Chapter Two

Light as Information

How does a picture give us information? Let us first sketch some principles that help explain how light operates in our environment, for we may best begin to understand how a picture provides information by first understanding how information is generally available. We will consider two propositions that arise from common observation.

The first proposition is that we are generally accurate in our perception of the physical, geometric arrangement of our world. We can tell where things are in relation to each other and to our own body without much trouble or error. In these matters, the senses are generally truthful. We sometimes overlook something, but we rarely misperceive. Accurate perception is so much the rule that we almost never think about it; instead, we treat any errors as odd and interesting because the incidents are unusual. (Beginning students are often lead into errors of perception, with illusions, in order to convince them that the problem of perception is important--as though the accuracy of perception is uninteresting once it is brought to our attention!) We live with accurate perception the way a fish lives with water, relying on it, trusting it, rarely needing to think about it.

The second proposition is that we do not need to make immediate contact with the objects that we seem to perceive so accurately. Eyes do not have to be adjacent to the things they see and ears do not have to be pressed to every sounding instrument. In these matters the senses are at one remove from their targets. Somehow, from a distance one can find out about objects and be quite accurate.

The problem set by the two propositions is this: How can perception be consistently accurate and yet operate at a distance from objects? J. J. Gibson (1950, 1966) of Cornell University has tried to answer this question, and his work forms the basis for my discussion.

How could accurate information ever be available? Light travels considerable distances before the eye receives it. A single, ray of light could have been emitted by a source at one inch, one mile, or one light-year from the eye. Is that spot of light a pinprick in a nearby screen, or is it a star in distant space? Those two spots of light separated by a few seconds of arc--are those close together, or are they as far apart as the planets?

In principle, the question is: Which properties of light provide information about light sources? To begin to answer, we must first establish conditions under which anything can be said to be informative about anything else. Starting with a subject other than optics, let us imagine that a radio has been taken apart, with its switches and resistors lying to one side and its case to the other. Now, is there anything about the switches and resistors that is useful information about their previous location in the radio? Imagine that each switch and resistor is labeled $A$, $B$, $C$, and so on. If each switch and resistor has a different label, and each location in the radio case has its own label (location $A$, location $B$, and so on), there is information on the switches and resistors about their previous locations. If each part is labeled differently, complete information
is provided. The labeling is unequivocal; if some of the parts are labeled similarly—say, there are two parts marked A but only one location A—there is some ambiguity. If all the parts are labeled identically, there is no information in the labels about their previous locations.

Labels are informative when they are unequivocal, just as words are informative when they are unambiguous. Similarly, in optics, a light pattern could be said to be informative about its origin if the light could have come from one particular origin and no other. At this point, it is easy to see why many authors reached the conclusion that light must be full of ambiguity: Could not the light have come from any distance, or from a picture of an object, or have been reflected off a mirror? This conclusion is unsatisfactory; it flies in the face of the accuracy of everyday perception. Light cannot be endlessly ambiguous; if it were, vision would make endless errors.

The Environment and Light

To show how light can be informative, let us consider the kinds of origins light comes from in our normal environment.

The Environment. In general terms the environment is a "terrain" dotted with "objects," changing in time to create "events." The terrain is the general surface of the terrestrial globe, and surfaces are boundaries between substances, often boundaries between the air and solid material. The objects in the environment are enclosed volumes of matter, the boundaries of objects being their surfaces. The events that occur in time are usually changes in the surface of the terrain or movements of the objects on the terrain. In general, events are changes in the properties of the environment.

Light. Most surfaces are enclosed in the transparent medium we call air. Surfaces can reflect light in any direction in which there is a transparent medium. The reflected light passes through the transparent medium, maintaining its original direction until there is a change in the medium. The light traveling through a transparent medium is "available" to a perceiver, ready for him to use if he puts his eyes at the right place. The places at which light is available can be thought of as points, called either points of observation or station points. (Either of these terms, derived from projective geometry, may be used, though "station point" is sometimes used only when a picture is present and "point of observation" only when an observer is actually present.) These points at which light can be registered are places to which light comes from the terrain. The light passes through the point and continues without deviation. (Station points do not make light informative; the light coming to the point has its own characteristics, such as color and direction. Station points are just places. Station points all treat light identically, and differences in the light at different station points result from the different origins of the light.)

Optic Arrays. The light from the surfaces of the environment converges to a station point, passes through it, and diverges away from it. We shall consider only the convergent illumination, for, of course, anything true about the convergent illumination would be true of the divergent illumination, too. The convergent illumination has intensity and "color" (spectral composition), and we can measure the intensities of light from various directions or measure the wavelengths (spectral composition) of light from various directions.

In addition to intensity and spectral composition, the convergent illumination has a structure that is independent of intensity or spectral composition. The light from one direction and the light from an adjacent direction may be different, in which case there is a contrast, and the arrangement of contrasts is a pattern or structure that is independent of the intensity or color of the light. The same structure could be present with different intensities and spectral compositions—for example, raising the intensity of illumination does not change the structure. When the sun comes out from behind a cloud, the landscape brightens, but it still looks like the same place. And subtracting light uniformly from all the convergent illumination would not change the structure. Donning sunglasses can make a scene less glaring, but the same pattern is visible.

The structure or pattern made by the contrasts is called the optic array—the scene is "arrayed" before our eyes. The optic array at a station point is ambient, since it fully surrounds the station point. In general, the optic array is the arrangement of all the differences of illumination that arrive at the station point. The basic conception
of the optic array is made more useful when three important points
are added, as follows.

First, the optic array is not just an optic structure at a given
moment, not just a frozen pattern. There can be structure across time,
too, because of changes as time passes. From one moment to the
next, light patterns may change. Usually the light patterns change
when the point of observation is shifted. If a part of the terrain
moves, that usually creates changing light patterns, too.

Second, the contrasts of an optic array enclose three-dimen-
sional angles called solid angles to distinguish them from plane
angles, which exist in two dimensions. Where there are many con-
trasts in the optic array, the optic array can be said to have an optic
texture. Just as a surface may be stippled by many spots of color
and have a surface texture, a station point may have many contrasts
and have an optic texture.

Third, optic contrasts are one kind of optic discontinuity, this
being a general term for any kind of abrupt change. Optic dis-
continuities include abrupt change in the kind of optic texture pre-
sent in the optic array, and abrupt change in the density of optic
texture. An abrupt change in light from one moment to the next is
another kind of optic discontinuity—a discontinuity in time.

Optic Arrays and Their Origins

Now that some features of the environment and its light have
been described, we can face questions about information and
ambiguity. The basic question is: Are there properties of optic arrays
that are informative about their origins in the environment? To
answer this, we must show that some aspects of an optic array are
related only to certain, not all, aspects of the environment. Par-
aphrasing G. A. Miller (1951), origins may change and light may
change, but can we show that change in one is linked to change in
the other so light can be informative? Let us reexamine the descrip-
tion given so far.

Information for Direction of Origins. Light leaving a surface
maintains its direction in a uniform medium. In an environment
swathed in a uniform medium like air, adjacent elements of an optic
array come from adjacent directions (Fig. 1), and the direction

of any source is the direction its light comes from. To that extent,
there is some information for direction in an optic array. As the
direction of the origin changes, so will the direction of the light from
it, if the medium is uniform.

However, adjacent solid angles may not have come from
adjacent surfaces. In Fig. 1, areas A and B, two surfaces in the en-
vironment, project adjacent light to a station point. Areas B and C
also project adjacent solid angles of light. But only B and C are
adjacent surface areas. Area B is nearer to the station point than A.
It seems that the relative distances of surfaces can be ambiguous
despite the presence of information for their direction. Optical ad-
jacency—the adjacency of two optic angles—does not specify material
adjacency, which is the adjacency or continuity of the surface areas
from which the light originates.

Information for Adjacency. It is necessary to look a little
beyond optic adjacency for information for adjacency, for there are
conditions under which two adjacent solid angles will have come
from two adjacent parts of the environment. As Fig. 2 suggests,
surfaces are typically somewhat homogeneous in texture. That is,
surfaces usually show some regular distribution of patches of color,
and usually too there is also some regular distribution of the
Corrugations—minor indentations and elevations—of the surfaces. J.
J. Gibson, 1950, pointed out that surfaces are usually textured.
Metzger, 1936, showed that texture seems critical in how one
perceives an area as a surface. Beck, 1966, showed that areas of
different texture are quickly distinguished even if they are on the
same plane and are the same color. Brodatz, 1966, has made an
important set of photographs of surfaces, with each photograph of a
different surface showing unique surface texture. Brodatz includes
some black white reversed prints along with normal prints; the
textures of the normal prints and the reversed prints are the same
and even a brief inspection shows that the surfaces are clearly of the
same type.

What follows if surfaces are textured? If it is true that
surfaces are typically regions of the same kind of texture, then
abrupt changes (discontinuities) between kinds of texture will
usually occur only when there is a change in the material of the
surface. The related light-containing an abrupt change or
discontinuity of optic texture—provides optic information for the
FIGURE 1. Areas A, B, and C project light to the station point; B and C touch each other, while A is quite separate, though the light from A adjoins the light from B.

FIGURE 2. Each of the separate surfaces shown here, has, schematically, its own distinctive, fairly homogeneous texture. Perhaps most natural substances and many artificial substances have distinctive but evenly distributed textures.

change of surface. It follows that regions inside texture discontinuities are usually regions of continuous surface. So any light within a discontinuity of optic texture has come from a continuous surface. *Adjacent solid angles in the optic array that are enclosed within a discontinuity of optic texture come from adjacent surface areas.*

Thus, there is information in optic arrays about the direction and adjacency of parts of the environment. Perhaps there is information for other properties of the environment—for instance, the distance of parts of a surface from the station point. Areas may be adjacent to one another, but is one further from the station point than another?

Since the shape of an area (its silhouette) is often considered of primary importance to perception, it may be helpful to show some problems in using shape to understand relative distance of parts. Consider a discontinuity of optic texture in an optic array.

The discontinuity will have a particular shape. Now a particular surface area projects a particular solid angle to a given station point, but the shape of that solid angle could be projected by many different surfaces in the environment. In Fig. 3 various surfaces show all manner of slants and hence all variations of relative distances of parts. Some slant back, some slant forward, some are curved, and some are flat; but the shape of the solid angle of light they project to the station point is the same in every instance. So it may be difficult to use the shape of a particular solid angle of light as information for its origin.

Some of this ambiguity would evaporate if we knew all the possible shapes of all the possible origins in our environment. If we were familiar with all the possible shapes of objects, we might be able to make some good guesses about the origins of a pattern of light. For example, if it happened that all four-sided figures were squares, then any time a four-sided pattern of light appeared, the origin would have to be a square. Alas, objects have almost endless shapes. It may be best to turn to something that cuts across all types of shapes. Is there anything that is part of our perceiving just about any shape? Perhaps. If shapes are made of materials with definite surfaces, and surfaces are textured, then shapes are textured and perhaps once again texture may be useful.

**Information for Slant.** Solid, worldly objects have shape by having surfaces that are moulded and sculpted into facets that slant this way and that. If they are textured, these surfaces could provide information for slant—that is, relative distance of parts of a surface with respect to a station point—as follows. Each element of texture on a surface projects a solid angle of light to our eyes, and if the surface is uniformly textured, the average size of its texture elements is the same all across the surface—on areas near a station point and areas far from a station point. So, by and large, distant surface elements project smaller angles of light, and as the surface slants away from the station point, the projected optic texture becomes more densely packed, as Fig. 4 shows. Therefore, the parts of the surface projecting small, densely packed optic texture elements are further away from the station point, thus yielding information
observation is considered. Let the observer move or look with two eyes obtaining information across time or across space, and the ambiguities in Fig. 5 disappear. As Fig. 6 shows, parts of a surface that are not visible at one point can be seen from a nearby point. Put technically, the part that is only projected to one station point is said to be occluded from the other station point (Kaplan, 1969). The more distant surface has some of its area occluded by the nearer surface. With gradual movement of the station point, the occluded area gradually appears, texture element by texture element. As Kaplan puts it, there is gradual "accretion" of texture elements in the optic array showing which surface is more distant. The texture elements are "deleted" gradually if the direction of movement is reversed. Accretion and deletion of texture shows which of the two surfaces is more distant. To repeat, in the relation between two arrays at two station points there can be information for the separation of two surfaces and for which of two surfaces is more distant.

Direction, adjacency, slant, and relative separation—these basic aspects of layout—all seem to be specified by properties of light, provided what I have said about surfaces having texture holds true. Optic arrays need not be hopelessly ambiguous about the origins of light in the environment. Briefly put, the three key points are as follows:

First, information for the direction of sources is present,
provided that the illumination from environmental surfaces travels in uniform media, maintaining its direction.

Second, information for the adjacency of surface areas is present, provided that continuous stretches of surface of one material are uniformly textured.

Third, information for the separation of surfaces is present across optic arrays.

This analysis of the information in light is a promising beginning because it shows how a theory of perception needs a description of the environment and a careful description of optic arrays. Let us now try to fit depiction into the analysis.

**Depiction and Information**

We will begin with a puzzle. The whole notion of optical information depends on the condition that some properties of light are unequivocally related to some properties of the environment. If the environment can be pictured, then the light can come from two sources, the usual origin or a picture. But this threatens the idea that light is informative because it can have only one kind of origin.

Of course, pictures might not give information of the kind discussed so far. Pictures might be conventions, subject to fashion and momentary canons of whatever educational fancy was enforced. If so, pictures would be more like language than like light, more like a complex system of invented rules than like a device rooted in the optics of the environment. But if pictures are like language, how is it that we have machines that "take" pictures, but not machines to "take" names? Surely pictures provide information in a way that is unlike language, a way that makes use of the laws of light as cameras do. If so, the puzzle is how to introduce a concept of picturing into a theory about information in light and keep the theory consistent.

Let us rethink the basic terms. It has been shown that across station points there can be information for the relative distance of surfaces. It follows that if an observer is restricted to a single station point, then he may have no basis for determining which of two surfaces is nearer. Many arrangements of surfaces could then provide the particular array available to the observer. The observer could be restricted even more: Any information that depends on the texture of surfaces could be degraded or withheld by the use of special filters or by painting over the surface and hiding its texture. These circumstances could remove information about the slant of the surface, and the origins of the optic array would become quite ambiguous. Restricting the observer and changing the normal environment can create ambiguity where once there was faithful information. Also, it is possible to artificially create an alien texture on a surface. Scattered deposits of pigment can be painted on it. A texture can be cast on it with multiple shadows. The surface could be cut many times to give it a texture of grooves and cracks. This artificial texture could be on a surface equidistant at all points from an observer and yet create an optic texture normally coming from a slanted surface in a world where surfaces are uniformly textured.

The point here is that an optic array is physically distinct from its origins. Light can be manipulated independently of its origins. The origins themselves can be artificially treated to change the typical relations between optic arrays and their origins. Think of it this way: A kind of artificial source of light may have entered our ecology when man first made cave paintings. The new kind of source of light may have become more common and more important with each step along the way to photography, motion pictures, and television. The result may be that, for us to understand optic information, it may be best to distinguish "artificial" sources from "natural" sources at the outset. (The most useful criterion for making the natural/artificial distinction may be intervention by direct human action. The result of human action is that there are not only natural surfaces with regular texture but also artificial surfaces with irregular textures, or, like some plastics, no texture at all.) The difference between natural and artificial sources is not easy to define, but the precise definition is not of pressing importance now. The question is, what kind of theoretical value would the natural/artificial distinction have? Would it be useful for understanding picturing?

The argument could be as follows: There is information in light in a natural environment, in which surfaces are regularly textured. A naturally occurring optic array, originating in a natural environment bathed in a uniform medium, is informative about its
Man occasionally intervenes in the natural order of things. Man produces some artificially treated surfaces that yield information for differently arranged natural surfaces. The artificially treated surfaces represent or picture or depict other layouts. Hence, the concept of information is compatible with a concept of pictorial representation, for one is based on natural surfaces and the other on artificial surfaces.

The laws of optic information have to be established using one set of surfaces—the natural surfaces—and then pictorial representation is allowed for by acknowledging a second set of surfaces (so-called treated surfaces), which follow slightly different rules. The natural and the artificial sets of surfaces are closely related, but that does not mean that an observer necessarily has trouble distinguishing them. For example, someone might paint a continuous flat surface so that it provides an optic array like one from two or more separated surfaces. But if the observer moves the flat surface will not provide accretion-deletion information, whereas the separated surfaces would. Any observer who can deal with optic information from a static, motionless world should be able to accept information from the flat artificial surface. If the observer can use information across time, he should be able to distinguish the artificial case from real separated surfaces, and not confuse the two. Therefore, any observer who can use static information and kinetic information should understand the picture without confusing it with reality.

In summary, light is lawfully related to its origins and provides useful information about the world. The lawful relations between light and its sources allow pictorial representations to be created; that is, one layout of surfaces can be artificially treated to provide information for a different layout. The argument suggests that any organism that uses optical information should understand pictures. But there is an alternative to be borne in mind. It may be that many sketches violate the proposal that most pictures use naturalistic optical information. How will a theory based on optical information account for caricatures and outlines? Caricatures do not show us naturalistic shapes. Outline drawings omit all the naturalistic color and texture of the world. Then, too, don't most animals ignore even moving pictures? Aren't pets indifferent to television? Don't "primitives" peoples misunderstand photographs? Pets and