volume 1

encyclopedia of **perception**

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Some bat species using CF echolocation calls show specializations in the peripheral (inner ear) and central (brain) auditory systems for processing echoes in the CF range of their echolocation sounds. The greater horseshoe bat, for example, adjusts the frequency of its sonar vocalizations to receive echoes at a reference frequency of approximately 83 kHz. Its auditory system shows a large proportion of neurons devoted to processing this reference frequency, and an expanded representation of 83 kHz can be traced to mechanical specializations of this bat's inner ear.

Other specializations in the bat central auditory system for processing echolocation signals that may play a role in the perception of target distance. In several bat species, researchers have identified neurons in the midbrain, thalamus, and cortex that respond selectively to pairs of FM sounds, separated by a particular delay. The pairs of FM sounds simulate the bat's sonar vocalizations and the returning echoes, and the time delay separating the two signals corresponds to a particular target distance. The pulse-echo delay that elicits the largest facilitated response is topographically organized in some bat species that use CF signal components. Most delay-tuned neurons in the bat auditory system respond in the range of 2 to 40 milliseconds, corresponding to target distances of approximately 34 to 680 cm. These best delays represent a biologically relevant range for localizing prey items using echolocation.

Cynthia F. Moss

See also Animal Depth Perception; Animal Frequency and Pitch Perception; Depth Perception in Pictures/Film

Further Readings

Griffin, D. (1958). *Listening in the dark.* New Haven, CT: Yale University Press.

Moss, C. F., & Schnitzler, H.-U. (1995). Behavioral studies of auditory information processing. In R. R. Fay & A. N. Popper (Eds.), *Springer handbook of auditory research: Hearing by bats* (pp. 87–145). Berlin: Springer.

Suga, N. (1990). Biosonar and neural computation in bats. *Scientific American, 262*(6), 60–68.

Thomas, J. T., Moss, C. F., & Vater, M. (Eds.). (2004). *Echolocation in bats and dolphins.* Chicago: University of Chicago Press.

Ecological Approach

Ecological psychology, as it applies to the domains of perception and perceptual development, refers to the perspective developed during a 30-year period by J. J. Gibson and Eleanor J. Gibson, and elaborated during the past two decades by their students and colleagues. The impetus for this approach grew largely from J. J. Gibson's work early in his career on several practical problems, such as how individuals control their movement when driving a car or landing a plane. These investigations led him to conclude that traditional theories of perception, and their supporting evidence mostly gathered in laboratory conditions, did not apply well to more everyday circumstances of perceiving. This entry describes major concepts in ecological optics, perceptual learning and development, and philosophical implications of ecological realism.

The adjective *ecological* in ecological psychology refers to two distinguishing characteristics of Gibson's approach to perception that sets it apart from more traditional theories.

1. Traditional theories of visual perception begin their analysis with consideration of patterns of stimulation on the sensory receptors (i.e., the retina), and the ensuing patterns of neural firing to sites in the brain. The starting point for an ecological approach to perception is an analysis of the environment within which a species has evolved (i.e., its *econiche*). The environment for terrestrial organisms is filled with *substances* of a wide-ranging variety, from soils and grasses to bodies of animals and water. In the case of visual perception, these substances can be perceived because of the way light from a radiant source (e.g., the sun) interacts with their *surface* properties (e.g., orientation to light source, texture, pigmentation). The resulting array of reflected light that has been structured by such surface properties fills the *medium* (the air), and this array of structured light surrounding the individual (*ambient optic array*) can function as potential *information* for perceiving. The study of how light in the medium is structured by surfaces is referred to as *ecological optics.* J. J. Gibson proposed that psychologists begin to consider higher-order structure in the ambient optic array of information for perceiving.

2. Traditional theories of visual perception take as their primary focus a stationary perceiver positioned at a fixed observation point. In contrast, the ecological approach takes as its primary focus the *dynamic perceiver-environment relationship*. What is dynamic about the perceiver-environment relationship? On the one hand, environmental conditions are not static, but change over various units of time (e.g., seconds, hours, days, seasons) requiring perceivers to keep abreast of conditions. On the other hand—and significantly—perceiving involves ongoing, exploratory actions of the individual (the functioning of *perceptual systems*) in the detection of stimulus information. Just as it is far easier to identify an object through active touch (manipulating the object in one's hand) than passively grasping it, perceiving through vision is facilitated by actions of the individual, such as moving the head and body in relation to objects and to the overall environmental layout.

Why do actions of the body contribute to detection of stimulus information? They produce perceived changes in the ambient optic array, and in so doing reveal that which does not change, what is invariant in the array of reflected light. (An invariant is a set of relationships among structures that do not change across transformations of those structures over time.) Invariance in the ambient array is posited to be specific to stable and persisting features of the environment. For example, if a perceiver walks around a table, certain relationships, such as the adjacent order of corners and edges, will remain invariant across successive views, displaying the specific rigid structure of this object. Actions of the various perceptual systems play an essential role in revealing invariants in the ambient array over time. Concurrently, the perceived changes in the ambient array that are generated by the perceiver's actions provide information for self-movement.

Major Concepts in Ecological Optics

Texture Gradients

Early work in ecological optics emphasized the perception of filled space rather than abstract space. J. J. Gibson proposed that "space" could not be perceived in the absence of perceiving a continuous background surface and that the topic of "space" perception would be more accurate if called "ground" perception. The texture of the ground (e.g., dirt and clumps of grass) projects a regular pattern of decreasing image size, and increasing density, from observer to horizon. This regular change is an example of a *texture gradient*. The texture gradients of surfaces, especially the ground stretching to the horizon, became the basis of reformulating numerous classical problems, two of which are distance perception and size perception. The perception of the texture gradient of a surface from observer to horizon establishes a scale of perceivable distance for a given height of the observer's eyes. The topic of size perception often is stated in a way that features the problem of *size constancy*. This asks, How is it possible to see an object as having a constant size with changes of viewing distance when the image size changes with distance? Gibson criticized this way of stating the problem of size constancy in its failure to acknowledge that in terrestrial environments most objects rest on *textured* ground surfaces. The same object, seen at different distances on the ground, covers (occludes) the same number of texture units regardless of distance, illustrated in Figure 1(a). Likewise, when there is a horizon line present in the field of view, it will intersect equally sized objects at the same height even when the objects are located at different distances (Figure 1b). In short, relations in the field of view (i.e., object/ground surface texture, object/horizon) serve as perceptual information for object size constancy. Because these relations remain the same under changes of viewing distance, they are invariants.

Optic Flow

As a perceiver moves forward, an optic flow of structured light from reflecting surfaces is generated, appearing to stream past the perceiver. This experience of self-motion through vision—*visual kinesthesis*—explains the commonplace illusion of feeling that you are moving when actually movement is occurring in your surround (an adjacent car in a line of traffic).

Self-generated optic flow radiates outward from a stationary point in the optic array, and this point of outflow (center of expansion) specifies where one is heading (Figure 1c). As a result, perceivers can control their direction of movement by maintaining

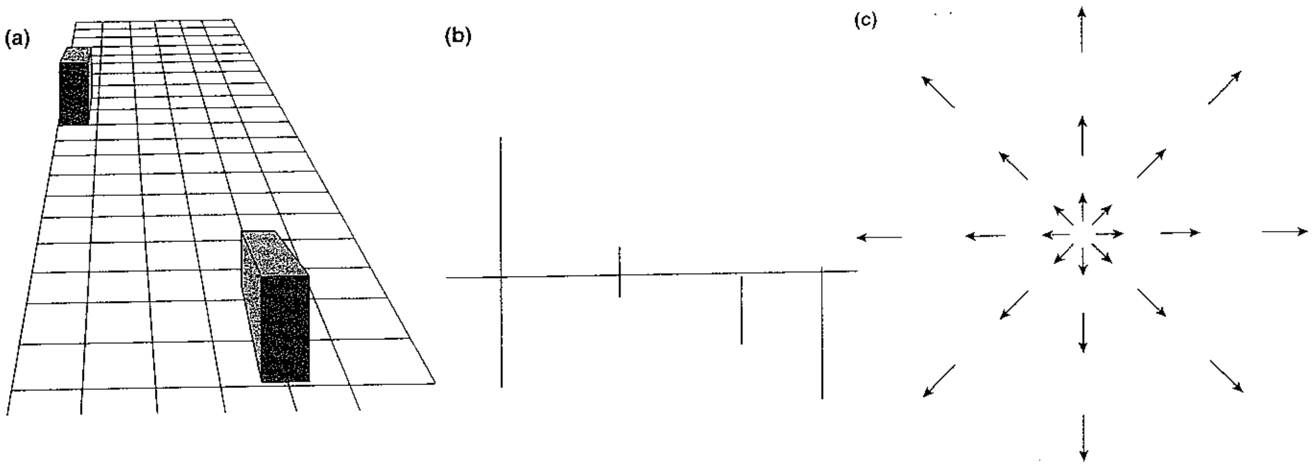

Figure 1 Perceptual Information for Depth and Size

Notes: (a) Object size—ground texture invariant: Objects of equal size occlude equal units of ground surface texture, even when they are positioned at different relative distances from the perceiver. (b) Horizon—object height invariant: The horizon line appears to intersect equally-sized objects in the same proportion, even when they are positioned at different relative distances from the perceiver. The two vertical lines on the left are depicted as twice the eye height of the observer. The two at the right are depicted as nearly the same eye height as the observer. (c) Optic flow showing the focus of expansion during approach to a flat surface.

the center of outflow on the target of interest. For example, a predator in pursuit of a prey must keep the prey at the focus of expansion of optical outflow. If the solid angle of the target changes (smaller or larger) in the optical flow field, this change is information for the predator that it is losing or gaining ground on the prey. In the case of a stationary target and a moving perceiver (or inversely a moving object relative to a stationary perceiver, as in the case of a thrown baseball), *time to contact* is specified by rate of flow. In general, time-to-contact (dubbed *tau* by David N. Lee) for a constant velocity of approach is given by the ratio of a changing quantity to its speed of change. An object in the world separated from an observer by a gap of 10 meters, traveling at 10 meters per second, will arrive in one second. This suggests that to perceive that time of arrival, an observer would need to know an object's distance and velocity as elements of a computation. However, the image of the gap on a retina, divided by the velocity of gap closure, yields the same time—without the need for separate estimates of distance and size. Lee proposed that this quantity is detected by animal nervous systems as a unit and is widely used in the control of timing.

Note that in each of these cases, perceiving is based on the *detection* of relevant higher-order information in the optic array *over time* rather than the mental calculation of separate variables, such as distance of the target and speed of movement. In this respect, self-motion and time-to-contact, like relative size constancy, is specified by information available to be *perceived* in the ambient optic array. During the past three decades, optic flow has been the subject of a great deal of research and discussion.

Occluding Edges

When a perceiver moves laterally with respect to two objects positioned one behind the other, the surface of the farther object will be gradually revealed (surface accretion) at the visible edge of the closer one. If the perceiver then reverses direction, the surface of the farther object will be concealed (surface deletion) at the occluding edge. These *reversible occlusion effects* serve as information for two perceptual phenomena: (1) the *relative distance* of two surfaces in the line of sight, and (2) the apparent *persistence* of objects that are presently not in view.

Relative Distance

A surface that is revealed or concealed at an occluding edge is experienced as being located farther away from the perceiver. In traditional theories, object occlusion is a pictorial cue for relative distance, but as a static cue (in the absence of movement), it is unreliable.

The earliest research pointing to the significance of occluding edge effects for moving perceivers was Eleanor Gibson's classic research using the *visual cliff* apparatus. Figure 2 shows a diagram of a visual cliff emphasizing the occluding edge.

A crawling baby at the edge of a visual cliff causes perceivable accretion and deletion of the lower surface at the edge of the upper surface with her movements. In this way, information for depth at an edge is available to be perceived by even newly crawling babies, and as Gibson found, they avoid venturing forth under such circumstances. This outcome contradicts what would be expected from a traditional empiricist view, which assumes that distance, not being presented in the retina, would require considerable learning. Likewise, it would be wrong to attribute this outcome to innate knowledge, as evidence with non-crawling babies has shown. Moreover, positing an innate "cognitive module," as is currently fashionable, merely begs the question of what is perceived. The individual discovers occlusion at an edge and its functional significance with exploration.

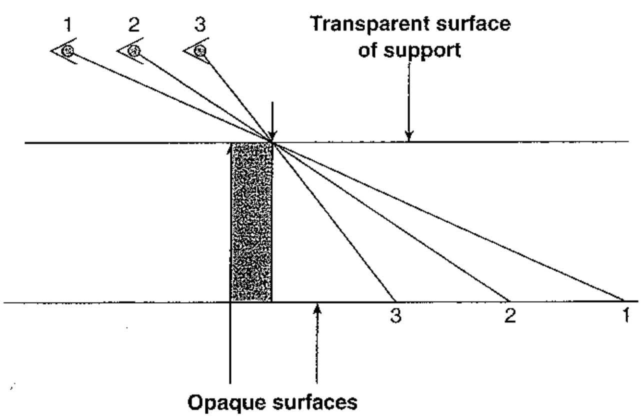

Figure 2 Occlusion Effects and the Visual Cliff

Notes: At position 1, the lower surface can be seen to the right of the numeral 1, but everything to the left is occluded. At position 2, the lower texture between 1 and 2 is revealed. At position 3, only the area to the left of the 3 is hidden. Moving from position 1 to 3, then, reveals texture (accretion) and from 3 to 1 hides texture (deletion). Thus, reversible transition of accretion or deletion of texture specifies depth at an edge.

Object Persistence

In the process of turning our heads and moving our bodies, some objects go out of sight, as others come into view. Curiously, objects that are no longer immediately visible are experienced as still being "there" (object persistence). They are not experienced as having gone out of existence, but rather as having gone out of sight. But how can this be? How is it that an object not immediately in sight can be experienced as persisting? If we bear in mind that perceiving is a process occurring over time, when surface information gradually goes out of sight at an occluding edge with perceiver movement, it can be brought back into sight by reversing the movement. This *reversible transition* at an occluding edge specifies the *persistence* of the object even when it is temporarily hidden (out of sight).

This effect has been demonstrated in a variety of ways. For example, if very young infants observe a moving object that gradually is occluded at the edge of a stationary object (it appears to go behind the latter), they will *anticipate* the reappearance of the moving object at the occluding surface's opposite edge. (Anticipation is gauged by indications of their surprise when it does *not* reappear.) From an ecological perspective, the infant's anticipation of the reappearance of an object that presently is out of sight indicates an awareness of the persistence of the hidden object. To generalize from this, it would seem that perceptual awareness of persisting objects and even places that are presently out of sight (such as the town over the next hill) is grounded in reversible occlusion effects. From this point of view, perceiving is an act of cognition.

Affordances

A number of perception researchers over the years have noted that some perceived characteristics of the environment appear to be meaningful (e.g., the cliff-edge affords falling-off, a surface at knee height appears to be a place to sit). It seems difficult, however, to reconcile apparent meaning in perception with the standard formulation of the stimulus for vision being some physical parameter of light. Light, considered as a physical stimulus, cannot carry a psychological quality such as meaning. But perhaps from the point of view of ecological optics, it can.

J. J. Gibson proposed a new concept, *affordances,* to refer to the perceived functional significance of environmental features, and he tied affordances to properties of the environment taken relative to an individual. For example, if a surface of support is roughly knee-high, it will be perceived as affording "sitting-on." Note, however, that because knee-height can vary across individuals, what might afford sitting-on for a tall person would not readily do so for a short person. This seemingly trivial fact has important implications for theory. An affordance points to a domain of properties that is not "in" the environment considered apart from an individual nor are these intra-psychic properties "in" the individual considered apart from the environment. *Affordances are relational properties.* Like optic flow and reversible occlusion, affordances arise from dynamic perceiver-environment relations.

Experimental work during recent decades has provided evidence for this supposition. For example, William Warren investigated individuals' judgments of whether a surface of support afforded stepping-up-on. He found that individuals' judgments were based on the ratio of step riser height to their leg length. Significantly, because this value is scaled relative to the body, rather than being a property of the environment independent of the perceiver, it is constant (invariant) across individuals of varying heights.

Subsequent research has examined numerous other affordances, including whether a surface affords sitting-on, whether an aperture can be passed through, whether an object is graspable as well as whether it is within reach, whether a barrier can be stepped over, and whether a task is perceived to require the participation of another person in addition to oneself. Each of these affordances is scaled relative to an individual; hence, they are not properties of the environment strictly speaking, but properties of a person-environment system.

An affordance approach to environmental properties underscores the significance of the body as a frame of reference in perception and cognition. The recent burst of activity on embodiment in cognitive and social psychology can be partially traced to J. J. Gibson's groundbreaking work on affordances, although much of this work fails to adopt the relational perspective of affordances.

Perceptual Learning and Development

The research programs of J. J. and Eleanor Gibson ran along complementary but parallel tracks. In one of their few collaborations, they proposed that growing perceptual awareness of new environmental properties over time (perceptual learning) is largely a process of discovery (perceptual differentiation) rather than of associative learning. As noted earlier, the ambient optic array is filled with light that has been structured by reflecting distal surfaces. This ecological fact indicates that a rich array of potential information is available to be perceived by individuals, and at any given moment, a perceiver is extracting only a limited portion from what is available. All of the concepts discussed in this entry refer to examples of higher-order information that are available to be perceived and that individuals become attuned to with exploration. Over time, a perceiver's awareness of properties of the environment becomes ever richer and extended with continuing opportunities to detect distinguishing relational and higher-order information specifying features, objects, and events.

Eleanor Gibson and her students have pursued these ideas through innovative developmental research, including investigations of rigid and nonrigid motion, traversability of surfaces, intermodal perception (e.g., detecting common invariants across different perceptual systems), perception of surface properties relevant to locomotion (e.g., slopes), reaching and grasping, and the use of tools. Much of this work has served as an impetus for psychology's recent wholesale reassessment of the perceptual world of infants.

Philosophical Implications: Ecological Realism

The ecological approach is unique among perceptual theories in its claim that the environment is perceived directly (*direct realism*). This view holds that our everyday impression that the environment, in most cases, is as it appears to be, is warranted. Historically, it has been pejoratively referred to as "naïve" realism. Why is that?

Traditional approaches to visual perception uniformly claim that what we experience when we perceive the environment is not the environment itself, but a mental construction of it (a view called *indirect realism*). The basis for this seemingly counter-intuitive position rests in its initial assumptions. As we have seen, traditional approaches take it for granted that the stimuli for vision are initially projected on a two-dimensional picture plane.

These stimuli are inherently equivocal (ambiguous) because as projections on a two-dimensional plane, they do *not* uniquely specify their sources in the environment. And yet it is our impression that we experience with considerable certainty a three-dimensional world around us. Hence, it must be the case—according to traditional views—that perceiving involves some intervening processes that interpret this two-dimensional display of equivocal stimuli, resulting in a "best guess" as to what the current environmental conditions truly are. The product of such processes is posited to be a mental image or a mental representation of the environment. Consequently, each individual is assumed to experience the environment as a private, intrapsychic mental construction. This assumption has created philosophical problems for centuries. Psychologists who operate from one of the traditional theories have either ignored these problems or dismissed them as being irrelevant to the research enterprise.

As we have seen, from an ecological perspective, perceiving is a dynamic process of detecting information in the stimulus array that univocally specifies features of the environmental layout. To review, the structured light of the ambient optic array carries information specific to environmental objects and events. Critically, actions of the individual introduce perceivable changes in the ambient optic array, thereby revealing non-change (invariant structure) in the context of change. Because these higher-order invariants are specific to particular stable and persisting features of the environment, they function as information for direct perception of those features. Reciprocally, change generated by the perceiver's actions specifies the self as a source of agency (intention).

This is not to say the perceiving is always free of error—under special circumstances the perceivable structure in the light can mislead, as in the case of an apparently bent stick in water. Nor is this to deny that sometimes individuals are forced to engage in guesswork when there is insufficient or equivocal information (e.g., conditions of fog, inadequate illumination), or under conditions of artificial constraints imposed in research laboratories. Moreover, all of us rely to a great extent on second-hand descriptions (e.g., reportage) or representations (e.g., photographs) of the actual state of things. This second-hand information is accurate only to the degree that it faithfully carries information about its sources. Information in the ambient array affords us the opportunity to perceive the environment directly and to look for ourselves.

William Mace and Harry Heft

See also Amodal Perception; Causality; Direct Perception; Event Perception; Navigation Through Spatial Layout

Further Readings

Flach, J., Hancock, P., Caird, J., & Vicente, K. (Eds.). (1995). *Global perspectives on the ecology of human-machine systems* (Vol. 1.). Hillsdale, NJ: Lawrence Erlbaum.

Gibson, E. J., & Pick, A. D. (2000). *An ecological approach to perceptual learning and development.* New York: Oxford University Press.

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

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

Gibson, J. J. (1986). *The ecological approach to visual perception.* Mahwah, NJ: Lawrence Erlbaum. (Original work published 1979)

Hecht, H., & Savelsbergh, G. J. P. (Eds.). (2004). *Time to contact.* Amsterdam: Elsevier.

Heft, H. (2001). *Ecological psychology in context.* Mahwah, NJ: Lawrence Erlbaum.

Pepping, G.-J., & Grealy, M. A. (Eds.). (2007). *Closing the gap: The scientific writings of David N. Lee.* Mahwah, NJ: Lawrence Erlbaum.

Reed, E. S. (1996). *The necessity of experience.* New Haven, CT: Yale University Press.

Warren, W. H., Jr. (Ed.). (1998). Visually controlled locomotion and orientation. *Ecological Psychology, 10,* 157–346.

Effort: Perception of

Perception of effort, also known as perceived exertion or sense of effort, refers to the conscious sensation of how hard, heavy, and strenuous a physical task is. This perception depends mainly on feelings of effort in the active limbs, and the sensation of heavy breathing (a type of dyspnea). Several authors think that somatic sensations such as muscle pain, thermal discomfort, and chest