The senses information systems

BY ELEANOR AND JAM

THE FIRST QUESTION a biologist asks in seeking to understand an organ is what adaptive function it serves in the evolution and survival of the species. The psychologist asks the same question and the organs of sense are no exception. Indeed, it seems obvious that this is the first question to ask. Man and other animals are endowed genetically with equipment designed for the reception of stimuli from the environment around them. They are also endowed with the ability to learn from what they perceive. Hence there is both adaptation of the species in the course of its evolution and adaptation of an individual in the course of his life.

The answer to the question of function now seems clear. The sensory systems—the organs and their related activities—provide the means of attending to and getting information from the world surrounding the organism that must survive in it. He must find food, a mate, shelter, escape from predators and from environmental hazards. He must have information about objects that are edible, friendly, unfriendly, sexually exciting and so on; about places that are safe for walking or flying, grazing or sleeping and for their spatial layout; and about events of all sorts.

Information about the world comes from the world. None of us believes that this information is innately given. Richard Gregory (whose article is on page 707) would certainly agree that an animal is constantly interacting with his environment, taking in information, doing something, and getting fresh information from what he has done. What is the nature of the information he is getting? This is the question that has produced controversial answers.

There is a contradiction at the very heart of the existing theories of sense perception which can be expressed by the following two assertions: the senses *cannot* be trusted and the senses *can* be trusted. From the biological point of view it would seem that the senses *must* be trusted since they are all we have. How else is an observer to keep in touch with the environment? But everything we know about the physiology of the senses seems to show that the inputs of the sensory nerves are inadequate for keeping in touch with the environment, since they are nothing but signals touched off by stimuli. How to resolve this contradiction is the chief problem for understanding sense perception.

Existing theories try to resolve this contradiction by assuming either that the inputs of the sensory nerves are corrected by the brain, or that the corresponding sense impressions are interpreted by the mind. There are many such theories of correction, inference, interpretation, compensation, equilibration, organization and the like, all taking it for granted that the process of perception is some kind of operation on the deliverances of sense. But there is another way of resolving the contradiction that seems to us more promising. It is to assume that the inputs of the sensory nerves are merely incidental to the process of perception and that the useful senses are actually perceptual systems. These are systems which adjust the sense organs instead of just receiving stimuli; systems that have output as well as input; systems that explore the light and sound and pressure of the environment for the information contained. This is information about the sources of the stimulus energy, not merely signals.

Professor Gregory believes that there is "a cognitive element in perception". He is saying that one has to *know* something about the environment in advance before he can *perceive* it properly. But there is a dilemma here. Surely one cannot know anything about the environment *except* as he perceives it, or has perceived it.

The trouble comes from the long-standing assumption that the senses at birth can deliver nothing but meaningless signals over the sensory nerves, signals that have to be interpreted in the slow course of learning by association. On that assumption it follows that knowing must precede perceiving. But perhaps the long-standing assumption is wrong. We might assume instead that the senses, even at birth, are perceptual systems that pick up facts about the world. On the first assumption learning is a matter of

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supplementing the infant's bare sensations with memories. (But memories of what? Sensations?) On the second assumption learning is a matter of distinguishing the information, of discriminating not of associating. Bare sensations have no meaning until they have been enriched in some unknown way by past experience. But primitive perceptions have primitive meanings from the very outset of life.

Psychologists and physiologists who are of Professor Gregory's persuasion take it for granted that lights, sounds, chemicals, and contacts are mere stimuli for the receptors in the eyes, ears, nose, mouth, and skin, and they suppose that stimuli as such carry no information about their sources in the world. But we reject this doctrine and try to show that an array of light, for example, specifies the surfaces from which the light is reflected. At least it does so in the world outside the laboratory. Similarly, a natural flow of sound specifies the vibratory event from which it comes, a taste or an odour specifies the substance from which it emanates, and the sequence of pressures obtained by feeling an object specifies the object. The notion of *information* in stimulation is novel and unfamiliar but it is the basis for a new theory of perception.

In life, the sea of stimulus energy in which an observer is immersed is always an array and always a flow. The stimuli as such, the pin-pricks of light or sound or touch, do not carry information about their sources. But the invariant properties of the flowing array of stimulation do carry information. They specify the objects of the world and the layout of its surfaces. They are invariants under transformation, non-change underlying change. Note that they are not in any sense pictures or images of objects and of layouts as so many psychologists have been tempted to think. Nor are they signals from the objects, and surfaces of the environment like dots and dashes in a code. They are mathematical relations in a flowing array; nothing less.

The demonstration that a natural array of light specifies the surfaces from which the light is reflected, together with the layout and composition of these surfaces, depends on a new approach to optics, an approach that is ecological instead of physical. It begins with ambient light at a point of observation instead of radiant light from a source. It studies the structure and transformations of this ambient array instead of rays or waves or photon-paths. It treats the eye as an organ instead of a camera, and rejects not only the doctrine that the retinal image is a picture but even th. notion that it is an *image*, properly speaking.

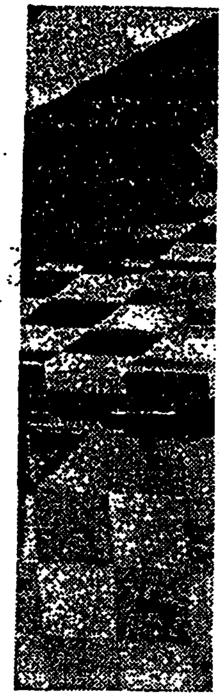
The old theories of sense perception assumed that it consisted of the operations of the mind upon the data of sense. If this notion sounded too philosophical it could be made to sound more scientific by asserting that perception consisted of the processing by the brain of the signals arriving over the sensory nerves. This is the modern formula, but actually it is the same old theory. It still says that the act of perceiving is something that occurs wholly inside the head. The new theory that we advocate says that the act of perceiving occurs in a circular process from the sense organs to the brain then back to the sense organs, and so on. It involves exploration by the eyes of the whole array of light and exploration by the hands of the whole layout of surfaces around one. Man's delicately mobile postural system, which includes the eyes, head, hands, and body, is beautifully adapted for this activity.

Perception therefore does not have to be conceived as the interpreting of messages or the learning of the so-called "sensory code". It is the exploring of an array, the enhancing of available information, and the optimizing of its pickup. The eyes, for example, look around, focus their lenses on details of the world, and modulate the intensity of the light when the illumination is too high or too low. For listening, the head turns to equalize intensity of input to the two ears so as to point the head towards the source of sound.

The assertion that the information in stimulation specifies its sources in the world does not imply that this information is automatically picked up. It is available, but it may or may not be perceived. An observer must extract the information from the flowing array of stimulation. And he must often learn to do so. What is it that the human observer learns? We suggest that, beginning as an infant, he learns the distinctive features of objects, the layout of places in the environment, and the invariant features of events. A human observer also perceives representations of things and places and events, of course, and in that case the information coming from the picture or the television screen is essentially the same as it is when it comes from the environment. Finally, a human observer learns to extract information from the constituents of spoken and written language, but this is information of a quite different sort. It is *not* essentially the same as that which comes directly from the environment. The child's learning about the world from speech, and then from writing, is a much more complex process than learning about the world from what we call first-hand experience.

Here is a brief account of the development of perception of objects. The process begins in the newborn infant with visual attention to certain salient stimulus properties that carry information: motion, brightness contrast, and the kind of contrast provided by the edge of a surface in the world. The infant's attention is "caught" by these properties. The world he perceives, then, is not at all a "blooming, buzzing confusion", as William James put it, for he at least sees surfaces and edges. But this is only the beginning, since objects gradually become differentiated from one another by their distinctive features, that is, by attributes that render each object different from other objects. For example, babies differentiate human faces from non-faces in their environment very early, although it is doubtful that they perceive the relations between the features of a face before they are three months old, or thereabouts. Individual faces are not differentiated from one another until six months have passed. Other properties of an object such as its size and shape are differentiated within the first few months of life, before the baby can walk or even reach. There is no substance in the old notion that such visual attributes must gain their meaning from touching and grasping.

A human face, of course, has properties that are not constant over time, as well as properties that are. The movement of the facial muscles produces different expressions that portend different events. Moreover a moving face usually produces sounds. Interestingly enough, an infant at twenty days perceives the



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voice as coming from the face—he does not seem to have to learn to connect these sensations by associating the sound with the sight.

An object comes to be perceived as permanent even when it is partially or entirely hidden by another object. If a screen is drawn in front of an object so that it is gradually concealed and then gradually revealed again, an infant soon learns that it has not gone out of existence and expects its reappearance. There is optical information for its continued existence and for its only having gone out of sight. This is not the same thing as remembering the object. Later on, when a child has learnt names for familiar objects that he has distinguished from one another by their distinctive features, he knows things about objects that he can remember and think about, but perceptual differentiation is basic to this knowledge.

The differentiation of the features of the environmental layout also develops without having to be supplemented by knowledge. When a crawling infant is placed on a platform with a visual cliff on one side and a very shallow drop-off on the

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other side (but actually a glass surface of support on both sides : see above) the infant will crawl to its mother over the shallow side, but not over the deep side. Is this because it has "knowledge" that a cliff is dangerous ? This seems unlikely. The baby has no past experience of falling and surely does not inherit racial memories of falling.

What about the perceiving of events ? Events occur over time and are of many degrees of complexity, since a short episode may be embedded in a much longer episode. If perception were really based on single elementary sensations, each successive sensation would have to be somehow integrated for the total event to be perceived. Again, it seems that learning proceeds by differentiation, not by integration. For example, if an object approaches an observer on a collision course he will blink or duck or dodge so as to mitigate or avoid the collision. The optical information for this imminent event is the progressive magnification of a silhouette in the field of view. Experiments consisting of the display of this information have been done with several species of animals and with human infants. The shadow of an object is cast on a translucent screen in front of the observer and its size is increased at an accelerating rate. The adult human observer perceives a virtual object approaching him. Turtles faced with this display pull their heads within their shells. Monkeys cry out and rush to the rear of the cage. Human infants, at two weeks, respond consistently with a backward jerk of the head and by raising the hands. A little later they differentiate between the information for an object on a collision course and that for an object on a non-collision course. This difference depends on the symmetry of magnification. A perception of this sort can hardly be a matter of successive sensations. It must be that optical motions of different kinds are distinguished from one another as perceptual development proceeds.

Different events involving motions are differentiated very early in life. The same animal that retreats from an approaching object may *follow* a retreating object. Baby chicks run away when they are faced with the optically expanding shadow on the screen but they move towards an optically contracting shadow on the screen. This response to the diminishing shadow is related to the imprinting that occurs early in the life of a young bird such as a chick or a duckling. It runs after a retreating mother and thus succeeds in staying with its protector and with its kind. And it demonstrates for us, incidentally, that two contrasting kinds of event are distinguished.

The early development of perception seems to us clearly to demonstrate the picking-up of information that is available in stimulation and not the supplementing of sensations by memories of past experience, or by some kind of knowledge. But, the reader may ask, what about symbols like words? They are perceived too. Aren't they at least a clear case of supplementing auditory sensations with an associated meaning?

The analysis of the information in a speech event tells us that it has

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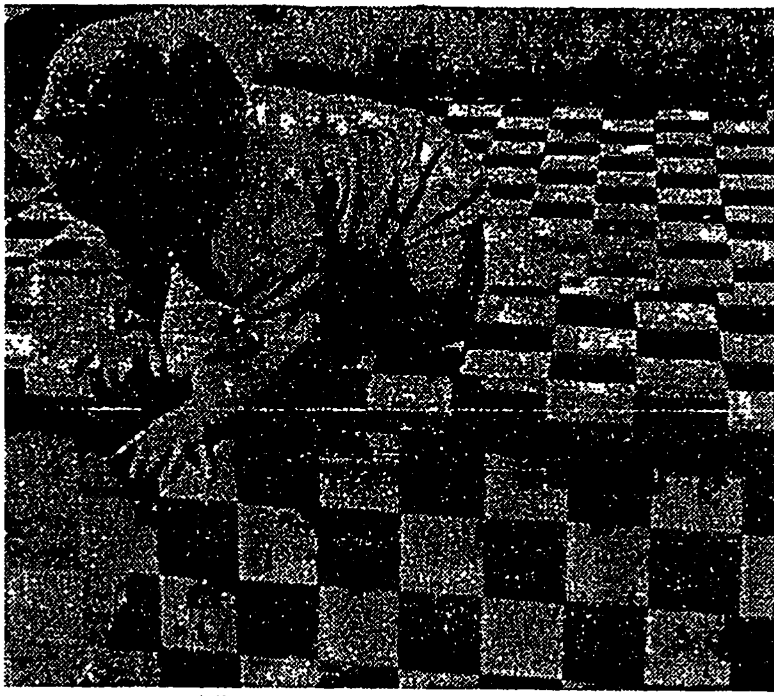
three quite different kinds of information, all of which must be comprehended. There is the sound itself, the phonetic sequence, to be perceived. There is the syntactic information, the rule system that governs how words are put together. And there is semantic information, the "meaning". How does a child learn to pick up all this information? One thing seems certain—he does not simply learn by association. How then?

The first essential to this development is what the linguists call *segmentation* of the sounds of the speech stream. Speech comes in a physically continuous flow, usually without the separation we seem to hear. This stream must be analysed. It is analysed at many levels, the lowest of which is considered to be the phoneme and the higher levels being syllables, words, phrases, etc. But phonemes themselves must be differentiated. They are differentiated from one another by sets of contrastive features. These distinctive features have a developmental sequence of their own, as the linguist Roman Jakobson has taught us. The first differentiation is between the optimal vowel and the optimal consonant, and development goes on from there in a series of ordered splittings.

It seems unquestionable that this process must be one of differentiation not of association. The features cannot be associated with anything, since, as Jakobson said, they indicate mere "otherness". The same twelve pairs of contrastive features serve to differentiate, in various combinations, all the phonemes in human speech. The phonemes themselves are abstracted, by a process of analysis, for one cannot be heard alone, chopped out of a speech segment. Yet we do all differentiate it and acknowledge its constancy. We do not learn to perceive phonological features of speech, then, by adding something on.

The second essential in the learning of speech is grammar. No one has succeeded in accounting for a child's acquisition of grammar by an associative process. A child's first



sting depth perception on the "visual cliff". The baby refuses to venture on the plate-glass surface.

sentences are not copies of the sentences of adults, but they nevertheless follow rules of grammatical construction in accordance with the relations expressed, such as agent-action, agent-object, and action-object. What the child has learnt appears to be the result of an inductive process—the extraction of relations from information presented to him in adult speech.

The third essential in learning speech is meaning. How do words come to have meaning for the child? By associating a word with a referent, like the word "kitty" with the animal referred to? This is the answer that used to be given, but it seems unlikely. Meaning in speech is not conveyed by single words, but always in a relational context. For example, when a child says "kitty all-gone" or "here kitty" he is referring to an event in the world. The meaning of the event has been perfectly clear to him for some time. What he has succeeded in observing is the correspondence between the event itself and what someone said about it while it was occurring. Children begin by making predications about the immediate environment. Again, there seems to be an inductive process involved, an extracting of the relation between the two kinds of information, one in the event itself and the other in the spoken words.

By this brief survey of the development of perception we have tried to show that a child uses his "senses" in an active and adaptive way to extract information that is present in the ongoing flow of events in his environment. He does not use previous knowledge to interpret his sensations, or to supplement them. He could not do so, for he must begin by picking up this knowledge from what goes on around him. The pick-up comes from differentiating the complex, embedded, relational, dynamic structure of the world.

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