People who live a few miles apart, in neighboring countries (such as France and Germany), often do not understand each other, for though they use the same elements of speech—that is, the same sounds—the combinations of sounds often mean nothing to the listener. Of course, the elements alone—isolated sounds—mean nothing to either speaker or listener. The same is true with written words. As separate elements, W, O, R, D are only nondescript letters, and together they mean word only to someone familiar with English. It is clear that to be familiar with a language one must acquire a huge vocabulary, for each word may mean something different; to know the elements of a new word, or words like it, will not help one to understand the word.

But in any country and in any age since the cave artists, once a man has learned about sketching he can, if he wants, represent things to his neighbors (Chapter 5), his children (Chapter 4), and even some of his pets (Chapter 5). Why is it that mere lines can be so versatile? What are some rules that could explain their usefulness to people from different backgrounds?

Elements of the Visible Environment

Logically, if lines can depict the basic elements that create a visible environment, then lines could have the power to depict anything that was visible. Perhaps every visible object and every scene is made of the combinations and arrangements of a few essential elements. The same essential elements and the same kinds of combinations may occur throughout the world. Can lines depict such elements? If so, the usefulness of line drawings across cultures would be understandable. Such elements would be properties of the environment that influence the light coming to the eye. They would be the elements about which light might provide information. Varying the order or layout of the elements would result in different objects, different landscapes, the entire visible world. And if line depiction is tied to some of the fundamental features of the visible environment, that would help explain why vision research such as Rubin’s inevitably became caught up in problems of depiction.

In one conception, the elements of vision are patches of color, stimulated by light of different wavelengths. This is a traditional and standard conception of vision, but it is not useful for analyzing depiction, because depiction, and outline depiction especially, usually violates the colors of the depicted objects. A black and-white sketch might depict a rainbow among the clouds, over a grassy field. Nowhere in the sketch would the colors of the rainbow be portrayed. To match the colors of the depicted object is a rare achievement in illustrations. It is necessary to find some other conception than color to describe elements of vision.

Another conception of vision could treat each object (or pattern) as an element. In this view, each object is an independent unit, and an arrangement of objects forms a scene—just as a still life is a scene made up of domestic objects, each independent of its neighbors, as well as all being together in one place. Verbal discourse involves fairly independent units—the various words we use. But depictions of two different objects are more alike than are two
different words. We can draw a picture of an unfamiliar object for a friend, and he will recognize the object if it eventually appears. When we simply tell our friend the name for the object, he cannot usually recognize the object when it appears. A picture of an unfamiliar object can tell our friend how many legs the object has, where its arms and neck are, and so on. Presumably, the picture tells our friend about familiar visual elements in a new arrangement. If so, pictures represent parts of objects, not just the whole object.

So, are the basic elements of pictures the parts of objects? Think of pictures of animals; the parts include arms, hooves, necks, ears, and the like. Indeed, these parts make up the animals, as elements of the whole animal. But different kinds of objects are made of different parts: animals are made of hooves, limbs, torsos, and so on; suitcases are made of flaps, handles, locks, and the like; wine glasses are made of brims, stems, etcetera. There is an infinite variety of objects and an infinite variety of kinds of parts of objects. If the parts we have been mentioning were the basic elements in outline pictures, a large vocabulary of parts would be involved in understanding them. Perhaps there are more basic elements than the kinds of parts mentioned so far, some kinds of basic elements that are few in number.

If objects can be analyzed into a few basic elements, perceivers might use a small set of units—a small vocabulary—to understand any and all outline drawings.

Is there a small set of basic elements in the visible world? When the question is put another way, a small set of elements is suggested. Consider: Are there just a few elements that create the optic array at the eye? One such element is a contour, so popular in figure-ground research, where the pigmentation on a surface varies from one area of a surface to an adjoining area. Another is shadowing, where the illumination on a surface varies because an opaque object intervenes between part of the surface and the source of illumination on the surface. Another element is given by variation in the relationship between a smooth surface, the source of illumination, and the location of an observer—yielding highlights. Yet another is provided by variation in the inclination of a surface—some facets of a surface may face the direction of illumination more directly than others and so receive stronger illumination. And still another is created by varying surface texture.

These elements are the main sources of variation in an optic array and are the basic features of the visible environment. Varying the layout of surfaces creates hills and valleys and the shapes of objects. Variation in pigmentation creates the coloring of a landscape and its objects. Variation in the locations and opaqueness and smoothness of objects and the locations of sources of illumination creates shadows and highlights. Variations in the material of objects and the forces they are subject to creates different textures. Optic arrays contain the information for a visible environment, and, in the last analysis, it is variation in surfaces—their layout and composition and their relation to sources of illumination—that create optic arrays.

Variation in surfaces and their relation to sources of illumination provide the basic elements of the visible world. If lines in outline drawings can depict many or all of the sources of an optic array, then the versatility of outline sketches is understandable. The visibility of objects and landscapes, the entire visible world, rests in the main on a few sources of optic structure. If lines can depict each of the main sources of optic structure, then lines can depict almost any visible object or scene. And these would be not simply normal familiar, objects, or familiar parts of objects, but anything that is visible except pure color and uniform surface—for arrangements of color patches on a surface may be outlined, but pure isolated colors or uniform surfaces cannot be.

Can each source of optic structure be depicted in outline drawings? Will an untrained subject be able to understand such outline depictions? Let us consider the elements of the visible world one by one.

Layout of Surfaces

Surfaces are either plane or curved. They can face toward or away from an observer, so a concept of a point of observation must be incorporated into any description of arrangements of visible surfaces.

One plane surface may join another plane surface at an
angle, with both surfaces being visible from a particular point of observation. The two surfaces form a two-sided plane angle, a dihedral angle as it is called in solid geometry. There are two types of dihedral angles. One type is concave to the point of observation, like the corner of a room (Fig. 24). The other type is convex to the point of observation, like the corner of a building (Fig. 25). An abrupt change in the inclination of visible surface occurs across a dihedral angle—a plane through the point of observation and the apex of the dihedral angle meets the two surfaces at sharply different inclinations.

One of two adjoining plane surfaces may not be visible from a point of observation because it is behind the other surface with respect to the point of observation (Fig. 26). The visible surface is the front surface, and it is said to occlude the other surface. A front surface occludes the back surface, and the visible terminations of the front surface are called occluding edges. The distance from the point of observation to sources of optic structure changes abruptly from one side of an occluding edge to the other. On one side of the occluding edge is the front surface and on the other side is background.

A different kind of occlusion occurs with curved surfaces. Instead of two plane surfaces meeting at a dihedral angle, one sur-

![Fig. 24](image1)

**FIGURE 24.** Concave corner.

![Fig. 25](image2)

**FIGURE 25.** Convex corner.

![Fig. 26](image3)

**FIGURE 26.** Occluding edge.

![Fig. 27](image4)

**FIGURE 27.** Occluding bound.

face gradually changes its inclination and joins the back side of the object smoothly, as in a sphere or the brow of a hill (Fig. 27). Again, the back side is occluded by the front surface. The surface layout is convex and rounded, not convex and angular. There is no edge, strictly speaking of a sphere; nevertheless, spheres can occlude. I will call the visible terminations of the front surface of rounded objects occluding bounds. A sphere has no edges, but it has occluding bounds. Any curved surface has occluding bounds when its tangent passes through the point of observation. There is an abrupt change in distance of surfaces from the point of observation on either side of the tangent from a point of observation to an occluding bound.

Beyond occluding surfaces lie backgrounds. A background lies behind an occluding edge or bound and does not make contact with the occluding surface. Occluding surfaces occlude not only their back surface but also parts of background surfaces. In some cases, the background is not another surface, as occurs when the sky is background. Whether the background is a surface or the sky, there is an abrupt change in distance from the point of observation on either side of a plane through an occluding edge or bound of any terrestrial object. On one side of the plane is the occluding surface, and on the other is the distant background.

Plane surfaces, curved surfaces, and dihedral angles are concepts of layout that are independent of any observer. When a point of observation is introduced, occluding edges, occluding bounds, and backgrounds result. Occluding edges and bounds and dihedral angles are visible features of surface layout. Arrangements of these features make up the visible terrain and objects standing on the terrain. Can an outline drawing depict some of these features? Which will be recognizable?

Cross-cultural research and research on children finds that the shapes of objects can be recognized in outline drawings. The shapes of objects are created by variation in the arrangement of plane and curved surfaces; shapes are arrangements of features of surface layout. So it seems that some of the features of surface layout are recognizable in outline drawings—without training. And depictions of all the features of surface layout occur commonly in newspaper and textbook illustrations, in drawings from many cul-
tures and times. Cave paintings are often in the form of outline drawings depicting the edges of objects and occluding bounds of objects. The most common use of outline depiction is depiction of features of surface layout--this is the usual vocabulary of the language of outline. It appears to be a language discovered by early man, universal in its understandability and inherent in the nature of man's visual perception, for it requires no training.

Fig. 28 is an attempt to incorporate into one picture outline depiction of all the features of surface layout. It should be instantly understandable to the normal Western reader. Words to describe it may be restricted to one culture, and the objects it depicts may be unfamiliar to some cultures, but the kind of features it shows should be identifiable in some line drawing or another by anyone reared in a world of solid objects that rest on a terrain that stretches to a horizon.

Figure 28 shows a seascape and a landscape with rounded hills and a house with a walled-in garden. Different segments of the lines in the figure depict the following six features: (1) An occluding bound with a background surface-the brow of a hill, with the surface of another hill behind. (2) An occluding bound with no background surface-the brow of a hill, with sky visible above the hill. (3) An occluding edge with no background surface--the apex of the roof of the house, with sky visible above the house. (4) An occluding edge with background surface--the termination of a wall, where the continuation of the surface of the wall is occluded by the near surface, with ground surface visible beyond the termination of the wall. (5) A dihedral angle forming a concave corner--two visible plane surfaces of wall meeting at an angle of less than 180 degrees, measured through the air enclosed by wall. (6) A dihedral angle forming a convex corner--two surfaces of the house meeting at an angle of more than 180 degrees, measured through the air around the surfaces.

As Fig. 28 shows, all the basic features of surface layout can be depicted by lines in outline drawings. A segment of line can depict an occluding edge or bound or a dihedral angle. What makes a segment of line depict at one time an occluding edge and at another time an occluding bound is the context in which it is viewed. The context can be other lines patterned around the line segment, as in Fig. 28, or the set of the observer, as pointed out in Chapter 6.

Besides the six features listed above, outline is capable of a seventh kind of depiction. Each of the basic features of surface layout is depicted by single lines in Fig. 28. However, sometimes a single line can depict more than one feature of surface layout. That is, representation of several features of surface layout can sometimes be achieved with the use of a single line. One example is contained in Fig. 28--namely, the crack between the door and the walls of the house. A crack results when two dihedral angles of two surfaces abut or adjoin each other. Two abutting dihedral angles can be depicted by a single line.

Another example of a single line depicting more than one feature of surface layout was shown in Fig. 19, in Chapter 6. That figure depicted a fence with a gap between two of the boards bridged by strands of wire, each strand depicted by single wires. If the strands were depicted as very thick, as thick as ropes, two lines would be present, one line for each side of occluding bound of the thick strands. Depicted by single lines, the strands are shown as thin wires.

To depict a thick strand, two lines could be used. Similarly, to depict a wide crack, two lines could be used. Dihedral angles and occluding bounds are depicted by single lines only. Thus, there is a critical difference between strands and cracks and single features of surface layout. Strands and cracks are created by several features of surface layout, and in principle each feature can be depicted by single lines. Wires are cylinders, with parallel occluding bounds. Looked at closely, the cylinder would become evident. Cracks are
The Substance of Surfaces

The substance of surfaces is often capable of structuring the light that comes to the eye. A surface can be smooth or planar and yet entail substances that have different capacities to reflect light. This difference in reflectance may be selective with regard to the wavelength of light, in which case one part of the surface is said to have a different color than other parts. Or the difference in reflectance may simply result in some areas being able to reflect more of die incident light than others, in which case some areas are said to be lighter than others. The differences in reflectance are said to be due to differences in pigmentation. So a surface may have no layout discontinuities of distance or inclination and yet provide pigment discontinuities.

To show depiction of pigment discontinuities alone it is necessary to represent layout in which the only discontinuities are provided by change in pigmentation on a smooth surface. Pure cases of pigment change without surface-layout discontinuities occur in the coloration of animals. The wings of butterflies and the hides of animals are often sources of pure pigment discontinuities that do not correspond to surface-layout change. Can pigment discontinuities be recognized in outline depiction?

Figure 29 is an attempt to show pure pigment change. The object shown is an animal. If a subject recognizes Fig. 29 as an animal, a horse in particular, information about features of surface layout is being recognized. If a subject sees the figure as depicting a zebra, the interior lines of the figure are functioning as depictions of the pigment-change on the hide of the animal. If the subject were to see the figure as a horse with lines painted on its flanks, then the interior lines would not be acting as depictions of boundaries of areas of pigment. In informal fashion, dozens of adults and two children have been shown Fig. 29. All the adults, usually faculty and graduate students, have taken the figure to be a depiction of a zebra, and thus the interior lines depicted margins of areas of pigment. The two children, visitors to the Cornell psychology laboratory, had interesting reactions. One, a five-year-old girl, thought of the figure as a horse with lines on it. The other, her eight-year-old brother, not only saw the figure as depicting a zebra, but even spontaneously identified some areas as showing the shape of light or dark areas on the pictured zebra. The guiding principle he offered was that zebras are light on the underbelly, and from this knowledge he was able to figure out where the dark and light areas should be!

The adults and children were simply shown Fig. 29 and asked "What is this?" No explicit hints were given. Once they had responded, they were asked "What is this line for?" They were asked about lines for the back and legs of the zebra before being asked about an interior line. The figure was recognized as a zebra by the adults and by one child. It seems likely from this informal evidence that lines can depict pigment discontinuities without training in any convention.

Lines can depict changes in layout of surfaces and the layout of pigmentation on a surface. The context for a line is a critical factor in determining what a given line is depicting. The more un-
familiar the context—the depicted configuration—the more difficult it may be to ensure that the observer sees only one definite feature of the environment as depicted by a given line. Presumably, the five-year-old girl who failed to see Fig. 29 as depicting a zebra was comparatively unfamiliar with zebras. Perhaps a depiction of a favorite pet with lines showing the shapes of the pet's markings would make the transfer from the solid, colored, textured, real world to the merely black-and-white line drawing easier. A drawing of a favorite costume, with its color patterns depicted only by lines, might be easily recognizable, too. Possibly the simplest thing would be to show examples of flags, like the American, British, and Canadian flags, in outline, omitting all color. Their distinctive patterns completely depend on pigment differences in otherwise uniform cloth.

Outline drawings restricting the observer to one unambiguous perception must usually both replay a highly specific optical structure and also capture the observer's understanding of environmental structure. Figure 29 seems to be specific enough for many subjects. Lines in the figure are identified as depicting pigment areas. The figure provides information about pigmentation without reproducing the full patchwork of a zebra. It seems that to identify a shape as an area of pigment one need not have all the coloring reproduced. Features of shape, without color, can be adequate. Informative features of the figure probably include, for example, the fact that none of the interior lines disturb the overall silhouette. The interior lines simply terminate at the exterior lines; they do not make exterior lines poke out, as gaunt ribs would. The exterior line is smoothly continuous. Thus, the interior lines do not indicate ribs and concavities, which would disturb the overall silhouette. The overall horse shape is probably critical, too. If the overall shape was not evident, the interior lines could easily be taken to be contours on a map. Many features of this zebra depiction are shared with other figures, but the zebra figure seems to include enough distinctive features to be specific to outline depiction of pigment areas. The lesson to be drawn is that outline depiction capitalizes on—and, if a depiction is to be unambiguous, is restricted to visible features of the environment that have distinctive form. This lesson will be reinforced as more figures are considered.

In sum, subjects recognize Fig. 29 as a zebra, taking some segments of line as depictions of pigment borders. Lines can depict discontinuities of pigment.

Layout and Illumination

From Surface layout and pigment layout we now turn to variation in illumination on Surfaces and variation in illumination from surfaces—that is, shadows and highlights.

Shadows. When shadows are present on a surface, it is not uniformly illuminated. A shadow is cast on a surface when an opaque body is situated between a source of radiant light, or the direction of illumination, and the surface. The opaque body intercepts light that otherwise would reach the shadowed Surface. Removing the opaque body allows the illumination to reach the surface. When an opaque body prevents illumination from reaching an area of a surface, the area is said to be cast in shadow.

Generally, terrestrial Surfaces shadowed from the prevailing illumination are not entirely without illumination. Usually, light reflected from other objects and the sky reaches terrestrial areas shadowed from the sun. Thus, there is not the extreme contrast
found with objects in empty space. Usually, too, terrestrial shadows result from objects intervening between surfaces and extended sources of illumination—not point sources. So there are penumbras to most shadows-regions where part of the extended source does offer illumination. Penumbras result in the softly blurred appearance of the margins of cast shadows.

Can cast shadows be depicted in outline? Outline drawings omit the brightness-darkness change entailed by shadows and the colors of shadows beloved of Impressionists. Outlines are made with fine, sharp lines and do not provide cross-hatching or other means to create gradients that would be like the gentle gradients in penumbras. These gradients seem important in recognition of shadow (Helmholtz, 1924; MacLeod, 1932). As a result, it may not be surprising that cast shadows are rare in outline drawings. In a sample of more than 10,000 line drawings from the Cornell Fine Arts Library, there were no examples of depictions of cast shadows. The majority of the drawings were recent European and American work, but collections from Japan, India and the Near East, and from Celtic and Anglo-Saxon times were included.

The rarity of outline representation of cast shadow suggested an experiment (Kennedy, 1970). Given this rarity, most subjects presumably have never been instructed that outlines can represent shadows. Would instruction be necessary for subjects to perceive shadows when shown (probably for the first time) an outline drawing in which cast shadows are represented?

To avoid problems with penumbras, photographs in which distant shadows were present were sought. Distant shadows can be far enough away that penumbra are not evident. For distant shadows, the angles subtended by the penumbra are so small that the transition between light and dark seems sharp to the unaided eye. Only photographs of terrestrial shadows were considered, those involving natural or ecological optics, not altered by darkroom or laboratory trickery such as reversing or altering illumination on the pictured scene with lenses or mirrors or artificial sources of light. In many of these photographs, shadows were easily recognized as such; thus, a penumbra is not necessary for a shadow to be recognized.

A particular line drawing (Fig. 30) was prepared from one of the photographs. The outline was made by "tracing" from selected portions of the picture. In particular, discontinuities of pigment representing shadows were traced from the photograph. In addition, human figures and luggage cases and a pole were depicted by lines in the drawing, traced from pigment arrangements in the photograph.

The photograph capitalizes on the laws of projection of light, and so it is in projective correspondence with an environment. The lines traced from the photograph are also in projective correspondence with features of the same environment. Can enough structure be retained in a projective line tracing to make the lines informative about corresponding features? In particular, will the pictured shadows be recognizable even to untrained observers?

Eight adult subjects--graduate psychology students at Cornell--were shown Fig. 30. They were asked, "What is this?" --- nothing more direct. Six immediately identified the picture as depicting shadows. If the subject did not specifically say where the relevant lines were, and name the objects casting shadows, he was asked, "Shadows of what?" and "Which lines represent shadows?" The six subjects correctly identified the lines in the lower half of the figure as depictions of the shadows of men in a row, carrying flags.
Two subjects did not spontaneously identify the shadows. One said, "I don't know what this is" while indicating the lower half of the picture. The other said, "Is it water?" Both of these subjects were given a hint, the one word "Shadows." Both then correctly identified the shadows and correctly said what was casting the shadows. The hint did not indicate particular lines or suggest particular objects casting shadows. Still less was it instruction in a convention or an arbitrary code. The objects casting the shadows were not depicted in the drawing, so subjects could not identify an object and then guess, following the hint, that otherwise-meaningless scribbles "must be meant to be their shadows." Nor were there any flags or men standing in a row anywhere in the scene.

Perception of shadows in the drawing is not due to a learned convention. At the time, November 1969, there were few if any outline depictions of cast shadows on which a convention might have been based. Since 1969, examples have emerged in recent "revolutions" in graphic art, inspired by high-contrast photography (which emphasizes the structure of optic arrays, often at the expense of recognizability of the environmental source of the more demurely-contrasted array).

It seems that the capacity of outline to depict recognizable shadows is inherent in the perceptual skills of untrained adult observers. What were the important attributes of Fig. 30 that made it depict shadows rather than any of the host of other possibilities, from comers to color patches? Presumably, Fig. 30 must present aspects of shape that are distinctive to shadows.

What attributes does Fig. 30 have in common with shadows? The figure presents some of the shapes of men, but there are anomalies. Parts of the figures are surprisingly wide, and other parts in comparison are unusually narrow. The nearest arm of the shadow of the nearest man is a particularly clear case. Notice, too, that the wide parts point toward the observer, and thin parts are at right angles to these. And the shoulders of the figures are oddly skewed with respect to the main axis of the figures. Thus, the lower figures are projected as would be flat figures, not as voluminous solid objects. Their flat character distinguishes them from real men.

Also, there is no interior detail to the lower figures. The flags being carried are continuous with the standard and the standard with the human figures. Absence of internal detail is a common characteristic of shadows, particularly shadows in a natural scene with no artificial lighting. Further, the baggage, the pole, and the erect human figures define a ground plane and its horizon. These objects in these erect postures should be resting on a solid surface. The three human figures project smaller subtended angles, as their feet are depicted higher in the picture plane. The location of the feet and the decrease in size corresponding to height in the picture plane is perspective information for the location of a surface and its horizon. One could even work out what height the photographer held the camera, which would be the height at which the horizon intercepts the standing figures.

Just as the erect figures define a ground plane and an imaginary horizon, so, too, do the figures in the lower half of the illustration. The figures decrease in size and width as they move up the picture plane. The axes of the human figures and the standards converge toward the horizon; continued, they meet in one point. Thus, these flat figures provide perspective information for a surface and a horizon that corresponds to the surface defined by the erect figures. It is characteristic of cast shadows that they lie on surfaces, the very surfaces defined by other features of the environment.

Familiar figures that are present in outline, appearing flat, with no internal detail, merging smoothly with the shapes of other figures, lying on terrain without suggesting surfaces at variance with the rest of the environment—in such ways Fig. 30 contains information for shadows. Probably none of the subjects who identified shadows in the illumination could have identified many of the attributes of the outlines that specify shadows. The figures presumably capitalize on intuitive or tacit understanding of features of the visible world, just as in sound localization we can say where a sound source is but not how temporal differences at the ears are used to identify the location.

To support the analysis of the illustration of shadows, the figures were redrawn in various ways. The expectation was that if any attribute was altered, no observer would identify the result as a depiction of shadows. The attributes were divided into (a) those for flatness, (b) those for absence of internal detail, and (c) those for concurrence between the terrain and the surface bearing the flat
figures. An illustration in which all three attributes have been altered is Fig. 31, which shows erect solid figures, men complete with internal detail. Compared to Fig. 30, attributes (a), (b), and (c) have been changed in Fig. 31. In Fig. 32, only (a) and (b) are changed.

Nine subjects (summer school students at Cornell) were shown Figs. 30, 31, and 32. They were simply asked to comment on the things pictured. Eight of the nine identified the shadows in Fig. 30. All nine identified the figures in Fig. 31 as being men standing in a row and did not mention shadows. No subject mentioned shadows for Fig. 32, seven of the subjects saying the figures were supine men. Two thought the men were strangely flattened--"cutouts," said one; "flattened," said the other.

When internal detail was added, but the flatness (or concurrence with a single plane) retained, subjects often commented on the flatness of the figures, saying for Fig. 33 that there was an impression of figures "painted on the ground" or "totally flat" or "flat and unreal." Again, no one mentioned shadows. However, when the internal detail was removed, as in Fig. 34, even if the outline was for a rounder, fuller figure, six out of nine subjects still mentioned shadows. The information for the solid silhouette of a man was not preventing subjects from using the lack of internal detail and location of the figures as information for a shadow.

Could the kind of difference between Fig. 30 and Fig. 34 be used by subjects? Perhaps the subjects were simply using lax criteria for form, assuming that the drawings are made roughly with no great emphasis on niceties of form. If so, subjects could be asked to compare two drawings including the kinds of difference distinguishing Fig. 30 and 34. Two extra drawings of vertical figures, different only in outline information for fullness or solidity (Fig. 35 and Fig. 36), were shown to all nine subjects. They were asked to say which looked more "bulky" and which looked more "flat." All nine subjects chose correctly--Fig. 35 was said to be more "bulky."

It seems that absence of internal detail, concurrence with surface, and flatness are distinguishing features of shadows. These aid subjects in recognizing outline depiction of shadows. Informa-
FIGURE 33. The supine figures are flat and detailed.

FIGURE 34. The information for solidity--rather than flat shadows in the supine figures is often not detected.

FIGURE 35. The erect figures contain information for roundness or bulkiness.

FIGURE 36. The erect figures contain information for flatness, unlike these in Figure 35.
tion for flatness may be the least helpful aid, if subjects are not discouraged from making allowances for imprecise drawing.

The general aim of the studies was fulfilled. They showed that outline can depict shadow, and shadows in outline depictions can be recognized without training in a convention.

**Highlights.** Shadows can be depicted in outlines. Can highlights, another phenomenon created by the relation of surface layout to illumination, also be shown in outline?

Highlights depend on surfaces being polished or smooth. Highlights appear when the relationship between three factors—a source of radiant light, a polished surface, and a point of observation—is just right. Shadows depend on surfaces and light sources and are independent of a point of observation; highlights are not. As an observer moves around, the surfaces showing highlights change. Just looking first with one eye and then with the other can produce remarkable changes in highlights.

In general, incident illumination is reflected off a surface either in a *specular* manner (minor reflection off a smooth, polished surface) or by *scatter* reflection. If the surface is polished or smooth, illumination is reflected at an angle equal to its incident angle. In contrast, a rough surface scatters incident illumination in many directions. Often there is a compromise between scatter and specular reflection, and the surface is said to be partially polished.

If the surface is at all polished, a station point will receive particularly strong illumination from a direction meeting the surface at an angle equal to the incident angle of prevailing illumination (Fig. 37). Station point i in Fig. 37 receives light from points a and b on a surface, but the light from a is particularly intense. Station point i lies in a direction from a where incident illumination is being particularly strongly reflected. For station point ii, the illumination from b is particularly intense, for similar reasons. For station point i, there is a highlight in the direction of a. For station point ii, there is a highlight in the direction of b. If one eye were at i and the other at ii, the direction of a highlight would seem to shift from a to b, as an observer looked with one eye and then the other.

So discontinuities in optic arrays—discontinuities in the intensity of light from a surface to a station point—occur, given the right arrangements of sources of light, polished surfaces, and station points.

Are highlights recognizable in outline drawings? They are not uncommon in line drawings. Objects such as balloons and bottles, rounded, with smooth surfaces, are often drawn to include outline depiction of highlights (Fig. 38). Lines mark the margins of directions of discontinuities of illumination.

Length of these arrows indicates amount of light reflected in the direction of the arrows.

Cross section of a partially polished surface

![Fig. 37](image-url)

**FIGURE 37.** If a surface is partially polished, most of the incident light is reflected at an angle equal to the incident angle.

![Fig. 38](image-url)

**FIGURE 38.** Highlights on balloon and bottle.
The Scope of Outline Pictures

Since outline depiction of highlights is fairly common, it is probably not necessary to test adults to see whether such outlines are recognizable, but it may be instructive to test children. My two child visitors (five and eight years old), mentioned previously, failed to identify the highlights depicted in Fig. 38. Asked what a highlight was, the younger was nonplussed. The older said, "Well, you take a light and put it up high!" Perhaps in that odd way that we can fail to notice our own shadow during the day, so children can fail to notice highlights until they are pointed out or become a source of play in a contemplative moment. At some point, tacit understanding is able to support outline depiction; the age at which that understanding is reached is still a matter for conjecture.

To summarize, line segments can depict discontinuities of illumination due to highlights or cast shadows, drawing on adult tacit understanding of the ecology of light.

Changes in Texture

A surface texture occurs when a unit is repeated over an area with stochastic regularity. A texture can be described in terms of the unit being repeated, the number of units in a given area, and the distribution of the unit. An arrangement of small areas of pigment may constitute a texture, as in a slab of speckled quartz. Small mounds and depressions may constitute a texture, as in ripples on a beach. Visible texture is created by arranging units defined by pigment or layout or illumination changes.

A discontinuity in texture occurs where a terrain abruptly changes its texture. On a beach, a pebbly area might adjoin an area of sand. A grassy area might change to lichen as underlying soils varied. As texture changed on a beach or area of vegetation, so, too, would color and general layout, in many cases. Finding a pure case of a texture change in nature is not easy.

Can a texture change be recognizably depicted by a line in an outline drawing? Since layout and pigment and illumination discontinuities can be depicted in outlines, it is necessary to find a pure case of texture change--one where no other kind of discontinuity is present. Otherwise, observers may recognize one kind of discontinuity being depicted and infer the other. So far I have discovered only one kind of pure texture change that is at all common; it is a kind found in garments. The hem of a sweater, for example, is often different from the body of the sweater, only in the arrangement of the strands that have been knit to form the sweater. The coloring is often identical in the body of the sweater and the hem. Except when the hem is folded up or rolled up, the surface layout remains at one level. The level of illumination from the sweater is the same from the body and hem. The distribution of tiny pockets of shadow, from the individual strands of the material, vary in the body and hem, creating a visible texture, but the general level of illumination remains the same. The discontinuity due to a hem is a pure case of a texture discontinuity.

Figure 39 is an outline drawing of a sweater, traced from a photograph, in which the junction of the hem with the body of the Sweater is depicted by a line. No difference in coloring marks the boundary of the hem. Differences in weave are not indicated by differences in stippling or hatching. Is the line for the edge of the hem an effective depiction of a texture discontinuity, so that there is no need for captions or training in a convention? Consider replies from eight adult subjects (students at Cornell) asked about Fig. 39.

FIGURE 39. An outlined sweater, with line depiction of the upper border of a hem, to show change in texture.

The subjects were shown the drawing and asked nondirective questions. First they were asked, "What is this?", when the drawing was presented to them. They generally replied "Its a drawing of clothing--a sweater" or words to that effect. If the subject did not mention clothes-as in the case of one who said, "It looks like a page from Sports Illustrated!"--he was asked to say a little more. All subjects mentioned garments or sweaters specifically. The second question was about a specific line. The subject was asked, "What is
this?", as the experimenter pointed to the line depicting the outer edge (outer occluding bound) of the arm, just below the shoulder. All subjects identified the line correctly. They were then asked, "What is on this side of the line?", as the experimenter pointed to the interior of the represented arm. All subjects identified the area as the interior of the arm. They were then asked, "What is this?", and the experimenter pointed to the exterior region adjoining the line. Subjects said "Nothing" or "Air" or "Background" or words to that effect.

The next line they were asked about was the topmost horizontal line (for the neck) of the same sweater. Again the first question was, "What is this?", and the next two questions were, "What is on this side?", as the experimenter pointed to the two areas on either side of the line. All subjects mentioned the neck of the sweater and the neck of the wearer and mentioned the neck of the wearer was not specifically represented.

What these questions established was that subjects understood the questions despite their very general nature and that the picture depicted a sweater in the appropriate orientation to the subjects. Line depiction of layout was clearly effective for all these subjects. The line of questioning was clear and meaningful to all the subjects.

The next question centered on the line depicting the hem and was again nondirective. The experimenter pointed to the line that was a tracing of the upper boundary of the hem as shown in the original photograph. Subjects were asked, "What is this?" Six of the eight immediately mentioned a change of weave or knit or a change of pattern or said "It's the top of the hem" and, asked to enlarge, mentioned a change of weave. Of the other two subjects, one said "It could only be ribbing" and, questioned, explained that a rib was an elongated ridge knit into a sweater, and that the line in question represented a rib that ran parallel to the bottom edge of the sweater. The subject was adamant that ribbing was the only thing the line could represent. The other subject said that the line represented the join of the hem to the body of the sweater. This subject was unable to enlarge upon her answer, repeating, "the top of the hem" when asked to explain. Asked to explain further, she said she could not. Asked to explain what a hem was she could only say it was the bottom band of a sweater. It did not seem possible to have the subject use terms like texture (for example, "weave," "knit," "pattern," "matting," "braiding," "reticulation," "plaiting") without suggesting them directly, so the subject was not questioned further. Whether she was thinking of a hem in terms of weave but could not express this remains unsure.

So, six out of eight identified the line depiction of a texture discontinuity. What makes the line provide information about a texture change rather than any of the other things a line can depict? Why was it not the top of the rolled-up edge of the sweater? Presumably, the line pattern in the sketch must contain distinctive features of a texture change.

The figure provides a familiar configuration—a clothed body. The lines fit the overall shape of a human torso but also have characteristics of sweaters—curves representing folds, proportions that are bulkier than a nude body, and extra lines cutting across the limbs and body to depict cuffs for sleeves and the termination below the waist.

Consider the curves of lines that depict the sides of sleeves and the lower body of the sweater and the neck. The neck line changes direction; it swerves to show the silhouette of the bottom section of the folded-over roll neck. The cuff line swerves to indicate the end of the sleeve. These swerves depict layout edges—edges that can be silhouetted. Similarly, the bottom edge of the body of the sweater is marked by a line that comes down the side of the body and then swerves to become horizontal before it divides in two, a horizontal continuation and the vertical continuation. The lines for changes of layout swerve to silhouette each layout change. But lines for the side of the sweater do not swerve as they approach and form a junction with the line for the upper part of the hem. At that junction, the lines for the sides of the sweater continue undeviatingly. Accordingly, that line does not suggest a layout change.

The line for the texture discontinuity occurs in the midst of information for a garment and is parallel to and a short way above a line for a change of surface layout, the end of the material of the sweater. The line does not indicate a change of surface layout (like a line for the top of a belt, for example), since if it did, the line for the side of the body would change direction when close to it. The
outline is in the appropriate place for the border of a hem; such borders in sweaters are typically texture discontinuities. Hems are sometimes marked by color change as well as texture change. Hems are not exclusively dependent on texture discontinuities. It is a little surprising that no subject mentioned a color change. Perhaps there is some feature of shape that distinguishes a pigment change from a texture change, and a drawing that includes such features would be a useful tool to explore the tacit knowledge underlying subjects' judgments.

In summary, subjects can recognize outline depiction of texture discontinuities, without training or captions. A drawing that subjects identify as depicting texture change by outline contains some distinguishing shape features of pure texture change. Recognition of texture depiction by outline adds one more ecological phenomenon to a long list that can be identified in outline drawings.

**Conclusion**

Corners, whether convex or concave, occluding edges and occluding bounds, with or without backgrounds, parallel combinations of features of surface layout like wires or cracks, edges of shadows, highlights, and pigment boundaries--all yield to outline along with texture discontinuities. Perhaps abrupt change is the factor tying all these phenomena together. Abrupt change of depth or slant with respect to the station point is the result of a feature of surface layout. Abrupt change of illumination underlies shadows and highlights. Abrupt change of reflectance defines pigmentation change. And abrupt change in weave was depicted at the hem of a sweater.

The rule that follows is that lines can depict discontinuities, any of the visible discontinuities of surface, pigment, illumination, and texture layout. These are the basic features that create the visible environment. It follows that anything that has distinctive features of shape and is visible should be identifiable in outline drawings. The power of outlines does not rest on showing whole objects, which, of course, they can do, but on being able to present information for the fundamental features of the visible environment. The language of outline is a language of discontinuities and distinctive features of shapes. Cave artists mastered the vocabulary of surface layout, and still today that is the great domain of outline, the common pictorial language of many cultures. It seems other basic features of vision can be a part of that domain, too, when need arises.

In sum, outline drawings capitalize on ecological information provided by distinctive features of shape and permit observers without training or captions to identify basic discontinuities of shape, slant, pigment, illumination, and texture. Outline can depict discontinuities without reproducing the colors or textures or intensities that define each discontinuity, by presenting the informative variables of shapes that help distinguish each discontinuity.