Pictures and Their Special Status in Perceptual and Cognitive Inquiry

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On December 18, 1994, in the Ardennes in the south of France, three explorers discovered a cave with elaborate wall paintings, now estimated to be 30,000 years old.[1] These are more than twice as old as those in the more celebrated caves of Niaux, discovered no later than the 17th century; of Altamira, discovered in the 19th; and of Lascaux, discovered in the mid-20th (see Chauvet, Brunel Deschamps, & Hillaire, 1995; Clottes, 1995; Lorblanchet, 1995; Ruspoli, 1986). Indeed, in what is now known as the Grotte Chauvet are works that may date to the time that *homo sapiens sapiens* appeared in Europe (Laboratoire de Préhistoire du Musée de l'Homme, 1982; Nougier, 1969; Wymer, 1982). What is most compelling about these paintings is that, given the migratory nature of our species and the unlikely survival of any such works, they are just about as old as they can be. They show more than 300 portrayals of animals, including bison, deer, elephants, horses, hyenas, ibexes, lions, oxen, rhinoceroses, a panther and an owl, many apparently depicted in motion and some never found in cave paintings before. They are etched or colored in black, yellow, or red; most are drawn with considerable grace and tech-

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[1] There is quite some controversy over dating of the Chauvet paintings. From a report of carbon dating, a relatively early indication in the press was that they were 30,000 years old ("*Les peintures de la grotte Chauvet datent de 30 000 ans avant notre ère*" *Le Monde,* Juin 4/5, 1995). Noting potential problems with this method, Clottes (1996) suggested that they were only about 20,000 years old. Lorblanchet (1995), however, met these criticisms and disputed the use of any criteria other than carbon dating. Whichever dating is correct, however, the Chauvet paintings are the oldest known, large collection of images.

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nique. With Mithen (1996, p. 156) we note: "Although this is the very first art known to humankind, there is nothing primitive about it."

Clearly, pictures have been with us a long time and, with the Chauvet discoveries, much longer than previously thought. Pictures can no longer be seen as an artifact of the development of a particular culture. They now seem likely to be a defining characteristic of our species. The antiquity and ubiquity of pictures suggests the ability to understand pictures is deeply embedded in the human mind, even the genome. The Chauvet discoveries promote reconsideration of many questions. What is the relation between a picture and the aspects of the world it represents? What is it about our mental makeup that makes pictures an excellent medium in which to communicate to others about the world around us? In some pictures, how is it that a few lines come to stand for the objects and desires of the artist? In this chapter we intend to outline answers to these questions. Our approach is broad and interdisciplinary (see also Hochberg, 1996); for focused discussions of perceived space see Sedgwick (1986) and Cutting and Vishton (1995), and for discussions of pictorial space see Goldstein (1979, 1987), Rogers (1995), and Hagen (1986).

I. PICTURES AND THE WORLD

A. Cognition and Fortuitous Pictures

> If you look at walls that are stained or made of different kinds of stones and imagine some kind of scene, you begin to see . . . picturesque views of mountains, rivers, rocks, trees, plains, broad valleys, and hills of different shapes. You can also find in them battles and rapidly moving figures, strange faces and costumes. (Leonardo, in Baltrušaitis, 1989, p. 61)

Here, as an exercise for students, Leonardo da Vinci appealed to a cognitive capacity within humans to interpret natural patterns and to reorganize them in novel ways (see also Chastel, 1952; Holt, 1957). Such stains, or more simply clouds in the sky, can be called *unintended pictures;* no artist created them but they are the result of natural processes. The idea in this perceptual exercise is that one can and should "go beyond the information given" (Bruner, 1973) in these patterned visual surfaces and mentally elaborate, confabulate, and simply see new things.[2] The roots of pictorial art may be similar. Soon after their appearance in Europe, paleo-artists began to modify the rock surfaces of caves with their own markings. For example, in the Altamira cave one finds a bison head that was created by painting eyes on a rock protuberance (Nougier, 1969), and similar works appear at Lascaux and Chauvet. Such acts transform a rock surface into a picture/sculpture; the paleo-artist used the *accidental* properties of the layout of a surface and elaborated them with a graphic act.

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[2] Indeed, even James Gibson (1979, p. 282) who otherwise did not ordinally deal with such matters, stated that "a Rorschach blot is a picture of sorts containing information not only for bleeding hearts and dancing bears but for dozens of other events" as well. See also Gibson (1956).

The major questions for this inquiry, then, are two: First, is this elaborative ability a part of our normal process of picture perception? Although representing very different perspectives, Arnheim (1974), Gombrich (1972), Sartre (1948), and Wollheim (1968) have all said yes; and we would generally agree, but only for some pictures and then only in some ways. (Later in this chapter we will discuss the interpretation of lines and line drawings that, to us, unequivocally invoke aspects of cognition). Second, is picture perception like our visual perception of the world around us? Costall (1990), Gibson (1979), Hagen (1986), and others have all said no, and again we would generally agree. Pictures typically have a dual character; the optical array does not. That is, pictures are both objects themselves and thus they typically depict, or *represent* other objects as well. This duality is most often carried by "conflicting cues" (e.g., Woodworth, 1938), which are not particularly common in the real world. Before discussing pictures further, however, we need to place pictures in a larger cognitive and perceptual context.

B. Pictures and Metatheory

> Pictures have cast a remarkable enchantment over the way we have come to think about vision, and not within psychology alone. The eye–camera analogy . . . has not only been very influential in its own right, but has also helped conceal a further, and highly persuasive, assumption: that our "normal" mode of experiencing our surroundings—the posture we adopt to the world—is that of a *spectator* looking at a picture. (Costall, 1990, p. 273)

With this indictment, Costall captured what could be a major problem in cognitive and vision science: If the projections of the world to our eyes are not like pictures, then we in our discipline may be in deep trouble. Almost all of our visual perception and cognition experiments over a century have used pictures as stimuli, and yet we almost always use their results as evidence of how we perceive in the natural world (see also Cutting, 1991b). Ittelson (1996) has called this the *pictorial assumption.* Our view is that the situation is not so bleak as Costall or Ittelson would suggest, but with them we agree that a proper understanding of the relation of pictures to the visual world is central to visual science.

The role of picture perception in the study of visual perception and cognition raises an important issue. Much of the history of interest in perception has been a debate between two classes of metatheory, one that emphasizes an elaborative (cognitive, "top-down") component to perception and another that emphasizes the adequacy of the information in the to-be-perceived objects and events, and thus the general lack of need for cognitive component (and hence is "bottom-up"). The former is represented, in different ways, by the views of Plato (Cornford, 1957), Leonardo (Richter, 1883), Berkeley (1709), Mill (1842), Helmholtz (1867/1925), Russell (1914), the Gestalt psychologists (e.g., Koffka, 1935), and others (e.g., Hochberg, 1968; Rock, 1983); that is, innate ideas, learned associations, unconscious inference, and principles of perceptual organization all emphasized what is not literally present in the stimulus. On the other hand and in modern terms, the views of Epicurus (C. Bailey, 1928), S. Bailey (1855), and Gibson (1966, 1979) emphasized what is present in the stimulus.

Despite centuries of debate, however, we see no particular conflict inherent in these theories as they have been applied in the 20th century; they simply apply to different domains to differing degrees. We believe the first class of theories—those endorsing elaborative processes that have by tradition come to be called theories of *indirect perception* (e.g., Ayer, 1956; Rock, 1997)—apply to many kinds of pictures, particularly line drawings. We believe the second class of theories—those endorsing stimulus properties and, since the time of John Locke, called *direct perception*—applies most easily to everyday situations (see Cutting, 1986, for an historical review). Theorists in support of the role of inference (or induction) in perception typically use, or refer to, "impoverished displays" (line drawings of various kinds) to show a role of cognition in perception, and from Gibson they would have received no quarrel. Gibson (1979) regarded picture perception as an instance of indirect perception. Those against a role for inference in perception have tended to use, or to refer to, more naturalistic displays, and ideally to natural environments, to show that cognition need not play such a role (see Cutting, 1991b).

The continuing fascination, of course, is that this bifurcation between the perception of pictures and the perception of the visual world is not nearly so neat as we have first drawn it; there are exceptions and gradations between. Moreover, a history of pictures can be interpreted, in part, as one of applying, through technological means, the wherewithal to make images that increasingly approximate three-dimensional worlds that we can easily understand and envision. The development of linear perspective (e.g., Kubovy, 1986; White, 1957), then photography (e.g., Scharf, 1968), then cinema (e.g., Toulet, 1988), and then the promise of computer-generated virtual reality (e.g., Ellis, Kaiser, & Grunwald, 1991) would seem to attest to this. Moreover, there are two corollaries to this progression. First, all of these technological advances make pictures less and less like a decorated surface and more and more like a world within which we can act, and all should, in principle, make their perception more and more "direct." Second, to discover the role of cognition in picture perception one might best look to the oldest kinds of pictures humankind has produced, rather than the newest.[3]

But the everyday world, of course, is not always as replete with information as some might have us believe. On and just under the surfaces of oceans and lakes, in deserts, polar regions, and rain forests, and almost everywhere at night (without artificial lighting, e.g., Schivelbusch, 1988), the layout of the world is not always sufficiently patterned and comprehensible for objects and events to be easily seen. All of these situations make the real world less and less like a place within which mean-

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[3] This is not to imply a temporal imperative, but instead to remove the discussion from a close reliance on photography and Renaissance art.

ingful action can take place on the basis of usable information and more and more like an information-poor void. Again, there are two corollaries. First, by our argument, all of these should make perception more and more "indirect." Second, the information still available in impoverished natural environments might be most like that found in pictures.

The overall idea, then, is that if there is sufficient information in the array (natural or pictorial) to specify to the observer what would ordinarily be needed for daily action and recognition, then no overtly inferential, cognitive process is deemed necessary; if, on the other hand, the information is somehow deficient, then inference and cognition stand ready and may, seamlessly, play a role. When, how, and if cognition plays such a role, of course, is still much researched and debated. There is, however, another entry in this short list of metatheoretical positions—*directed perception* (Cutting, 1986, 1991a)—and we will use its central tenet to set the stage for our further discussion. First, however, let us set up the contrasts.

Indirect perception has been characterized as a many-to-many mapping between the information available to the senses and the events or objects in the world. This potentially unruly mapping has given rise to the emphasis on "cues" as probabilistic sources of information (Brunswik, 1956; Cutting, chap. 4, this volume; Gibson, 1957; Hochberg, chap. 1, this volume). The idea is that, as a perceiver, one wanders through the world as a Bayesian algorist, computing the surety of what one sees based on stores of matrices representing the covariation of "cues" with objects and events (see Massaro, 1987; Massaro & Friedman, 1990). To us, such a view seems computationally cumbersome and unlikely (see also Hochberg, 1966).

Direct perception, on the other hand, has been characterized as the one-to-one mapping between information and events or objects, hence the emphasis on invariants and the surety of information (e.g., Burton & Turvey, 1990). The idea here is that one wanders through the world as an actor and collector of information, with perceptual systems exactly fitting the requisites of the ecological niche (see Cutting, 1991a). To us, such a view seems biologically implausible because it implies preadaptation of perceptual systems to ecological niches, and thus would make evolution difficult, if not impossible.

Directed perception, in contrast to both, is characterized by the many-to-one mapping between information and events or object properties. That is, more than one source can specify a particular aspect of the object or event to be perceived.[4] This idea emphasizes that the world is typically a plenum of adequate information (reducing cognitive demands), and the observer wanders through it selecting or combining information as it is useful and as it matches the capacities of the perceptual system (allowing evolution to occur). This metatheoretical viewpoint will

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[4] Clearly, there is much potential mischief in the idea of specification (Schwartz, 1996). Cutting and Vishton (1995) suggest that the traditional "cues," or sources of information, about depth specify only ordinality, and then only when their assumptions are valid.

be important in our discussion to follow because, with a picture or a sculpture, an artist can select, enhance, or exaggerate one class of information sources from the world and use them in an artwork, letting other sources lie idle and unused (see also Massironi, 1982, chapter 2).

II. PICTURES, REPRESENTATION, AND COMMUNICATION

To encompass cave paintings, photographs, sketches, and caricatures, Gibson (1971, p. 31) defined a picture as "a surface so treated that a delimited optic array to a point of observation is made available that contains the same kind of information that is found in the ambient optic arrays of an ordinary environment." Thus, a picture is a *surrogate* for ordinary visual perception, and the contents of the picture are surrogates for objects in the real world (see also Gibson, 1954; Hochberg, 1962).[5] The picture brings things into view that might otherwise be at great distance, in time or space, or it even imports them from imagination.

This definition would seem to be appropriate to many kinds of pictures and, with the technological extension of motion, to cinema and television as well. Such a view is not particularly comfortable with modern or abstract art of many kinds (see Gibson, 1979, p. 268), and it promotes a boundary between pictures and sculpture that seems awkward. One of the attractions of this definition, however, is that it is quite clear and concrete. Moreover, it makes an assumption prevalent in most all approaches to pictures, which we also endorse—most pictures are *representations.* Although Gibson was not comfortable with the idea of representations (e.g., Gibson, 1979, p. 279; Cutting, 1985), it dominates his and most other approaches to pictures.

A. Representation, Pictures, and Sculpture

> A picture can only light upon some aspect of reality; the rest it must consign to the shadows. No picture, however fond of its subject, can embrace all of its aspects. . . . So realism is no simple matter, each picture makes a highly intricate choice of features, playing upon some, ignoring others. (Schier, 1986, pp. 162–163)

Discussions of representations are at the core of late 20th-century cognitive psychology; in fact, it is difficult to imagine a cognitive psychology that did not have representations as a foundation (see, for example, Epstein, 1993; Hochberg, chap. 1, this volume; Johnson-Laird, chap. 12, this volume; Rumelhart & Norman, 1988). Representations are typically couched as mental entities bearing some rela-

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[5] Some theorists have tried to drive a wedge between issues of surrogation and representation (e.g., Schwartz, 1997). From our perspective there is none; both take the elements within pictures to stand for something else in another world.

tion to the world outside. Pictures, however, are different; they are physical entities whose contents typically bear some relation to this same world (see also Hagen, 1979, 1980; Willats, 1997). What is this relation? We believe that five things must be considered:

a. The *representing medium*. This includes the physical nature of the surface(s) and the choices made in altering them. For photographs, paintings, and engravings such a surface is typically planar and two-dimensional, but these are textured in different ways; for a sculpture the surface typically has local two-dimensionality, but wraps around in three dimensions. Consideration must also be given to the markings on the surface(s), the lines, brush strokes, pixels, etchings, or moldings.

b. *The depicting array.* This concerns the composition of the elements in (a)—the particular arrangement of lines, brush strokes, pixels, and so on, for a picture and the surface arrangements in a sculpture.

c. *The depicted array.* This contains a selection of aspects of the modeled world (that is, a selection from the possibilities of (d) below). Concretely, this could be a landscape, a collection of flowers, a face, or even a set of ideas; but equally it can focus on the light at a given time on the landscape, the particular riot of color in the flowers, or the expression in the face that the artist wishes to model. Typically, any talk about the depicted array is simply a description of the scene without reference to larger aspects of culture.

d. *A depicted world,* "real" or imaginary, only a small part of which is depicted in the picture. This world traditionally has had considerable cultural significance and history, and these provide a background context for how the picture was to be seen when it was composed.

e. The concern with the *mapping,* or correspondence, between (b) the depicting array and (c) the depicted array.

This scheme is adapted from Palmer (1978, in press), who discussed representations in general, but when adapted to our purposes the system works reasonably well. For pictures and sculptures, the success of (e)—the mapping from (b) to (c)—is measured in our recognition that a particular piece of art is an artifact that stands in place of a landscape, a collection of flowers, a face, or even an idea. We claim this mapping, or surrogation, is not culturally relative (e.g., Hochberg & Brooks, 1962; Hochberg, 1995, 1996), it is not dependent on photographic assumptions, and it is also not the basis for aesthetic judgment.

1. Six Examples

To be concrete about representation in pictures and sculpture, let us consider six cases—a photograph, an engraving, a painting, two sculptures, and then a final painting. Traditionally, the first four would be called examples of "representational" art, the last two would not.

a. Sam Shere's Explosion of the Hindenberg

For example, this piece, in the collection of the Museum of Modern Art, New York, is (a) a black-and-white photograph that is (b) a surface with a particular pattern of light intensities that mimic (c) the explosion of a large dirigible against a metal tower, representing (d) the event of the *Hindenberg*'s destruction in Lakehurst, New Jersey, in 1937. What makes the picture a representation, according to our account, is the relationship between what is seen in the patterns on the photograph and what might be imagined about, or have been seen during, the actual burning of a dirigible. When the picture is reproduced, as in a book (e.g., Newhall, 1964), the picture of the picture is no less a representation, or mapping between (b) the pattern of light intensities and (c) the explosion of a large airship. Even a bad photocopy of the photograph remains a representation to the degree that the scene is still discernible. If it were discovered that somehow the picture did not actually depict the explosion of the *Hindenberg,* but perhaps of some other dirigible at some other time, this would not detract from it as a representation. Thus, the truth of the situation—which is part of the relation between (c) and (d), and sometimes called denotative reference—is not at issue in our scheme, although it can be very relevant other contexts (see Goodman, 1968; Mitchell, 1992; Schier, 1986).

b. Albrecht Dürer's St. Jerome in His Study

This piece, in the collection of the Metropolitan Museum of Art, New York, is (a) a two-dimensional black-and-white surface, (b) engraved to look like (c) an old man in a rather lavish study with a lion, wolf, skull, and other objects near his side, (d) denoting St. Jerome and the iconographic symbols associated with him. For a complete understanding of the picture it is important to know the iconography of the image (Panofsky, 1955; see also, for example, Ivins, 1969; Mitchell, 1995)—another part of the relation between (c) and (d)—but this knowledge is not pertinent to the discussion of representation as we define it. As before, any photographic reproduction of this work for any purpose (e.g., Carlbom & Paciorek, 1978) is no less a representation than the original, as long as the quality of the reproduction allows retention of the perceived relations of (b) to (c).

c. Leonardo's Mona Lisa (La Joconde)

This piece, in the Louvre, is (a) a two-dimensional varicolored, painted canvas, (b) composed to look like (c) a lady with an enigmatic expression of repose on a balcony in front of a surreal landscape, who was, according to the traditional account, (d) the wife of Francesco del Giocondo. Because the painted surface looks like a woman with an interesting expression, it is a successful representation—the mapping (b) to (c)—but this tells us nothing of cultural or historical significance (see, for example, Baxandall, 1985). That the painting may be, in the late 20th century, the most famous painting in Western culture,[6] that is, it has been parodied by Duchamp, Warhol (see Solso, 1994), Monneret, and others, or that the image of the woman was almost certainly never meant to be considered a portrait of Giocondo's wife (Turner, 1993) does not add or detract from it as a representation as we define it. Again, a photograph (or even a bad photocopy of a photograph) of *Mona Lisa* is as good a representation as is the original so long as the image is recognizable as a woman on a balcony in front of a landscape; it still reveals the relationship between (b) and (c).

d. Michelangelo's David

This piece, in the Academy in Florence is (a) a three-dimensional arrangement of dappled marble surfaces, (b) sculpted into the complex shape of (c) a muscular young man with outsized hands, carrying a sling over his shoulder, in a pose of reflection, denoting (d) the mythical character who defeated Goliath. Because of the perceptually close relationship between (b) the sculpted shape and (c) a young man, regardless of one's vantage point, the mapping is apt. That the story of David and Goliath is a myth is not relevant here. Similarly, that the piece of work is beautiful and justly renowned has to do with many things not necessarily a part of (b) and (c). Moreover, and what makes the discussion of the sculpture relevant to pictures, a photograph of the artwork preserves the basic relationship of (b) to (c), except that the viewpoint is now constrained. Clearly, however, there are canonical views (Palmer, Rosch, & Chase, 1981); a picture of *David* from the front seems likely to be a better representation *of the artwork* than one from the side or back.

e. Henry Moore's Two Forms

Consider a traditionally less "representational" example, in the Museum of Modern Art, New York. It is (a) a set of varnished, wooden block surfaces, (b) carved into two objects; the first a small, roundish one and the second a gourd-like one with a hole in it with its concave surface facing the first, suggesting (c) a relationship; "the smaller of the two units is compact and self-sufficient . . . although straining noticeably towards its partner . . . [t]he larger seems wholly engaged in its leaning over the smaller, dominating it, holding it down, protecting, encompassing, receiving it" (Arnheim, 1974, p. 272), and denoting (d) an infant and mother. The fact that Moore's sculpture does not physically look like an infant and mother does not, in our view, detract from it as a representation. The shapes suggest a set of relations between the two objects. A photograph of the sculpture does the same, although again it constrains the viewpoint. Notice here that, unlike the cases above, the depicted array is not a physical space; instead, it is a set of relations, even of ideas triggered by Moore's abstract title. Thus, in our view, pictorial representation can

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[6] The results of a poll published in the September 24, 1995, London Sunday Times (The Culture, Section 10, p. 29) found that Michelangelo's Sistine Chapel ceiling was thought to be the most famous painting by 20% of the *Times* readership; Leonardo's Mona Lisa ranked second with 17%.

easily diverge from realism, both in art and in science (as in the case of graphs, discussed below). The import here is that most discussions of representation would not easily admit Moore's work.

f. Peter Joseph's Dark Ochre Color with Red Border

Our notion of representation, however, is not unbounded. For completion's sake, consider this piece in the Lisson Gallery, London. This late-20th century work is (a) a two-dimensional canvas (b) painted in two colors, with a large central rectangular patch of ochre (a dark yellow) and red border around it. The painting does not particularly suggest anything other than what it is, and we would claim it represents nothing in particular. Thus, it is "nonrepresentational," both in our terms and in traditional descriptions of certain classes of modern art. A photograph of the work may be a representation of the work (see, for example, Denvir et al., 1989), but there remains no depicted array allowing a mapping of the work to anything else.

2. Fidelity: The Attempt to Quantify the Mapping

With these examples in mind, the scheme outlined above is intended to clarify certain aspects of the nature of representation. The power of the concept, however, is in (e) the mapping of the relationship between the two arrays, (b) and (c), which we claim is based on recognition. Other theorists have tried to quantify this relation in a more rigorous way. The idea that such a quantification is possible across all the various kinds of pictures is, we think, based broadly on assumptions of "progress" in the arts, and particularly on photography and the idea of photorealism (e.g., Friedhoff & Benzon, 1991). Such schemes assume that a picture is best considered as a frozen optical array (the projection of the real world to a particular station point); that is, that the depiction is physically and measurably similar to the depicted array.

Initially, for example, Gibson (1954, 1960) was concerned with the *fidelity,* or optical similarity, of the picture to the world it represented, and he held out promise for measuring degrees of fidelity between the two. This view is essentially Pirenne's (1970, 1975) as well. In principle, and in the parlance of the late 20th century, one could compare the image, point-for-point in a photograph or pixel-by-pixel in a video image, with corresponding regions in the optical array, and achieve a measure of similarity between the two. There are, however, several kinds of problems. For example, most pictures most of the time are not looked at from the point of composition that would make them best mimic an optical array of a real world. This creates few problems perceptually (Goldstein, 1979, 1987; Halloran, 1989, 1993), but in a reconstruction of the depicted space behind the picture plane it creates projective distortions in planes parallel to the picture plane and affine distortions in planes orthogonal to it (Cutting, 1987, 1988). Moreover, walking in front of a picture creates continuous distortions of this kind, which appear to be of little perceptual consequence (Wallach, 1987).

In addition, the idea of fidelity suggests a progressive scale: A 140-mm film image of a landscape would typically have better fidelity than a 35-mm film image of it which in turn would typically have better fidelity than a video image of it, than a detailed line drawing of it, and so forth. Such a progression makes a certain amount of sense, and one could indeed quantify such relations. Nonetheless, it sets up at least three other problems when one considers pictures in general.

First, and most simply, any principled comparison between the composition of a picture (the depiction) and the world (the depicted) needs a real world. Thus, despite the fact that most Renaissance and Baroque paintings are constructed in rigorous perspective, the paintings are of fictitious, idealized environments, so no fidelity computation could in principle be made. At most, they could only "look" real, and hence we are back to similarity by recognition, not similarity by physical measurement.

Second, and more insidiously, the fidelity assumption leads further to the idea that the photograph of a landscape has more fidelity than a painting of it by Constable, which might have more fidelity than an engraving by Piranesi, and so forth. These comparisons make little sense because the media and the intents of the artists have shifted. We would probably all agree that Piranesi's 18th-century engraving of the Roman Forum was very faithful to what one would see in the Roman Forum, even today (see Levit, 1976). Any concrete measure of the engraving's fidelity, however, would entail the comparison of lines in a picture with the projection of "lines" from the real environment. These latter lines, however, are often fictions. Despite the influence of Marr (1982), in a computer analysis of images any filtering or thresholding technique which produces lines from a naturalistic scene will produce many lines one had not wanted and will omit many lines one would have wished to see (Willats, 1990; but see also Hayes & Ross, 1995). The abstraction of the environment to an array of lines assumes a relationship between (a) the medium of engraving and (c) the Roman Forum that is not part of the mapping between (b) the composition of the lines and (c) the Roman Forum. Thus, if one were still concerned with measuring fidelity, one must use different metrics for photographs than for engravings and other line-based images.

Third and most importantly, the idea of fidelity generally ignores the selection processes in composing a pictured scene. Consider some choices of various artistic schools. It can be said that many Renaissance artists were fascinated by the geometric properties of architectural environments and how they could be used to create the impression of the layout of a space. It can be said that many Baroque artists were fascinated with object shape and textures and how light and shadow played upon surfaces. It can be said that many Impressionists were fascinated with ambient light itself, and it can be said that the Italian Futurists were fascinated with motion and how it interacted with form or could be stripped from it. Following the central tenet of directed perception, the natural world is a plenum of information and the artist may only use some of it in a depiction. Thus, to suggest that some artistic images have greater fidelity than others is to flirt with unwarranted glosses over history, culture, and artistic intent.

3. Retreat from Fidelity

Gibson (1966, 1979), for one, later realized that fidelity was not the answer to the understanding of the utility of pictures. His rationale centered on a concern with portrait caricatures, which were poor in fidelity (however it be measured) but which nonetheless were recognizable and understandable, sometimes more so that line drawings of a face they were intended to represent (Brennan, 1985; Rhodes, Brennan, & Carey, 1987; see also Gombrich, 1963; Hochberg, 1972; Perkins, 1975). From our perspective, Gibson's concern divides two ways—first the difference between line drawings and photographs, and second the difference between exaggeration and veridical proportioning. The first will be addressed in a later section on the functions of lines, and the second concerns communication, addressed in the next section.

Gibson (1971, 1973) next proposed that the mapping was not at the level of lines, pencils of light, or pixels, but at the level of something more abstract—*information,* even *invariants.* He felt that the information in the depicting and depicted arrays must be the same. We think such an approach loses the strikingness of the concept of fidelity but, with the exception of the discussion of invariants (Cutting, 1993; Topper, 1977, 1979; but see Costall, 1990; and Hagen, 1986), it is probably closer to the truth. Nonetheless, it passes off any explanatory power of fidelity to the concept of information, a topic of another chapter (Cutting, chap. 4, this volume).

At present, then, we suggest the best way to address the mapping function in pictorial representation is a pragmatic one: One should simply appeal to the psychology of recognition. The contents of a picture (the depiction) resemble what is depicted not solely in terms of information, but to the degree "there is an overlap between the recognitional abilities triggered by" the picture and the depicted (Schier, 1986, p. 187). Such an appeal forces the realization that in any theory of picture perception the perceiver, not some objective measurement, determines whether or not a picture depicts as the artist had intended.

B. Communication

> Communication is essentially a social affair. Man has evolved a host of different systems of communication which render his social life possible. (Cherry, 1957, p. 3)

1. Sharing

To communicate means, among other things, *to share* and there is an important sense in which this is what pictures do best; the artist, among other things, shares with the viewer some of his or her intents. Pictures—like utterances in language—are composed to communicate intents; they are often, but not always, composed to represent objects and events. Thus, even traditionally defined, nonrepresentational pictures are intended to communicate, and communication is thus a broader purpose of pictures than is representation.

2. Selecting

To communicate also implies to select. This 20th-century idea comes from Shannon and Weaver (1949). They proposed a rigorous, albeit somewhat counterintuitive, mathematical definition: Communication is based on information; information occurs through the selection of one entity from a set of entities; and information is measured in the size of the set from which the selection occurs.[7] Artists select their medium for a particular work; they select the style with which they will compose their work; they select what they wish to portray (even if it is to portray nothing); and they select which world or domain they wish to represent. Selections and choices delimit possibilities, and they emphasize intent.

3. Constrained by Purpose

The artist, however, is not all powerful in his or her ability to make the selection process successfully communicate. Some representations are inherently better than others to communicate particular ideas about the same object or event. For example, a rendering of a room in perspective might nicely illustrate its contents and their general spatial relations, but if the aim of the picture is to have another person construct that room, a multiview orthographic projection would be better (e.g., Carlbom & Paciorek, 1978). Thus, communication is sharing by selection as *constrained* for a particular *purpose;* the choices of what to communicate are not wholly independent of how to communicate it (Massironi, 1989); there are important reasons why recipes, musical scores, and architectural plans look different.

If the aim of scientific research is to broaden and continuously redefine the limits of nature and its contents, it can be said that the aim of an artistic research is to broaden and continuously redefine the limits of communication and its contents. However, the artist alone is not charged with discovering new methods and establishing new rules for the communication of new contents; scientists are so charged as well. When new contents arise and need to be transmitted and when old methods do not suffice, a new way to represent them is found. This fact is perhaps no clearer than in a special kind of picture drawn by scientists for other scientists and students—the graph.

4. The Example of Illustrations, Charts, and Graphs

Illustrative drawings, more broadly, have always been a part of geometric presentations in mathematics. For example, Euclid's *Optics* (from the third century B.C.) contains many graphical constructions (Burton, 1945). These represent two-dimen-

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[7] When dealing with finite sets, this idea has great appeal and application. The problem with this idea in many applications, however, is that the size of set one is dealing with is generally unknown. If there is an animal present and you declare it to be a tiger, how many possible animals have you selected from? Has the same information been relayed if we declare it a house cat? See Cutting (1986) for more criticisms, see also Dretske (1981) for a lengthy defense of this and related issues, and see Cutting (chap. 4, this volume).

sional geometric space. In addition, charts and maps have been a part of nearly every culture known (e.g., Harvey, 1980; Snyder, 1993). These, too, represent two-dimensional space. In most scientific illustrations, however, graphs or diagrams use a paper's space more abstractly. To anticipate later discussion, the functions in graphs plotting the data are *objects,* when more than one is present they are typically *textured* differently, and the axes framing the plotted space are *edges.*

The graph is an unusual prototype in the domain of pictures: (a) It is unequivocally representational (it represents data); (b) it is nonrealistic (it stands for no possible optical array); (c) it is conventional (one needs to know some rules to understand it properly; most pictures do not require this); and (d) it communicates effectively (it can show a trend embedded in hundreds, even thousands, of data points). In the late 20th century roughly about 10% of scientific journal space seems to devoted to graphs (Cleveland, 1984), although disciplines and subdisciplines vary widely in how often graphs are deployed.[8]

The first scientific graphs, with x and y axes and plots of data, seem to have appeared with the works of Johann Heinrich Lambert and William Playfair in the 18th century (see, for example, Tufte, 1983). Important conceptual advances in graphing were made by Marey (1878) and by Tukey (1970), and overviews and explorations can be found in Bertin (1967), Cleveland (1985), Kosslyn (1994), Schmid (1983), and Tufte (1983, 1990).[9] Each of these latter works makes suggestions about how to construct graphs, and perhaps most interestingly, although they are written by scientists, there is very little direct evidence in support of many of their specific claims. Tufte (1983), for example, deplored pie charts, but Spence (1990) found them to communicate most efficiently of all graphical forms.

More importantly in our context, Tufte (1983, chap. 4) also made a suggestion directly relevant to pictorial communication. That is, he proposed a data–ink ratio for measuring the utility of graphs; the more data that could be displayed with the least amount of ink, the better the graph communicated. The idea is that, in a graph or figure, scientists share condensations of their data, where each visible data point excludes (or selects from) other possibilities, constrained by the presentational space and perceptual capacities of the reader. Too many functions are visually confusing; too few are wasteful; dense maps are best. As attractive as, and as closely tied to information theory as, the data–ink idea is, it seems largely an aesthetic appeal; ease of reading a graph does not seem correlated with data and ink. As with pictures more generally, communication by graphs seems a craft, not a science. Culture, education, and history all matter in reading graphs, much more so than in perceiving pictures more generally. Graphs follow conventions and, despite the claims of Good-

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[8] Perhaps the quintessence of refrainment from using images is Staudt (1847), a treatise on projective geometry without any figures.

[9] Bertin's (1967) is perhaps the most striking and comprehensive, suggesting that shape, orientation, texture, color, luminance (value in his terms), and size are the primitive graphical elements; almost four decades later such a list sounds remarkably like a list of neurophysiological channels in vision (e.g., Spillman & Werner, 1990).

man (1968) and others, the grip of conventions is not large on how pictures, in general, are to be perceived.

As suggested by our choice of graphs, we believe that most theoretical approaches to pictures are fraught with at least two difficulties. First, they are often too enamored of photographs, a technological johnny-come-lately in the domain of pictures. Second, at least within psychology, theorists have also been too enamored of the relationship of figure to ground, a distinction attributed to Rubin (1915). With Kennedy (1974), we feel this distinction has been often overplayed and overinterpreted (see also Hochberg, 1995; Hochberg, chap. 1, this volume). Instead, in the pictorial medium that is the oldest to our species, the communicating elements are *lines,* and it is in understanding line drawings that cognition appears to play its clearest role.

III. THE BASIC PICTORIAL ELEMENTS

Whether one drags a finger across the sand, a burnt stick across a wall, or a pencil across a sheet of paper, the result is the same; one has drawn a line, a marking of more length than width. Lines are part of the root elements of pictures; they are abstract, they are surrogates, they have power to represent, and most importantly they communicate form and depth. They are only a part of the root elements because their perceptual and cognitive impact does not accrue from their isolation; their impact depends on their juxtaposition to two vacant, adjacent pictorial areas along their flanks. We will call each such area a region. Both lines and regions are often part of depicted objects, and regions are often part of the background. More importantly, it is the relation between lines and regions that creates objects and layout within a picture.

We claim the various line–region combinations exist in four basic forms. They create pictorial objects, edges of objects, cracks within or between objects, and texture. Interestingly and importantly, these four line–region types are present in the oldest yet-discovered cave paintings (see Chauvet et al., 1995). Thus, no development, no sequence of discovery, no process of pictorial understanding appears to mark their use. For these reasons, these four types of line–region appear to be good candidates as primitives for pictures—and of course they are in good use today by artists (e.g., Hirschfeld, 1970; Levine, 1976; Steinberg, 1966, 1982) and by children (e.g., Gardner, 1980; Kellogg & O'Dell, 1967; van Sommers, 1984; Willats, 1997).

A. Taxonomy of Pictorial Lines

> Intricacy of form, therefore, I shall define to be that peculiarity in the lines, which compose it, that *leads the eye a wanton kind of chase,* [italics in original] and from the pleasure that it gives the mind, entitles it to the name of beautiful. (Hogarth, 1753, p. 25)

1. Lines as Edges

Perhaps most important pictorial elements are the lines that produce a segregation across regions, and this was Rubin's (1915) fundamental insight. That is, the presence of a line can make the region on one of its sides fundamentally different than that on the other (see also Hochberg, 1972). This type of line is an *edge*. The line-as-edge pictorially creates an object by representing its contour, and it dictates that the one region is closer to the observer in depicted space than the other. The line typically belongs to the object region, making its border; it does not belong to the background region.[10] Leeuwenberg's (1971; Leeuwenberg & Boselie, 1988) structural information theory made this relation formally explicit. Such lines often do not have free terminals, but either abut or join other edge lines, or curve eventually making a convex shape. When they do have free terminals they typically run in pairs into the central region of a larger convex shape, representing the contour of a part protruding from a larger object (see Koenderink & van Doorn, 1982). The perceived object lies generally within the convexity of the line, and the line denotes the object's self-occluding contour or shape, as seen from the perspective of the viewer.

Edge lines would seem to constitute the bulk of all large traces in line drawings, and they are also the grist for a plethora of visual illusions. Many cases of multistability are predicated on the reversal of polarity in depth of the two regions around lines-as-edges, and many cases of impossible figures are predicated on different assignments of depth to regions along the same line (cf. Figure 11 in Hochberg, chap. 9, this volume). Edge lines form the basis of the Rubin's (1915) faces–goblet illusion (which was commonly invoked with real goblets in the Victorian era with the profiles of Victoria and Albert on opposite sides; see also Hoffman & Richards, 1984, for an earlier attribution); they play in Ratoosh's (1949) figure of ambiguous interposition; they beguile in central regions of Schuster's (1964) devil's pitchfork; and they delight in many more. See Figures 1a–1d, and see also Kanizsa (1979), Robinson (1972), Rock (1984), Shepard (1990), and Gillam (chap. 5, this volume).

2. Lines as Objects

Some pictorial lines represent long, thin *objects*—trees, branches, or twigs; the horns or legs of animals; the fingers of a hand, or eyebrows; television antennae; and as suggested above, functions on a graph. An early television antenna is suggested in Figure 1e.[11] Such lines cut through a background but in an important sense do not segment it; the region on one side of the line is to be interpreted as made of the same stuff as the region on the other, be it atmosphere, ground, another object, or

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[10] This claim is different from Leonardo's (Richter, 1883, p. 29), who suggested that an edge line did not belong to the object and, although of infinite thinness, lay between the object and the background.

[11] These lines have also been generalized to create entities that are not really objects at all, rays of light, or even motion. For example, Gombrich (1972, p. 229) noted: "There is hardly a picture narrative in which speed is not conveniently rendered by a few strokes which act like negative arrows showing where the object has been a moment before." It may be that Töpffer invented this technique in the mid-19th century (Groensteen & Peters, 1994), and these lines, symbolically or otherwise (Rosenblum, Saldaña, & Carello, 1993), act as emblems denoting motion. See also McCloud (1993) for an illuminating discussion of such lines in contemporary comics.

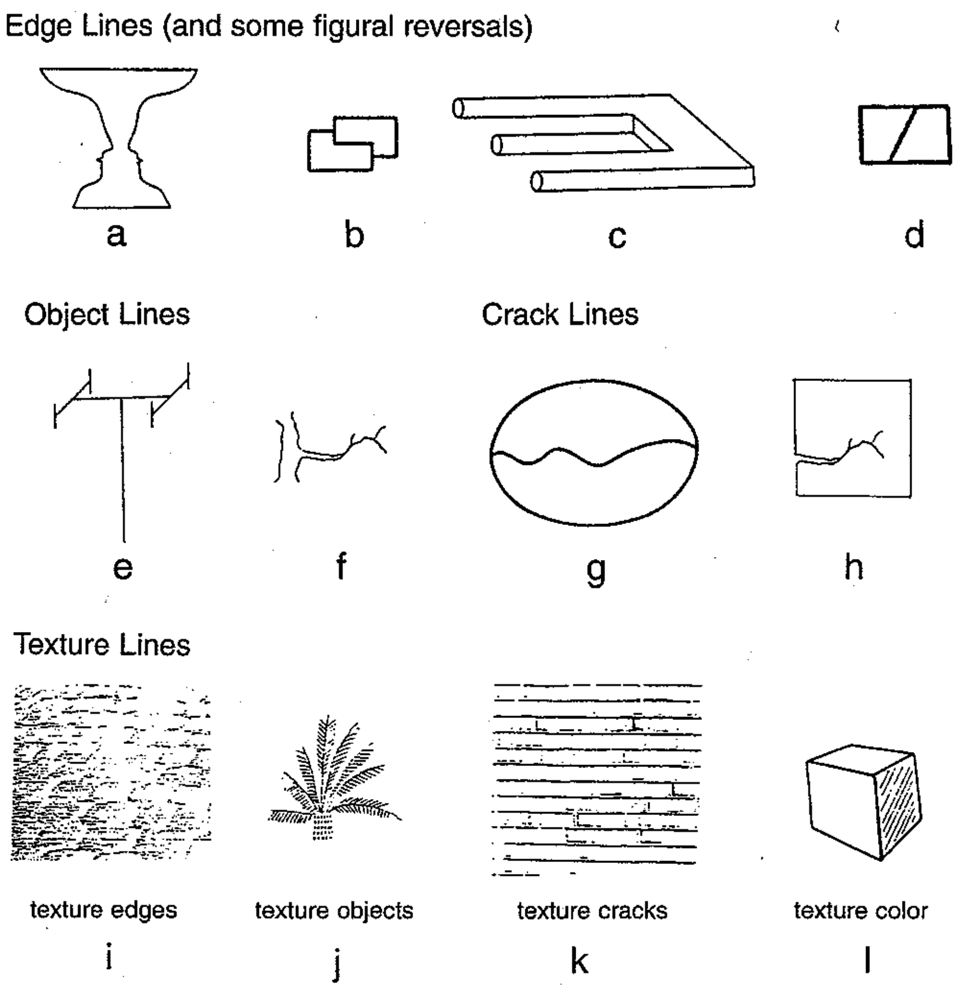


FIGURE 1 A taxonomy of lines. Edge lines separate the regions on either side and assign them different ordinal depth. Four figures that play with this relationship are shown: (a) the faces/goblet illusion, after Rubin (1915); (b) an ambiguous occlusion figure, after Ratoosh (1949); (c) the devil's pitchfork, after Schuster (1964); and (d) a rectangle/window, after Koffka (1935). Second are shown some object lines: (e) is a mid-20th century version of a television antenna; and (f) shows the twigs at the end of a tree branch. Third are figures with crack lines: (g) is the mouth of a clam, after Kennedy (1974); and (h) is a crack in a block. Note that (f) and (h) are exact reciprocals—switching from an object-line to an edge-line interpretation. Finally, four texture line types are shown: (i) texture edges and color in cobblestones, after de Margerie (1994); (j) texture objects, after Steinberg (1966); (k) texture cracks, after Brodatz (1966); and (l) texture color, indicating shadow.

graphical space. Moreover, such a line represents an object in front of the two regions; that is, the layout of the picture is such that whatever is on either side of such a line is farther from the observer than is the object depicted by the line itself. Lines-as-objects typically terminate freely at one or both ends, with the surrounding regions often, but not always, wrapping around the point(s) of termination.

When an object represented by a line gets sufficiently large, the line-as-object bifurcates and becomes two opposed lines-as-edges, as suggested in the tree branch of Figure 1f.

3. Lines as Cracks

Some lines represent a rupture in a continuous surface, drawn as an edge shared between two similar objects, or parts of an object. Following Kennedy (1974), we will call these *cracks.* Some such lines are drawn to represent, for example, the small gap between elevator doors; or, on a face, a mouth (the shared edge between the upper and lower lips), a shut eye, or a crease in a forehead. A clam's mouth is suggested in Figure 1g. When cracks get sufficiently large, the line representing it bifurcates and, as with object lines, becomes two lines-as-edges, as suggested in the lower right panel. Except in portraits and other drawings involving animals and people, however, single lines-as-cracks appear to be relatively rare in pictures. Perhaps this is because, when they exist outside of faces, they are often relatively unimportant. See Stevens (1974) for a discussion of the structure of natural cracks.

Just as there can be ambiguity with edge lines, there can be ambiguity between objects lines and crack lines. Koffka's (1935, p. 153) example of a rectangle and line, shown in Figure 1d, is a case in point. The figure can be seen many ways; for example, as a rectangular figure with a diagonal cut through it (leaving a crack), or a rectangular window with a diagonal wire (an object) crossing behind it. Notice that, here, as the object and crack interpretations interchange, so typically does the polarity of the edge line around the rectangle. Compare also with Figures 1f and 1h.

4. Lines as Texture, as Mass

Finally, perhaps the second most important type of line is typically quite short and drawn in groups, repeating the same stroke successively or repeating it with some patterned deviation. These are *texture.* Such lines are usually close to one another, with correspondingly smaller flanking regions. Indeed, these lines are often as much as, or more than, an order of magnitude closer together than nontexture lines, and thus their regions are correspondingly smaller, even nonexistent. Texture lines tend to cover a surface, even overlap it, which is often defined by an edge line. On the larger scale of the picture the small regions between lines, together with the lines themselves, both become aspects of the texture of a surface. Hair, grass, waves, cobblestones, cloth, glass, and shadows are often drawn with such lines and their impression creates a sense of smoothness or roughness, softness or hardness, blockiness, transparency, or opacity. In the traditional art literature these are called *mass* (e.g., Speed, 1913; see also Baxandall, 1995), and Hayes and Ross (1995) have suggested ways in which they are processed differently by the visual system than the other types of lines. A few examples of texture are shown in Figures 1i–1l. Closer inspection reveals these textural elements subdivide, and some have the same general properties as the first three classes of lines only at a smaller scale, giving the structure of many pictures a fractal-like quality.

a. Texture-Lines-as-Edges

These depict small objects nested within a larger object. Examples include depictions of cobblestones in a street (Figure 1i), the patternings in tree bark on a trunk, or waves on a large body of water. Each such edge has a near side and a far side, but in a drawing or painting seldom is there any attempt to draw all cobbles, all bits of bark, or all waves. What is drawn are only a few emblematic strokes. Gombrich (1979) called this the etcetera principle, and it is applicable to texture of all types.

b. Texture-Lines-as-Objects

These appear on larger objects. Examples include palm fronds (Figure 1j), ripples on a pond, hairs on a head, fur on a pelt, and grass on a lawn. In such cases each line represents a single small object. Moreover, at a particular local pictorial depth around the stroke each such texture line appears against a pair of regions of slightly greater depth.

c. Texture-Lines-as-Cracks

These may or may not create small objects, but they always make patterns on a larger object. The mortar lines between bricks are created by texture lines (Figure 1k) and designate small objects within a larger one, but the tessellated cracks in the dried mud of a lake bed do not inherently create smaller objects; they are simply texture patterns on a large objects. But in each case what lies unseen inside the crack is at a slightly greater depth.

d. Texture-Lines-as-Color

These typically represent shadow or different shades of lightness (e.g., Figure 1l). Thus, they are surrogates for achromatic color. At a normal viewing distance from the picture, dark lines and tightly spaced light regions tend to assimilate and approach a gray. No depth relations are implied, except perhaps as inferred by a light source. For examples and discussion, see Baxandall (1995), Cavanagh and Leclerc (1989), Hayes and Ross (1995), and Wade (1995).

5. Overview

Logically, these line types create many spatial, scalar, and segmental possibilities. First, the layout of the surface of the picture can mimic spatial properties of an optical array. That is, what is on the left of the picture is to the left of the viewer's central visual field, what is on the right is on the right, what is near the top of the picture is above the level of the viewer's eye, and what is at its bottom is below it, and everything else ordinally in between. Such relations were axioms in Euclid's optics (Burton, 1945), and we will return to this idea. Second, global differences between large and small are often denoted by the difference between lines depicting objects and their edges (whose regions are relatively large) and lines depicting texture (whose regions are relatively small). Moreover, in architectural drawings and in engravings, intermediate scale differences can also be carried by variations in line width, with larger lines binding more important aspects of the picture, intermediate lines binding intermediate-size objects, and smaller ones associated with texture. And finally, most of these lines are used to segment objects and parts of objects in depth. Let us develop this latter idea in more detail.

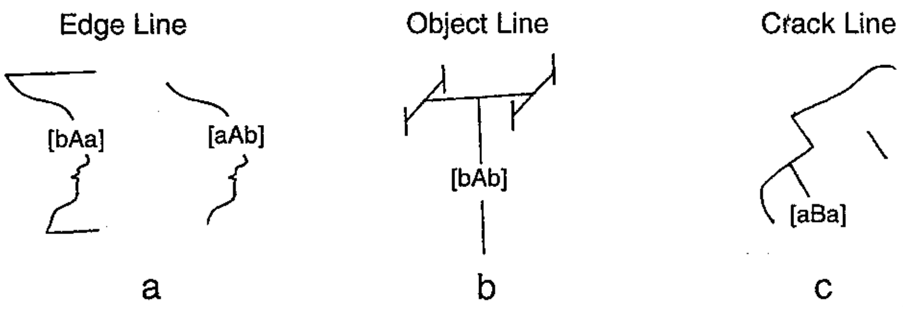
B. From Phenomenology to Structure: How Lines Create Local Pictorial Depth

> We stick to the convention that a wall or a piece of paper is flat, and curiously enough, we still go on, as we have done since time immemorial, producing illusions of space. (Escher, 1967, p. 15)

Locally, lines and regions appear to depict as many as, but no more than, two implicit distances from the observer, which we will call *depth A* (the nearer) and *depth B* (the farther). Thus, the specified local depth around a line is always ordinal (see also Hochberg, 1995); that is, one can never know (and we would claim one shouldn't be expected to know) how much distance is between depth A and depth B, only that the first is portrayed to be closer to the observer. Moreover, given the plethora of possible perceptual ambiguities of relative depths around lines in line drawings, depth assignment appears to be done cognitively. Locally, edge lines, objects lines, and crack lines can all appear identical; their ability to trigger recognition appears part and parcel of their ability to assign depth structure.

1. Local Depth Discontinuity from Lines-as-Edges

Figure 2a again shows part of Rubin's figure but superimposed on the right side are the depth relations for a line-as-edge when seen as a face; the line itself is at depth A and is attached to the region to the left, which is also at depth A. Thus, the line belongs to a depicted object. The other region, to its right, is at depth B and belongs to the background. The left side of the figure is reversed, for the goblet interpretation. We will code such configurations [aAb] or [bAa] as one runs across the region/line/region configuration, where a capital letter indicates the local depth of a line and a lower-case letter the local depth of the associated region. Many things enhance the interpretation of such lines as edges and the determination of which region is nearer, such as curvature (objects tend to be seen within the convex side of the line; see Attneave, 1954; Hoffman & Richards, 1984). Relations among shape curvatures can also suggest three-dimensional form (see Koenderink & van Doorn, 1976; Koenderink, 1990; Richards et al., 1986, 1987).



from paired edge lines to a crack line

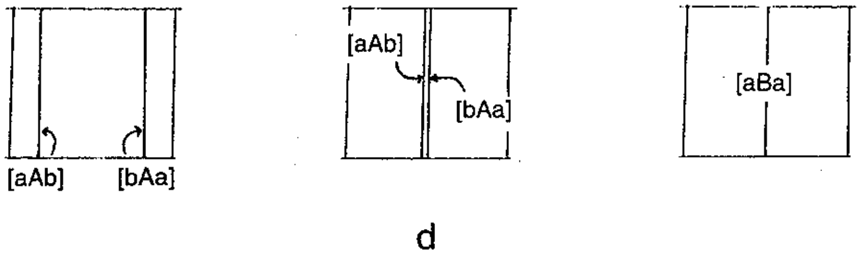


FIGURE 2 Ordinal depth relations implied by three types of lines. Lines are coded by capital letters; regions by lower-case letters; and depth by ordinal position in the alphabet. In (a) the reversible edge lines in Rubin faces/goblèt shows an edge of [bAa] for the left-hand edge in the goblet interpretation and [aAb] in the face interpretation. In (b) the object line seen as an antenna shows depth relations of [bAb]. In (c) the crack line of the mouth in the upturned, sleepy face is interpreted as [aBa]. The process of how paired edge lines can become a crack line is suggested in sequences in (d), for elevator doors.

2. Local Depth Discontinuity from Lines-as-Objects

Figure 2b shows the schematic depth relations for a set of object lines, representing an antenna. The lines are at depth A and the two adjacent regions are both at depth B. We will code such configurations [bAb] for the depth relations running across region, line, and region. Such lines-as-objects are always part of the nearest local depth to be seen and the line-as-object is itself different than, and in front of, the regions on both sides, which are at the farther local depth. According to our analysis, because only a two-valued ordinal depth pattern is possible, both sides of the background must be generally at the same depth. A more conservative version of this idea, however, can be seen in the consideration of slanted surfaces, particularly of a ground plane. In Figure 3, there is a schematic tree and a horizon line behind it. One can assume that the ground plane as it is represented on either side of the tree is behind the tree, but the ground plane below the trunk (where the line terminates) is in front. The relation of this terminal to the horizon is the only information available about the slant of the ground surface. We will return to this figure later in applying rewrite rules to depth order.

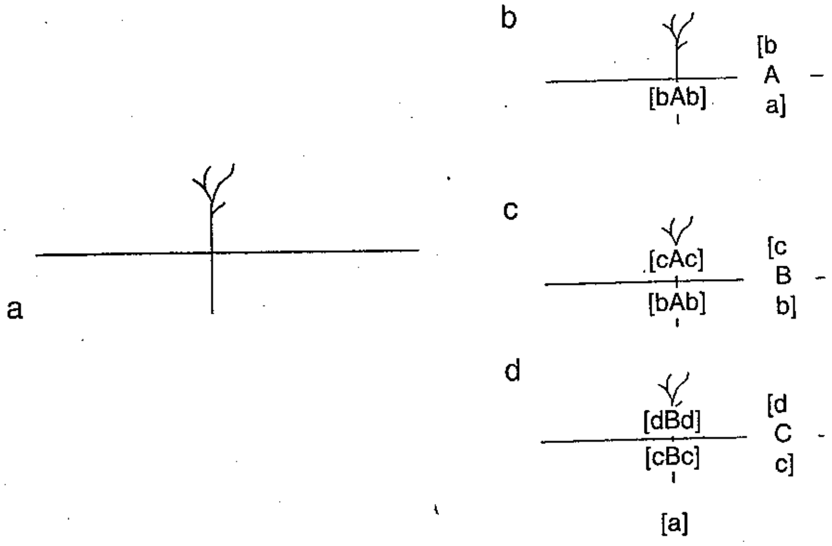


FIGURE 3 A tree in front of a horizon, and several stages of rewriting depth rules to build up depth.

3. Local Depth Discontinuity from Lines-as-Cracks

In Figure 2c is a schematic face with a mouth marked by a sideways T. Since the near vertical line is interpreted as the edge of the profiled face, then the horizontal branch is a crack representing the mouth. Such line–region configurations will be coded [aBa], the opposite local depth polarity to lines-as-objects. This is the only case where the line represents something at more distance than the neighboring regions, so let us offer proof of this relation. Consider the drawings in Figure 2d, representing the closing of elevator doors. As the doors close, the two door edges (reading left to right) are represented as [aAb] and [bAa], respectively. Notice that the line edges themselves belong to the doors. But when the gap between the door is too small to represent with two lines, the representation changes. The line now belongs to the gap that disappeared, and represents the spatial arrangement of [aBa]. Thus, [aAb] + [bAa] → [aBa].

4. Local Depth Continuity and Lines-as-Texture

At a global level (that is, with respect to the whole picture) small texture lines do not really segregate their regions; both lines and regions are part of the same entity (the texture elements) and are at the same general depth and create mass (e.g., Speed, 1913). Thus, although texture edges, texture objects, and texture cracks denote particular depth relations at a local scale, at the level of the whole picture we propose that all texture should be notated as [aAa]; suggesting that texture is interpreted as markings on a surface (Ittelson, 1996), generally as shadow, or as color.

C. Toward a Grammar of Multiple Lines and Regions: A Sketch of How Pictorial Depth Is Built Up

> The information in a line drawing is evidently carried by the connections of the lines, not by lines as such. (Gibson, 1979, p. 288)

From the local depth relations inherent in lines, and from a few constraints concerning the lines themselves, we can begin to formulate a grammar of pictorial lines and regions. Lines can end in three ways: they can terminate freely, join another line end, or abut a line flank. For the latter two cases let us establish some nomenclature: Lines typically meet at places we will call *junctions.* In general there are three types of junctions: (a) *joins,* which are of two types: the first occur where the end of one line meets the end of another (although sometimes there is a small gap), which we will call an L-junction (although the two lines, of course, need not meet at right angles—indeed, any angle will do). The second occur where one line meets at the ends of two or more, which we will call a Y-junction. Next there are (b) *abutments,* where the termination of one line is generally against the flank of another, which we will call a T-junction; and (c) *intersections,* where two or more lines cross, which we will call an X-junction. Anderson and Julesz (1995) partly developed a similar system.

1. Joins or L- and Y-Junctions

L-junctions have strict interpretation. Each line must be the same type; other combinations, we claim, would be agrammatical and lead to illusions of depth. Thus, an edge line can only meet another edge line with the same polarity ([aAb] or [bAa]), an object line can only meet another object line, and a crack line can only meet another crack. Y-junctions are even more restrictive; line elements are generally all objects or all cracks, and no mixtures or edges are allowed. Edge lines are generally excluded due to the unlikely co-occurrence of a bend in the edge (or contour) of one object and the intersection of the edge of an occluded object behind it. This is a version of what is sometimes called Helmholtz's rule (see Hochberg, 1971) or more generally a nonaccidental property (see Witkin & Tenenbaum, 1983).

2. Abutments or T-Junctions

These come in several kinds. The line elements could be homogenous: a T-junction could be made of object lines, as in Figure 2, or of crack lines. They could also be made of edge lines. For example, if one interpreted Koffka's rectangle in Figure 1d as a rectangular window with the edge of an object partly seen (with open background on the other side), then there are three ordinal depths—the window edge, the object edge, and the background. On the other hand, the line elements could be inhomogeneous. Consider again Koffka's rectangle. If one sees a wire behind the window, the object line (wire) abuts the edge line and is at a different (farther) distance. Abutments of the shaft at a nearer distance would imply an accidental property, and are typically avoided in pictorial representations (but see Hochberg, 1995).

3. Intersections or X-Junctions

These come in two types, again homogeneous and inhomogeneous. Homogeneous intersections occur when all four lines are objects or cracks, and thus they are no different than Y-junctions. Inhomogeneous intersections are more interesting, where an object line can cross an edge.

4. An Example of Building Depth

Consider the example of a tree crossing the horizon line in Figure 3a. Notice from Figure 3d that at least four relative depths can be built up: The ground in front of the terminal of the trunk is closest to the observer (depth A); the trunk is next (depth B); then ground behind the trunk (depth C); and finally the sky beyond the horizon (depth D). By our scheme, this is done in three ways, applying recursive rewrites of the spatial rules above.

a. Pass 1

Figure 3b is dominated by an X-junction. The whole line system, then, could represent a more or less X-shaped object, a mostly X-shaped crack, or an object and an edge. If the latter is entertained, the vertically oriented set of lines may be recognized as tree-like. Thus, this line and the regions around it are assigned depths of [bAb]. The horizontal line is an edge line; again reading upwards, it is assigned [aAb]. At the intersection, then, there is an inconsistency of depths. The horizon edge must be behind the object tree. (In X-junctions, edges are always behind objects, never the reverse, because edges belong to objects that are not usually transparent).

b. Pass 2

As shown in Figure 3c, these initial assignments must be then rectified. Given ordinal depths A and B, we can now assign further ordinal depths C, D, and so on. The object/tree line below the horizon remains [bAb]; the edge/horizon line becomes [bBc]; and the object/tree line above the horizon becomes [cAc]. Thus ordinal consistency is almost restored.

c. Pass 3

As suggested earlier, the space beyond the terminal of an object line is not necessarily at the same depth as the regions on either side of it. Thus, given that a horizon has been recognized, height in the visual field is now appropriate to the interpretation of the image, and the space below the terminal of the object/tree will be seen as closest to the observer (the ground occluding the roots of the tree). Thus, that space is now [a], the object/tree line below the horizon is [cBc], the edge/horizon line becomes [cCd], and the object/tree line above the horizon becomes [dBd].

We make no claim that this explicit order of recursion is a psychological instantiation of what actually happens. Nonetheless, we suggest that ordinal depth in a line drawing can be built up by lines and their intersections. We claim further that cognition, not perception, governs the assignment of depth and depth order through application of rules about lines and regions, and through recognition of objects that result from them.

D. A Note on the Problems and Successes of Linear Perspective

> The eye can never be a true judge for determining with exactitude how near one object is to another . . . except by means of . . . the standard and guide of perspective. (Leonardo, in Richter, 1883, p. 53)

Linear perspective, perhaps because at the end of the 20th century it seems to be the major predecessor to photorealism, has played a dominate role in discussions of picture perception. We believe that linear perspective is important but not fundamental to pictures. It is the fruit of a particular culture and requires much training to employ well. Its import here, however, is that linear perspective, along with its allied projections (see Carlbom & Paciorek, 1978; Hagen, 1986), create new pictorial elements—rectilinear surfaces. As suggested by Leonardo da Vinci, these play a powerful role in extending the interpretation of picture beyond the mere ordinality of lines. In our view, this power comes at a price.

Conflicts of depth arise in some of these projective representations—the Necker cube, Mach's folded sheet, and Schröder's staircase are but a few (see, for example, Robinson, 1972, p. 175; Gillson, 1996), as suggested in Figure 4. In each of these cases, the rectilinearity of surfaces has tried to replace lines as information about depth and shape. The result, for us, is that edge lines no longer can dictate which region is closer to the observer; many edges do not have either a near or a far side, and multistability results. This problem also plays itself out in the agrammatical figures of Escher (1967), based in part on Penrose and Penrose (1958).

The benefit of linear perspective, of course, is that with the use of projections of parallel lines one can build up a much richer representation of the geometric layout of a given space. To be sure, that space must be architectural, because parallel lines are exceedingly rare in nature, but the effect is powerful and robust (Kubovy, 1986).

Linear perspective is a system. It is a systematic combination of at least five "pictorial cues," or sources of information, some of which have been in use since the first pictures. For example, the Chauvet paintings show the use of both occlusion (near objects interpose and clip the contours of farther objects) and height in the visual field information (near objects attached to the ground are lower in the visual field than are farther objects of the same size). Evidence for the use of relative size (closer objects are depicted as larger than farther objects of the size physical size) existed in pre-Renaissance art and in traditional Japanese and Chinese art. Relative density (more objects or textures placed within areas representing more distance

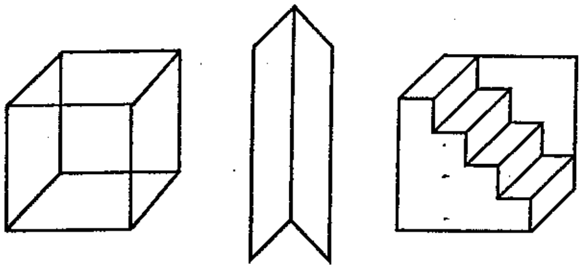


FIGURE 4 (a) The Necker cube, (b) Mach's folded card, and (c) Schröder staircase. We claim depth ambiguity occurs, in part, because the regions astride edge lines cannot be assigned ordinal depths.

regions) and aerial perspective (distant objects taking on the color of the atmosphere) arose in Renaissance times. A rigorous use of linear perspective incorporates all of these while copiously using linear, parallel lines. These lines are extremely effective in reducing noise in the assessment of the five sources of information.

We began this essay noting that pictures have a dual character—they are objects and they typically depict objects. We now believe that different information carries this dual quality. Cutting and Vishton (1995), for example, noted that picture perception is normally done at close range, and the other sources of information for depth—accommodation, convergence, and the lack of binocular disparities and motion perspective—all dictate that a picture is a flat surface. The traditional pictorial sources—occlusion, relative size, relative density, height in the visual field, and perhaps aerial perspective—indicate that a scene is depicted. Thus, pictures are a natural testing ground for the notion of "conflicting cues" (e.g., Woodworth, 1938), but the conflict is resolved by treating the picture either as an object, or as a depiction.

IV. SUMMARY

Pictures are ubiquitous in most cultures and times. Not surprisingly, then, they have exercised considerable influence on psychological theory over the course of this century. In particular, they have been used to shape and guide the forms of perceptual and cognitive theory. Those emphasizing cognitive influences on perception have generally chosen to illustrate their points with pictures that are simple line drawings (e.g., Rock, 1983); those emphasizing the relative independence of perception from cognition have, when using pictures at all, used pictures as rich in information as possible (e.g., Gibson, 1950, 1979). Any thorough investigation of pictures reveals it to be an extremely broad class, offering much to any theory.

From our perspective, pictures are a means of representation and communication. They, themselves, are typically two-dimensional objects crafted in such a way that the markings on their surface usually stand for (represent) something else, displaced in time and space. The information in the picture typically copies, mimics, or accentuates what might be available to the eye in a given situation at a given time.

Pictures allow an artist/draftsperson/photographer to share his or her ideas by selecting them from the indefinitely large number of things to represent. This selection is constrained by the purpose of the artist and the means of communication.

Because so much has been written, much of it quite excellent, about psychological aspects of photography (e.g., Pirenne, 1970; Scharf, 1968; see also Adams, 1980) and art (e.g., Gombrich, 1972; Hagen, 1986), particularly linear perspective (e.g., Kubovy, 1986)—all of which emphasize latter-day developments in the history of pictures—we have chosen to concentrate on primitive elements in pictures that have been with our species for at least 300 centuries. These elements are lines, considered in conjunction with their bordering regions. These lines appear to come in four kinds; they can represent edges of objects, objects themselves, cracks in objects, or texture on objects. Moreover, no process of development seems to mark their use; they can be found in the oldest art known (Chauvet et al., 1995; Lorblanchet, 1995). Each of these lines can be used to build up ordinal depth in a picture and in doing so seem unequivocally to invoke cognition in their perception. Later developments in pictures, particularly linear perspective and photography because of their richness of perceptual information, would seem to make the role of cognition less apparent, if not less important.

But most importantly, we claim that to understand the perception and cognition of everyday environments, one should also consider the perception and cognition of pictures. This is not simply because many psychological experiments use pictures as surrogates for everyday environments, but because, although we did evolve to look at natural environments, we emphatically did not evolve to look at pictures. Thus, pictures, insofar as they work, rely on preexisting capacities. They can be used as experiments, often naturalistic experiments, in discovering how we perceive and know what we see.

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Perception and Cognition at Century's End

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