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THE PERCEPTION OF MOTION

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THE PERCEPTION OF MOTION

Relativity of motion furnishes the chief clues to the perception of it, yet we ascribe motion to objects as if they had acquired an absolute quality. This way of perceiving plays strange tricks

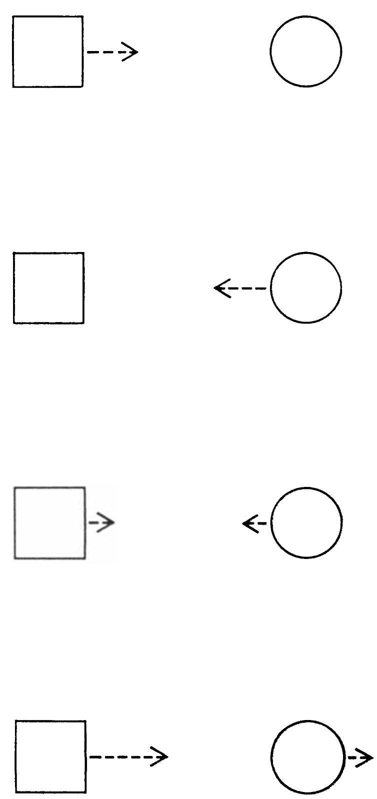
by Hans Wallach

Most of us have had the experience of staring from a waiting train at a train on an adjacent track and sensing momentarily and mistakenly that it was our train that had started to move forward. Alternatively we have idly gazed at a branch reaching upward from a running stream and have seen the branch apparently drift upstream. Or we have looked at the moon through wind-swept, broken clouds, framed in treetops, and have wondered as the moon appeared to sail through the sky against the motion of the clouds.

These are familiar instances of a peculiar aspect of our visual perception of motion. As strictly defined by the physicist, motion is the displacement of one object relative to other objects. But the physicist does not help us to clarify our perception of motion, for he will add that motion is a matter of definition. Which object is displaced and which serves as the frame of reference is an arbitrary choice. Visually perceived, however, motion has no such relative aspect; it is an attribute of the moving object, even if only a temporary one. We say that an object is at rest when this property is absent. Thus, in experience, motion and rest are absolutes, inherent in the object perceived. We
absolute quality of motion especially when we must correct a first impression. Though we can certainly make ourselves aware of the displacement of a moving object in relation to other objects in our field of vision, this awareness is by no means a genuine part of the perceived motion, which remains entirely an affair of the moving object.

It is tempting to ascribe this absolute, nonrelativistic aspect of experienced motion to the manner in which the experience is caused. Is not motion perceived when an object changes its position in relation to the observer, causing the eyes to pursue it? The perception of motion would thus seem to accord with the conditions of stimulation, quite independent of the presence of other objects in the visual field. But matters are not quite so simple. We also experience motion when it is caused by the displacement of one object relative to another. At first glance it might seem impossible to distinguish between these two modes of perception, for the displacement of one object in relation to another must always involve the displacement of at least one object in relation to the observer. The distinction may be proved, however, by experiment. As everyone who has watched the hour hand of a clock knows, motion may be too slow to be perceived; one may notice change of position, but not motion. With a luminous dot in a homogeneous dark field, we can measure the threshold of velocity at which motion is perceived. But if we now light up a second, stationary dot near the moving one, we discover that the threshold is lowered considerably. Motion at a lower velocity will be seen so long as the two dots do not move too far apart. We
distinguish between motion perceived on the basis of an "angular displacement" of an object relative to the observer and of an "object-relative displacement" of one object in relation to another.

This experiment reveals a further interesting fact. When the moving dot moves too slowly to excite perception of motion by virtue of its angular displacement, object-relative displacement will lead the viewer to experience the motion of one dot or of the other or of both in various patterns, as shown in the illustration on this page. The results reported by observers are as varied as the ambiguity of the situation would suggest. We
tion: How do perceived motion and rest in such a situation distribute themselves among the objects that are being displaced relative to one another? The



OBJECT-RELATIVE MOTION may give a viewer perceptions of motion quite different from the objective motion. Relative dis-

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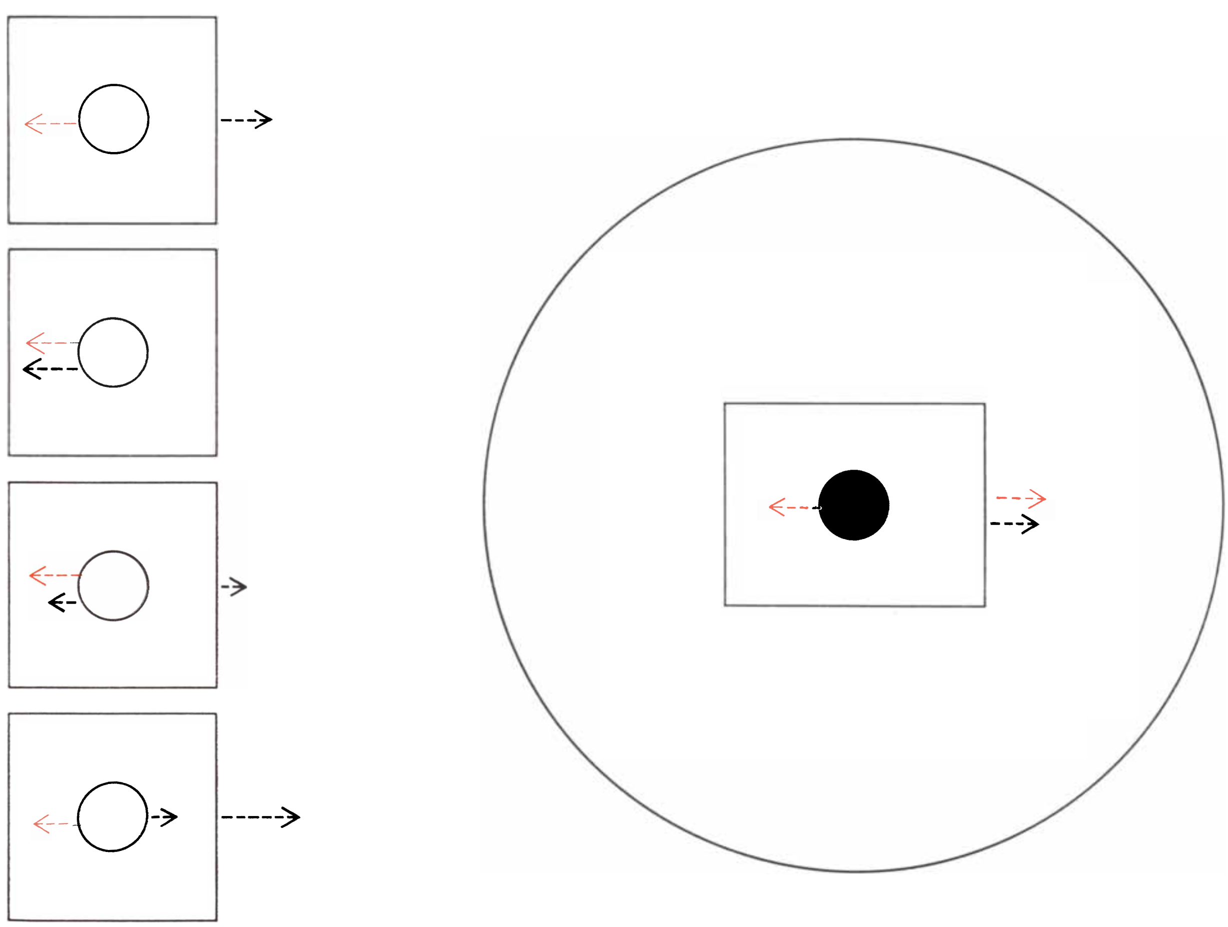
question suggests further experiments which reveal some significant principles that rule the visual assignment of the properties of motion and rest to the objects perceived.

Consider what happens when one of the two objects surrounds the other, the first object in effect forming the background of the second. For example, the viewer is presented with a dot surrounded by a circle. No matter which object is moved by the experimenter, the result is invariably the same: the viewer sees the dot move and sees the circle remain at rest.

This rule is rather strict and pervasive. It even holds under conditions in which it gives rise to experiences that are at variance with the objective situation. For example, the viewer is presented with a dot surrounded by a rectangle which is in turn surrounded by a ring. If the rectangle is now moved, the viewer perceives motion in both the dot and the rectangle and sees the ring remain stationary. The perceived motion of the rectangle is in the direction of its objective motion, while the motion of the dot is in the opposite direction. But this distribution of motion and rest among the objects is quite inappropriate. That the dot appears to move and the ring does not is inconsistent with the fact that there is no objective displacement between the dot and the ring. The nature of this discrepancy is clarified by removing the ring from the picture. Without the ring only the dot is seen to move. The addition of the ring adds the motion of the rectangle to that of the dot, for the rectangle is now a surrounded object. Thus the two motions perceived arise from the two different relative displacements.

The rule that the surrounded object appears to move holds even when the surrounding object is moved at a velocity above the threshold for perception of angular displacement. In the ring, rectangle and dot experiment, the stationary dot still appears to move in the direction opposite that of the objectively moving rectangle. The ring, however, is no longer a necessary part of the situation, because the motion of the rectangle can now be perceived in the absence of the ring. We have here, in fact, the scheme of the illusion of the sailing moon or of the drifting branch. The moon corresponds to the dot, and the clouds represent the rectangle. The trees or rooftops in our line of vision may serve as the ring, but their presence is not essential because the clouds are moving above the angular-displacement threshold. Similarly the objectively stationary branch in the stream is the surrounded object, and leaves or other debris on the sliding surface of the stream are analogous to the moving rectangle.

This illusion is usually called "induced" movement. The term has been in use a long time; it has been commonly assumed that the induced movement is caused merely by the perceived movement in the environment, and that it is always in the opposite direction. But as



placement of the circle and square at left, produced in four different ways, may be experienced as any of the three upper combinations of motion. A surrounded object, as in center panel, takes on uniform perceived motion (*colored arrows*) despite varying combinations of objective motion (*black arrows*). If surrounded object is itself surrounded (*right*), it too acquires perceived motion.

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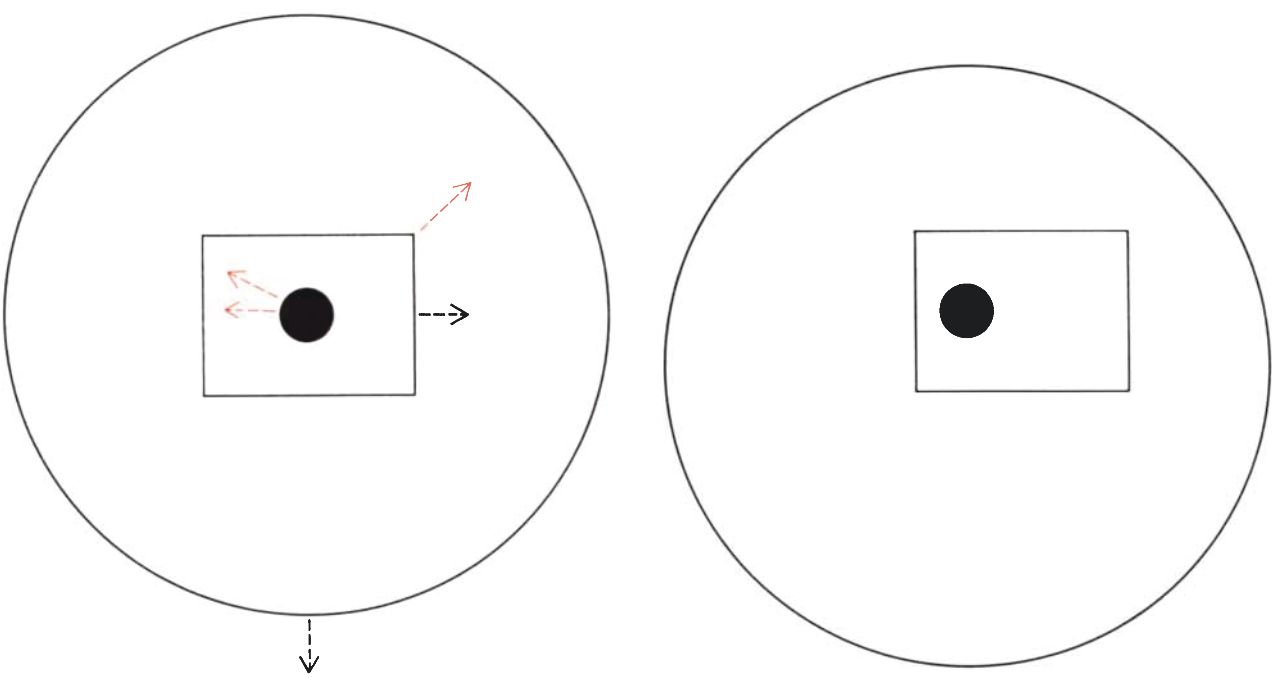
our experiments have already suggested, this simple view of the matter is inadequate. The crucial element in the picture is the relationship of the surrounded object to the surrounding object. We can, in fact, contrive an experiment in which induced movement is not opposite to the perceived movement of the surrounding object. The dot, rectangle and ring again provide the elements of the picture, but this time the ring is moved downward as the rectangle is moved to the right (in each case at a velocity below the threshold for perception of angular displacement). These objective movements produce a displacement of the rectangle upward and to the right in relation to the ring, and a displacement of the dot horizontally leftward in relation to the rectangle [*see illustration below*]. As in the previous experiments, the perceived motions correspond to these relative displacements: the rectangle is seen to move obliquely upward to the right and the dot horizontally to the left. Under certain conditions the leftward motion of the dot may be slightly oblique in the upward direction. But what has become of the induced motion of the dot relative to the perceived motion of the rectangle? In accord with the original notion of induced motion, the dot should move obliquely downward and to the left, since the perceived motion of the rectangle carried it upward and to the right. But the dot is never seen to do so. Its induced motion relative to the rectangle is fundamentally determined by the fact that the rectangle surrounds it. The displacement of the surrounded object relative to its surrounding remains unaffected by the secondary displacement of the surrounding object relative to a third object or to the observer.

Once we recognize the effectiveness of the object-relative condition of stimulation, we find it playing an ascendant role, even in situations that might otherwise seem to be dominated by perception of angular displacement. Consider, for example, our judgment of speed, taking this term to stand for the perceptual counterpart of objectively measured velocity. A crucial discovery was made in 1927 by J. F. Brown, then working at the University of Berlin. He had his subjects, in a darkened room, observe the speed of a small black disk moving up or down in a lighted aperture. They were to match the speed of the disk by adjusting the speed of a smaller disk moving up or down in a lighted aperture half the size of the first. The experiment yielded a result that at the time was quite unexpected. It turned out that, in order to match the speeds of the two disks, the velocity of the disk in the smaller aperture had to be set at a little more than half that of the larger disk. This transposition of velocity in accord with the relative size of the two fields held over a wide range of velocities, from as little as two inches per second to as much as 10 inches per second. It also held over larger contrasts of field size, although the ratio of matching velocities tended to depart from the ratio of field sizes when the difference in size became very large. When the room was fully lighted, however, and common frames of reference became visible to the experimental subjects, the transposition of velocity became a good deal less exact.

We can explain these results quite readily in terms of the object-relative mode of motion perception. With no general frame of reference available, the judgment of speed in this experiment depends upon the size of the field in which it is observed. Speeds in two different fields are seen to be



SURROUNDING OBJECT plays the decisive role in determining what motion is perceived and in allocating perceived motion to various objects in the visual field. Here the ring and rectangle at left are moved (*black arrows*) to new positions (*right*). The perceived motion of the rectangle (*colored arrow*) is the outcome of these two motions. The central spot, objectively motionless, acquires perceived motion in either one of two directions: with reference to the rectangle alone or with reference to the circle as well.

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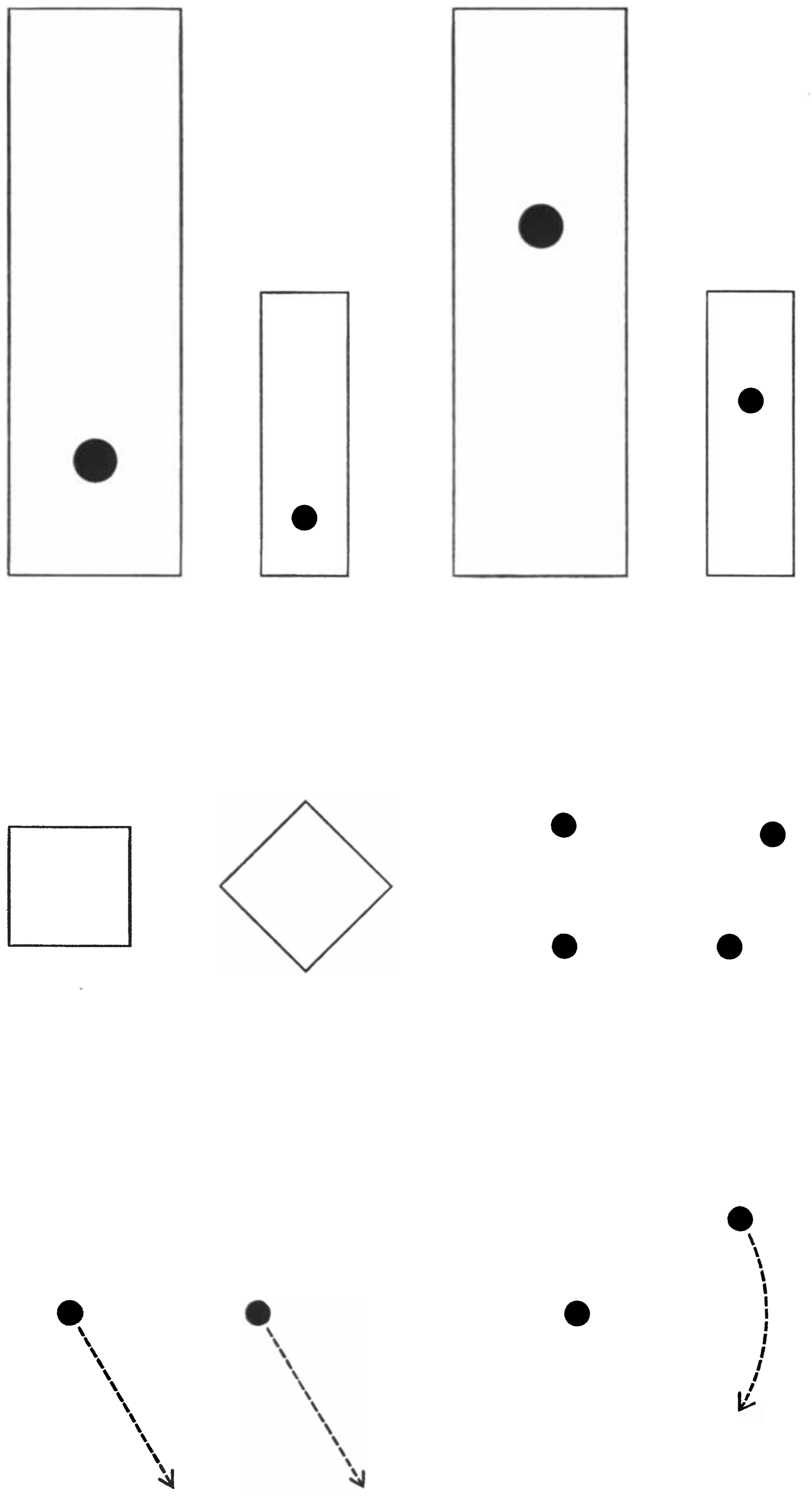
the same when the moving disks traverse equal fractions of the apertures in the same unit time. The transpositions are not, of course, 100 per cent perfect. This is because the perception of angular displacement also plays some role in our estimate of speed. But the close match of velocity ratios with the ratios of aperture sizes indicates the preponderant role of the object-relative mode of motion perception.

The important factor of form enters the discussion at this point; it plays a critical role in perception of object-relative motion. A pattern of visual stimulation may be transformed in a number of ways without changing the form. The most familiar, and the one relevant here, is the transformation of size. Two apertures of different size, each with moving disks at the same relative point, present identical forms to the observer. As the disks move at matched speeds, the two forms go through identical changes.

Whereas a change in size does not affect perceived form, another simple transformation produces surprisingly impressive changes in our perception of form. A pattern may change its form entirely when its orientation to the upright is altered. Turn a square through 45 degrees and it looks so different that it commands a different word in our language. The same is true of such a simple configuration as a pair of dots, because the dots produce, in their perceptual relationship to each other, an impression of direction [*see middle illustrations at right*]. Our perception of motion reflects this quality of form perception. For example, if two dots are moved in the same direction at the same velocity below the threshold for perception of angular displacement, they do not appear to move at all. There being no change in the distance between them, there is no object-relative displacement. On the other hand, if one dot is held stationary and the other is moved around it in a circular path, one or the other or both dots are seen in motion. Although the change in form here does not involve change in distance, it acts exactly like object-relative displacement and produces perceived motion.

Our perceptual dependence upon object-relative displacement and form change accounts for a number of engaging phenomena. Frequently the movement of an object along a given path gives rise to the experience of two simultaneous movements. We produce an impressive experience of this kind if we place a light source on the rim of a wheel



FORM PERCEPTION plays an important role in the perception of motion. At top the motion of the spots in the two similar rectangles appears to be at the same speed because the patterns are identical (*as at right*) at each stage of motion. Rotating a square through 45 degrees makes it into a "diamond." Similarly a change in the position of two dots (*right middle*) conveys quite a different sense of form. If two dots move slowly in the same direction (*bottom left*), no motion is perceived. However, circular motion of one dot (*bottom right*) causes a change of form and excites definite perception of motion (which may involve both dots).

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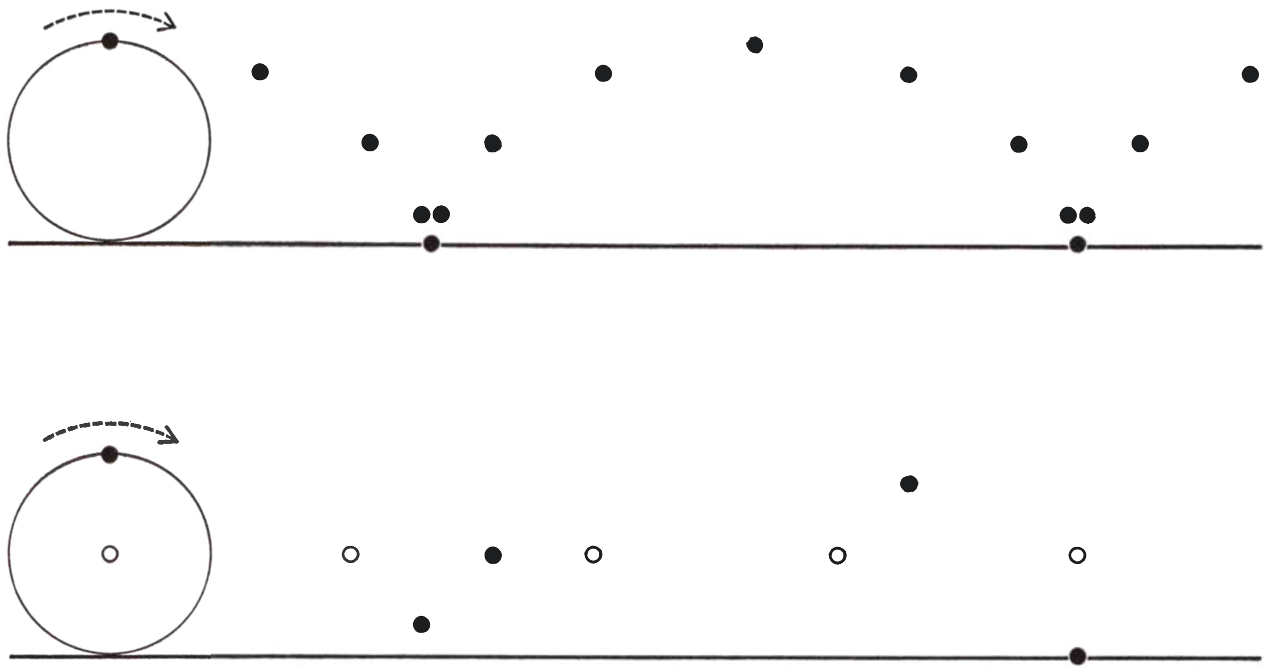
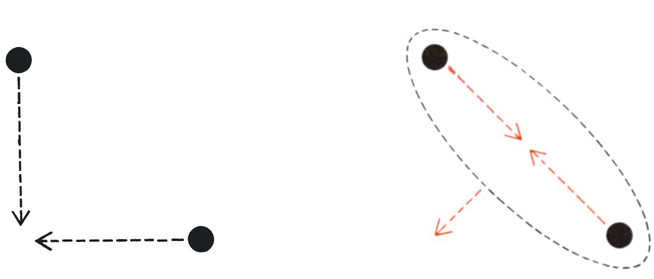


DIFFERENT EXPERIENCES in the observer are caused by the same objective motion of light on the rim of a rolling wheel. At top, the perceived motion (*on a cycloidal curve*) fits the objective motion. However, if the hub is lighted (*bottom*), this perceived motion gives way to a compound motion: the light on the rim now seems to rotate about the hub as the wheel rolls from left to right.

and another at its hub and observe the wheel rolling in the dark. The light on the wheel is seen to move in a circle around the hub and to travel forward along with the light at the hub. If we turn out the light at the hub, both of these motions disappear entirely. The perceived movement of the light at the rim now resembles its objective path, moving along through successive arches of a cycloidal curve [*see illustration at top of this page*].

The experience of two simultaneous movements of a single object can be obtained under even simpler conditions. In an experiment, first performed by Gunnar Johansson, then at the Psychological Institute of the Stockholm Högskola, two round spots are moved along the legs of a right angle toward its apex, and then back to their starting position [*see illustration below*]. Observers invariably see the two spots moving straight toward each other as they travel a slanting path together, and then moving apart as they retrace the same slanting path. Each spot appears to be going through two simultaneous motions. One motion is in the direction of the other spot; the other motion is at right angles to the first and parallel to the slanting path on which the two spots converge. It is as if the true objective motion of the spot were the resultant of the vectors of these two motions. Observers usually find the movement of the spots toward and away from each other to be much the more conspicuous of the two simultaneous motions. About 35 per cent must be prompted before they perceive the second motion and "confirm its presence without hesitation."

To the extent that one's awareness of one's own motion is mediated by visual perception, it may be subject to the vagaries illustrated in these experiments. The illusion of motion experienced when the train on the neighboring track pulls out is an example of induced motion in the perceiver. If the scene that fills the observer's field of vision is in some manner displaced with respect to him, he will feel himself in motion and perceive his environment at rest, even when some large objects in the foreground are not displaced. The visually induced sensation of locomotion seems quite indistinguishable from that which arises from kinesthetic stimuli and on these occasions overwhelms them. This is another instance of our paradoxical tendency to experience motion as an absolute rather than a relative process, even though its perception depends upon relative displacement. In allocating the qualities of motion and of rest to ourselves and to our environment, visual perception follows the rule that keeps the surrounding at rest and bestows motion upon the object surrounded.



COMPOUND MOTION is perceived in two dots which objectively move (*black arrows*) along straight lines at right angles (*left*). To an observer, however, the dots seem to move (*colored arrows*) toward one another and simultaneously to move as a unit obliquely downward. Observers often fail to note the second component of this compound motion.

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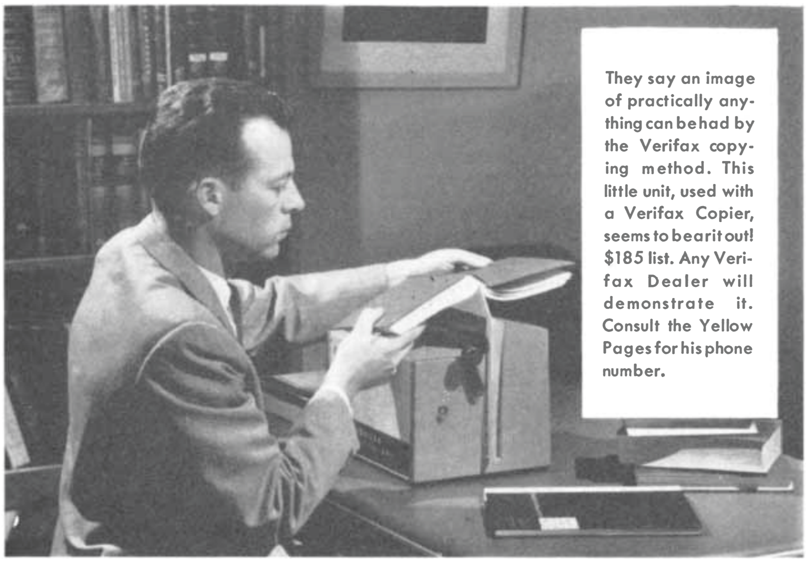

Film to view a planet by

Speaking of fresh approaches to old problems, let's get rid of complex and heavy equipment that an airborne (or better) vehicle on photographic duty must carry to adjust exposures as it moves into different illumination conditions. Let's expose the whole roll of film at the same settings and forget the light level. Let's make the adjustment during processing at the lab, not zipping through the sky.

We now sell a film you can treat that way—*Kodak Plus-X Aerographic Film.**

First thing after it comes back from the ride is to put it through a certain developer for 7 minutes. Inspect. Cut off the part of the roll that shows printable image and put the rest through *Kodak Developer D-19* for 2 more minutes. Inspect. Cut off whatever part of the roll still shows no printable image and put that part back in the *D-19* for another 10 minutes. Whatever you don't have by then, you just don't have. If there are regrets, you can sadly conclude that standard aerial emulsion speed, even with spectral sensitivity extended to 710mμ as it has been in the new *Plus-X*, is inadequate for what you were trying to do.

*Down, boy! You can't have this emulsion yet on 16mm, 35mm, or sheet film. There are honest technical reasons for this, but you have to work in a film factory to appreciate them.

We do have one, *Kodak Tri-X Aerecon Film*, that's quite a lot faster. It doesn't offer as big a definition boost as has been built into *Plus-X*, nor does it tolerate fishing in the developer for the proper effective emulsion speed.

On the contrary, we sort of feel that the brightest prospects for the future of photography to see a planet by lie in films *slower* than the new *Plus-X*. Trading in film speed for film definition strikes us as a good bargain. We suspect that with recent advances in lenses, image movement compensators, and vibration control, the customers don't need as much film speed as they have been used to. We know where we can lay hands on some slow aerial films of astounding definition. The exposure index-by-development technique works very well on them.

In youth you learned to develop paper prints by inspection. This is a different ciple, and the inspection is by infrared. You'll need plenty of advice. Write to Eastman Kodak Company, Government Sales Division, Rochester 4, N. Y., for encouragement.

Acido orotico

Around the turn of the century it was brought to the world's attention that the inhabitants of certain Bulgarian villages were a) living to ripe old ages and b) consuming vast quantities of the ripe old fermentation products of the local dairying. Echoes of this coincidence have rumbled forth at intervals since.

In the twenties a certain elderly biochemist who had seen much importance in the correlation was a celebrated figure of Paris. In the thirties American milk wagons were bedizened with signs advertising a certain brand of fermented milk. In the forties the word "yogurt" entered the vocabulary of the American intelligentsia. With the dawn of the fifties, the Journal of the American Chemical Society (*72*, 2312) reported that certain strains of *Lactobacillus bulgaricus* throve when supplied with 6-carboxyuracil, a substance first synthesized in 1897 for academic exercise and later shown to be identical with orotic acid. This name was derived from οροσ, whey, by two Italians who had encountered the substance while making lactose from milk whey liquors.

The flowering of biochemical sophistication in the mid-fifties has excited a deeper curiosity about orotic acid. To some it looks like a significant intermediate in the process by which living organisms fabricate nucleotides for their DNA—the stuff of genes—out of the amino acids at their disposal. This is big talk.

In Italy interest in *acido orotico* has been rekindled to a small-scale frenzy. At the University of Urbino last June a colloquium on pyrimidines (*Acta Vitaminologica*, *12*, 195-328) devoted much of its attention to the compound. One man claimed his evidence showed that a dietary deficiency of orotic acid affects pregnancy, lactation, and growth in the rat, that it is a vitamin-like factor essential for the survival of the newborn. One senses the closing of a circle.

If we had not been invited to quote on 100 kilos of Orotic Acid *recently, we might not have looked up all this lore. We didn't get the order, but in trying we made enough of it to stock as Eastman 7784 (along with* 2-Thioorotic Acid, *Eastman 7783) for the convenience of biochemical investigators. Anybody who wants to sell it from milk trucks is strictly on his own.*

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