of the perceptual organs yields _no_ change of stimulation there exists _no_ external source of stimulation and one is imagining, dreaming, or hallucinating. As a corollary, it may be added that if nothing one does has any effect on a persisting stimulus the source is within the body itself. Such is the case with an intense afterimage, or a pain caused by tissue-damage. The reader should note the difference between this rule and the formula proposed by Von Holst (1954).

What does the theory of perceptual systems have to say about the kind of perception induced in the psychological laboratory with a tachistoscope? The purpose of this instrument is to prevent the occurrence of exploratory eye movement, and, by limiting the input of the optic nerves to that from a single fixation, supposedly to simplify the problem of perception. In this case the taking of successive samples is blocked, as are accommodation and convergence, and the completion of an "external loop" of visual activity is cut short. The system is held down to the completion of its internal loops of activity, to that component of perception confined within the central nervous system, that is, the arousal of images. The tachistoscope thus forces perception to be a process of supplementing a momentary input. It becomes a matter of "enrichment" instead of "differentiation" (Gibson and Gibson, 1955). This kind of visual perception is very interesting but there is some question as to whether it is not a mere laboratory curiosity, unrepresentative of day-to-day activity.

According to the theory of perceptual systems the act of perceiving is essentially different from the act of summoning up images. The perceptual systems are modes of overt attention, not channels of sense. But according to previous theories of perception that take the inputs of the sensory nerves as their point of departure perceiving has to be essentially similar to having images. Memories have to be combinable with sense impressions, and are perhaps confusable with them. There is a genuine theoretical issue between these two positions. Is it empirically true or not that a person can always tell the difference between an image and a percept when his perceptual system is active?

References

Perky, C. W. An experimental study of imagination. Amer. J. Psychol., 1910, 21, 422 ff.

Titchener, E. B. A textbook of psychology. New York: Macmillan, 1924.

Gibson, J. J. The senses considered as perceptual systems. Boston: Houghton Mifflin, 1966.

McDougall, W. Hallucination. In Encycl. Brittan., 1929, Vol. 11.

Masters, R. E. L. & Houston, Jean. The varieties of psychedelic experience. New York: Dell, 1966.

von Holst, E. Relations between the central nervous system and the perceptual organs. Brit. J. Anim. Behav., 1954, 2, 89-94.

Gibson, J. J. & Gibson, E. J. Perceptual learning: Differentiation or enrichment? Psychol. Rev., 1955, 62, 32-41.

August, 1970

A Terminology for Describing the Layout of Opaque Surfaces and the Occluding of One Surface by Another

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A surface is defined as the interface between an opaque reflecting substance and the medium (air) in which points of observation exist and in which animals can move about.

1. The concave corner. The apex of the dihedral angle formed by two plane surfaces when the substance is on the side of the obtuse angle and the medium is on the side of the acute angle.

2. The convex corner or edge. The apex of the dihedral angle of two surfaces when the substance is on the side of the acute angle. As the angle becomes more acute the edge may be said to become "sharper."

3. The curved concavity. A curved surface area when the medium is inside the curve and the substance is outside.

4. The curved convexity or protuberance. A curved surface area when the substance is inside the curve.

Occlusion is defined in ecological optics as the non-projection of a surface to a point of observation in the medium. It is caused by a convex corner or by a curved convexity; a concave corner and a concavity do not occlude. Concealment and hiding are synonymous terms for occlusion.

5. The occluding edge. The borderline between the projected and the unprojected surfaces (faces) of the dihedral angle forming a convex corner, i.e., the apex of the angle. The projected surface is said to "face"

the point of observation and the unprojected surface not to do so; the former sometimes is called the "front" and the latter the "back." The edge also occludes that portion of any other surface that lies behind it, commonly called the "background."

6. The occluding convexity. The borderline between the projected and the unprojected portions of the curved surface at a given point of observation (the locus of a set of tangents to the surface). It also occludes the portion of any other surface that lies behind the protuberance.

A precise meaning can now be given to what we most commonly call an object in the environment: it is a composition of convex and concave corners and of convexities and concavities as defined above. (A polyhedral object is composed of the first two and a curved object of the second two, but all combinations are possible.) This description is superior to one in terms of analytic geometry for the purposes of visual perception. It enables us to speak of the distinctive features of an object--any object whatever.

We can now distinguish between an object and the outline or closed contour of an object in an optic array, and we can observe that the latter corresponds only to the occluding edges (and occluding convexities) of the object. The figure-ground phenomenon in perception (as usually described) results when the optical information normally available for the perception of an object is limited to an outline or silhouette, that is, to the information for the perception of its occluding edges (or occluding convexities). The figure-ground phenomenon is therefore a case of reduced perception rather than a prototype of perception, or the basis of perception.

In most displays of optical information the outline or silhouette is frozen in time, that is, change of occlusion is eliminated, and the phenomenal object tends to become depthless except for the separation of the "figure" from the "background." Also when the closure of lines or contours is experimentally manipulated, ambiguous or equivocal perceptions arise of concavity and convexity, and of occlusion. Thus the dihedral angles in the staircase figure will appear to reverse between concave and convex; or the direction of occlusion will reverse so as to convert a goblet into two facial profiles.

The new hypothesis is that the perceiving of corners, edges, convexities, and concavities (the first four definitions above) together with the perceiving of occlusion (the next two definitions) is based on the pickup of "formless invariants" in the structure of the optic array. This pickup is more basic than form perception; it develops in animals and children before the perceiving of "forms" develops. It is assumed that the back of an opaque object and the background behind an object are not unseen (contrary to the usual assumption) unless a special attitude is adopted enabling one to experience the world as if it were a flat patchwork of colors. Only when the patchwork is taken to be the basis of perception, developmentally and logically, does it become theoretically necessary to interpret the figure-ground phenomenon as evidence for a process of sensory organization. Otherwise it can be interpreted in the way suggested above, as a by product of the perception of occlusion.

Mathematical note. Ordinary three-dimensional geometry includes some of the concepts and terms employed above but not others. Dihedral angle, apex, plane vs. curved, acute vs. obtuse, inside vs. outside of a curve, tangent to a curve, line-closure and perhaps projection are ordinary geometrical terms. But the concept of opaque substance vs. medium (along with interface and reflecting surface) is foreign to abstract geometry, since geometrical space is "everywhere perfectly transparent" (Nicod). The point of observation with its ambient optic array does not exist in such a space. The convexity-concavity concept only arises when a point of observation is recognized as being in the medium. So does the notion of the facing of a surface and the notion of frong and back (or in front and behind). And the occlusion of one surface by another is wholly relative to a given point of observation. The notion of changing occlusion with movement of the point of observation is foreign to abstract geometry, although the latter admits motion relative to a coordinate system.

The question is whether or not the kind of space defined by these concepts, a space that takes account of the features of layout and the fact of occlusion, is a "geometrical" space, and if so what kind it is.

Acknowledgement. This memo owes much to discussions and collaboration with John M. Kennedy. He is developing, however, a descriptive system of his own, in his doctoral thesis, which may differ from this one in some respects.

September, 1970

Memo

On the Visual Perception of Tangible and

Intangible Things

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Tangible things are almost always visible but visible things are not always tangible. The only invisible but tangible surfaces are large smooth plates of transparent material like glass, which do not exist in nature, whereas there are many visible but intangible things in the natural environment, such as the sun and stars, the sky itself, rainbows, sunsets, mirages, reflections, the beams of light in a dusty atmosphere, and the images in a pool of water. sometimes

The existence of things that can be seen but not touched has puzzled observers from the beginning of observation itself. The belief in spirits, ghosts, and Gods comes in part from this fact. Things that can be seen and touched do not puzzle us; we take their perception for granted, but the others are very puzzling and we strive to explain them. The history of physics and physical optics is largely a history of our attempts to explain intangibles like rainbows, reflections, light-beams, and images (Minnaert, 1954; Bragg, 1933).

The optical explanation of how we see intangibles is highly successful and is nowadays widely understood. They are not ghosts or Gods but products of light. We know about light rays and their reflection, refraction, diffraction, and scattering. But the explanation of how we see tangibles is not at all clear and is not understood. Every student of high school

and the sun and the moon put the same problems as other things do

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physics knows why a rainbow looks as it does but no one knows why the ground under one's feet looks as it does. Why should this be so?

It is probably because we have a persuasive physiological theory of how we see radiant light and spectral color, the theory of *sensations* of brightness and color caused by the stimulation of photoreceptors, but no adequate theory of how we see illuminated surfaces and the layout of such surfaces. We have assumed that the perception of surfaces is constructed out of sensations of light--that the elements of perception are sensations. We have assumed that an illuminated surface is composed of a dense set of luminous star-points, or bits of the rainbow. And, indeed, something like this is what most physicists believe. We take the phenomena of light and color in our environment as a model for the phenomenal surfaces of our environment. Because we understand the curious phenomena of meteorology and astronomy we have tried to understand the ordinary and familiar phenomena of terrestrial objects in the same way.

The intangible and often ephemeral things like rainbows, sunsets, light-beams, the play of sunlight, and fires are unlike the surfaces and objects of the world in that the perceptions are not invariant despite varying sensations of light (Gibson, 1963). The perception changes as the light changes whereas the perception of an object, a layout of reflecting surfaces, is more or less constant as the illumination changes. The colors of the former are the spectral colors of light whereas the colors
7 of the latter are the *pigment colors* of surfaces. The intangible phenomena generally do not have a definite surface texture whereas the tangible phenomena do.

It is vastly more important for animals and men to see the composition of surfaces and their layout for what they are than to see the rainbow for what it is. To see the rainbow as a bridge in the heavens does no harm so long as one does not have to walk on it.

The unsolved problem of perception, then, is how we see the <u>tangible</u> things of the world. A persistent explanation, ever since Bishop Berkeley's <u>New Theory of Vision</u> (1709) has been that the sensations aroused by these things are supplemented by memories of touching them whereas the sensations aroused by intangibles are not. The underlying assumption is that the perception of things by touch (mechanical stimulation) is self-evident while the perception of things by vision (light stimulation) is not. But this, of course, is not true.

The alternative is to assume that the tangibility of some things and the intangibility of other things is <u>visible</u>, and to search out the information in ambient light that makes it possible to distinguish the two kinds of things. This is what ecological optics tries to do. The invariant information in an optic array for perceiving surfaces and their layout is distinct from the changing variables in the ambient light that enable us to see the curious phenomena that result from regular reflection, refraction, diffraction, polarization, and scattering. When these phenomena are isolated and controlled in the laboratory they reveal the laws of radiant energy. But they are not the basic phenomena from which an understanding of surface perception can be derived.

I said at the beginning that the optical explanation of how we see these intangibles is very successful. But even so there is something strange about them which has been a source of confusion in psychology and philosophy: they do not look like what they really are, or, more exactly, the source of the colors and forms in the light is not revealed. A textured surface with its edges and corners looks like what it is; the layout is revealed. The refraction of light by raindrops, however, is not evident in the rainbow and the differential scattering of wavelengths is not revealed by the blue vault of the sky. The sun looks a bit like a chariot of fire and the stars look like chinks in a roof. The wondrous discoveries of physics and astronomy have led some observers to mistrust their vision of ordinary terrestrial things, to celebrate an unseen world, and even to believe the nonsense that things are never what they seem.

References

Bragg, W. *The universe of light.* MacMillan, 1933.

Gibson, J. J. The useful dimensions of sensitivity. *Amer. Psychol.*, 1963, *18*, 1-15.

Gibson, J. J. Chapter on ecological optics in *The senses considered as perceptual systems.* Boston: Houghton Mifflin, 1966.

Minnaert, M. *The nature of light and color in the open air.* Dover, 1954.