Stabilized Images on the Retina

When the involuntary movements of an image across the retina are prevented, the image fades and reappears in a manner that provides new information on two major theories of perception

by Roy M. Pritchard

In normal vision the eye is constantly in motion. Small involuntary movements persist even when the eye is "fixed" on a stationary object. As a result the image of the object on the retina of the eye is kept in constant motion. One movement of the eyeball makes the image drift slowly away from the center of the fovea, the region of maximum visual acuity in which the cone receptor cells are most densely concentrated. The drifting motion terminates in a flick that brings the image back toward the center of the fovea. Superimposed on the drift motion is a tremor with frequencies up to 150 cycles per second and an amplitude of about half the diameter of a single cone receptor.

These three involuntary movements of the eyeball, all much smaller than the voluntary movements involved in looking at the visual world or in reading, have been known to physiologists for many years. During the past decade Lorrin A. Riggs of Brown University and R. W. Ditchburn of the University of Reading in England succeeded in measuring them with great accuracy. Though the movements cannot be stopped without incapacitating the subject or endangering the eye, Ditchburn and Riggs found ways to circumvent them and so make an image stand still on the retina. They were thereby able to show that the motion of the image plays a significant role in the sensory function of the eye. When an image is stabilized on the retina by one means or another, it soon fades and disappears. Just how this happens is not yet completely understood.

It was also observed, however, that the stabilized image regenerates after a time and again becomes visible to the subject in whole or in part. The image—or fragments of it—alternately fades and regenerates over prolonged periods of observation. This finding has attracted the attention of psychologists interested in the perceptual aspects of vision, those aspects which involve the functioning of the brain as well as the cells of the retina. At McGill University, D. O. Hebb, Woodburn Heron and I have been investigating the stabilized visual image as a source of data for the formulation of a comprehensive theory of visual perception. We have found that the fragmentation, or the alternate partial fading and partial regeneration, of the image is related to the character and content of the image itself.

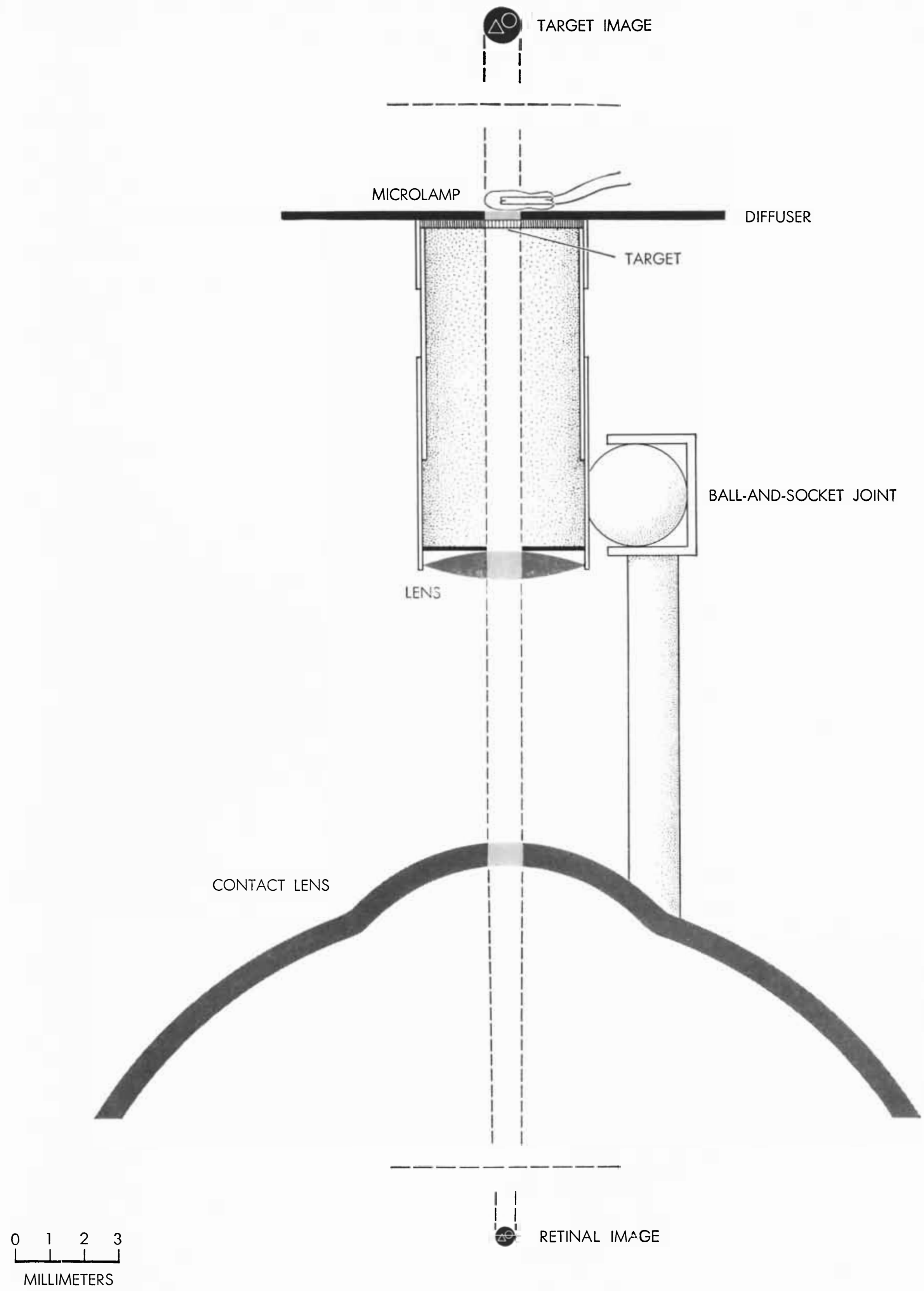
Our evidence supports to some extent the "cell assembly" idea that experience is needed to develop the innate potential of perception: a pattern is perceived through the combination in the brain of separate neural impressions that have been established there and correspond to various learned elements. But the evidence also sustains the Gestalt, or holistic, theory, which holds that perception is innately determined: a pattern is perceived directly as a whole and without synthesis of parts, a product of unlearned capacity to perceive "form," "wholeness" and "organization." It is becoming apparent that the complete explanation of perception must be sought in a resolution of these opposing views.

We stabilize the image by attaching the target to be viewed to the eyeball itself. The device we use for this purpose consists of a tight-fitting contact lens on which is mounted a tiny, self-contained optical projector [*see illustration on opposite page*]. With the subject lying on a couch, the device is set in place on the cornea and focused to project an image on the retina. The experimenter changes the target film from time to time, and he keeps a continuous record of the subject's report of what he sees.

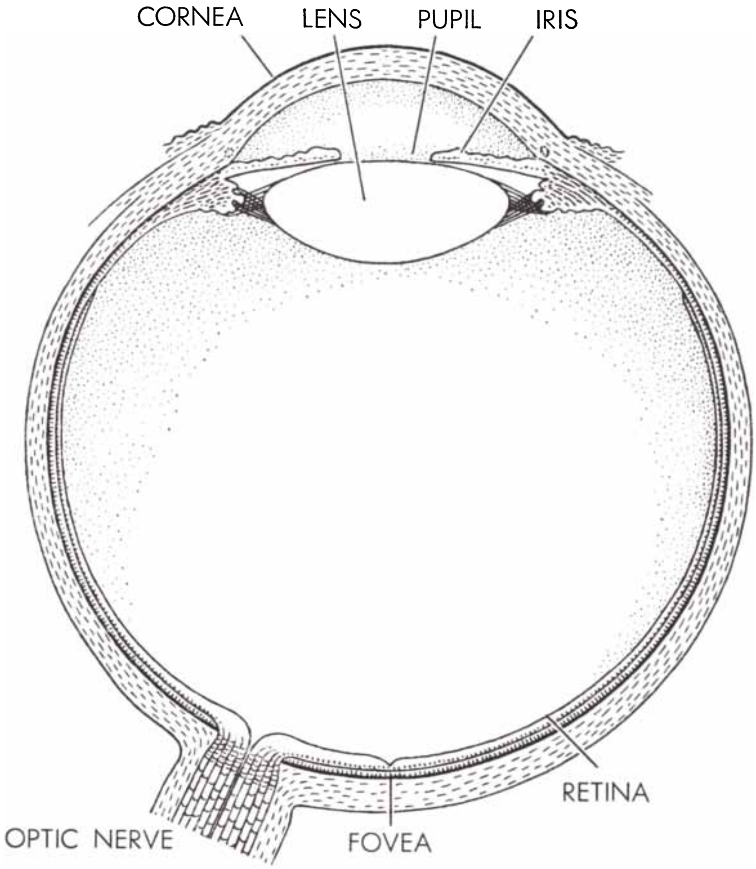
What the subject sees, before fading sets in, is an image located at apparent infinity and subtending a visual angle of two degrees in a patch of light that subtends an angle of five degrees in the surrounding darkness. Provided that the contact lens does not slip on the cornea, the image remains fixed on the retina and does not move with movement of the eyeball.

After a few seconds of viewing, the image disappears progressively and bit by bit, leaving a structureless gray field of light. Later this gray field may darken, and with complete loss of sensation of light the field becomes intensely black. When the image disappears or reappears the uninitiated subject at first rotates his eyes in an effort to bring the image or a center of interest in the image back to the center of the fovea. These movements are, of course, futile because they cannot change the geometrical relationship between the target, the lens of the eye and the retina. Soon the subject learns to view the image passively and discovers that he can still transfer his attention from point to point over the limited visual field.

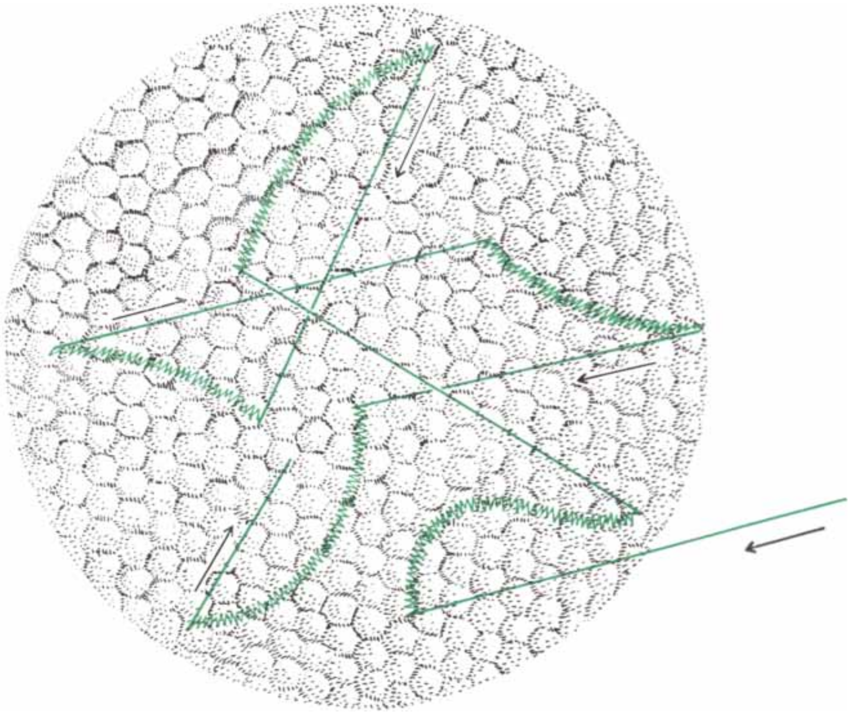
In general we have found that the image of a simple figure, such as a single line, vanishes rapidly and then reappears as a complete image. A more complex target, such as the profile of a face or a pattern of curlicues, may similarly disappear and reappear as a whole; on the other hand, it may vanish in fragments, with one or more of its parts fading independently. We have found in addition that the length of time an image persists is also a function of its complexity. A single line may be visible for only 10 per cent of the aggregate view-



STABILIZED-IMAGE DEVICE is a tiny projector mounted on a contact lens worn by the subject. The contact lens moves with every movement of the eyeball; so, therefore, does the projector, and as a result the target image (*at top of illustration*) is kept fixed at one point on the retina (*as suggested at bottom of illustration*). The convex lens focuses parallel rays of light on the retina, so the target is viewed by the subject as if it were at an infinite distance. The entire optical system weighs only .25 gram.



HUMAN EYE, seen here in horizontal cross section, works much like a camera. Light entering through the pupil is focused by the lens upon the retina's light-sensitive receptor cells, from which impulses travel via the optic nerve to the brain. The fovea, the area of most acute vision, is 1.5 millimeters in diameter and subtends a visual angle of five degrees.



EYE MOVEMENTS that are halted in stabilized vision normally carry an image across the receptors of the retina as shown here. The three movements are a drift (*curved lines*) away from the center of vision, a faster flick (*straight lines*) back toward the center and a high-frequency tremor superimposed on the drift. The magnitude of all these movements is very small; the diameter of the patch of the fovea shown above is only .05 millimeter.

ing time, whereas a more complex figure may remain visible in whole or in part for as much as 80 per cent of the time.

The contrasting manner in which complex images fade and regenerate lends support to the role of learning in perception. For example, the figure of the human profile invariably fades and regenerates in meaningful units. The front of the face, the top of the head, the eye and the ear come and go as recognizable entities, separately and in various combinations. In contrast, on first presentation a meaningless pattern of curlicues is described as extremely "active"; the individual elements fade and regenerate rapidly, and the subject sees almost every configuration that can be derived from the original figure. After prolonged viewing, however, certain combinations of curlicues become dominant and these then disappear and reappear as units. The newly formed groupings persist for longer periods than other combinations, and the figure can no longer be considered unorganized and meaningless.

In the cell-assembly approach to a theory of perception these observations are explained in terms of "perceptual elements," as opposed to purely sensory elements. The "organized," "meaningful" or "recognizable" parts of the image correspond to perceptual elements previously learned or established by experience. The parts of the human profile would thus function as perceptual elements at the outset in the behavior of the stabilized image. Given time for learning, parts of the originally meaningless curlicue pattern become recognizable in turn and operate as perceptual elements. These elements may be excited, it is argued, by the minimum retinal stimulation provided by the stabilized image. To evoke and maintain the image of the entire figure would require the additional information normally supplied by the movement of the image across the retinal receptors.

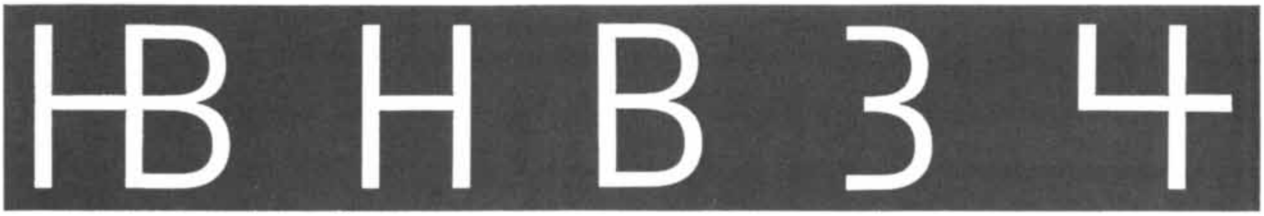
This interpretation gains additional support from what subjects report about the stabilized images of monograms that combine such symbols as the letters *H* and *B*. One or the other letter, or a fragment such as *P*, constitutes the unit that is perceived from one period to the next, with periods of complete fade-out intervening. When entire words are presented, the partial fragmentation of letters can cause different words to be perceived [*see bottom illustration on opposite page*]. In a figure that presents a meaningful symbol such as *B* obscured by hatching lines, the subject sees either the intact *B* or the hatching lines independently. He may also on occasion see the two elements together, but then the *B* appears to float in a plane in front of the one containing the hatching lines. There is nothing haphazard about the fading of such figures, and these effects cannot be attributed to random fluctuation of threshold in various parts of the retina. Even if such fluctuation is thought to occur in the retinal system, the organized or meaningful unit remains visible longer than the unorganized one, in keeping with the presumed importance of learning in visual perception.

But the Gestalt psychologist can argue that it is unnecessary to bring learning and experience into the explanation of these effects. The same effects show up in experiments with meaningless or only semimeaningful figures and can be explained in terms of the Gestalt concept of perception as a process that works by "the whole." If an irregular shape, like that of an amoeba, is obscured by hatching lines, for example, the subject may report the same unitary and separate fading of the amoeba shape and of the hatching lines that he reports in the case of a letter of the alphabet. The two parts of the complete figure may also appear separated in different planes. More commonly in this case, however, parts of both the amoeba shape and the obscuring lines disappear together, and the remaining elements amalgamate to form a new composite figure. The hybrid is a more compact, tidy figure, with fewer disrupting elements.

When the amoeba shape is presented alone, parts of the figure tend to disappear. One or more of the bulges in the figure fade from view, and a line or lines are hallucinated to seal off the gaps produced by their disappearance. The limb or limbs that fade are invariably the grosser or more distorted features of the figure, and their disappearance, together with the closures, produces a "better" or more rounded figure. Any other comparatively irregular or jagged figure similarly appears unstable on first

STABILIZED IMAGES typically fade as in the illustrations on this and the following two pages. The parts of a profile drawing that stay visible are invariably specific features or groups of features, such as the front of the face or the top of the head.

MEANINGLESS CURLICUES first come and go in random sequence. But after a while small groups of curlicues organized in recognizable patterns start to behave as units. This suggests that they have themselves become meaningful perceptual elements.



MONOGRAM formed of the letters *H* and *B* also seems to illustrate the importance of elements that are meaningful because of past experience. When the monogram breaks up it is the recognizable letters and numbers within it that come successively into view.

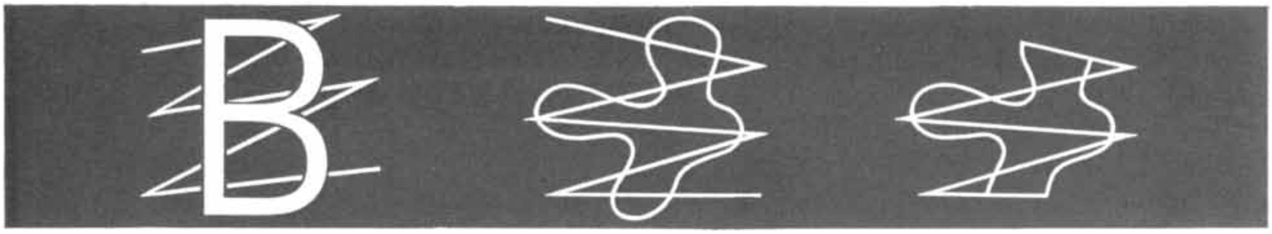
WORDS containing other words behave in much the same manner as the monogram. Here, for example, the subject sees new words made up of letters and parts of letters in the original. He is far less likely to report seeing meaningless groups of letters such as *EER*.

viewing. Its individual elements come and go until the holistic "editing" process reduces it to a more rounded configuration. A smooth, rounded figure, in contrast, appears more stable at the outset and tends to operate more as a whole in the alternate process of fading and regeneration.

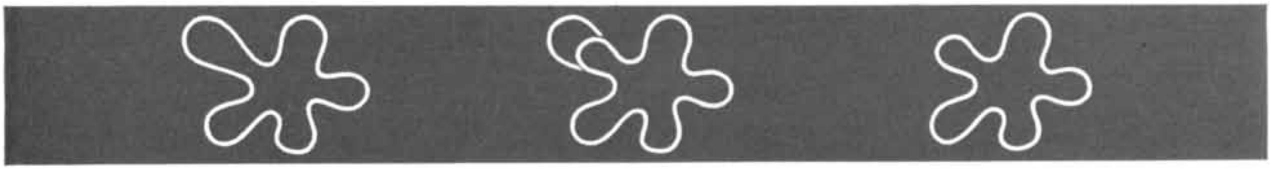
As Gestalt theory would predict, contiguity and similarity strongly determine the functioning of the groups as entities isolated from the total figure. A target consisting of rows of small squares usually fades to leave one whole row—horizontal, diagonal or vertical—visible. Similarly a random collection of dots will fade to leave only those dots which lie approximately in a line, and it is the disappearance of the remainder that reveals this linear association. At the same time it must be emphasized that the original figure as well as each configuration that can be derived from it may function as a single unit, disappearing and reappearing as a whole.

Our experiments with stabilized images have thus produced evidence to sustain both of the major theoretical approaches to visual perception, which have for so long been considered mutually exclusive. It may be, however, that the two concepts are really complementary. As in the historic clash of the wave and the particle concepts in physics, the apparent opposition may arise solely from a difference in approach to the same problem. We have performed a number of experiments that conform equally well to both interpretations. This supports our expectation that a modern theory of perception will eventually result from a mating of the two systems.

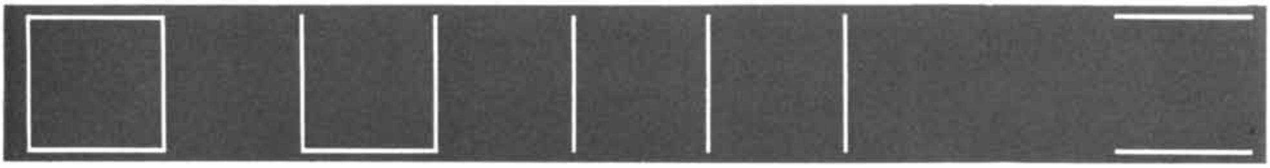
In experiments with simple straight-line figures the cell-assembly approach is supported by the observation that the line is the apparent unit of perception just as the line is the unit of structure in the figure. It is always the whole line that fades or reappears, independently or in association with others, and the breaking, when fading occurs, is always at the intersection of lines. In fact, the overwhelmingly independent action of



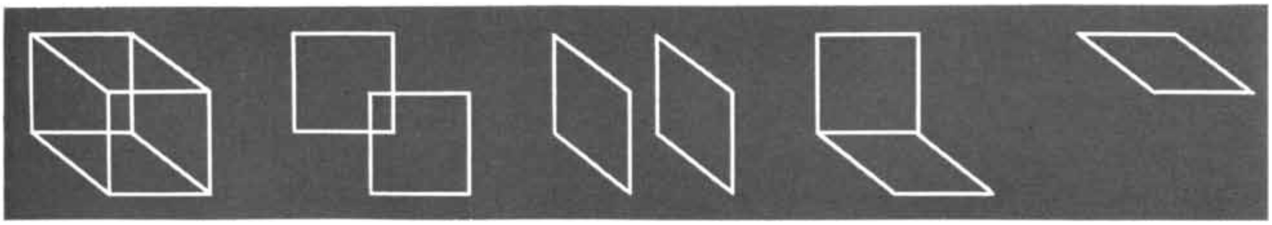
OBSCURING LINES drawn over a figure act in various ways. In the case of the *B*, the lines often drop into a plane behind the meaningful letter. But lines over a less meaningful amoeba shape usually combine with the amoeba to form a more compact figure.



AMOEBA SHAPE standing alone usually fades by losing one or more bulges. What fades, as in this case, is always the most distorted feature, and it is replaced by a new closure "ghosted" by the subject and tending to form a more symmetrical and rounded figure.



LINES act independently in stabilized vision, with breakage in the fading figure always at an intersection of lines. Adjacent or parallel lines may operate as units. This independent action of lines tends to support the cell-assembly theory of perception.



PLANES operate as units in three-dimensional figures. In this Necker cube (which gives an illusion of reversing in stabilized as well as in normal vision) a line may act alone. But usually lines defining a plane operate together, leaving parallel planes.

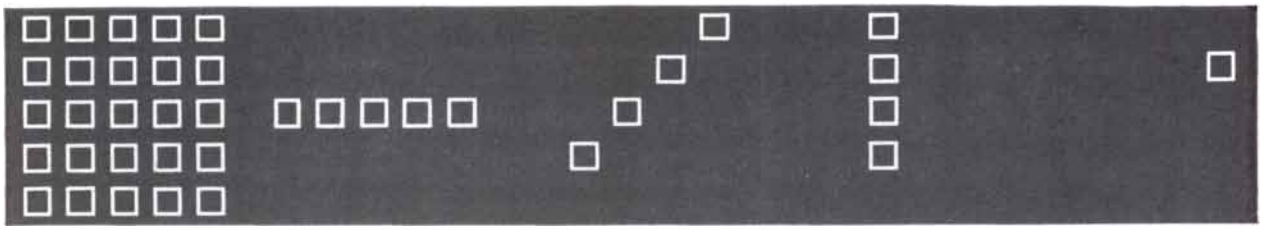
lines makes inevitable the inclusion of some cell-assembly concepts in any complete theory of perception.

In a figure composed of a circle and a triangle, either the circle or the triangle may fade to leave the other visible. One could take this independent action of meaningful figures as evidence for the role of learning in perception. On the other hand, the Gestalt psychologist can just as readily explain the unitary action of the circle or triangle as evidence of the behavior of wholes.

But the fading process may also dissect the figure in other ways—for example, it may leave only one side of the triangle and the segment of the circle closest or most nearly parallel to it in view. Gestalt theory explains this report by the so-called field effect. The minimal sensory stimulus provided by the stabilized image is said to excite a perceptual response that goes well beyond the region of actual stimulation. In straight-line figures, furthermore, there is a tendency for noncontiguous parallel lines to operate together, and lines of the Necker cube [*see bottom illustration on preceding page*] usually vanish to leave parallel planes visible in space, with one of the planes in advance of the other. These observations can also be advanced as evidence of a field effect.

Most figures are seen as three-dimensional when viewed as a stabilized image. Most line drawings appear at some stage as "wires" suspended in space. The small squares in a repetitive pattern are perceived as protrusions or depressions. And a simple hexagon has been reported to be the outline of a cube in three dimensions that "reverses" in the same manner as the Necker cube.

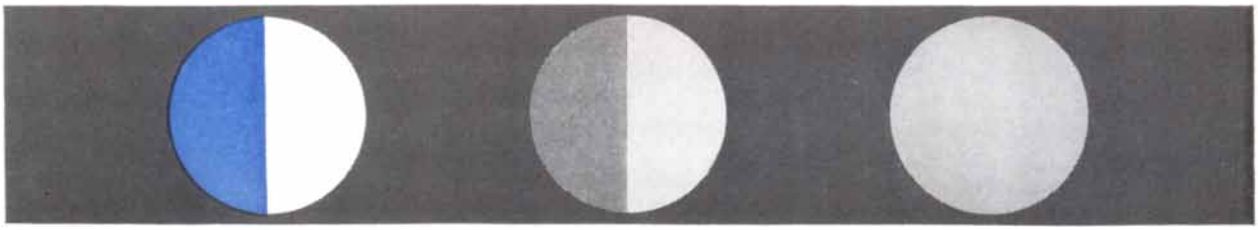
In the case of figures drawn in solid tones as distinguished from those drawn in outline, the behavior of the stabilized image seems more consistent with cell-assembly theory. The corner now replaces the line as the unit of independent action. A solid square will fade from its center, and the fading will obliterate first one and then another corner, leaving the remaining corners sharply outlined and isolated in space. Regeneration



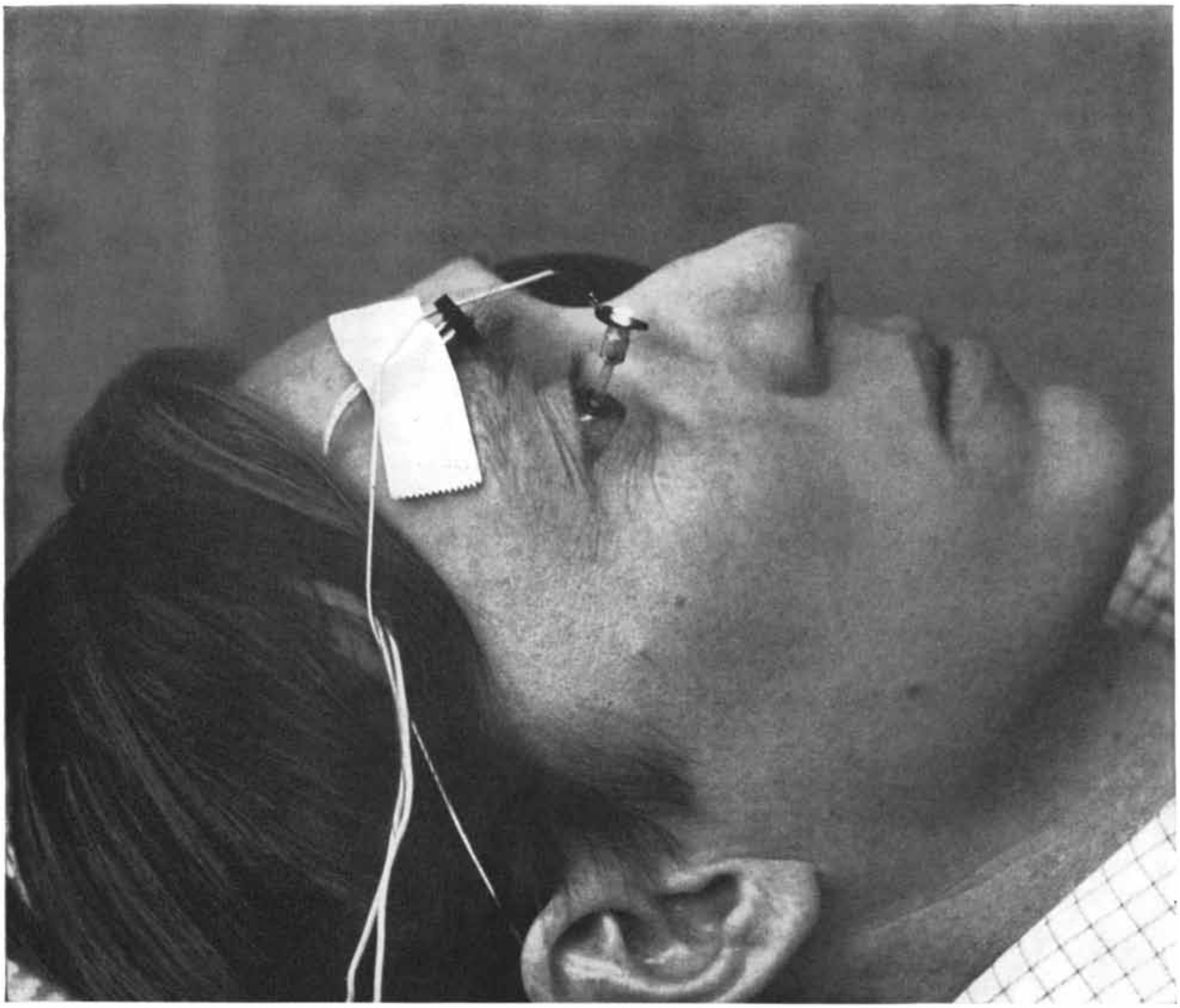
LINEAR ORGANIZATION is emphasized by the fading of this target composed of rows of squares. The figure usually fades to leave one whole row visible: horizontal, diagonal or vertical. In some cases a three-dimensional "waffle" effect is also noted.

CIRCLE AND TRIANGLE may fade as units, leaving one or the other in view. When there is partial fading, a side of the triangle may remain in view along with a parallel segment of the circle, suggesting the "field effect" postulated in Gestalt visual theory.

CORNERS are the basic units when solid-tone figures are used. The fading starts in the center and the sharply defined corners disappear one by one. This target, like the others in the series, was presented to subjects both in white-on-black and black-on-white.



SENSE OF COLOR is lost with particular speed. A two-color field like this fades almost immediately when stabilized, to leave two values of gray; then the brightness difference disappears. The stabilized technique promises to be useful for studying color vision.



TAKING TURN AS SUBJECT in a stabilized-vision experiment, the author wears on his right eye a contact lens on which the projector is mounted. The other eye is occluded by a patch. Wires lead from the small projector lamp to a battery through a connecting jack taped to his forehead. The experimenter inserts a target film under the diffuser. At first the image is clear to the subject, but it soon fades and then regenerates. The subject makes a continuous report of what he sees, and the experimenter records his comments.

correspondingly begins with the reappearance of first one and then another corner, yielding a complete or partial figure with the corners again sharply outlined.

The basic concepts of Gestalt theory receive strong support in our experiments from the observed importance of field effects, from the dominance of "good" figures and from the action of whole figures and of groups of design elements as perceptual entities. But it is the independent action of the parts and not the whole of a figure that is paramount in stabilized vision. This observation agrees with cell-assembly theory and the perceptual elements it postulates. On the other hand, the perceptual elements themselves appear as organized entities and so conform to Gestalt concepts. Perhaps the Gestalt perception-by-the-whole theory can best be used in interpreting perception in a broad sense, while the cell-assembly idea of perception by parts may turn out to be most useful for analysis of perception in detail.

Meanwhile stabilized images have opened up a promising approach to another significant problem in the field of perception: color vision. Color disappears quickly in the stabilized image of a colored figure. In a field composed of the three primary colors, the red, green and blue hues disappear to leave a colorless field of three different brightnesses. These brightness differences also disappear with time, but it is the color that goes first. This supports the suggestion that the hue of a color is produced by radiation of a given wavelength on the retina and that the perception of hue is maintained by continuous changes in the luminosity of the radiation falling on a receptor cell or cells. Movement of the edges of a patch of color across the retina, produced by normal eye movements, would therefore be necessary for continuous perception of color. We are now making an investigation of the amplitude, frequency and form of movement necessary to sustain or regenerate a particular color.

20,000 GOOD CHARACTERS PER SECOND

EACH CHARACTER ON THIS PAGE WAS DRAWN INDIVIDUALLY IN ITS PROPER PLACE BY A BEAM OF ELECTRONS AND PHOTOGRAPHED IN 50 MICROSECONDS. A MAGNETIC TAPE GAVE THE COMMANDS. THE BEAM WAS TAUGHT HOW TO DRAW BY A PHOTOGRAPHIC DEVICE. FOR NEAT COLUMN EDGES THE COPYWRITER WAS TOLD TO EXPRESS WHATEVER NEEDED TO BE EXPRESSED IN LINES OF EXACTLY 47 CHARACTERS AND SPACES. A MERE TOUR DE FORCE, OF COURSE, BUT IT SERVES AS AN INTRODUCTION TO THE DACOM SYSTEM OF GETTING ALONG IN AN AGE THAT WANTS TO DANCE TO THE TUNE OF THE COMPUTING MACHINE.

WITH THE DACOM SYSTEM WE PUT THE TUNE INTO A BETTER TEMPO FOR HUMANS TO DANCE TO. COMPUTERS PLAY INHUMAN LYRICS TOO FAST. AMONG THE TRANSLATING DEVICES NOW AVAILABLE, A FEW OFFER PROSPECT OF ADEQUATE SPEED. BUT SPEED ALONE IS NOT THE WHOLE PROBLEM. THERE ALSO ARISES THE PROBLEM OF COPING WITH ALL THE PAPER GENERATED FROM THE TRANSLATING DEVICE.

THE DACOM SYSTEM HOLDS OFF ON THE GENERATING OF PAPER AT THIS STAGE. THE OUTPUT OF THE COMPUTER GOES DIRECTLY ON MICROFILM. MICROFILM IS THE PERFECT MEDIUM FOR MASSIVE DETAIL. WE SUGGEST THAT PAPER NEED COME IN ONLY AT THE END OF THE LINE, WHEN A HUMAN DECISION-MAKER CAN REACH A DECISION AFTER LOOKING AT A FEW SHEETS OF IT.

THIS IS THE HEART OF THE MICROFILM APPROACH. NOW DACOM MICROFILM BRIDGES THE GAP BETWEEN THE CAPABILITIES OF THE ELECTRONIC COMPUTER AND THE VIRTUES OF THE OLD BOOKKEEPER ON THE HIGH STOOL WITH GREEN EYESHADE AND BEAUTIFUL PENMANSHIP.

WE HOPE YOU AGREE THAT THE DACOM PENMANSHIP, AS YOU READ IT HERE MAGNIFIED FROM A TINY FRAME OF 16MM MICROFILM, IS OF A QUALITY THAT EVEN AN EXTRAORDINARILY CONSERVATIVE FISCAL INSTITUTION MIGHT UNHESITATINGLY USE IN COMMUNICATIONS WITH IMPORTANT CLIENTS. SHOULD THE CLIENT DESIRE TO SEE MORE THAN THE SUMMARY OF HIS POSITION, SUPPORTING DETAILS IN THEIR FULL COMPLEXITY CAN BE PRESENTED FOR HIS INSPECTION SIMILARLY ENLARGED FROM THE MICROFILM RECORD.

OUR SUBSIDIARY, RECORDAK, HAS WORKED OUT ALL MANNER OF SCHEMES FOR ALL SORTS OF ENTERPRISES, WITH OR WITHOUT ELECTRONIC COMPUTERS, TO PERMIT SUPPORTING DATA TO BE KEPT ON MICROFILM INSTEAD OF CLUTTERING UP THE CHANNELS OF COMMUNICATION. TO THE RECORDAK ARMAMENTARIUM IS NOW ADDED THIS NEW TOOL. WITH THE COMPUTERS RAPIDLY EXTENDING THEIR SWAY OVER THE BUSINESS WORLD, OFFICE WORK MORE AND MORE WILL CONSIST OF LOOKING UP INFORMATION FROM QUICK-ACCESS MICROFILM READERS SUCH AS RECORDAK ALREADY MARKETS. FOR EFFICIENCY IT BEATS PAPER-SHUFFLING.

THE PRESENT DACOM SYSTEM UTTERS ONLY ENGLISH LETTERS--NO FOREIGN ACCENT MARKS AS YET--, ARABIC NUMERALS, AND # @ / , % - $ * & ★ . PLUS ¤, A CUTE LITTLE CHARACTER OF UNSPECIFIED SIGNIFICANCE. THE NEXT GENERATION OF DACOM EQUIPMENT. AS THEY SAY IN THE MISSILE TRADE-- WILL BE ABLE TO PLOT POINTS FROM TAPED DATA, 2500 POINTS PER SECOND, VERY CLOSE, VERY LINEAR, QUITE REPEATABLY. TO SAY MORE AT PRESENT HERE WOULD BE PREMATURE.

SHOULD ANY OF THIS APPEAR TO BE PERTINENT TO YOUR INTERESTS, IT CAN BE PURSUED FURTHER WITH RECORDAK, 415 MADISON AVE., NEW YORK 17, N.Y.

THIS IS ANOTHER OF THOSE EASTMAN KODAK COMPANY ADS THAT PROBES FOR A LITTLE REVENUE FROM THOSE ORIENTED TO TECHNICAL PROGRESS. ONLY THE FORM IS SPECIAL HERE AND THE REVENUE IN VIEW NOT SO LITTLE.¤¤

KODAK