2

✦ ✧ ✦ ✧ ✦

An Ecological Approach to Perceptual Development

The ecological approach to visual perception (J.J. Gibson, 1966, 1979) provides the framework for the view of perceptual development we present here. It is a theory about perceiving by active creatures who look and listen and move around. It is a theory about everyday perceiving in the world, and it differs greatly from theories that begin with a motionless creature haplessly bombarded by stimuli. Perceiving creatures are part of a world from which they seek information and in which they use it. Perceiving begins at least as soon as an animal is born and well it should, for its function is to keep an animal in touch with the environment around it.

The Reciprocity of Perceiver and Environment

The ecological approach takes as its unit of study the animal in its environment, considered as an interactive system. The relations within this system are reciprocal, with the reciprocity including a species evolving in an environment to which it becomes adapted, and an individual acting in its own niche, developing and learning.

How does this reciprocity work for perceiving? The environment provides opportunities and resources for action, and information for what is to be perceived so as to guide action. Action has consequences that provide more information for the perceiver. The animal and the environment are dynamic players in the systemic whole. The dynamic system is a cycle that can begin with events in the world, such as a looming object like a predator or a truck, or with action instigated by the animal itself, such as driving the truck, since animals are animate and can act spontaneously. This cycle is truly one of mutuality. Animal and environment (including other animals) make a complementary whole. What the environment offers can be physical, such as a comfortable surface that provides babies with needed support, or pins pricking them that arouse cries of distress; or social, such as caretakers smiling and cuddling them or responding to their cries by feeding them or rearranging their clothing. Older children can change their immediate environments by seeking a more comfortable surface, discarding clothing, or seeking out caretakers.

To understand perceiving within this system requires accounts at three levels. First, we need to describe the *environment* in particular, what there is to be perceived. This description must be on a scale appropriate to the animal and its niche, in neither micromillimeters nor light-years. Such a description includes the *sources* of information for the layout, the objects in it, and the events that take place in it. Second, we need to describe the *information* for perceiving. The information consists of the energy changes in a physical medium corresponding to their sources—the layout, objects, and events of the environment. Finally, we must describe the process of perceiving, how the animal *obtains* the information about the environment and what it actually does perceive.

The ecological approach to perception, as envisaged by J.J. Gibson (1979), includes three major ideas that distinguish it from other theories of perception. One is the concept of *affordance,* the user-specific relation between an object or event and an animal of a given kind. A second is the concept of *information,* how events in the world are specified for perceivers in ambient arrays of energy. Third is the process of *information pickup,* how the information is obtained by an active perceiver and what is actually perceived. These concepts and their implications form the core of the theory.

Three Concepts

Affordance

We begin with affordance because the central tenet of the ecological approach is the complementarity of the animal and the environment. An "affordance" refers to the fit between an animal's capabilities and the environmental supports and opportunities (both good and bad) that make possible a given activity. For example, a chair affords sitting for creatures possessing a flexible torso and hip joints, and legs with knees that bend at the height of the chair's seat. A path affords traversal to a destination, and it may contain obstacles that afford collision or turning aside to avoid. Affordances are properties of the environment as they are related to animals' capabilities for using them. They include not only objects but layout properties such as surfaces, corners, and holes. Affordances are also offered by events, including social events such as a looming, loving, or angry face.

To perceive an affordance is to detect an environmental property that provides opportunity for action and that is specified in an ambient array of energy available to the perceiver. Since an affordance is an objective property of the environment, it exists whether or not it is perceived or realized. Affordances vary with species and with development. Water provides a surface of support for a bug but not for a human. What affords sitting for an adult human differs in size and scale from what affords sitting for a child. Affordances vary in availability with habitats, since potential tools and resources may be present in some climates and cultures but not in others. Furthermore, affordances ordinarily must be discovered through perceptual learning. Knowledge of affordances and the probability of using them varies, even among humans. Chopsticks afford carrying food to the mouth, and igloos afford shelter for all adult members of the human race, but the number of people who use them is limited by climate and social custom.

Fundamentally, the realization of an affordance requires that animal and environment be adapted for one another. Bipedal locomotion in humans is possible when they have the necessary anatomy, postural control, and strength for balancing on two legs and lifting their body weight with them, *and* when the terrain is tolerably flat, solid, rigid, extended, and relatively uncluttered.

There is a second reciprocal relation implied by the affordance concept: a perception-action reciprocity. Perception guides action in accord with the environmental supports or impediments presented, and action in turn yields information for further guidance, resulting in a continuous perception-action cycle. Realization of an affordance, as this reciprocity implies, means that an animal must take into account the environmental resources presented in relation to the capabilities and dimensions of its own body. Children begin learning to do this very early and continue to do so as their powers and dimensions increase and change.

We find awareness of body-scaling of resources even reflected in children's literature. Remember the tale, "The Three Bears"? Father Bear, Mother Bear, and Little Bear go for a walk while their porridge cools. They return to find their home raided, remarkably individualistically. All the opportunities have been explored, but only Little Bear's small portion of porridge has been eaten, the little chair sat in, and the junior-size bed slept in. The body-scaling metaphor is, indeed, the major point of the story, and little children always enjoy it. Even when they are not yet perfectly in tune with their own proportions, they realize that Goldilocks had more to learn; she didn't know how big she was and she broke the chair!

Affordances evolve in a niche unique to a species, and in this sense are anticipated for its individual members. But as we pointed out, this potential does not mean that affordances are automatically perceived and acted upon. Humans, at least, must *learn* to use affordances. We have emphasized that affordances reflect a fit between an environmental property and a possibility for action. But such a fit does not imply that the learning of affordances is necessarily simple or automatic. Some affordances may be easily learned; others may require much exploration, practice, and time. Darwin understood this, as his observation on the hand suggests:

> Although the intellectual powers and social habits of man are of paramount importance to him, we must not underrate the importance of his bodily structure. . . . Even to hammer with precision is no easy matter, as everyone who has tried to learn carpentry will admit. To throw a stone with as true an aim as can a Fuegian in defending himself, or in killing birds, requires the most consummate perfection in the correlated action of the muscles of the hand, arm, and shoulder, not to mention a fine sense of touch. . . . To chip a flint into the rudest tool, or to form a barbed spear or hook from a bone, demands the use of a perfect hand. (Darwin, 1974, p. 135ff.)

Even a universal affordance for humans, such as the graspability of an object of a given size and location, shows developmental changes that involve learning. Arms grow longer; posture and balance change, and so do ways of controlling the grasp. Children accommodate to such changes during growth, and their skills develop accordingly. Further development of expertise may involve learning to realize affordances unavailable to nonexperts. A three-inch-wide beam affords performing backflips for a gymnast, but the affordance is not realizable by others; rock climbers learn to use certain terrains for support that do not appear to others to provide a surface of support.

To study the development of perception of affordances requires both describing the objective basis for an affordance in the perceiver-environment relation, and describing the information that specifies the affordance and makes possible its perception.

Information

Information is the second essential concept in the ecological approach to perception. The way in which it will be used is similar to the commonsense meaning of information *about* something, but the term "information" is also used by others in different ways, so we review its history in psychology. The term was adopted in the 1940s by scientists in the Bell Laboratories for measurement of the amount of information that a channel could carry (Shannon and Weaver, 1949). They invented a system of measuring information in "bits," an either-or alternative especially suited to evaluation of communication systems. The notion was thought to be useful to psychologists, who found it a way of dealing mathematically with variability (G.A. Miller, 1956), uncertainty, or number of alternatives (Garner, 1962). It was applied extensively to attention (Broadbent, 1958), where the notion of a "channel" became popular. The practice of measuring information in this way continues, but in psychology the quantitative emphasis has been lost. The term, for many psychologists, has come to mean "input" that is "processed" in various ways after entering a cognitive system; hence the term "information processing."

The various uses of "information" were commented on by J.J. Gibson: "These meanings of 'information' contrast with the term 'stimulus information' that I wish to use, that is, specifying of an environmental source by a stimulus, i.e., the conveying of information about the world by ambient light, sound, and odor, and the information obtainable by mechanical means" (1962).

We use information in his sense, as the structured distribution of energy in an ambient array that specifies events or aspects of events in the environment (see J.J. Gibson, 1966, ch. 10, and 1979, pt. 2). The *sources* of the information are the events, objects, and layout of surfaces in the world. The correspondence of information with these aspects of the environment is one not of similarity, but rather of specificity. The optical disturbances created by an approaching car, for example, do not resemble the car; rather they uniquely specify it and its path of locomotion in relation to oneself. The specification relation is critical because if information is fully specific to its sources in the world, then perception of the layout and objects and events in it is possible without hypothesizing processes of supplementation such as intermediary concepts and representations. The possibility of perceiving a property of the environment directly, without supplementation, exists when there is sufficient information to specify it *and* a perceiver who is attuned to that information—again emphasizing the perceiver-environment fit.

Information is not punctate, instantaneous, or fleeting. It is spread over space and over time. Describing the information for an ongoing event is not a matter of identifying dimensional quantities of physical energy. J.J. Gibson called the description of visual stimulus information "ecological optics" to distinguish it from the optics of physics. It is a description of the distribution of light at a level appropriate for perceptual systems. Information is contained in arrays, for example, the ambient array of light surrounding us. It is structured by the surfaces, boundaries, objects, and layout of the environment. The order in the array is not lost. But this structured array is not static. It changes or flows as one moves one's head around, stands up, sits down, or walks about (see fig. 2.1). These changes are essential for extracting information about the relatively permanent aspects of the environment, since they are the result of continuously shifting points of view. Information that specifies the persisting layout is only made available by one's movement in the layout. Gibson referred to it as "invariant over transformation."

Identifying and describing the information that specifies constant and changing features of the world, over events as well as things, has been a major part of the research program of the ecological approach to perception (J.J. Gibson, 1979). One example is research on optical information that specifies "time to contact" in such events as an object looming or an observer approaching an obstacle or surface that must be contacted or not contacted in some way (e.g., a diving bird approaching water, a person avoiding a collision or about to jump

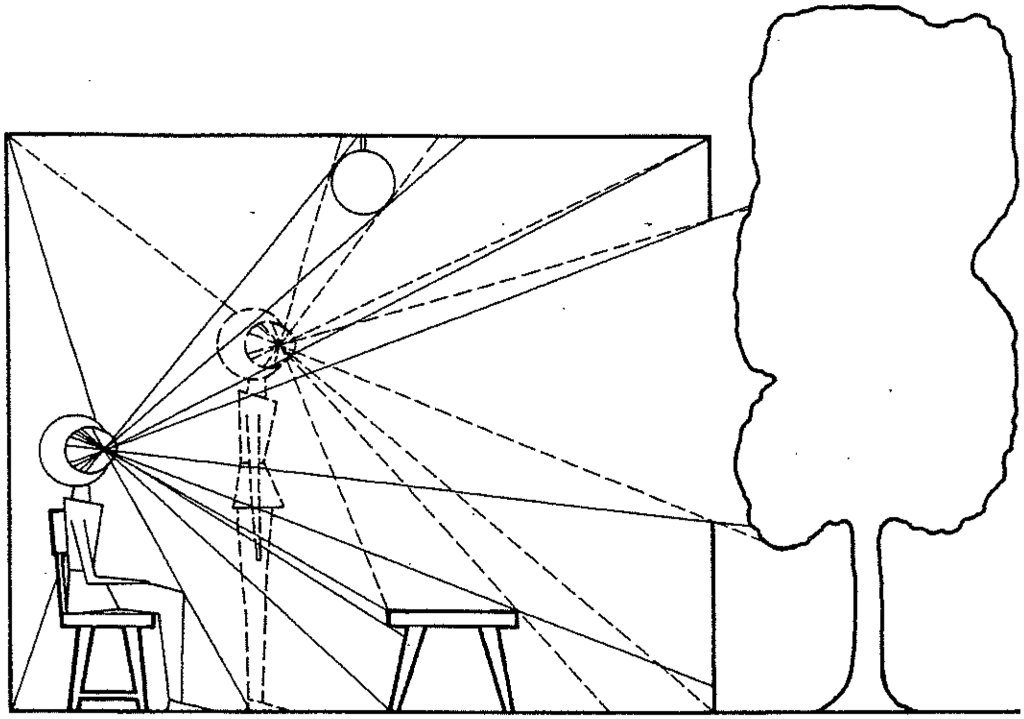

FIGURE 2.1. A structured array with an observer sitting and rising. The thin solid lines indicate the information in the ambient optic array for the seated observer, and the thin dashed lines the altered optic array after standing up and moving forward. From *The Ecological Approach to Visual Perception* (p. 72), by J.J. Gibson, 1979, Boston, MA: Houghton-Mifflin. Copyright © 1979 by Houghton-Mifflin Company. Reprinted with permission.

over a barrier). Lee (1980) showed that the ratio of the size of the projected image of an object to its rate of expansion for objects approaching at a constant velocity at any moment is a constant that specifies time-to-contact. He described this information as a mathematical constant (Tau). The information has wide generality, and animals (including humans) make use of it.

The transformations of the optical array during locomotion constitute information for objects and the layout. Such transformations are created both by movements of observers and by motions of objects. The perspective changes in optical structure revealed by one's own movement specify one's path of locomotion. Furthermore, as a person moves about, information is made available specifying persisting features of the environment such as sizes of things, and the solidity and shape of objects. When a person or object passes in front of us, our view of another object may be temporarily occluded, but as it emerges again, the accretion and deletion of optical texture elements at its edges specify its shape and permanence. As an object itself moves, it gives us information for its unity—all its parts move together.

A person's movements through the layout also provide information for the *self:* where one is, where one is going, and what one is accomplishing. Self-produced movement in the world yields information at the same time for events in the world and for oneself as an independent object interacting with it. J.J. Gibson said, "One perceives the environment and coperceives oneself" (1979, p. 126).

It is not only optical information for visual perception that we obtain through changes. As we handle things and move over the terrain, we bring about mechanical information in our joints. Acoustical information is produced by surfaces contacting each other. Information is available in mechanical, acoustic, and other modes of array, even in a changing array of smell against an existing background.

Information must be actively sought; it does not fall, like rain, on passive receptor surfaces. We move our heads to disocclude a portion of a temporarily invisible scene; we step forward to magnify a wanted view; we lean to peer around a corner or glance in our rearview mirror as we back the car. In sum, activities of observers result in changing points of view, perspective transformations, continuous occlusion and disocclusion of edges and boundaries, and flow patterns that specify one's continuously changing relation to objects, paths, obstructions, and goals. The function of perceptual activity is to obtain information. As we shall see, as soon as they are able, young infants bring objects closer than arm's length to scrutinize them or test them by mouthing, and they crawl around objects to explore them from all sides.

Pickup of Information

Animals, including humans, actively seek information for guiding their actions and knowing their surroundings, sometimes using elaborate strategies, as in the case of animals that seek prey or keep track of their whereabouts by echolocation. Bats do not guide their flight visually, as a human flier does. Their keen hearing is adapted to detect fine binaural differences and temporal gradients inherent in reflected sound from prey, obstructions, and open flight paths, a kind of structuring of the acoustic array. As they fly, they obtain the information by sending out high-pitched squeaks that are modulated by the objects and surfaces around them in relation to their own position and direction of movement. Their hearing systems are adapted, even, to distinguishing the two sound sources—their own squeaks and the echoes—to prevent interference.

Humans have an equally keen and unique perceptual adaptation. We can pick up an object and twist it about with our fingers, feeling it with different fingers and combinations of flexing and pressing that might seem (to a creature not possessing hands) random and aimless, but that nevertheless allow us to recognize the object. This skill (J.J. Gibson, 1966) is known as active touch, useful to all of us, with the potential to be developed as a virtuoso skill. We are impressed by persons who can read Braille; physicians who locate fractures and tumors by delicate prodding; graders of fine textiles; musicians; or blind watchmakers who can repair and even construct a delicate timepiece. Human infants have systems for obtaining information tactually, and they do it from birth, with emerging and developing skills.

We can differentiate two general kinds of active information pickup. Actions can be *exploratory,* functioning primarily to yield knowledge, such as when one fumbles in the dark for a light switch or when a blind or blindfolded person feels someone's face for impressions that will permit identification of it. Or an action can be primarily *performatory,* such as when one presses a clearly identified light switch, puts on one's coat, or inserts and turns a key in a lock. These performatory acts have certain expected results; they are performed to produce them. They depend on and confirm an already learned affordance. Of course, they may also yield knowledge and spur exploration, for example, when the key does not turn nor the lock yield and one must proceed to manipulate the key in a different manner or try other keys.

Exploratory activity is especially prevalent in infancy and is, as we shall see, spontaneous and striking. Exploratory activity yields knowledge about environmental possibilities, affordances, and one's own capabilities. Perception and action are closely intertwined in both exploration and performance, and learning is an important outcome of both types of action. Perception guides action; action makes information available for perception. Exploratory actions seem especially useful for learning by a novice, but the confirmational consequences of expectant performances are essential as well.

Action has a central role in cognitive development because of the intertwining of perception and actions. Much of the information that is essential for perceptual development cannot be obtained until appropriate action systems are functional. In later chapters we will trace the development of action and exploratory activity, showing how maturing perceptual systems interact with growth of postural control and how development of the systems potentiates perceptual learning, the very foundation of intelligence.

Perceptual Learning

Where does learning fit in the ecological view of perceptual development? Newborn infants are capable of very few performatory actions, but their perceptual systems, while immature in many respects, are functional and are used. Babies have a great deal to learn about—everything that the world has to offer—and perceptual learning is their way of discovering what particular things and people afford for them, where things and people are in relation to themselves, what is happening, what characterizes their permanent surroundings, and what they can do.

We can profit from comparative psychologists who have made intensive studies of what and how animals of many species learn early in life: for example, what songbirds learn about singing; what various species learn about foraging for food; what migratory species learn about finding their way (Gallistel, 1990). Learning goes on in the young of all species, but especially in the human species; what is learned is what is relevant to the animal's environmental niche and the kind of creature it is. Learning occurs along with general growth and maturing of action systems, so we should study it early, relating it to attainment of essential ways of adapting to the environment, as Johnston observes:

> Although it has been a frequent concern of learning theorists to draw a sharp line between learning and the rest of development, that is not a position from which the ecological approach can proceed. Successful adaptation requires that the entire life cycle of the organism, from conception to maturity, be able to cope with the demands of its environment, and processes of learning must be integrated with other developmental processes to ensure success. (1985, p. 18)

What is learned is the first question to ask, because the animal-environment fit has characteristic requirements depending on the animal and its way of life. Just as young birds may learn to sing and to fly, bees to forage, and migrating birds to orient by the stars, so human infants have their own developing behavior systems. The major behavioral systems that develop during human infants' first year are (1) communication and interaction with other people; (2) reaching, grasping, and manipulating objects; and (3) locomotion. Many affordances are learned as each system emerges and develops. We need to study what is learned and its necessary conditions as the development of each system proceeds. We will especially consider infancy, emphasizing development within the three domains, examining perceptual learning as it occurs in the context of development, and relating controlled observations and experimental research that help to reveal its underlying conditions. To do this, we will need to examine first the ways in which we can find out what an infant perceives, an achievement that eluded developmental psychologists until a few decades ago.

The task of infants is to learn about the affordances their world offers them. We will see that this happens in an orderly fashion. As growth provides them with more effective action systems and sensory equipment, their perceptual world is expanded and differentiated by their own activities. They have the motivation to explore with these systems, and exploration, spontaneously undertaken, is the crux of learning what the world offers and how to use it.

Development of Action

Since our major concern is with perceptual development, we must also consider the development of capabilities for action and its contribution to perceptual development. We noted that the perception-action relation is a reciprocal one, a kind of continuous cycle with perception guiding action, and action furnishing new information for perception—information about the animal itself, its own dimensional and dynamic properties, and the environmental consequences of its actions. Development is marked by growth of bodily dimensions and dynamic capacities, so there are many sources of change in this cyclical perception-action relation. Developmental changes in eyeball dimensions and interocular distance make visual adjustments imperative. When the body grows larger, or when a part of it grows larger or more capable in relation to the whole, potentials for action change. A shift in proportions as the child grows less top heavy and stronger in the legs are among the factors that make walking possible. The gradual achievement of control of posture underlies all forms of perception-action development.

Indeed, postural development is a leading factor in all behavioral development. At one time, psychologists tended to favor the rather simplistic assumption that action begins as individual reflexes and attains greater complexity by combining reflexes, as elements, through some associative process such as conditioning. But we know now that action, even the simplest, is always organized, related to what is going on in the rest of the body, potentially flexible, nearly always intentional, and frequently anticipatory, in the sense of preparing for later action.

Individual actions, such as an infant lifting a hand to the mouth, always occur against a postural background and, in fact, can occur only to the extent that the infant is supported and posturally stable. Differentiation of actions occurs as postural control develops, beginning with control of head and shoulders and proceeding downward, depending on growth of limbs and many other factors. As new actions become possible, infants' potential for exploring their surroundings and themselves grows.

The ecological approach to perceptual development is compatible with views of development expressed in recent years by naturalists and comparative psychologists. Learning should be studied in the context of development as it proceeds, starting as early as possible. Even prenatal development is part of the study to be undertaken, because it has become clear that the fetus is an active organism and that interaction with environmental factors is an essential aspect of growth during the gestation period, as well as from birth on. Internal (physiological, biochemical) and external environments affect the growing fetus as it differentiates. This position emphasizes that development is the result of interaction of genetic and other factors within a growing organism, and of the organism and its environment from the beginning. Development is a dynamic process, and an organism undergoes its own processes of organization and creation, so a simple dichotomy (or even interaction) of genetic and environmental factors cannot be separated out as discrete factors in the organism's ongoing transformations (Goodwin, 1990; Oyama, 1985; Johnston, 1987). Thus, it is the relation and interaction of the organism and its environment that we focus on and emphasize here.

What Is Perceived?

We have considered three general questions: What is there *to be* perceived? What is the information for perceiving? And how is the information obtained? A final question is: What *is perceived?* Not information—information is specification for its sources in the world. Not light, color, form, space, intensity, or other isolated sensory properties. We perceive what is in the world as it relates to us: (1) the *layout* of the environment; (2) the *objects* in the layout; and (3) *events* that go on over time, situated in the layout and involving the objects, in terms of what they afford for us.

What is meant by *layout?* It refers to the permanent arrangement of the surfaces of the world, which support and surround the objects that furnish the world and move around in it. The term "space" has often been used in textbooks to refer to the locations of things, but it conveys too strongly the notion of empty space (for which there is no specification). We perceive the surfaces that we walk on and the ceiling above us, and we perceive these surfaces as permanent places for situating ourselves, the objects, and the events that happen there. The ground, for terrestrial animals, is always perceived as stretching away from us, at our feet. We locate ourselves in this layout and locate other things in reference to us and to the ground that stretches under them as well as us. The layout is pretty circumscribed for an infant: the walls of a room and a ceiling, plus the surface the infant lies on, for the most part. But these basic, permanent, underlying and surrounding surfaces are perceived as background for everything else very early. As a child achieves first reaching and then locomotion, the layout of the world available to be perceived expands enormously, and how this happens has a big share in the story of perceptual development.

The layout we perceive around us is far from empty; it is furnished with *objects* of many kinds, animate and inanimate. Objects, on the whole, are moveable or move on their own, as is the case with animals. Some of them, like houses, do not afford moving by individual persons, some can be moved by a sturdy adult, and some small ones can be moved easily, but they are not permanently fixed in the sense that the ground or a mountain is. The categories of objects are many—people, animals, things to sit on, things to eat, pictures of things, and even symbols, such as letters and numbers. Learning to perceive the affordances and the features of all these things is a task that begins at birth and continues throughout life.

The third category of what is perceived is the largest—the *events* that take place within the layout. The events are the movements and actions that occur, some performed by ourselves and some external to us. They implicate objects and provide the dynamics of all scenes in the layout. Events have a special importance, because it is only through events that properties of things, including permanent properties of both things and the layout, are revealed. What is permanent is revealed through change and nonchange. When an object moves, parts of the object all move together, revealing it as a unit. I walk out my front door and down the sidewalk and what I am seeing—the vista ahead—is continually changing. But I can reverse the vista, walk back again, and the surrounding layout will look the same. My path could be shifted by a moveable object appearing or being thrust in front of me, but the basic layout is perceived as constant, revealed by my locomotion through it. The fact that perceiving is an active process, a search for information about the layout and what goes on in it, is in accord with the emphasis on movement and change. Perceiving is an event that provides us with changes that reveal the properties, permanent or impermanent, of things and places. We move our heads to see what something is, and we look back again to see if the order is the same.

Growing children learn to find their way around the layout, at some point using objects as landmarks to help them. But they must discover that such objects should not be very moveable if they are to be useful (a concept Hansel and Gretel had not yet mastered when they marked their path of locomotion with a trail of bread crumbs). They learn about the layout of a small world around them fairly early, but as they become able to move themselves to new places, creating larger events, the layout that can be perceived expands and the objects encountered are multiplied, and so are the events that can be witnessed.

Perceiving a layout, objects in it, and events going on is not a mere registration of presence. Perceiving involves both perception and action, inevitably, as we have stressed, and also involves perception of oneself in relation to everything else. It is an active process of obtaining information; even a newborn infant moves eyes and head in an exploratory searching fashion, turning the head to look, for example, when a voice speaks or a rattle is shaken at one side. These exploratory movements provide information about something in the environment. In later weeks, more and more kinds of activity are possible as a baby learns what the layout of the world and the objects and happenings in it afford. Learning about the affordances, objects, and happenings around us is a lifetime pursuit that begins early and elaborates as actions and environmental opportunities emerge and broaden. Our aim is to understand how this happens. How do we come to perceive the world so richly? And how do we, as psychologists, find out about this? Ways of finding out emerge from the properties of infant behavior and infants' own readiness and capabilities for seeking information about the environment and about themselves. We consider how this happens in the next chapter.