VISUAL MOTION PERCEPTION

The eye has no shutter, and yet a moving world does not appear as a blur. The visual system works not like a camera but more like a computer with a program of specific mathematical rules

by Gunnar Johansson

The eye is often compared to the camera, but there is one enormous difference between the two. In all ordinary cameras a shutter "freezes" the image; even in a television camera, which has no shutter, the scanning raster of an electron beam serves the same purpose. In all animals, however, the eye operates without a shutter. Why, then, is the world we see through our eyes not a complete blur? As we walk down a street the buildings we pass seem quite stationary. We do not perceive them as the bundles of streaks they optically create on our retina. Other pedestrians and moving vehicles all seem to be traveling through the same static visual space with sharp outlines, even though they are moving in various directions and with quite different velocities. Whether we are standing still or moving through space the eye effortlessly sorts moving objects from stationary ones and transforms the optical flow into a perfectly structured world of objects, all without the benefit of a shutter. How is this remarkable feat accomplished?

From the evolutionary point of view the feat was clearly necessary for survival. The eye has evolved to function essentially as a motion-detecting system. The concept of a motionless animal in a totally static environment has hardly any biological significance; the perception of physical motion is of decisive importance. In many lower animals the efficient perception of moving objects seems to be the most essential visual function. A frog or a chameleon, for example, can perceive and catch its prey only if the prey is moving. A motionless fly, even within easy reach, goes quite unnoticed.

Evidence for a similar dependence on changes in the visual stimulus pattern can also be demonstrated in man. In experiments where a special device holds an image motionless on the retina the corresponding percept rapidly fades and disappears. Tennis and many other sports testify to man's remarkable ability to visually determine the precise spatiotemporal position of a small fast-moving object.

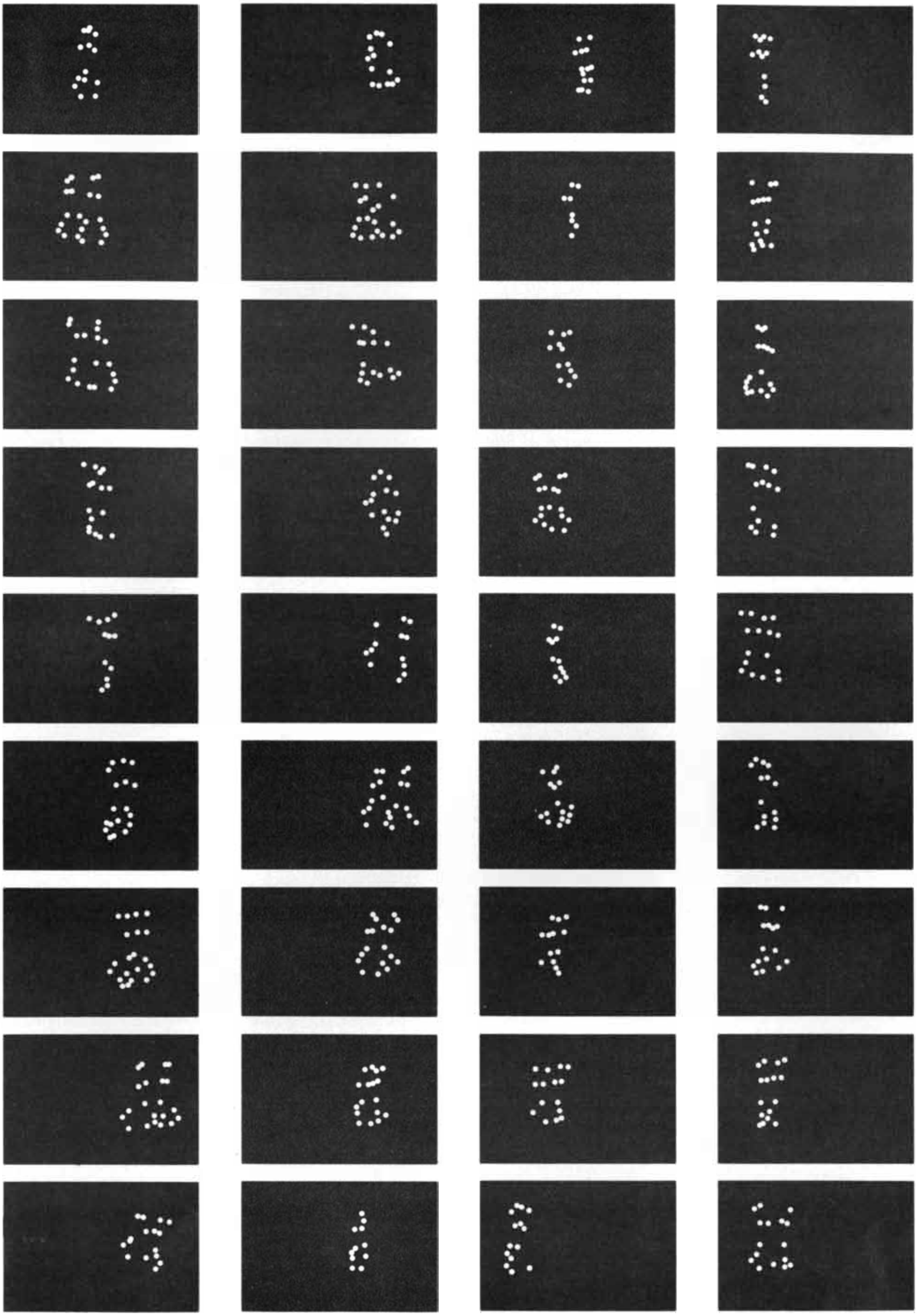
The traditional comparison of the eye and the camera serves the useful didactic purpose of explaining how light rays are focused to produce a two-dimensional image on the surface of the retina. Difficulties arise, however, when the photoreceptors embedded in the retina are likened to a photographic film. Unless one deliberately wants to get a blurred image on the film it must be exposed to the incident light rays for only a brief period, just enough for the photosensitive chemicals in the film to "capture" the image. Although it is true that the retinal receptors have a similar ability to capture photons, their real function is not to capture images but to mediate changes in light flux. The light impinging on the receptors (the rods and the cones) gives rise to a continuous change in the structure of photosensitive molecules. The change in structure releases a flow of ions in the receptor, culminating in a bioelectric signal that travels from the receptor into adjacent nerve cells.

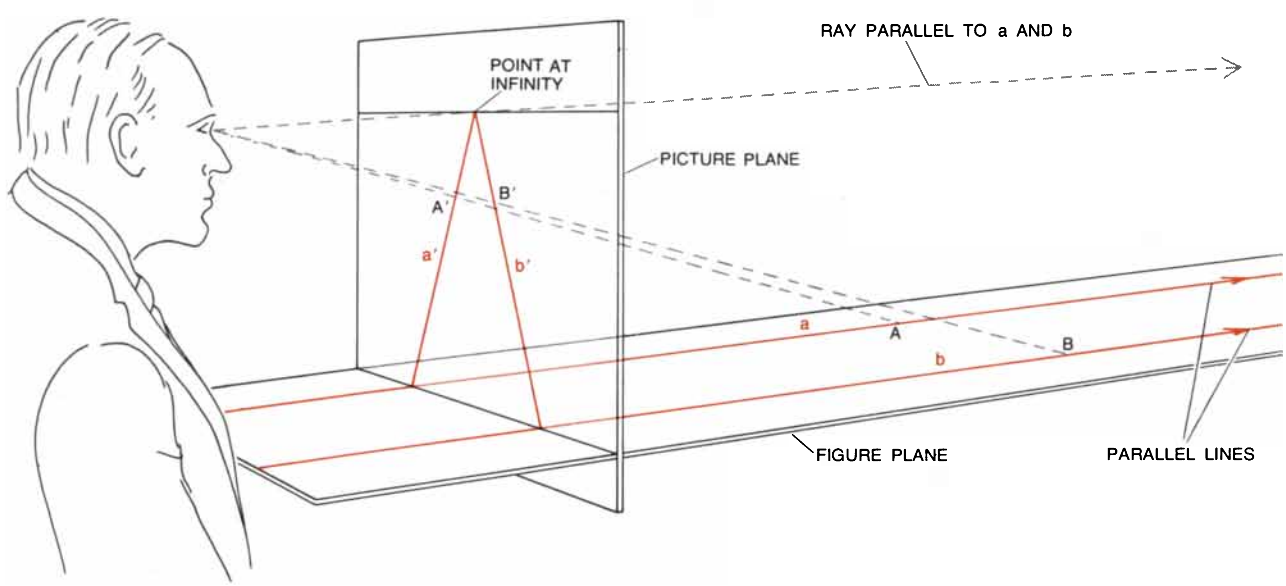
The strength of the signal varies with the light flux. Within a few milliseconds the myriad changes in signal pattern over the entire retina are combined and transformed by an intricate neural network within the retina itself, by other networks at relay stations in the midbrain and finally by the neural networks within a number of receiving terminals in the cerebral cortex. The result at the conscious level is the perception of motion in visual space. Thus the eye is basically an instrument for analyzing changes in light flux over time rather than an instrument for recording static patterns. Roughly speaking, without a change in the light striking the receptor there would be no change in ion flow and no neural response.

In studies of visual perception it is often important to distinguish between monocular and binocular vision. For the range of phenomena I shall take up here, however, the contribution made by binocular perception can be ignored. In our laboratory at the University of Uppsala my colleagues and I have contrived a variety of experiments to examine how the eye deals with moving visual stimuli. We include under this heading the motion of stationary objects perceived by a moving observer as well as the motion of moving objects perceived by a stationary observer.

As an introduction to our experiments, consider what happens when you use a camera to make a picture of a friend. You look through the viewfinder and customarily take a few steps forward or backward until you have the subject properly framed and the image expand-

TWO FIGURES DANCING IN THE DARK appear on the opposite page in a sequence of 36 motion-picture frames from a film made in the author's laboratory at the University of Uppsala. Each dancer is "outlined" by 12 lights: two each at the shoulders, elbows, wrists, hips, knees and ankles. This sequence, which proceeds in vertical columns starting at upper left, consists of every sixth frame from a portion of the film. Naïve subjects shown the film can tell in a fraction of a second that they are seeing the movements of two people.





IN PERSPECTIVE DRAWING parallel lines converge at a fictitious "vanishing point" located on the viewer's horizon. The diagram shows how points *A* and *B* on parallel lines *a* and *b* are converted into their perspective equivalent on a transparent screen.

ed or contracted to the desired size. As you move toward the subject every optical element in the viewfinder streams radially outward from a central point. Conversely, when you step backward, the image contracts radially toward the center. If you are a careful photographer, you probably also check the effects of moving the camera up and down and from side to side. Such movements generate optical flows considerably more complex than the radial flow produced by moving directly toward the subject. All such changes in the viewfinder, however, follow the laws of central perspective. They are continuous perspective transformations.

The optical flow of images into the viewfinder of a camera (or into the camera itself when the lens is open) corresponds to the optical flow impinging on the retina during locomotion. From the geometrical point of view it does not matter whether it is the camera that is moving or the subject in front of the camera. It would be trivial to say that asking your friend to take a step toward you has the same effect on the size of his image as your moving a step toward him. It is significant, however, that in the first case the image of the surrounding environment remains fixed and in the second the image of the environment expands outward slightly from the optical center. To generalize, when objects move in our field of vision, they give rise to local flow patterns; when we move around in the environment, there is an optical flow across the entire retinal surface.

In everyday perception the optical flow across the retina usually represents a complex combination of patterns generated by the observer's own motion and patterns generated by the motion of moving objects. Even when the observer is simply standing still or sitting, the sway of his body or small movements of his head add a small "locomotion component" to the flow of the retinal images. Movements of the eye itself introduce a further component into the total flow; the movement can be smooth, as when an observer follows the flight of a ball, or jerky, as when your eye follows these words by a number of saccadic eye movements. The summation of all such optical flows over the retina determines the character of the incessant flow of nerve impulses from the retinal receptors. In order to study the visual information supplied by a light-reflecting space we must consider the geometry of the optical flow reaching the retina.

A theory of the perception of visual space was outlined as long ago as 1709 by George Berkeley (later Bishop Berkeley). The theory was further developed by Hermann von Helmholtz in the 19th century and is still familiar today in a modified version known as cue theory. According to this theory, the two-dimensional image on the retina is visually interpreted as being three-dimensional by a number of cues, or signs. The cues are available not only in the image itself but also in the activity of the oculomotor apparatus. The cues include binocular disparity in the images seen by the two eyes, convergence and accommodation of the lens, size of image, interposition of figures, binocular perspective and so on. The theory also invokes visual-motor experience and learning as important supplementary factors.

Berkeley knew only Euclidean geometry (the discovery of other geometries was still in the future), and as a result he began his study of the relation between a stimulus and a percept by analyzing the retinal image as if it could be adequately measured with a ruler and a protractor. Even today many excellent theorists stay within the tradition of measuring optical projections in millimeters and degrees of arc. This approach has given rise to many artificial problems, such as trying to explain how retinal images of different sizes and forms can evoke perception of the same object.

New geometries that have come into existence since Berkeley's day are free of the Euclidean parallel axiom, which leads to the postulate that parallel lines do not meet. One of the geometries that is not fettered by the parallel axiom is projective geometry. That geometry is of special interest for the study of vision because it is the geometry of optical paths through pinholes and lenses and provides the theoretical basis for perspective drawing. It is characterized as being a nonmetric geometry because it deals exclusively with relations rather than particular measurements.

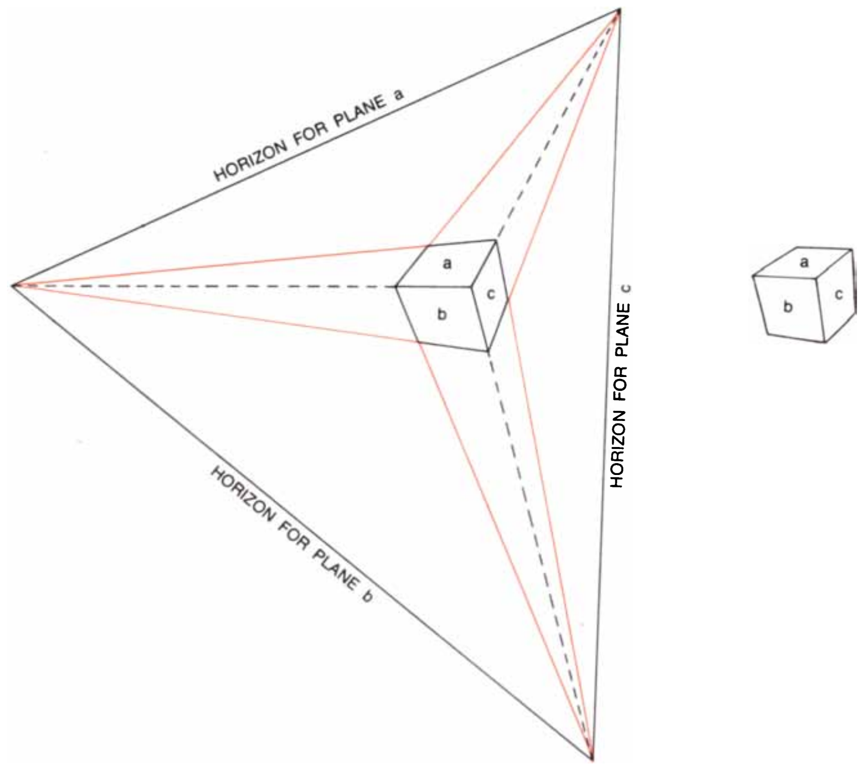
The first comprehensive use of the principles of central perspective in the theoretical analysis of visual space perception was made by J. J. Gibson of Cornell University in his book *The Perception of the Visual World,* published in 1950. Gibson's main thesis is that traditional cue theory is an unnecessary and even misleading construct. According to Gibson, the image itself contains all the information needed for three-dimensional perception, a fact overlooked in cue theory because of its unsophisticated description of the visual stimulus. Mathematical lawfulness in the structural change from point to point in the optical image, involving what Gibson termed "gradients" and "higher-order variables," is the effective stimulus. The gradients and variables are essentially consequences of central projection. Gibson also applied these principles to moving patterns, speaking of stimulus flow rather than stimulus images.

My own thinking closely follows Gibson's. Experimental work over the past two decades has led me to break completely with the Euclidean model and to adopt projective relations as the theoretical foundation for investigations of visual space and motion.

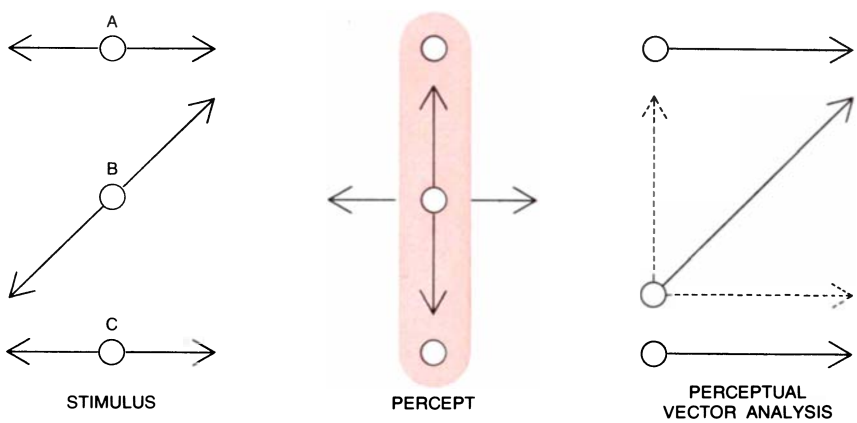
In retrospect it seems strange that it should have been hypothesized, as it was in the classical theory, that organisms searching for spatial information from reflected light developed an eye with a lens and then failed to take advantage of the mathematical laws determining spatial information, available in the trajectories of light through a lens. So strong are the Euclidean and Berkeleyan traditions, however, that a direct experimental approach is needed in order to gain acceptance for a model based on central projection.

The reader may ask how a geometry lacking a fixed metric can be of any use for transferring information about the rigid three-dimensional space that surrounds us, in which the Euclidean metric certainly holds true. The answer is that projective geometry is a geometry dealing with certain relations that remain invariant under perspective transformation. These invariances serve as a counterpart in terms of figural equivalence for the Euclidean figural congruence under the conditions of rigid motion. Mathematicians have also developed a special system of coordinates (homogeneous coordinates) that are determined by distance relations rather than by absolute distances and that make it possible to deal analytically with projective transformations.

For the purposes of the rest of this discussion it is sufficient to say that projective geometry underlies the rules of central perspective [*see illustration on opposite page*]. It is well known that in perspective drawing parallel lines must be pictured as converging at a fictitious "vanishing point." Thus in the perspective system the parallel axiom is abandoned. The angle between the "parallel" lines (actually converging lines) depends on the angle between the figure plane (the surface being pictured) and the picture plane. Hence we know that a rectangular tabletop in a drawing or in a photograph will be trapezoidal, a circular table will be elliptical and so on. No matter how the viewing angle or the distance to an object is changed, the object



CUBE REMAINS A CUBE even when it is seen from different angles. Strictly speaking, each face of the two cubes drawn here is a trapezium. The visual system, however, automatically corrects for the distortions and delivers percept of regular solid with square faces.

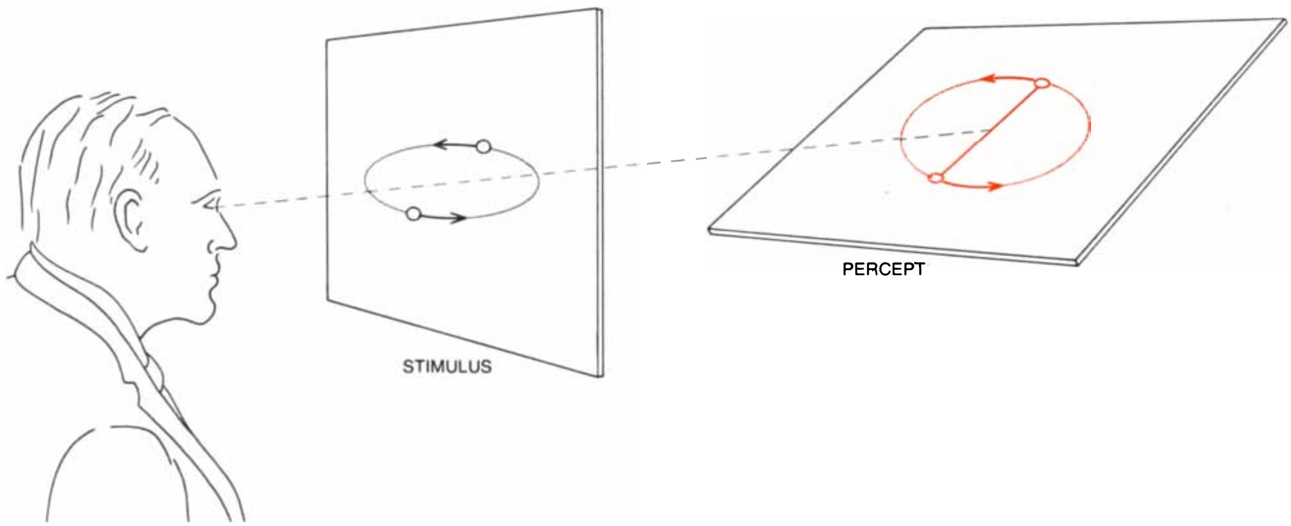


MOVING REFERENCE SYSTEM is formed by three spots of light, *A*, *B* and *C*, traveling along the paths indicated by the arrows at the left. If seen by itself, *B* simply moves back and forth on a slanting path. When the motions of *A* and *C* are added, however, the three spots form a perceptual unit (*middle*), in which the trajectory of *B* no longer seems to slant. Instead *B* seems to oscillate vertically as if bouncing back and forth between *A* and *C*. In this case the motion of *B* divides into two component vectors: one horizontal and equal to the motion of *A* and *C*, and one vertical, representing the motion of *B* relative to *A* and *C*.

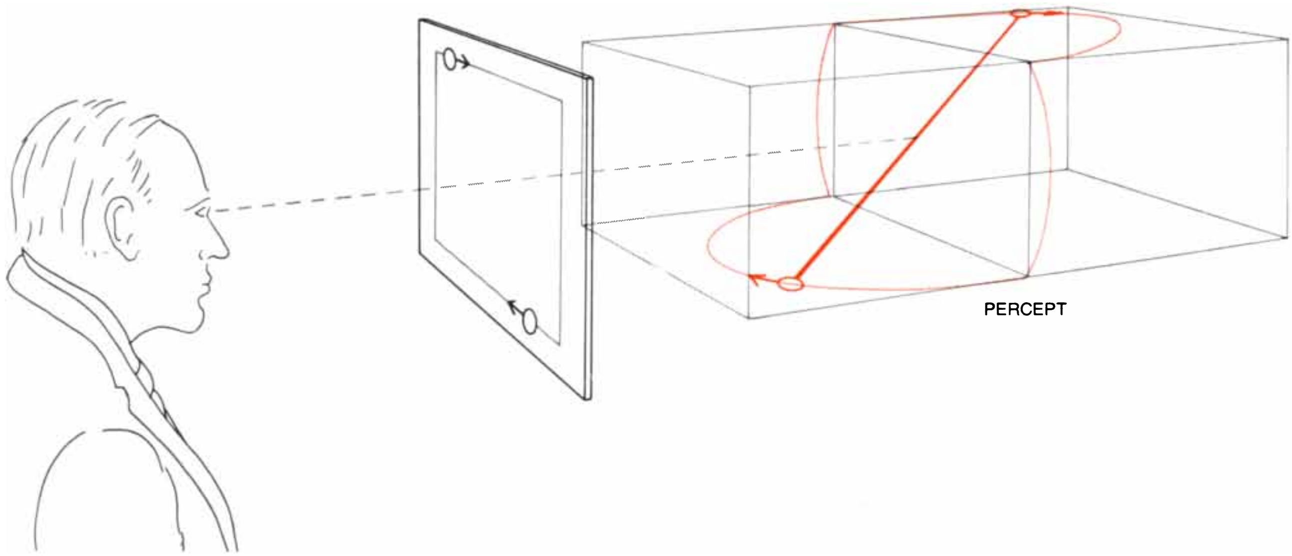
is recognizable as the same object seen at different angles [*see upper illustration on preceding page*]. The forms in the pictures are equivalent because of certain invariant relations, although from a Euclidean point of view they are all different.

From recent studies of motion perception in which continuous figural changes of this type are presented without three-dimensional depth cues we have overwhelming evidence that the visual system spontaneously abstracts relational invariances in the optical flow and constructs percepts of rigid objects moving in three-dimensional space. Indeed, it has been found that continuous perspective transformations always evoke the perception of moving objects with a constant size and shape. This means that the particular projection chosen perceptually by the visual system is one that represents Euclidean invariance under the conditions of motion in rigid three-dimensional space.

A basic and well-established conclusion from a large body of experimental research dating back to the 1920's is that the visual system, in its decoding of a total optical flow, tends to extract components of projective invariances in accordance with specific rules. An example from daily life is perhaps the best way to make this rather abstract statement easier to grasp. My little granddaughter runs across the floor of my study, eager to show me a ladybug walking on her finger. The optical flow produced in my eyes by this scene includes the following components: the light reflected from (1) the floor, the walls and the furniture in my study, (2) the child's body, (3) the child's hand and finger reaching toward me and finally (4) the ladybug moving on the child's moving finger. All these components moving relative to my eyes contribute to the complex optical flow, but



IMAGINARY ROTATING ROD is formed when the stimulus consists of two spots of light moving in an elliptical path. Because the visual system "prefers" to perceive the rod as maintaining a constant length, the viewer has the impression that the rod is rotating in a plane that is slanted either toward him or away from him, as is depicted here. The slants approximate those of projected circles.



BIZARRE THREE-DIMENSIONAL FIGURE seems to be traced by an imaginary rod that is created when two spots of light move at constant speed on the opposite sides of a rectangular path. The built-in tendency for the visual system to perceive the moving spots as being connected to each other and forming a rigid structure leads to the perception of a rod that is rotating around a stationary central point in a jerky manner, executing a strange three-dimensional motion the observer quite probably has never seen before.

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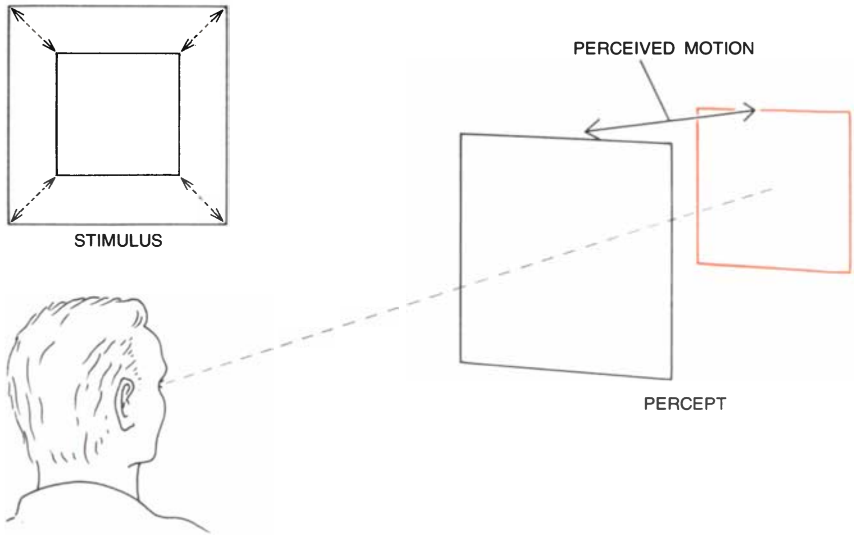
I quite clearly do not perceive them in this way as having a common frame of reference. Perceptually I experience the room as being static, the child as running across the floor, the child's hand and arm as moving relative to her body, the child's finger as moving relative to her hand and the ladybug as moving relative to the child's finger. Thus my visual system abstracts a hierarchical series of moving frames of reference and motions relative to each of them. The perceptual analysis of the optical flow as a hierarchical series of component motions follows closely the principles of ordinary mathematical vector analysis; hence it has been termed perceptual vector analysis. In our laboratory at the University of Uppsala we have devoted much experimental effort to a search for the basic principles underlying this perceptual function.

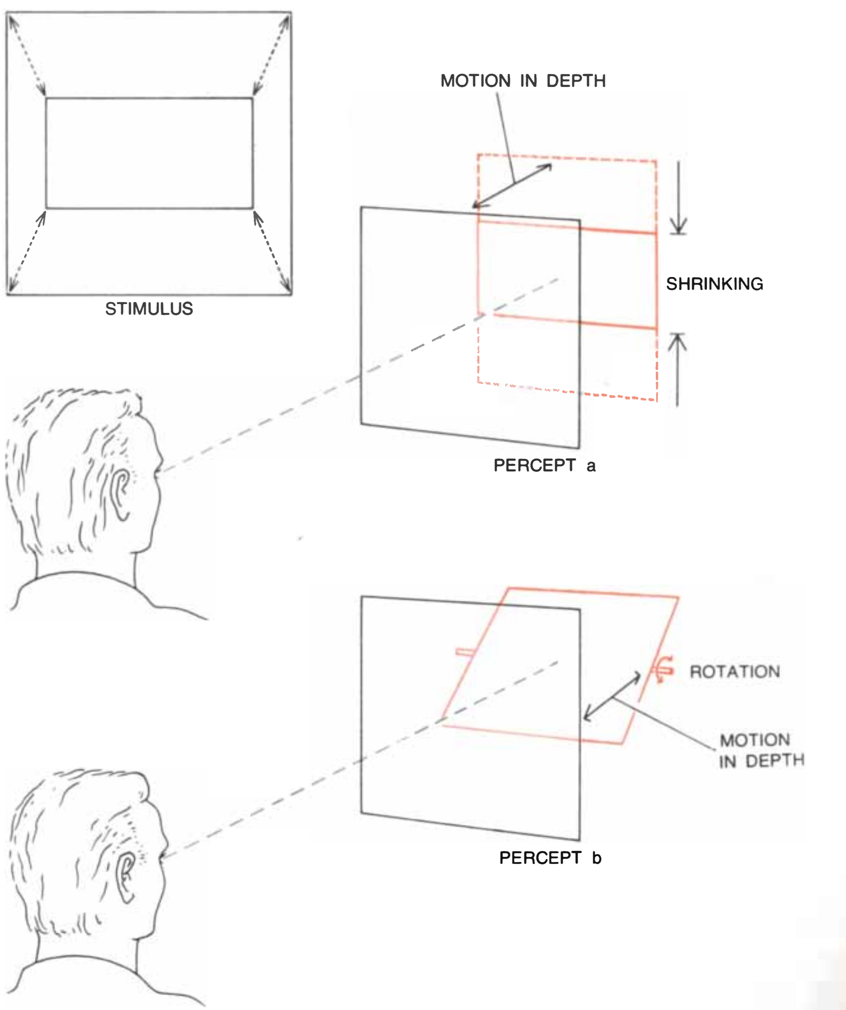
I shall now briefly describe some typical experiments in my laboratory involving perceptual vector analysis and its geometric basis. In most of the experiments the visual stimuli consist of computer-controlled patterns displayed on a televisionlike screen and projected into the eyes of our subjects by means of a collimating device that removes parallax as well as the possibility of seeing the screen.

Some of the fundamentals in the general principle of perceptual relativity are demonstrated in one of my earliest experiments. The stimulus pattern consists simply of three bright spots, *A*, *B*, *C*, one above the other, moving back and forth along straight paths [*see lower illustration on page 79*]. When the top and bottom spots, *A* and *C*, are displayed alone, moving horizontally to the left and to the right, they seem to be rigidly connected. When the middle spot, *B*, is presented alone, it is "correctly" seen as moving in a sloping path. When the three elements are presented simultaneously, however, we get an example of perceptual vector analysis. The entire unit *ABC* seems to be moving horizontally as a unit, but the path of *B* does not appear to be sloping; instead *B* seems to be moving vertically up and down in a straight line. This result can be generalized: Equal vectors or vector components form a perceptual unit that acts as a moving frame of reference in relation to which secondary components seem to move.

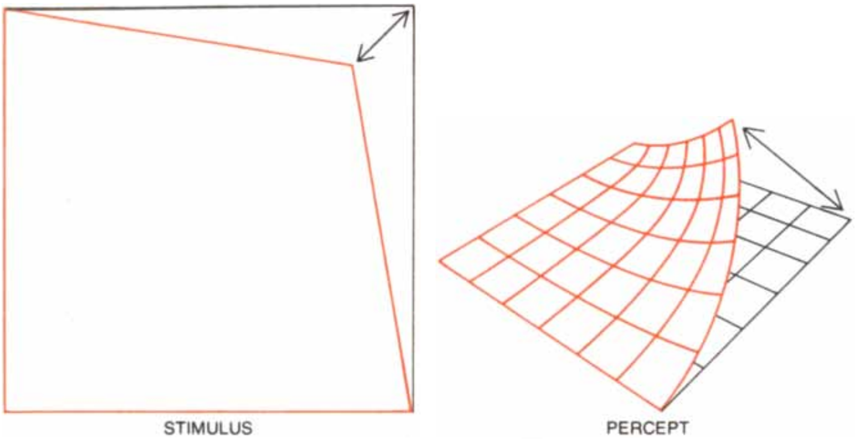
A more recent series of experiments in which a few points trace an ellipse or some other conic section provides other striking insights into the geometry of perception. If we present on our display screen two spots opposite an imaginary



ADVANCING AND RETREATING SQUARE is perceived when the stimulus consists of a square that simply contracts and expands. The visual system interprets change in size as a perspective change produced by a figure of constant size moving back and forth in depth.



ALTERNATIVE VISUAL PERCEPTIONS are evoked if the stimulus square not only contracts and expands but also is simultaneously transformed into a rectangle as it is shrinking. One group of observers sees a figure receding and advancing while it is changing simultaneously from a square into a rectangle and back again (*percept a*). To other observers the square remains a square but one that is oscillating on its horizontal axis (*percept b*).



BENDING MOTION is perceived if one corner of a square figure is moved along a diagonal path. The perception of bending may continue until the moving corner actually touches the opposite corner. A given observer will initially perceive bending as being either toward or away from him, but with some effort he can reverse apparent direction of motion.

center point tracing an ellipse, observers always seem to see a rigid rod of which only the end points are visible [*see upper illustration on page 80*]. Even more surprising, the rod is seen as rotating in a plane that is tilted away from (or toward) the observer. The perceived plane has a slant corresponding roughly to the computed slant of a projected circle. Even though the observer is fully aware that the points on the screen are really tracing an ellipse, he is unable to see the "true" Euclidean pattern; he always sees the ellipse as a circle in perspective. Thus we meet with a convincing indication that the perceptual analysis spontaneously follows the principles of central perspective.

A still more fascinating "illusion" is created by a variation of the experiment in which the two spots of light follow a perfectly rectangular path [*see lower illustration on page 80*]. I must admit I was surprised to find that even in this case the two spots appear to be the lighted ends of a rigid rod rotating around a fixed central point. One might expect that one would simply see two spots (perhaps elastically connected) chasing each other around a rectangular track. Instead an imaginary rod is again seen; its length seems to be constant as the rod describes a curious path in which it rotates for part of the time in a nearly vertical plane and then slants rapidly away from the vertical and back again. So strong is the perceptual tendency toward abstract projective invariance that a highly complex and "unnatural" motion—one that may not have been seen before—is preferred to the simple rectangular track traced by two moving spots. Evidently it is obligatory that the spatial relation between two isolated moving stimuli be perceived as the simplest motion that preserves a rigid connection between the stimuli. The general formula is spatial invariance plus motion.

In a related but slightly different class of experiments the display screen presents the full outline of a simple geometric figure whose shape is systematically altered in a particular way. For example, the observer may be shown a square alternately contracting and expanding [*see top illustration on preceding page*]. What the observer perceives, however, is a square of fixed size alternately receding and approaching. He never perceives the square as a stationary pattern that is changing in size. The result again means that the visual system automatically prefers invariance of figure size, obtained by inferring motion in three-dimensional space.

The next experiment I shall describe is perceived two different ways by different observers. Some observers seem to see it only one way whereas for others the two types of percept alternate. In this presentation the top and bottom of a square alternately shrink and expand as in the preceding experiment while the sides of the square move in and out a smaller distance. Geometrically a large square collapses to form a somewhat smaller rectangle, then expands to its original shape [*see bottom illustration on preceding page*]. All observers have the impression that the figure is alternately advancing and retreating. For one group of observers, however, the figure seems to change during its translatory motion from a square into a rectangle and back again. For a second group of observers the square seems to remain a square at all times, but a square that is rocking back and forth around its horizontal axis as it advances and retreats. Thus we encounter two variants of a vector analysis in the geometric framework of central projection. The first variant is particularly interesting because it represents perception of simultaneous motion and change of shape, such as one might see in a moving cloud or a ring of cigarette smoke.

A final example, taken from a set of experiments that Gunnar Jansson and I have recently published, involves a rather subtle change in the geometry of a square: one corner is made to move slowly toward the center of the square and back again [*see illustration at left*]. The result is interesting because it demonstrates a new type of perceptual invariance. The observer has the illusion that the square is a flexible surface with a corner that is bending toward him. This may seem surprising, but it is just what one would expect if the figural change is interpreted as being a continuous perspective projection.

It is a common characteristic of all the experiments I have described that the observer is evidently not free to choose between a Euclidean interpretation of the changing geometry of the figure in the display and a projective interpretation. For example, he cannot persuade himself that what he sees is simply a square growing larger and smaller in the same visual plane; his visual system insists on telling him that he is seeing a square of constant size approaching and receding. Hence he perceives rigid motion in depth, rotation in a specific slant, bending in depth and so on, paired with the highest possible degree of object constancy.

The theory of visual perception I have outlined here is based on studies with artificial and highly simplified stimulus patterns. Such experiments helped to demonstrate that the visual system uses the geometry of central perspective and enabled us to formulate the principles of perceptual vector analysis. It was natural for my colleagues and me to ask ourselves: Is there any way to show experimentally that the principles of perceptual analysis also hold true for the more complex patterns of motions encountered in everyday life? In an attempt to answer this question we began some years ago to study experimentally the complex patterns of motion generated by men and animals, patterns that might be called biological motions.

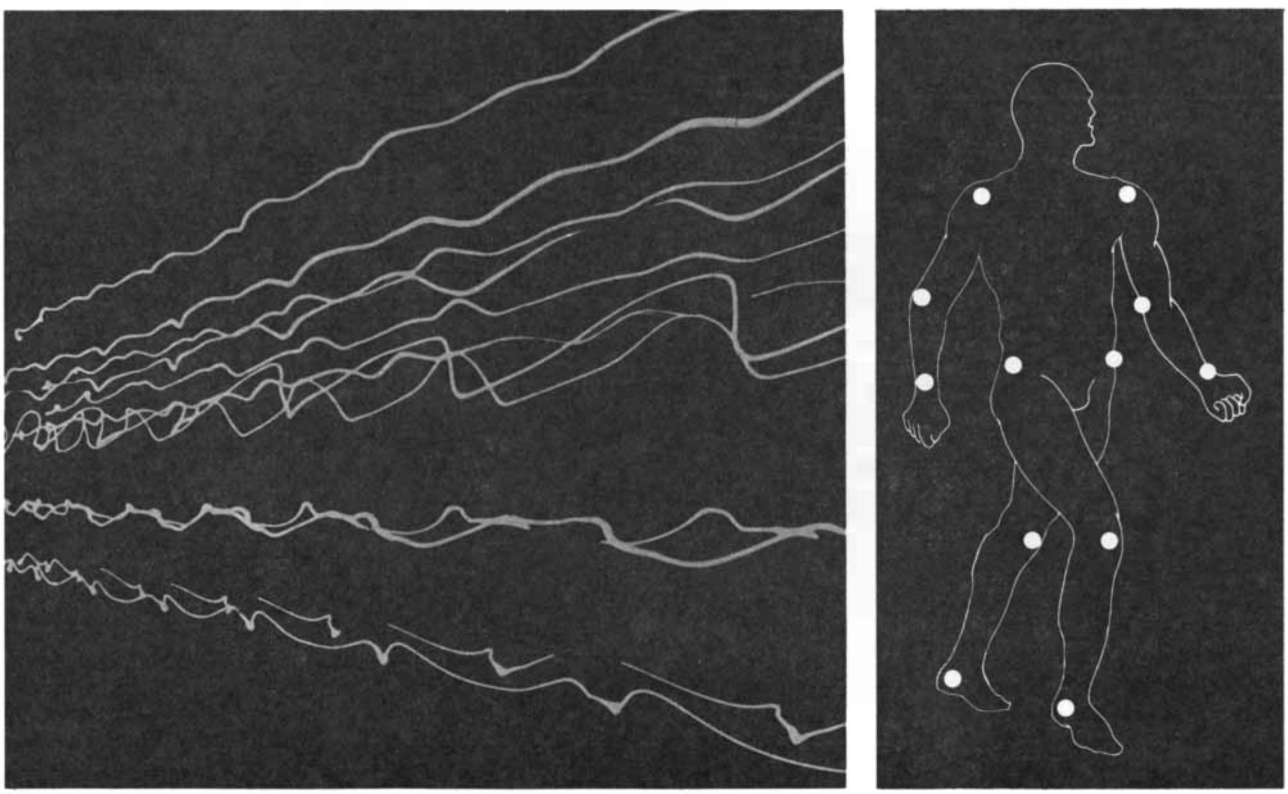
Consider, for example, all the intricate coordinations of frequencies, phase relations, amplitudes and acceleration patterns that are accomplished by one's skeletal structure when one merely walks across the floor. Even in such a simple act scores of articulated bones make precise rotations around dozens of joints.

Our simple early experiments had demonstrated that the moving end points of an otherwise invisible straight line carry enough information to convey the impression of a rigid line moving in three-dimensional space. We therefore hypothesized that if we presented the motions of the joints of a walking person in the form of a number of bright spots of light moving against a dark background, an observer might perceive that the spots represented someone walking. We attached small flashlight bulbs to the shoulders, elbows, wrists, hips, knees and ankles of one of our co-workers and made a motion-picture film of him as he moved around in a darkened room [*see illustration below*].

The results, when the motion picture was shown to naïve observers, exceeded our expectations. During the opening scene, when the actor is sitting motionless in a chair, the observers are mystified because they see only a random collection of lights, not unlike a constellation. As soon as the actor rises and starts moving, however, the observers instantly perceive that the lights are attached to an otherwise invisible human being. They are able not only to differentiate without hesitation between walking and jogging movements but also to recognize small anomalies in the actor's behavior, such as the simulation of a slight limp. In another experiment we filmed two people, similarly festooned with lights, performing a lively folk dance. When the film is projected, anyone can see immediately that the 24 swirling spots of light represent a dancing couple [*see illustration on page 77*].

The surprising ability of the human visual system to perceive a dozen or two dozen moving lights as the motions of people led us to study the minimum exposure time required for the sensory organization of such patterns. The result, recently published by our group, is that a tenth of a second (the time needed to project two motion-picture frames) is often enough to enable a naïve observer to identify a familiar biological motion. This finding, together with results not yet published, has led me to believe that the ability of the visual system to abstract invariant relations from the kind of patterns I have been describing is the product of "hard-wired," or fixed, visual pathways originating at the retina and terminating in the cortex. It is as if the hierarchies of relative invariances in the optical flow were filtered out and established before the visual signals reach the level of consciousness. And contrary to expectation the more complex a projectively coherent pattern is from the mathematical point of view, the more effective the sensory decoding is. (Witness the decipherment of the dancing lights.) Evidently as the degrees of freedom are reduced the stimuli become rich in redundant information.

From our investigations we now know that the component in the optical flow that is a consequence of locomotion generally represents a continuous perspective transformation. Generalizing further from our experiments, we conclude that



LIGHT TRACKS OF WALKING PERSON (*left*) are recorded by making a time exposure in a dark room of a subject fitted with 12 small lights at his principal joints, as is shown at the right. The continuous streaks generated in this way have no obvious interpretation. If, however, the moving-light patterns are recorded on motion-picture film, one can see instantly when the film is projected that it portrays a person walking. Motion-picture frames of two similarly lighted subjects dancing in the dark appear on page 77.

during locomotion the components of the human visual environment are interpreted as rigid structures in relative motion. In this regard the theory and our experiences are in good correspondence; there can be no doubt that we perceive the environment as being rigid.

The term relative motion can imply, however, that either the perceiver or the environment (or both) can be regarded as moving relative to the other. Both experiments and experience indicate that the environment forms the frame of reference for human locomotion. The world is perceived as being stationary and the observer as being in motion. From the point of view of theory we may nonetheless ask: Why is the eye itself not the ultimate reference? Why does one not perceive the ground to be moving instead of oneself? From the point of view of function, the answer is easy: The perceptions supplied by a "stationary" eye would be less informative. But let us ignore function, since we are considering the principles of decoding.

We recognize, of course, that visual information about locomotion does not stand alone; it interacts with signals from other sense organs that report bodily movements: organs in the joints, in the muscles, in the inner ear and so on. It is evident, however, that our consciousness of locomotion requires something more. Experiments have shown that the visual perception of locomotion is able to override conflicting spatial information from those other sensory channels. Thus it seems that the optical flow that covers the retina during locomotion takes precedence over all other sensory information.

The work I have reported, together with comparable studies from many other laboratories, provides the outlines of what one might characterize as a relativistic theory of vision. The central finding is that the geometry of the decoding of visual stimuli is a relational one similar to projective geometry. In accordance with this geometry, series of relative invariances, or perspective transformations, are abstracted from the total optical flow. This results in hierarchical systems of different components that are perceived both in common and in relative perspective transformations. As our experiments make clear, human beings tend to perceive objects as possessing constant Euclidean shapes in rigid motion in a three-dimensional world. In real life these principles of visual analysis taken together give rise to a satisfactorily close correspondence between the physical world and what we perceive that world to be.

Conversation Pieces

Prospecting for Minerals with Mini-Computers

Some of the most valuable photographs of earth from space are not very spectacular to look at. In fact, their most interesting features are often so subtle that they can only be brought out by skillful manipulation of the raw, digital data, from which the pictures are made. After enhancement, a lot of expert interpretation is needed before even speculative decisions can be made. But the results are beginning to interest some very perceptive executives of petroleum and mining companies.

To do this kind of work both quickly and economically, TRW has gradually built up a specially equipped laboratory. It's staffed by people who got their early experience using computers to enhance pictures of the Moon. They now routinely process data from NASA's Landsat spacecraft, which provide synoptic views of earth's surface geology and vegetation.

Data for particular colors can then be computer-enhanced to bring out significant details. Anomalies in rock formations, variations in the overburden, even slight differences in the color of vegetation can indicate the presence of oil-bearing strata or mineral deposits.

Not only does TRW's system use inexpensive mini-computers instead of big, costly machines but certain repetitive functions are completely automated by a TRW system that helps speed the whole process. As Dr. Gary Kang, who runs the lab, points out: "Prospecting by satellite and mini-computer is a lot quicker than doing it with a burro, or even a jeep. From the businessman's point of view, it saves a lot of money, too. You can get synoptic surveys of promising locations and zero in on the best of them. Then, the really promising sites can be explored by drilling teams and evaluated on the basis of actual test cores."

System analysts scrutinize imagery from single pass landsat before enhancing specific area of interest from multi-pass data.

The problem, of course, is to find potentially useful needles of information in the haystacks of recorded data. The first step is to define areas of interest and put the tapes for those areas through a processing system based on mini-computers. Spacecraft position and attitude data are fed in at the same time and the computer is programmed to compensate for distortions caused by spacecraft motion and sensor errors. The result is a set of dimensionally accurate color separations, formatted into a map projection that suits the user's needs.

For more detailed information on this capability, please write on your company letterhead to:

TRW®
SYSTEMS GROUP

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