CHAPTER 36

THEORETICAL APPROACHES TO PERCEPTUAL ORGANIZATION

Simplicity and Likelihood Principles

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1. INTRODUCTION

Our sensory receptors do not detect all aspects of the world around us. What information our receptors *do* manage to detect is integrated by the nervous system to yield perceptions of the world that are sufficiently accurate for us to identify visual objects, recognize speech sounds, and generally make our way around the world. The concept of perceptual organization is central to the key question of perception: how do we make the leap from the information detected by our sensory receptors, which some theories hold to be incomplete or at least ambiguous, to our perceptions of the world, which are typically accurate, unambiguous, and phenomenologically complete? Achieving this feat requires not just the *detection* of information from the environment but the *organization* of that information into veridical (accurate) and informative percepts.

The goals of this chapter are to describe the major theoretical approaches to perceptual organization and to present evidence relevant to these approaches. Two points should be made at the outset. First, the precise mechanisms that govern perceptual organization, and the rules by which these mechanisms operate, are not yet well understood. Second, and despite the former, the processes of perceptual organization are indispensable to understanding the pervasive fidelity (and the occasional infidelities) of human perception.

1.1. Basic Concepts

One example should demonstrate the problem. Consider the perception of an ellipse, as shown in Figure 36.1. When we view this pattern in isolation, it is usually perceived "veridically" as an ellipse drawn on paper. But when we view it in the context of a scene, as in Figure 36.1b, it is now perceived as a circle viewed at an angle. It should be clear that the elliptical pattern presented to the eye could represent either the ellipse of Figure 36.1a or a circle. In fact, the distal stimulus might even be a horizontally oriented ellipse (that is, an ellipse whose major axis is parallel to the horizontal) viewed from an extreme line of sight almost parallel to the plane of the ellipse. In any event, the decision our perceptual system makes may be based on information from the shape of the retinal projection of the stimulus, from its surrounding context, from memory about similar

Figure 36.1. The coupling of perceived shape and perceived slant. (a) An isolated ellipse; (b) the same elliptical shape in a scenic context rich with depth cues. For a variety of factors, including these depth cues and familiarity with the objects likely to occur in the scene, the elliptical shape is perceived in (b) as a round hoop oriented at an angle to the picture plane. ((b) From R. L. Gregory, *Eye and brain; The psychology of seeing* (2nd ed.). McGraw-Hill Book Co., 1972. Reprinted with permission.)

shapes seen in the past, from rules that are "wired" into our nervous systems, or from any combination of these.

Under rich, ecologically valid viewing conditions, where enough information arrives at the receptors to determine the precise identity and position of the stimulus, organizational processes are required to ensure that, for example, the various regions in the retinal mosaic are grouped together properly and the orientation of surfaces is specified accurately. But the need for organizing processes in perception is most critical when the information in the proximal stimulus (i.e., the information picked up by our receptor organs) does not sufficiently specify the distal stimulus (the object we wish to perceive). When this situation arises, the perceptual system may resort to heuristics to obtain an interpretation (or "hypothesis") regarding the distal stimulus, and no correct solution is guaranteed. Thus we must settle for what is at best an educated bet. For this reason, theories of perceptual organization must account for *errors* of perception that arise with imperfect stimulus information as well as for the cases when perception turns out to be veridical.

If conditions for perception are poor (e.g., if the viewing conditions are impoverished), no unique solution may be found; two or more equally good solutions may exist. This state of affairs is demonstrated with the Necker cube shown in Figure 36.2a. The Necker cube can be perceived with at least three different organizations: (1) as a two-dimensional design drawn on paper; (2) as a wire cube seen from above, Figure 36.2b; or (3) as a wire cube viewed from below, Figure 36.2c. Most observers (those who are aware of the alternative organizations of the stimulus; see Girgus, Rock, & Egatz, 1977) report that the Necker cube undergoes spontaneous reversals in its perceived organization, mostly between the two three-dimensional interpretations shown in Figures 36.2b and c. Such percepts that alternate between two or more distinct organizations are called *multistable* (Attneave, 1971). Theories of perceptual organization must account for some stimuli being multistable (and others not), certain organizations being preferred over others, and for the various parameters of multistability, such as the rate of perceived alternation, the role of attention, the role of familiarity with the alternative organizations, and the like.

The manner in which the parts of an object form a perceptual whole is another stock question facing theories of perceptual organization. Complex stimulus configurations, such as faces, are defined by the parts from which they are composed (eyes, noses, mouths, etc.) as well as by the arrangement of those parts. Similarly, simpler stimuli such as letters may be described by the arrangement of their component line segments or strokes. The organization of parts into global shapes is often assumed to be accomplished by *grouping* together subsets of parts into higher-order parts or features. Grouping can occur at several levels of hierarchy, with groups of lower-order features themselves being grouped into intermediate-level features, which are in turn grouped into higher-order features. Figure 36.3 shows some classic examples believed to illustrate what the rules of perceptual grouping might be; the putative rules themselves are discussed later in this chapter.

Theories of perceptual organization must also explain how *figure-ground segregation* is achieved in perception. The multistable stimulus shown in Figure 36.4 may be perceived as a white triangle on top of a black square that lies, in turn, on top of a white rectangle. Alternatively, it can be viewed as a black square, with a triangular hole cut out of its center, lying on top of a white rectangle. In the first case, the white triangular region is seen as a *figure* lying atop a black square, which serves as the *ground*; in the second case, the black square is seen as the figure, and both the white rectangle and the white triangular region are seen as part of the same continuous ground underlying the figure. Inspection of Figure 36.4 will show that yet other figure-ground organizations are possible.

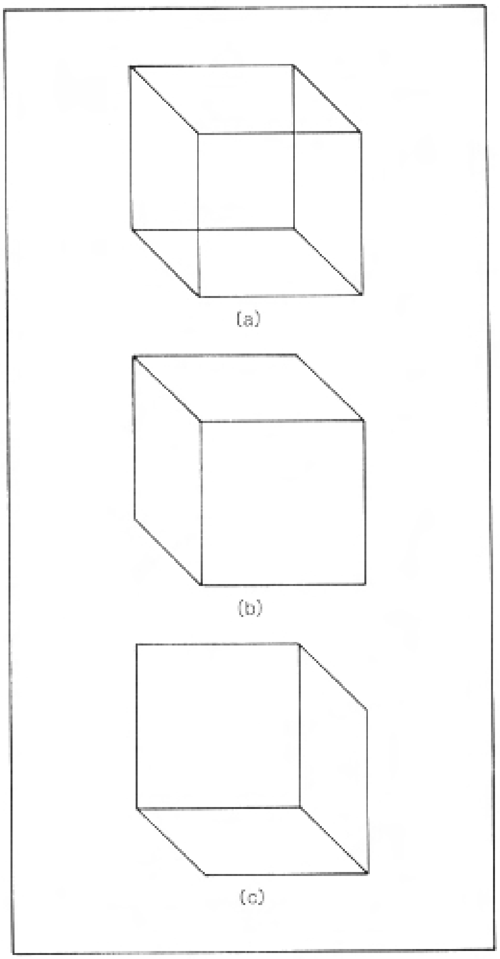


Figure 36.2. Three views of a cube. (a) The well-known Necker cube, a perspective drawing of a wire (or outline) cube. It is usually perceived in either of the two orientations shown unambiguously in (b) and (c) with solid cubes. The orientation of the Necker cube in (a) tends to change spontaneously for the observer, a phenomenon known as multistability.

1.2. Four Major Phenomena of Perceptual Organization

This chapter discusses theoretical approaches to perceptual organization and therefore should maintain a broad perspective on general principles. However, the only way to communicate these principles effectively is through a description of particular phenomena. At least two perils are unavoidable in this approach. The first is that the particular phenomenon we present to illustrate a general principle might prove to be a poor choice, even though the principle itself remains valid. Some of the phenomena we present are not understood thoroughly enough for anyone to proclaim them definitive illustrations of general principles. Second, it is possible that there are *no general principles* governing perceptual organization, in which case we would be left with a morass of independent phenomena, each requiring its own ad hoc explanation. If this were true, there would be

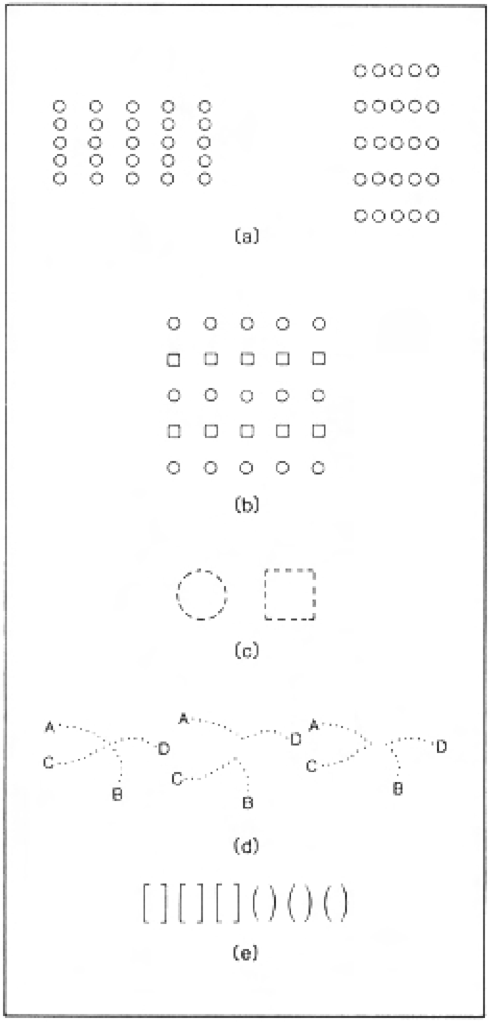


Figure 36.3. Illustration of five Gestalt principles of grouping. (a) Proximity: the dots tend to group into rows if the horizontal interdot spacing is less than the vertical. Otherwise they group into columns. (b) Similarity: the items tend to group into rows of identical shapes rather than into columns of alternating shapes. (c) Closure: when elements are arranged so they define a closed region, they will group together to form perceptually unified shapes. (d) Good continuation: elements will group so as to minimize abrupt changes in a contour's direction. Here, dots group into smoothly curving lines. At the point of intersection, the two lines of dots group such that the dots A and B belong to one line, and C and D belong to the other. The alternative groupings suggested to the right are not usually perceived. (e) Symmetry: elements will group in such as way as to maximize the symmetry of the resulting organization. We tend to organize the discrete elements into three pairs of square brackets and three pairs of parentheses. As the text indicates, there are many other laws of grouping. These laws are not inviolate, and their explanations are not entirely clear.

little need for any theoretical approach to perceptual organization as a whole; rather, an explanation for (or a mechanism capable of reproducing) each phenomenon would be sufficient. Given that this chapter is intended to discuss theoretical issues, we concentrate on evaluating correspondingly broad claims, in particular the *prägnanz* and *likelihood* principles.

The examples we have given are not an exhaustive compendium of the phenomena to be explained by theories of perceptual organization, but they do capture the breadth of the problem. We group the perceptual phenomena to be explained into four major classes.

1.2.1. The Problem of Perceptual Coupling. The shape of an image as projected onto the retina is a function of two variables: the shape of the distal object (or surface), and the orientation of the object with respect to the eye. This fact of optics creates a chicken-and-egg dilemma for perception: how can the true shape of the object be determined until its orientation is known, and how can its orientation be determined until its shape is known? It is easy to demonstrate that shape and orientation are coupled in perception. (For reviews of perceptual coupling see Epstein, 1982; Hochberg, 1981a, 1981b.) If the shape in Figure 36.1a is perceived as a circle, its perceived orientation will be different than if it is seen as an ellipse. Similarly, size and distance are coupled perceptually. Consider the ball next to the set of faces in Figure 36.5. If it is perceived to be the size of a ping-pong ball, it will be seen as nearer to the observer (and so closer in depth to one of the larger faces) than if it is perceived to be the size of a basketball. The perceived lightness of a surface and its perceived illumination are coupled as well. Given a patch of fixed luminance, the more strongly it appears to be illuminated, the darker its surface color will appear.

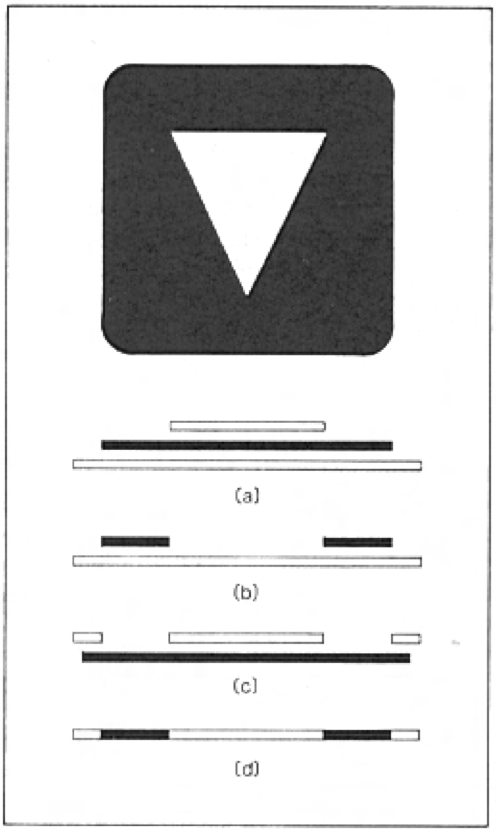


Figure 36.4. A multistable figure-ground demonstration. The pattern at the top can be perceived in several different depthful organizations, as indicated in the side views shown below. In interpretation (a), a white triangle is seen as lying on top of a black square, which in turn lies on top of the white page. In (b) the center white triangle is perceived as a hole cut through the black square; the white background of the page shows through the hole. In (c) the background is black; placed on this background are a white triangle and a large, surrounding white region with a square hole cut through. Finally, (d) shows an inlayed or mosaic interpretation, in which all regions lie in the same depth plane. All four of these interpretations are reasonable and correct. The fact that the interpretation in (a) is the one most observers prefer must be explained by the laws of figure-ground organization. (From G. A. Miller, *Psychology: The science of mental life.* Harper & Row, 1962.)

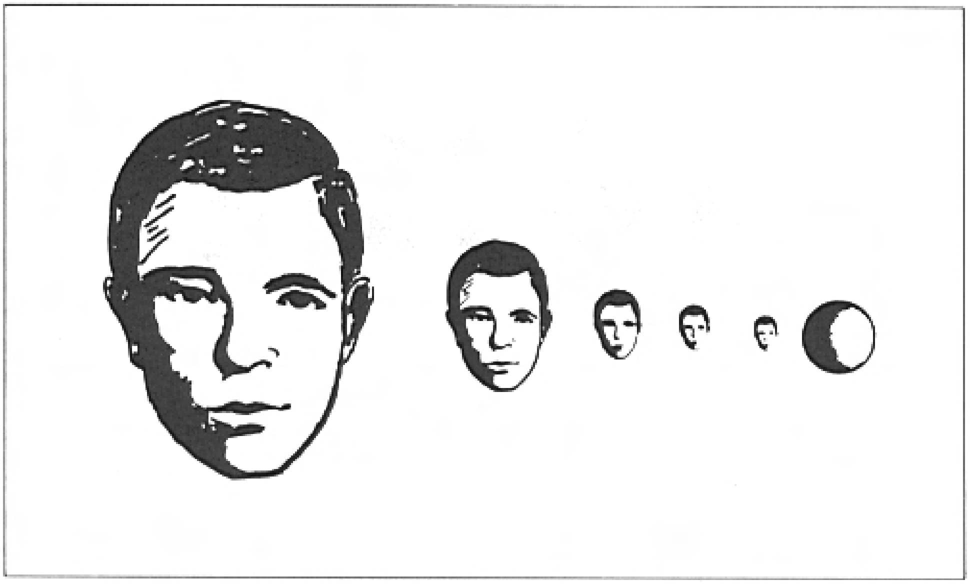


Figure 36.5. The coupling of perceived size and perceived distance. The size variations in the five faces shown make them appear to recede into depth, partly because the size of human faces is well known to observers. The ball on the right lacks any familiar size cue; it could be as small as a marble or as large as the moon. Depending on the size the observer assigns to the ball, its apparent position in depth changes. For example, if it is seen as a ping-pong ball, it will appear at about the same distance as the nearest face; if seen as the moon, it will appear behind the furthest face. (From G. A. Miller, *Psychology: The science of mental life*. Harper & Row, 1962.)

How the perceptual system achieves these couplings is the first of the four classes of problems. (See Rock, Chapter 33, Section 1.1, for arguments why coupling should be considered a problem for theories of perception in general and not of perceptual organization in particular.)

1.2.2. The Problems of Grouping and of Part-Whole Relationships. One of the enduring contributions of the Gestalt psychologists was found in their demonstrations of how the perception of a whole stimulus is different from the mere sum of its perceived parts: the organization of those parts makes further contributions to perception that can override the role of the parts considered separately. Two factors contribute to this organization (see Rock, Chapter 33): the grouping of parts into wholes, and the emergent features that arise from these wholes. (Cf. Koffka's, 1935/1963, pp. 132, 168, distinction between unit formation and shape and Metelli's, 1982, p. 223, distinction between an aggregation and a Gestalt.) The human face may be the quintessential whole, or Gestalt. It has been noted how a face may possess beauty although none of its features may be attractive; similarly, a face composed of attractive features is not guaranteed to be attractive. To take another example, consider a stimulus first investigated by Duncker (1929/1950). If a light is mounted on the rim of an otherwise unseen wheel, and the wheel is rolled across the floor, the light will be perceived (veridically) as following a cycloidal path. But if a second light is added at the hub of the wheel, the cycloidal path vanishes; the light on the rim is now perceived (again veridically) as revolving in a circular path about the hub light, as the whole wheel rolls across the floor. Thus the appearance of the whole (the constellation of lights) is quite different from the sum of the parts (the component lights) seen in isolation.

1.2.3. The Problem of Figure-Ground Organization. It is rare outside the laboratory for an isolated object to stand against a plain, unpatterned background. More frequently the eye regards a complex scene that is better described as a multitude of surfaces seen at different distances against varied backgrounds, with some surfaces occluding our view of others, casting shadows on others, and so forth (Gibson, 1979). Perceptually isolating a single object in a cluttered field is no minor accomplishment; merely deciding where one object stops and the next begins is a thorny problem in computational vision (see Barrow & Tenenbaum, Chapter 38), despite the apparent ease with which the human perceptual apparatus achieves rapid and (usually) veridical solutions. Identification of words in a speech stream poses a similar problem: in a speech spectrogram, it is not obvious to the eye where the boundaries separating the words lie. Figure 36.6 reproduces a well-known demonstration in which the visual system has difficulty determining which regions of the field are figure and which are ground. This demonstration illustrates the visual system's use of rules for deciding figure-ground assignments, rules that in this case lead to difficulty in perceiving a "hidden" but familiar stimulus (the word THE).

1.2.4. The Problem of Multistability. Multistable stimuli have played an important role in theories of perceptual organization. This is mainly because the flip-flop status of the perceived stimulus lays bare the operation of processes that are attempting to converge on a single, stable organization. Multistability implies that the rules of perceptual organization do not always impose a rigid, permanent organization on the stimulus. Instead, fluctuations in attentional processes, in the weights assigned to the various rules, or perhaps even in the neural substrates of perception can lead to changes in the perception of the stimulus. Multistable phenomena also remind us that we always perceive a single, internally consistent organization of the stimulus that does not involve compromises between the competing possibilities. Thus when we perceive the Necker cube of Figure 36.2a we experience at any instant a single, coherent

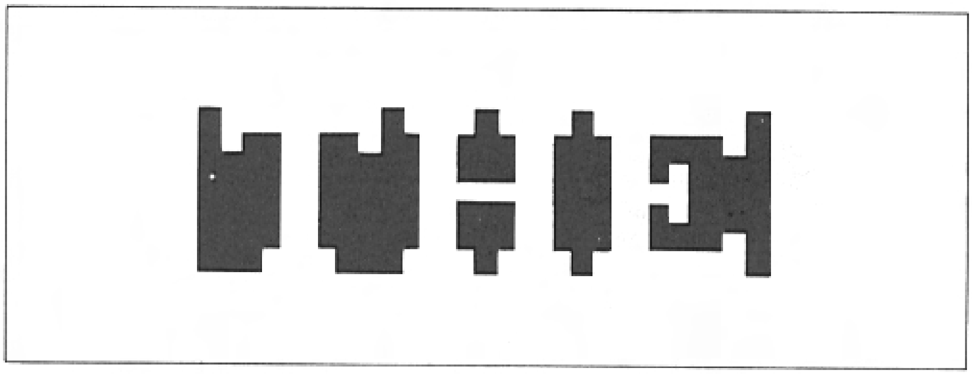


Figure 36.6. The robustness of figure-ground organizational rules. Naive observers perceive this pattern as six black rectilinear figures. If this figure-ground organization is reversed so the white spaces between the black regions are seen as figure, a common word will appear. The text describes a number of rules for figure-ground organization that make the hidden word difficult to perceive. (Adapted from G. Miller, 1962.)

organization of the stimulus rather than a jumble of organizational compromises in which one part of the pattern is seen in one three-dimensional orientation, another part is seen in an incompatible orientation, and a third part is seen as flat. This suggests that the overall organizational process is constrained to fit the stimulus into a unitary and internally consistent configuration. This idea is discussed further later.

1.3. The Central Questions Surrounding Perceptual Organization

The preceding section described four major phenomena of perceptual organization, but it presented no definition of the concept. Let us offer the following: perceptual organization is the process by which particular *relationships* among potentially separate stimulus elements (including parts, features, and dimensions) are perceived (i.e., selected from alternative relationships) and in turn guide the interpretation of those elements. These relationships can occur in space, time, frequency, and so forth (see Kubovy, 1981). Perceptual organization does *not* concern itself with the psychophysics of specific attributes such as loudness, except in cases where the perception of relationships or the effects of context arise. In sum, perceptual organization is concerned with how we process sensory information *in context*.

The principles of perceptual organization are more restrictive than the principles of perception itself. For example, there may exist stimulus properties that, although unquestionably perceptible, nonetheless play no role in perceptual organization. For example, there is little doubt that symmetry is a property of visual patterns that is often salient to the perceiver. However, it is a separate matter whether our perception is organized so as to maximize the degree of symmetry in our interpretation of the proximal stimulus. For example, in attempting to determine the orientation of an object in three-dimensional space, do we take into account the degree of symmetry associated with each potential orientation?

1.4. Distinguishing These Questions from Other Related Questions

The major focus of this chapter is on evaluating the two primary organizational principles that have some degree of plausibility. These are the principles of simplicity and likelihood. These principles suggest, respectively, that perception is organized to achieve the *simplest* or most economical interpretation of the stimulus, and that perception is organized to achieve the interpretation *most likely* to match the source of distal stimulation.

It is important to keep the distinction between these two organizational principles separate from several other distinctions. These others include the distinctions between nativism and empiricism, between "hardware" and "software," and finally between unconscious inference and direct perception.

The nativism-empiricism debate is among the most venerable and treacherous in psychology. In the words of Boring (1942), "No simple exposition of this great and largely fruitless controversy can, however, be adequate to its complexities" (p. 233). It is neither possible nor appropriate to take on that question in this chapter. However, there is an unavoidable link between the simplicity-likelihood issue and the nativism-empiricism issue. The link occurs because the principle of likelihood seems inexorably tied to an empiricist position, for what is likely in the environment must be learned. As we argue later, the internalization of these likelihoods (or ecological probabilities) could be learned ontogenetically or could be the result of phylogenetic adaptations on an evolutionary time scale. The simplicity principle is linked with a nativistic position, perhaps because the Gestaltists instantiated this principle with a model based on innate brain functions. However, organizing percepts on the basis of simplicity or economy could just as easily be a strategy learned during the organism's development. With practice, after all, humans learn to find parsimonious and elegant solutions to many sorts of problems, both intellectual and physical. The same could apply to the problem of organizing sensory data.

Our aim is to disassociate the issues of perceptual organization from the nativism-empiricism issue. These are two separate (albeit interrelated) issues. Ultimately we must determine whether the rules of perceptual organization are innate, are acquired, or (most likely) arise from some combination of these two. Where our rules come from, however, is a question for another time and place.

The second separate-but-related distinction concerns "hardware" versus "software," or (in roughly equivalent terms) whether our organizational tendencies in perception are imposed through fixed neurophysiological mechanisms or result from more flexible (and possibly voluntary) procedures. Not surprisingly, this question can become confused with the nativism-empiricism question if one assumes that neurophysiological mechanisms (hardware devices) are necessarily innately endowed and not acquired. However, there is no reason to suppose that brain mechanisms could not evolve during the lifespan of the organism. Again, we do not tackle this thorny problem in this forum; it is difficult enough to establish any broad principles of perceptual organization without at the same time taking on the question of whether these principles can be reduced to physiological mechanisms.

Finally, the distinction between unconscious inference and direct perception must be kept separate from distinctions involving principles of perceptual organization. The former contrast, discussed at length later, concerns whether perceptual interpretations are essentially inferences drawn from ambiguous stimulus information supplemented with information from memory, or whether there is enough information in the stimulus array alone to specify accurately and directly how the stimulus array should be interpreted, without need for inferences based on information stored in the perceiver's memory. The principles along which perception is organized are separate from processes (or mechanisms) that employ these principles. One could imagine, for example, an unconscious inference system striving to maximize either *likelihood* or *simplicity*. There may be some link between the unconscious-inference-direct-perception contrast and the empiricism-nativism contrast, but that is not directly relevant to principles of organization.

2. THE STRUCTURALIST, GESTALT, AND HELMHOLTZEAN APPROACHES

There have been three major approaches to perceptual organization. The first, Structuralism, denied the existence of the problem. The second, put forth by the Gestalt psychologists in reaction against the Structuralist solution, proposed that perception is organized so as to simplify the representation of the stimulus. The third approach, linked most clearly with Hermann von Helmholtz, also acknowledged the existence of the problem but held that likelihood, rather than simplicity, was the crucial factor in structuring perceptions.

2.1. The Structuralist View

In the Structuralist view no global processes are needed to integrate the component parts of a stimulus. The perceived whole is nothing other than the sum of its perceived parts. By the structuralist account, perceptual organization is not implicated in perception, except to the extent that a linear concatenation of parts (or simple sensory elements) is considered an organization of those parts. The Structuralist view holds primarily that there exist innately endowed sensory organs that relay to the brain highly specific and irreducible sensory elements (specific nerve energies, or most simply, sensations). Sensations leave enduring traces, called memory images, that can be evoked on subsequent encounters with the stimulus. Any nonlinear effects would have to be attributed to interactions of these memory images, not to elementary sensations. The brain at birth is seen as a tabula rasa, and so no specific structures exist for combining these elements into percepts, or do any preconceived links exist between sensations. Percepts instead evolve gradually over time as associations (learned by way of contiguity) link various memory images.

The main experimental tool of the Structuralists was *analytic introspection*: a "highly trained" observer would examine a stimulus closely and report verbally the primary sensory elements that stimulus evoked. The purpose of the training was to eliminate any learned interpretation of the stimulus (all associative embellishments that the stimulus might trigger) and to focus on the "pure" sensory responses engendered by the stimulus. For example, an observer asked to describe his or her perception of a red book lying on a wooden table would be admonished not to use the words "book" or "table" in describing the stimulus; instead, the book should be reported in less meaning-laden terms, such as a "reddish parallelogram," adjacent to (not "lying on") a mottled brown surface whose texture contained wavy streaks running roughly parallel to each other (not adjacent to a "table") (Köhler, 1929/1947, chap. 3; Miller, 1962). The verbal protocol resulting from such sessions formed the data base for the structuralist's explanation of perception.

2.2. The Gestalt View

The first major analysis of perceptual organization was provided by the Gestalt psychologists (most notably Koffka, Köhler, & Wertheimer), who in the first half of this century launched a counter-offensive to the then-prevailing Structuralist view. (For a review of this history see Boring, 1942.) The Gestalt view differed from the Structuralist view in almost every important feature, including the structure and function of the brain and the role of learning versus innate functions in perception. The widely heralded slogan of the Gestalt psychologists was that "the whole is more than the sum of its parts." Their claim was actually that "the whole is different from the sum of its parts," because in their view, "summing is a meaningless procedure" (Koffka, 1935/1963, p. 176; see also Pomerantz & Kubovy, 1981). However, even that rephrasing is problematic if summing is regarded as meaningless. Probably the best statement of the Gestalt view is that elementary parts or sensations interact nonlinearly in perception, whereas in the Structuralist view sensations are superimposed upon one another within a fully linear perceptual system (Kaufman, 1972).

Nevertheless, the commonly cited claim that the whole is greater than the sum of its parts correctly conveys the key notion that it is the particular *arrangement*, patterning, or organization of the parts into perceptual wholes that determines the apperance and identity of a stimulus; the mere enumeration of parts plays little (or sometimes even no) role in the appearance or identity of the stimulus. The Gestalt psychologists in no way denied the existence of parts, although that claim, as well, is often attributed to them. According to Köhler (1929/1947, p. 98), "No statement could be more misleading . . . one of the main tasks of Gestalt psychology is that of indicating the genuine rather than any fictitious parts of wholes."

The Gestalt psychologists put little weight on the role of learning in perception; learning was seen as a consequence, not as a cause of organization (see Köhler, 1929/1947, pp. 81, 158; see also Metelli, 1982, p. 228). Instead they placed the burden of perceptual organization on the innate structure of the brain. (Here we restrict our definition of learning to ontogenetic changes within an organism; later we discuss the possibility of phylogenetic adaptations.) They argued that the brain is structured to deal directly with the holistic properties of the stimulus, such as the configuration, symmetry, and closure of a visual form. Although conceding that the component parts of a stimulus can be attended to, the Gestalt psychologists argued that dismantling a stimulus into its parts is not the norm in perception and that such analysis can be achieved only through deliberate acts of scrutiny. These acts were not elaborated upon, but presumably they require unusual viewing conditions or attentional strategies, such as viewing a whole stimulus from so close a vantage point that only its details (and not its global structure) may be perceived clearly.

The Gestalt psychologists made their model of the brain's operations more concrete by borrowing from then-current notions of field theory in physics the idea that the brain could act as a volume conductor of electric currents (Köhler, 1920/1950; for a complete account see Köhler & Wallach, 1944). The brain was held to contain fields of electric currents whose topological configuration was believed to be isomorphic with perceptual experience. Koffka (1935/1963, p. 98) asserted that "Things look as they do because of the field organization to which the proximal stimulus distribution gives rise." According to the principle of brain-experience (or psychoneural) isomorphism, "all experienced order in space is a true representation of a corresponding order in the underlying dynamical context of physiological processes" (Köhler, in Boring, 1942, p. 303). Just as local perturbations in a field could alter the distribution of electric currents over great distances, so could a change in a local part of a stimulus alter the appearance of the whole stimulus pattern. Another metaphor for brain functioning is the soap bubble (Koffka, 1935/1963): applying a force to a single point on a soap bubble's surface film may produce wide-ranging distortions in the shape of the bubble. Similarly, Köhler (1929/1947, p. 77) advanced an analogy to the manner in which droplets of oil distribute themselves in a medium such as water.

2.2.1. Prägnanz. The field model of the brain was held to account for the specific characteristics (and not just the existence) of global or holistic processes in perception. According to the Gestalt view, the brain organized its representations of stimuli to make them into *better* patterns, just as a soap bubble automatically configures itself into the simplest possible form (i.e., the one that minimizes variations in surface tension and the total surface area required to contain a fixed volume; see Almgren & Taylor, 1976, and Boys, 1912/1959). Köhler (1929/1947) vowed that "Dynamic self-distribution in this sense is the kind of function which Gestalt Psychology believes to be essential in neurological and psychological theory" (p. 78). The Gestalt notion of *pattern goodness* is elaborated later, but for now we are concerned with only the claim that stimuli were organized in the way that most *simplified* their global structure. This organization rule, known as the *principle of prägnanz* (or equivalently as the *minimum principle*), is clearly the heart of the Gestaltist's view of perception. The rule of prägnanz constitutes a claim (both supported and refuted later in this chapter) that of all the alternative organizations possible for a stimulus, the organization perceived will be the one that is the simplest (or that minimizes the complexity of the stimulus, as the term minimum principle would imply). The prägnanz principle, devised originally by Wertheimer, was summarized by Koffka (1935/1963) as follows: "Psychological organization will always be as 'good' as the prevailing conditions allow. In this definition the term 'good' is undefined. It embraces such properties as regularity, symmetry, simplicity and others . . ." (p. 110).

2.2.2. Differing Conceptions of Prägnanz. Like many other concepts devised by Gestalt psychology, prägnanz has been interpreted in three different ways not entirely compatible with one another: (1) stimuli will be organized into the simplest possible configuration, even if that involves distortion of the percept with respect to the stimulus; (2) stimuli will be represented by the simplest, most economical description compatible with the physical stimulus; (3) stimuli will be organized using the simplest possible organizational mechanism.

The third interpretation can easily be dismissed. Although soap bubbles (and the like) provide a simple method for solving otherwise formidable geometric problems, this metaphor was adopted by Gestalt psychology because of the simplicity of the configurations it produces, not because of how simple those configurations are to achieve. Of course, parsimony dictates that the simplest mechanism consistent with available evidence be favored in constructing models, but that is not the point of prägnanz. Architects, biologists, and mathematicians use soap bubbles to help solve spatial problems in part because of the elegance and economy of the solutions achieved and in part because of the ease with which the solution is obtained (Schechter, 1984). Soap bubbles were used for such purposes before it was known exactly *how* soap bubbles achieve optimal spatial solutions to problems and before it was proven that they *do* do so. The prägnanz principle is a testable hypothesis that perceptions are organized so as to minimize their complexity. Our first order of business is to test this hypothesis. If it turns out to be correct, then the soap bubble should be pursued further as a possible model for how the prägnanz principle is instantiated.

The first two interpretations require a deeper analysis. The main difference between them is whether the organizational process will allow regularity to be imposed upon percepts at the expense of veridicality. It is not clear how far the Gestalt psychologists were willing to go in allowing a percept to be distorted in the interests of good configuration. On the one hand, they attempted to show how figures are altered in perception and memory in the direction of good or closed form. On the other hand, the law of prägnanz stated that psychological organization will be as good *as the prevailing conditions allow*. Even Koffka conceded that an observer, given a long, close look at an irregular form, would be unlikely to perceive it as a regular form. He did claim, however, that minor irregularities would be discarded in perception (or at least in memories of perceptions) and that even a conspicuously irregular form would be perceived primarily as a regular one with its irregularities (such as dents and protuberances) being perceived only secondarily.

Koffka (1935/1963, p. 138) distinguished between two kinds of organizing forces in perception, the external and the internal. The external forces were presumed to be retinal in origin and acted to make the neural representation veridical to the distal stimulus. The internal (or autochthonous) forces were those acting within the dynamic field of the brain, often in opposition to the external forces. Following Wulf (1922), Koffka noted that the internal forces could produce three types of distortions (1935/1963, p. 499): normalizing (distorting the representation in the direction of a familiar figure); pointing (exaggerating features of the configuration that are attended to); and most important, autonomous changes, which distort percepts in the direction of greater symmetry and better configuration. Although the evidence supporting autonomous changes is quite thin (Zusne, 1970), it is clear that Koffka allowed for some distortion or nonveridicality in both memory and perception of form. It is not clear, however, how large these distortions could become (cf. Attneave, 1982; Restle, 1982).

There is more to prägnanz than distortion aimed at achieving simplicity, however. For example, many of the Gestalt laws of grouping, illustrated in Figure 36.3 and reviewed in detail later, describe our perception of "what goes with what" in the perceptual field without necessarily entailing a distortion of our perception of the stimulus. (Coren & Girgus, 1980, found that elements in a visual array that are perceptually grouped appear to be closer together than elements that are not grouped. Although this indicates that grouping can lead to nonveridicality, the observed effect was quite small.) In view of the marginal evidence supporting the Gestalt prediction of distortion, it might prove more profitable to focus on the second interpretation of prägnanz given, namely, that stimuli will be organized in the simplest fashion possible consistent with the distal stimulus.

When the proximal stimulus fails to specify the distal stimulus uniquely, two or more interpretations may be equally possible and so be equally likely to be veridical. By the second interpretation of prägnanz, the simpler interpretation(s) should dictate the organization perceived. As we demonstrate later, the experimental evidence for this second version of prägnanz is much more favorable than for the first. But this evidence can be explained as well by the Helmholtzean as by the Gestalt approach.

2.2.3. Gestalt Methodology. The methodological sophistication of the Gestalt psychologists was comparable to that of the Structuralists, although the former group (sanctimoniously, it would seem) deplored the methods of the latter (Köhler, 1929/1947, chap. 3; Koffka, 1935/1963, chap. 3; but see Metelli, 1982, for a defense of the Gestalt scientific method). The experimental approach of the original Gestaltists, which has been improved upon in recent years, was based almost entirely on the *method of demonstration*. In this method the observer was asked to view a stimulus and to describe its apparent organization. These stimulus patterns were designed so that, in principle, a number of different and distinct organizations were possible. An example is shown in Figure 36.7a. This pattern consists of a row of equally spaced, alternating parentheses. This row could, in principle, be perceived as (1) an undifferentiated row of discrete elements that may be denoted as {1, 2, 3, 4, 5, 6}; or (2) as a row of elements perceptually grouped into pairs as {1, 2} {3, 4} {5, 6}; or (3) as grouped into the sets {1} {2, 3} {4, 5} {6}; or (4) as grouped into two sets as {1, 2, 3} {4, 5, 6}; or (5) as organized into any other possible grouping. Typically, observers report seeing the organization described under the second of the foregoing organizations. To the extent that different observers agree on the organization they report perceiving, we have evidence for rules of perceptual organization, rules that are claimed to produce the simplest possible organization of the stimulus.

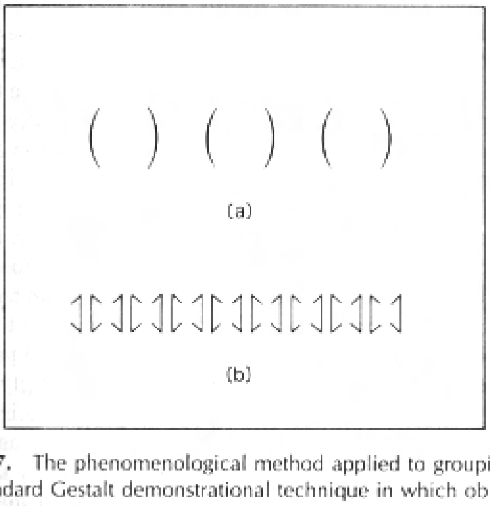


Figure 36.7. The phenomenological method applied to grouping. (a and b) The standard Gestalt demonstrational technique in which observers are asked only to view the displays and indicate how they appear to be organized. In both parts the preferred organization tends to produce pairs of adjacent elements that form closed figures. Part (b) is intended to show the factor of closure overcoming the effects of proximity and good continuation. [(b) Adapted from Koffka, 1935/1963.]

2.3. The Helmholtzean View

The third view of perceptual organization derives mainly from Helmholtz (1910/1962), although the ideas presented here come also from Hebb (1949), Hochberg (1978; 1981a), Brunswik (1956), and Gregory (1974). This view holds much in common with Structuralism; in fact, it can be thought of as an elaboration of Structuralism. The Helmholtzean view shares the Structuralist position that sensations are the starting point for perception and that sensations are combined with acquired associations (memory images) to complete the perceptual process. However, the Helmholtzean view is more flexible in that it allows the organization of sensations to extend beyond their mere concatenation. In fact Helmholtz (1910/1962) stated that "We are not in the habit of observing our sensations accurately, except as they are useful in enabling us to recognize external objects" (p. 6). Moreover, Helmholtz adds the *likelihood principle*, which states that sensory elements will be organized into the most probable object or event (distal stimulus) in the environment consistent with the sensory data (the proximal stimulus).

By the Helmholtzean view, the perceptual process acts as a problem solver assembling clues to form the most likely hypothesis that matches the facts to an acceptable goodness of fit. Although the reasoning processes involved in problem solving are often available to consciousness, perception (according to Helmholtz) proceeds by way of *unconscious inferences*. In fact, not only are the inferences of perception unavailable to consciousness, but also conscious knowledge per se does not affect perception. Our conscious knowledge that the Necker cube (a drawing on paper) is not changing has little effect on its multistable perception. Despite psychologists' concern over the *stimulus error* ("confusing our knowledge of the physical conditions of sensory experience with this experience as such"; Köhler, 1929/1947, p. 95), most organizational effects persist when the observer learns the characteristics of the true (distal) stimulus. The goal of perceptual theories is to determine what sensory evidence (clues) is available to perception and how this evidence is weighted or combined to determine what we perceive.

The Helmholtzean approach shares little with the Gestalt view save for the agreement that percepts can be organized in ways that go beyond the simple concatenation of parts. First, the Helmholtzean view places great emphasis on learning and little emphasis on the hard-wired organization of the brain (although the response characteristics of the receptors are important to this view because these determine the raw material on which perception operates). Second, Helmholtz believed that perception follows logical rules of inference not unlike those used in thought; the Gestaltists, by contrast, rejected this idea (Kanizsa & Gerbino, 1982). The third and most crucial point of contrast is Helmholtz's commitment to the likelihood principle as opposed to the Gestalt alignment with the minimum principle. Finally, the methodology underlying Helmholtzean investigations more easily allows for proper experiments (often in the psychophysical tradition) to demonstrate specific predictions, for example, regarding learning processes or the utilization of certain cues in perception; the Gestalt commitment to innate and sometimes mysterious brain processes made experimentally testable hypotheses somewhat harder to come by.

How would the Helmholtzean view accommodate the prägnanz principle, if sufficient evidence were available to support this concept? The most direct approach would be to claim that "simple" interpretations of the stimulus are in fact the most likely. This point of view was stated succinctly by Attneave (1982), who argued that "a possible distal source that contains certain regularities . . . is more probable than one that does not, or one that contains them to a lesser degree" (p. 21). That is, if, of the various possible interpretations of the proximal stimulus, one stands out as highly regular and symmetrical, then that interpretation is likely to be the veridical one. This view represents an educated guess not that the world is simple but rather that it is more likely that a detection of good configuration represents a "hit" than a "false alarm." (See Hoffman & Richards's, in press, notion of deception probability.) For how probable is it that a distal stimulus that is a poor configuration would arrive at the receptors as a proximal stimulus that could be interpreted as a good configuration? The optical transformation of a visual stimulus from distal to proximal entails distortion, but this distortion is much more likely to destroy symmetry than to create it.

2.4. The Gibsonean View

Before examining the evidence bearing on the Gestalt versus Helmholtzean approaches, it is important to acknowledge yet other views of perception that are not allied with either camp. Most prominent among these is the *direct perception* view of J. J. Gibson (1950, 1966, 1979). According to Gibson, perceptual organization is not a problem for theories of perception because our percepts are organized in a way that parallels the environment. In other words, the organization resides in the stimulus, and no special organizational processes (operating either by unconscious inference or by automatic, *autochthonous* brain forces) need be hypothesized to account for the structure of our percepts. Rather, our perceptual systems need only be tuned somehow (the precise mechanism was of no particular concern to Gibson) to pick up the structure ("affordances") of the environment from the stimulus array available at the receptors.

According to Gibson, it is only under abnormal, ecologically invalid conditions of perceiving that any contribution of the perceiver to organization manifests itself. The primary perceptual phenomena used to demonstrate such contributions (e.g., multistable stimuli) are mere laboratory contrivances that seldom occur under ecologically valid conditions. Ordinarily, information in the proximal stimulus *overdetermines* the distal stimulus; there is such a wealth of diagnostic information available to the receptors that no inferences or other mental processes are needed; normally, only one distal stimulus is commensurate with the sensory data.

One of Koffka's (1935/1963) answers to his own question, "Why do things look as they do?" was, "Because the proximal stimuli are what they are." In other words, the stimulus itself contains all the information needed to direct its organization in perception. This answer parallels the Gibsonean position that all the information necessary for veridical perception is available in the stimulus array that meets the receptor surfaces. Koffka explicitly rejected this answer on the grounds of multistable percepts, filling-in of the blind spot, and the like. Gibson's position is that the organization we perceive actually exists in the physical stimulus distribution. Köhler (1929/1947) dubbed this reasoning the "experience error," in which "certain characteristics of sensory experience are inadvertently attributed to the mosaic of stimuli" (p. 95).

Gibson has persuaded many psychologists that there is more information in the stimulus than they realized previously. In fact, some of the dilemmas of perceptual theory (e.g., which of the infinity of distal stimuli does the proximal stimulus actually indicate?) disappear under Gibson's analysis. For example, the distal shape that produces a given retinal shape can be determined from invariances picked up regarding texture gradients on the shape's surface, motion parallax produced by movements of the perceiver relative to the object, and so forth. When outline shapes drawn on paper are flashed tachistoscopically to observers, such invariances disappear, and the distal stimulus may no longer be overdetermined. Gibson (1979) conceded that under such impoverished viewing conditions, multistability may surface and cognitive factors may begin to affect perception. In sum, Gibson's most important and lasting contribution centers around his insight that there is rich information in the stimulus that may eliminate the need to resort to information from memory and to inferences to disambiguate and organize the stimulus. This emphasis on exploring useful diagnostic properties of the proximal stimulus is one major component of the computer vision approach discussed by Barrow and Tenenbaum in Chapter 38.

Granting Gibson his due, most perceptual psychologists still believe that the contribution of the observer to perceptual organization is a necessary topic of inquiry. Their reasons are many and varied, but they include at least the following five (see Gregory, 1974, pp. 273–274, Hochberg, 1978, pp. 130–131, for further reasons). First, although some of the information necessary for a veridical organization of the stimulus may reside in the stimulus itself, there is no evidence that *all* (or even most) of it is there, even under "ecologically valid" viewing conditions. The status of this claim must await more detailed investigations of the stimulus of the kind performed by Gibson himself, by Lee (1974), Shaw and Turvey (1981) and others. Second, even when the information in the stimulus is sufficient to specify the stimulus unambiguously, it must be shown that the necessary information is detectable by the observer. It is necessary but not sufficient to show only that the information is available in the proximal stimulus. Consider the case of texture information, an example drawn upon heavily by Gibson himself. As Julesz (1981) has shown, humans are not sensitive to certain "higher-order variables" of texture that are physically available and that could be used for figure-ground segregation and stimulus discrimination. Third, even if the necessary stimulus information exists and can be detected, that too does not guarantee that the information is in fact used by the observer. Granting the artificiality of laboratory viewing conditions, observers in ecologically valid situations may, in effect, impose on themselves degraded viewing conditions. That is, they may not have the time or the capacity to pick up all the detail in a rich perceptual field and so may sample the stimulus input sparingly and rely on (usually helpful) cognitive processes to organize their percepts. Extending the Helmholtzean analogy of perception as problem solving, it is well known that humans do not fully utilize all the information potentially available to them in making decisions but instead use partial information supplemented by heuristics to arrive at their decisions (Kahneman, Slovic, & Tversky, 1982). When people are performing under time pressure or are in a fatigued state, serious perceptual errors occur (e.g., errors in landing an airplane) that suggest a similar incomplete processing of the perceptual field.

Fourth, even under ecologically valid conditions, it can be shown that observers use inferences to organize their perceptions despite all the necessary information being available in the stimulus. An example is the Ames trapezoidal window, depicted in Figure 36.8. Although this "window" could be perceived directly as having a trapezoidal shape, observers apparently presume (following either the minimum or the likelihood principle) that it is rectangular. This error in turn leads to errors in the window's perceived direction of rotation. Most important, this error persists under normal, ecologically valid viewing conditions (binocular viewing, free movement of the observer relative to the stimulus, unlimited viewing time, etc.). Other illusions attributed to faulty perceptual organization are obtained under ecologically valid viewing conditions (e.g., the moon illusion; Kaufman & Rock, 1962; Restle, 1970a). Fifth, and finally, even granting that Gibson's position could successfully accommodate all of the foregoing, we must still explain how percepts are organized under impoverished viewing conditions. If our perceptions were unorganized (or amorphously organized) in these situations, we might justifiably conclude that our perceptual apparatus is not equipped to process ecologically invalid stimulation. Why, after all, should organisms have evolved to perceive under conditions that do not arise in the environment? But our percepts *are* demonstrably organized in these situations (as, for example, the Gestalt demonstrations show clearly), and so we must explain the underlying processes that achieve this organization. Such an explanation would shed light on how perception works not only under unimpoverished stimulation but also in impoverished cases that arise with information displays studied by human factors psychologists.

In sum, the point of the Gibsonean camp is well-taken: in some situations the stimulus itself may contain all the information needed for veridical perceptual organization. Nevertheless, it is both legitimate and necessary to understand the processes through which this information is picked up as well as the contribution of the observer in organizing percepts.

Therefore, the following sections focus on evaluating the relative merits of the Gestalt versus the Helmholtzean approaches to perceptual organization; they deal no further with the Gibsonean viewpoint or address such other approaches to perception as computer vision and artificial intelligence (see Barrow & Tenenbaum, Chapter 38). Our rationale is that a chapter on theoretical approaches to perceptual organization should focus on general principles by which organization proceeds; the Gestalt and Helmholtzean approaches provide the two broadest sets of principles. By denying that organization presents any theoretical problem, Gibson's position provides no principles of perceptual organization. Other approaches, such as computer vision, do address in great detail the processes required to organize a stimulus, but they do so mainly with large numbers of highly specific mechanisms difficult to describe in terms of general principles. That is, it is not clear if there is any unitary theoretical approach shared by those working in computer vision; in fact, computational theories could be constructed that embody virtually any approach to organization, including the Gestalt or the Helmholtzean approaches.

3. GESTALT VERSUS HELMHOLTZEAN APPROACHES: EVIDENCE

We have delineated three areas of contrast between the Gestalt and the Helmholtzean views, including the role of brain mechanisms that organize stimulation, the role of learning, and, most important, the prägnanz versus likelihood principles of perceptual organization.

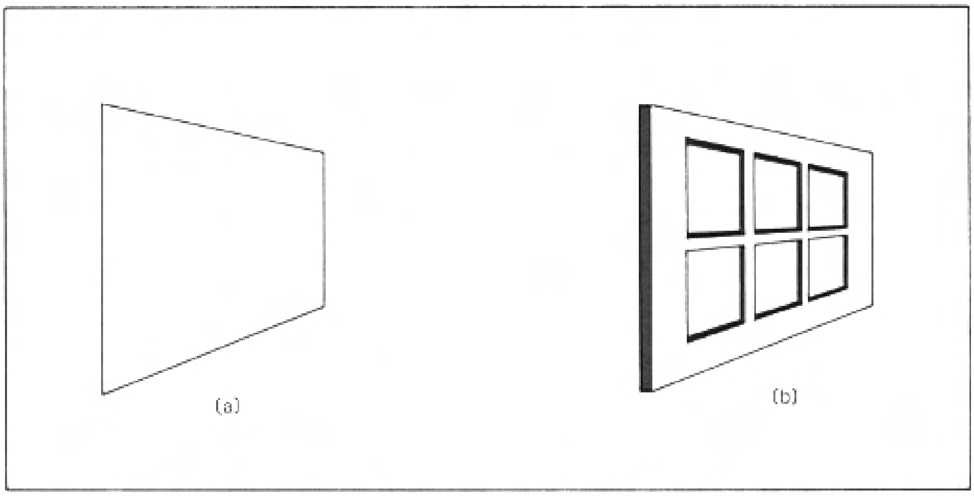


Figure 36.8. The Ames trapezoidal window. (a) The actual shape of the window as oriented perpendicular to the line of sight. (b) The window in the same orientation but with additional depth cues (of shading and linear perspective) that cause it to be perceived as a rectangular window viewed at a slant. The misperception of the window's orientation and shape leads to further misperceptions of its direction of motion when the window is rotated about its central, vertical axis. This figure illustrates the couplings that exist in perception between shape and slant and between size and distance. The figure also argues against the Gibsonean position of direct perception. (Adapted from Rock, 1975.)

3.1. Physiology

The only specific brain mechanisms proposed by the Gestaltists were readily falsified (Lashley, Chow, & Semmes, 1951; Sperry & Miner, 1955). It is now clear that although the brain is a volume conductor of electric currents, these currents are irrelevant to perception and so cannot be used as a plausible physiological mechanism for achieving prägnanz. But this specific disconfirmation cannot be taken as evidence against the general notion that the brain is somehow structured to organize stimuli automatically. The Gestaltists may merely have advocated the wrong mechanism, and so we must ensure that we do not needlessly dismiss the entire Gestaltist concept.

Neither can the Helmholtzeans claim to have won the battle about brain processes because they remained noncommittal and so avoided neurophysiological speculations that could have been falsified. Helmholtz believed that humans' perception of the color yellow was an unconscious inference from sensory data regarding the relative components of red and green in the stimulus (Hochberg, 1978, p. 106). Today, evidence exists for cells that respond directly to yellow. So what might have been a problem requiring a solution in "software" (i.e., learned methods of interpreting sensory data) turned out to have been solved in "hardware" (see Pomerantz & Kubovy, 1981; Runeson, 1977; Simon, 1978).

It could be argued that such cells represent the anatomical embodiment of a Helmholtzean unconscious inference mechanism, although we cannot say whether Helmholtz would have granted inferential capacities to single neurons. Certainly one cannot credit the Gestaltists with winning this particular battle, since the sensory mechanism that codes yellow does not in any way operate in a manner they could have anticipated. In sum, neither camp described the intrinsic organization of the brain with sufficient clarity to credit it with victory. As we discuss later, the question of which principle, prägnanz or likelihood, better describes how percepts are organized is separate from the question of whether that principle is instantiated in hardware or in software.

3.2. Learning

Regarding the role of learning in perceptual organization, the scorecard is equally indecisive. A vast and growing literature exists on the issue of learned versus innate mechanisms in perception, including the discriminative abilities of human infants, the neural effects of sensory deprivation in early development, and the response of adult observers to altered sensory input. The general conclusion from this literature (Movshon & Van Sluyters, 1981) is that although organisms are endowed innately with a powerful complement of perceptual capabilities and neuronal mechanisms, these structures require experience with stimulation to remain viable. Further, experience may alter the functions of these structures, so that their role in perception is not firmly dictated at birth. Such a finding undermines the often tacit assumption held by many (including Helmholtz, as cited in Hochberg, 1978, p. 68) that if a structure exists at birth, it must have a fixed and unmodifiable function that will be unaffected by learning.

However, disappointingly little is known about the role of learning in the *organization* of percepts, as opposed to its role in more basic perceptual processes. Many of the most critical phenomena of perceptual organization, such as the perceived fluctuations of multistable stimuli, are difficult or impossible to test with infants or with animal subjects. Newborns of many species perceive depth fairly well, and human infants seem to organize the visible spectrum into the same color categories that adults perceive (Bornstein, 1976). Certain of the categorical effects in speech perception appear to be present in humans at birth too (Eimas, Siqueland, Jusczyk, & Vigorito, 1971). It has been claimed (Bower, 1974) that infants have some capabilities for figural completion that parallel those of adults. Similarly, it has been argued (Hebb, 1949) that some rudimentary capacity for figure-ground segregation must be present from birth, for without the capability to distinguish an object from its background, the process of learning the distinctive features of objects could not begin. Infants respond to the optical expansion (looming) of an image as though the image were rushing toward them. Moreover, they seem able to determine whether the object is or is not approaching them on a collision course since they show signs of startle and distress only in the former case (Ball & Tronick, 1971; Bower, 1974).

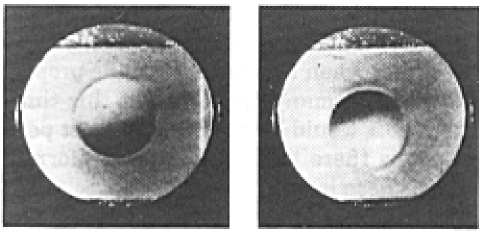
3.3. Prägnanz versus Likelihood

The main feature that distinguishes the Gestalt and Helmholtzean views is surely the opposition of the prägnanz and the likelihood principles. It is worth noting that almost 80 years ago, Mach (1906/1959) drew the same contrast between a principle of economy and a principle of probability in perception. Brunswik, who developed the likelihood principle further than anyone else, discussed this contrast and appeared to endorse the view that the two principles could co-exist and in fact reside at different, sequentially arranged stages of perceptual organization (Brunswik, 1956, pp. 133–134).

3.3.1. Physiology. In retrospect it is unfortunate that the Gestalt position linked its advocacy for prägnanz with strong claims about innately endowed brain processes underlying perception, since the issue of prägnanz is largely orthogonal to the issue of nativism versus empiricism, which in turn is at least partly orthogonal to the issue of brain processes. Humans could acquire through learning a minimum principle for perception in much the same way that problem solvers (e.g., scientists) are putatively trained to adopt the principle of parsimony in their theorizing.

The underlying neural structures that could embody a prägnanz principle are not necessarily different from or incompatible with those that could embody a likelihood principle. Although the Helmholtzean view might seem linked inexorably to brain processes that depend on neural plasticity, functionally equivalent brain mechanisms could evolve either *ontogenetically*, through learning in a single organism of what environmental stimuli are most likely, or *phylogenetically*, through evolutionary adaptation favoring organisms with a perceptual bias toward perceiving likely stimuli (see Kaufman, 1974, p. 411; Rock, 1975, p. 142).

3.3.2. Examples. For example, consider the illusion in which bumps protruding outward from surfaces can be seen either as bumps or as indentations, shown in Figure 36.9. Shading provides a critical clue that determines whether bumps or dents will be perceived. If a vertical surface is illuminated from above, the lower half of a bump will be in shade, as will the upper half of a dent; the reverse will be true, however, if the surface is illuminated from below. Although this effect could be based on an organism's learning through experience that illumination from above (as with sunshine) is more likely to occur than from below in the natural environment, chicks reared



(a) (b)

Figure 36.9. Perceived depth and the assumed direction of illumination; (a) tends to be perceived as a bump extending outward above the page, whereas (b) is seen as a dent extending inward below the page. If the figure is turned upside down, these depth relationships reverse. The effect appears to be due to an assumption within the visual system that the source of ambient illumination is from above, so that shadows are cast toward the bottom of bumps but toward the top of dents. A similar effect can be seen in photographs of craters; if the photographs are inverted, mountains will appear. (From I. Rock, *An introduction to perception*. Macmillan Publishing Co., 1975. Reprinted with permission.)

in cages illuminated only from below show the same bias (Hershberger, 1970). Evidently, organisms are biased from birth onward to presume that illumination comes from above, which suggests that natural selection has programmed an element of the likelihood principle into the nervous system. There may be a further component that is learned from perceptual experience; according to Gregory (1972, p. 185), David Brewster (1847), who discovered the present effect in the nineteenth century, showed that this bias was stronger in adults than in children. Although Brewster's finding is open to varying interpretations, even if the effect is partly learned, any innate component would show that brain mechanisms may serve as embodiments of the likelihood principle. At a minimum, this shows that the prägnanz-likelihood debate is at least partly independent of the nativism-empiricism debate.

The remainder of this section focuses on the deepest difference between the Gestalt and the Helmholtzean view, the prägnanz versus likelihood principles. The issues of brain mechanisms and nativism versus empiricism reappear periodically because of their fundamental importance in understanding perceptual organization, but the particular Gestalt positions on these issues need not be explored further.

Are human perceptions organized in a fashion that maximizes their simplicity or that maximizes their likelihood of matching a probable distal stimulus? When asked in this fashion, the question presupposes that perceptual organization follows from general principles rather than from a conglomeration of ad hoc rules. Further, it presupposes a single, overriding rule governing organization, based either on simplicity or likelihood rather than on a combination of the two. Later in this chapter we address a possible coexistence of the two. Last, the question presupposes the availability of measuring techniques for simplicity and likelihood that will allow us to confirm whether either of these two principles governs organization. Two techniques for measuring simplicity (one based on information theory and one on coding theory) are described at length in subsequent sections of this chapter. No formal measures for assessing likelihood have been proposed, except for Brunswik's concept of *ecological surveys*, in which the frequencies of occurrence of various stimulus configurations and events in the natural environment are assessed (Brunswik, 1956, p. 43). A proper and representative ecological survey would be prohibitively costly, although some less ambitious surveys could be attempted for narrow ranges of stimuli.

To illustrate the problem, consider again Ames' trapezoidal window, oriented perpendicular to the line of sight. The window itself (the distal stimulus) is trapezoidal, but it is seen as a rectangle viewed from an oblique angle. Whenever possible, observers prefer to interpret ambiguous shapes as containing only right angles (Attneave, 1972; Perkins, 1972, 1982; Shepard, 1981). Does this organization of perceived shape and orientation occur because a rectangle is perceptually *simpler* than a trapezoid, or because when the retina receives a proximal stimulus that is trapezoidal the distal stimulus is *more likely* to be a rectangle viewed from an oblique angle than a trapezoid viewed head-on? Both of these propositions are plausible, which makes it difficult to determine whether only one or both of these principles are responsible for the rectangular organization that is perceived.

In Euclidean geometry a rectangle is described more simply (with fewer parameters) than is a trapezoid. A rectangle requires only one parameter (ignoring those irrelevant to its shape, such as its size, orientation, color, etc.), which specifies its height-width ratio. A trapezoid requires three; one for its height-width ratio and two for the two angles that are free to vary. If the prägnanz principle means that the organization with the most economical description is the one perceived (Attneave, 1954), then the principle successfully accounts for the shape perceived. This notion, much simplified here, is the rationale underlying coding theory (Leeuwenberg, 1971, 1978; Restle, 1982), discussed later.

Are rectangles more common in the environment than trapezoids? This is difficult to say, since no satisfactory ecological survey has been performed. Rectangles are rarely encountered in the natural environment; they are mainly artifacts of human civilization. According to the "carpentered world" hypothesis (e.g., Segall, Campbell, & Herskovits, 1966), rectangles are in fact more commonly encountered than trapezoids, at least by the kinds of observers who participate in psychological experiments. If this assertion is correct, then the likelihood principle, too, correctly predicts our perception of a rectangle (as well as predicting that people living in cultures where rectangles are rare will more likely see the shape as trapezoidal). Note that this analysis implies a learned rather than an innate mechanism, since carpentered environments are relatively new on the time scale of evolution.

3.3.3. Globality. The trapezoid example so far has assumed that the prägnanz and likelihood principles operate on the whole shape as their unit of analysis. This appears reasonable, but smaller units could be chosen, such as the lines or angles comprising the trapezoid. As noted previously, the perceptual system may be biased toward perceiving all angles as right angles seen in perspective or all line segments (converging or diverging) as parallel. The corresponding arguments in this case would be that right angles (or parallel lines) are simpler or more probable in the environment than are their alternatives. This tack has its pros and cons. On the positive side, right angles and parallel lines are common in the environment: tree trunks grow at right angles to the ground, dropped objects fall at right angles to the horizon, and so on. Also, in the case of trapezoids, nothing is lost by shifting the locus at which these principles operate, since any trapezoid can be seen as a rectangle viewed from some vantage point; thus, the same final organization will result regardless of which level is chosen.

On the negative side, the unit of analysis should not be reduced to an overly atomistic level. Global scenes vary in simplicity and likelihood, as do the objects and patterns within the scene. Subpatterns too may have these properties, but if stimuli are reduced to their indivisible sensory elements, the organization of the elements is lost; concepts like simplicity and likelihood lose their meaning, for how can an irreducible element be complex? Brain fields and soap bubble models have been postulated specifically to account for global effects that involve whole patterns, not just local regions. Although there are some cases where our percepts are not clearly organized globally by way of either principle (as with impossible figures, discussed later), we must explain the majority of cases where organization *is* global.

The thrust of the Gestalt argument is that perceptions are organized globally to simplify maximally the representation of holistic stimulus configurations. To argue that perceptions are organized to minimize the complexity of *components* might sound distinctly anti-Gestalt. Hochberg's (1981a) recent research, discussed later, has focused on demonstrating purely local determination of perceptual organization. He argues persuasively that his findings are incompatible with the Gibsonean view, and also with the Gestalt view which he and his colleagues now refer to as the "*global* minimum principle" Peterson & Hochberg, 1983).

Still, global organization could be achieved by simplifying all of the local regions or features of the stimulus. In fact, soap bubbles work in this fashion (Attneave, 1982; see also Marr, 1982), since the simultaneous achievement of local equilibria produces the global shape of the bubble. That is, there is no executive process or homunculus that oversees the process to ensure that the final, global organization is satisfactory (see Section 4.3). When viewed this way, a local minimum principle seems less incompatible with the Gestalt position and may help the prägnanz principle explain such phenomena as impossible figures, discussed later.

4. THE GESTALT LAWS

We next consider the Gestalt "laws" of perceptual organization and explore whether they support the prägnanz over the likelihood principle. Again, we are not especially concerned with how the Gestaltists or the Helmholtzeans would implement these laws at the neurophysiological level; although the Gestalt psychologists had ideas about how this might be done for certain of the laws, for others (such as figure-ground segregation) no viable mechanism was developed. At the same time, both views involve not just one but a packet of propositions that ought to be evaluated independently. For example, the Gestalt view holds that the minimization of a form's complexity operates directly, without trial and error. Although this assumption is not logically entailed by the prägnanz principle (witness the problem solver's successive approximations to a parsimonious solution), it is so much part and parcel of the Gestalt approach that evaluating it separately from prägnanz would be difficult.

In 1933 Helson compiled a list of 114 Gestalt laws. Boring (1942) whittled them down to the 14 shown in Table 36.1. Few of them, however, are formulated with sufficient precision to allow an adequate evaluation (Garner, 1981). Consider the fifth law regarding strong and weak forms, of which Boring states, "A strong form coheres and resists disintegration by analysis into parts or by fusion with another form" (p. 253). More recent research (described by Rock, Chapter 33 and Treisman, Chapter 35) has shown that this law (among others) can be operationalized; and in fact when this has been done properly, the laws have been upheld in many cases. But at this time not all the laws in Table 36.1 would be accepted by most perceptual psychologists, nor is there to this day any uniform and agreed-upon listing of these laws.

Consider the thirteenth law concerning fusion of forms, of which Boring states, "Two forms can fuse, giving rise to a new form; or in combination, the stronger one may persist, eliminating the weaker. Simple, poorly articulated forms fuse more easily than complex, good forms" (p. 245). Here Boring links complexity with good configuration and simplicity with poor. This runs counter to the prägnanz principle and to certain information-theoretic accounts of pattern goodness (discussed later) that link simplicity with good configuration (Garner, 1970). This conflict is probably due to the original Gestalt interpretation of prägnanz as entailing both a minimum principle (emphasizing uniformity) and a maximum principle (emphasizing articulation); see Koffka (1935/1963, chap. 4) on "maximum-minimum properties."

The twelfth law, regarding meaningfulness, is described as follows: "A form tends to be meaningful and to have objectivity. The more meaningful the form, the stronger it is, the more easily it is perceived, and the longer it tends to persist." Although it is unclear what "meaningfulness" means here, the law comes perilously close to an empiricist (Helmholtzean) position, to the extent that meaning is acquired through experience. Although the Gestalt psychologists did not deny the importance of learning, they did deny it any role in shaping perceptual organizations.

Finally, some important and easily operationalized laws are missing from Boring's abbreviated list, including: *good continuation*, in which figures are organized to make the fewest changes or interruptions in straight or smoothly curving lines; *area*, in which smaller closed regions of the visual field are more likely to be seen as figure than are larger ones; *convexity*, in which convex regions are more likely to be seen as figure than are concave; *common fate*, in which elements in the field undergoing simultaneous, correlated changes are grouped to-

Table 36.1. Boring's Condensed "Laws" of Gestalten

1. Naturalness of form.
2. Figure and ground.
3. Articulation.
4. Good and poor forms.
5. Strong and weak forms.
6. Open and closed forms.
7. Dynamic basis of form.
8. Persistence of form.
9. Constancy of form.
10. Symmetry of form.
11. Integration of similars and adjacents.
12. Meaningfulness of forms.
13. Fusion of forms.
14. Transposition of forms.

These are the 14 laws that, according to Boring (1942), "represent the major contribution of Gestalt psychology." These laws deal almost exclusively with visual form. Boring credits these laws, or principles, to Wertheimer, Koffka, Köhler, Rubin, and Sander. Certain of these laws are explained in the text. (From E. G. Boring, Sensation and perception in the history of experimental psychology. *New York: Appleton-Century-Crofts, 1942, pp. 253–254. Reprinted with permission.)*

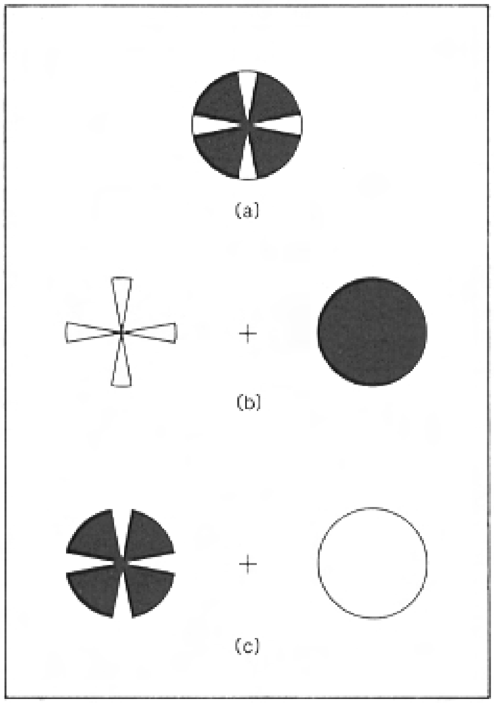


Figure 36.10. A demonstration of the Gestalt law of area. The pattern in (a) is multistable and can be organized with either the white region (b) or the black region (c) as figure. The interpretation in (b) is preferred because, according to this law, the white regions occupy less area than do the black.

gether; the notion, central to the figure-ground phenomenon, that a given contour will be seen as belonging to only one of the two regions it delineates at any one time (called by Rubin the one-sided function of contour); and the notion that the ground is perceived to continue behind the figure. It remains uncertain too whether certain key phenomena of the Gestalt school, such as apparent motion and the multistability of the Necker cube, can be predicted from this list of laws; they probably cannot without substantial elaboration.

Let us examine the Gestalt laws in some detail to see how well they fit with the prägnanz and the likelihood principles (cf. Gregory's 1974 and Hochberg's 1978 analyses). For the time being, we are concerned only with laws describing properties of the stimulus that influence perceptual organization. These include area, proximity, similarity, closure, good continuation, convexity, and symmetry. Our examples are drawn from the visual domain. For comparable phenomena in audition see Bregman (1981), Kubovy (1981), and Vicario (1982).

4.1. Area

First, consider the law of area, previously defined. This law predicts that the white regions forming a cross in Figure 36.10a will be seen as figure, lying on top of a solid black disk (b). (Which regions are white and which are black is arbitrary.) The figure could be organized as a black (Maltese) cross lying on a solid white disk (c), but this should not happen (according to this law) because the black regions occupy more area than the white. Is the predicted interpretation (b) simpler than its alternative (c)? Not in any obvious way. To be sure, there is less total stimulus area in (b) than in (c), but this should not affect complexity any more than a large square should be construed as more complex than a small one. The likelihood principle might explain the result by appealing to the manner in which occlusion occurs in the everyday world. Any opaque object can occlude our view of another object by falling in the latter's line of sight; the relative size of the two objects is irrelevant. However, it may be more often the case that the occluding object is smaller than the occluded one, as when a tree is seen against the sky, a boat is seen against the water, or a set of objects is seen lying atop a desk.

To be sure, larger objects sometimes occlude smaller objects, as when a desk partially blocks our view of a chair. Still, the largest areas in the two-dimensional proximal stimulus often correspond to the largest distal surfaces. For example, when we are seated in a room, the largest bounded regions in our visual field are often surfaces such as walls and desktops that serve as backgrounds for smaller objects lying in front of or on top of them. By definition, a ground must be extended in space (although it may be occluded). But a figure does not have to be extended; it can be arbitrarily small.

To summarize, no complete explanation for the Gestalt law of area has yet emerged. However, the phenomenon seems to have nothing to do with simplicity or prägnanz (even though prägnanz has been suggested as a unitary principle that captures the essentials of the major Gestalt laws). By contrast, it seems to be closely related to the way in which surfaces occlude one another most frequently in our visual field. A survey of the type proposed by Brunswik (1956) would be of great value in clarifying the specific frequencies; but in the absence of such a survey, it does not strike us as being overly speculative to note that small surfaces in our visual image most often correspond to figures that lie in front of larger background surfaces rather than vice versa. Thus area could be a cue, with some limited but nonetheless significant validity, that could be used probabilistically in conjunction with other sources of information to organize our percepts. Clearly this problem has not yet been resolved. But given that the area effect seems unrelated to simplicity, a solution seems more likely to arise from within the likelihood than from within the prägnanz approach.

4.2. Proximity

Second, consider the law of proximity (listed eleventh in Table 36.1). It holds that two regions are more likely to be perceived as belonging to the same form the closer they are to each other, all other factors being equal. This law is usually demonstrated with gridlike arrays of objects, first used by Schumann (1900a, 1900b; Boring, 1942, p. 248) and shown in Figure 36.11. Part

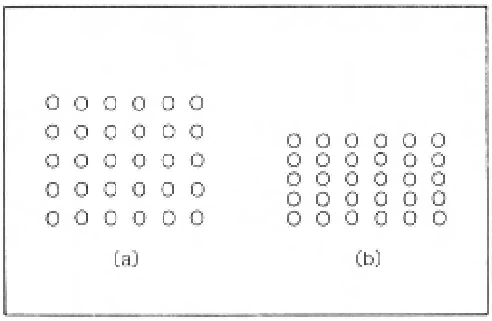


Figure 36.11. A demonstration of the Gestalt law of proximity. (a) The horizontal and vertical interdot spacings are identical, and so the display is readily perceived as grouped into either rows or columns of open circles. (b) The spacing has been altered so that a grouping into columns is more readily perceived.

(a) shows rows and columns that are spaced identically. Because proximity does not bias us to see the objects grouped into rows or columns, both organizations can readily be seen. In Figure 36.11b the spacing has been altered to bias perception toward groupings of columns rather than rows. Is our perception of column groupings in (b) simpler than the alternative row groupings would be? Again, not in any obvious way (cf. Restle, 1982).

This phenomenon might be most readily explained by a model (such as dynamic brain fields) in which neighboring foci would be more likely to interact than distant ones. (Note that it might be simpler to group nearer rather than distant objects in the sense of requiring less effort to accomplish. But the point of prägnanz is to simplify the organization achieved, not to simplify the process of achieving that organization; see Section 2.2.1.)

Alternatively, a spatial frequency model (see Ginsburg, Chapter 34), in which low spatial frequencies determine perceptual grouping, may be capable of accommodating the law of proximity. Indeed, for some theorists the existence of low spatial frequency channels in vision satisfactorily explains grouping by proximity. From the perspective of this chapter, holding forth a physiological mechanism as an explanation ignores the more central and logically prior question of how the grouping of proximal regions serves the purpose of veridical perception. To be sure, once the usefulness of such grouping has been established, a mechanism must be sought; and quite possibly many mechanisms other than low-pass filtering could perform this task. But the particular mechanism involved is secondary to the principle that mechanism subserves, and it would be a mistake to think that the presence of a mechanism automatically explains its *raison d'être*. As explained in Section 1.4, the prägnanz versus likelihood contrast is largely independent of issues concerning the hardware of the perceptual system.

The likelihood principle handles grouping by proximity merely with the claim that the regions of the visual field bounded by a single object are usually close to one another and are usually contiguous. (It might be argued that a single object need not be physically contiguous, but such an argument is specious; even dictionary definitions of the work "object" are based on appeals to human perception.) Occasionally the components of a single stimulus are not contiguous, as when an occluding tree splits a building's retinal image into two parts. Again we lack an ecological survey, but the facts of ecological optics seem clear in this particular case. The prägnanz principle makes no predictions whatsoever about proximity; by contrast, the likelihood view has at least the potential to explain the law of proximity. The same would be true, by close analogy, with the law of *similarity*, which was shown in Figure 36.3 and need not be discussed further here.

4.3. Closure

Third, the law of closure (listed sixth in Table 36.1) is described by Boring (1942) as follows: "An open form tends to change toward a certain good form. When a form has assumed stable equilibrium, it has achieved closure. Thus a nearly circular series of dots may achieve closure by being perceived as a circle" (p. 253).

Closure entails two components. First, closed or bounded regions are preferred to open regions. Second, the perceptual system fills in or closes gaps to convert open regions into closed forms. Each dot constitutes a closed form. These dots are then grouped on the basis of proximity, similarity, good continuation, and the like, and the resulting form is open. The gaps between the dots are "filled in" perceptually and so a "circle" is perceived.

A clearer example of closure might be a real circle broken by a single gap. The law predicts that this gap should be closed perceptually to achieve a fully closed figure. Yet a gap in a circle may either be closed or be accentuated in perception, depending on whether the gap is attended to (for a review, see Zusne, 1970). Because of such complications, Gestalt psychologists never reached agreement on the phenomenon of closure, and most explications of the law are vague.

The law of closure holds that with the row of parentheses shown in Figure 36.7a, adjacent elements should group into left-right parenthesis pairs (which tend toward a closed, circular configuration) rather than right-left pairs (which tend toward an open, hourglass configuration). Figure 36.7b shows a similar demonstration that controls for proximity and good continuation. The contours are not actually seen as closed: the empty spaces separating them are still visible. Rather, the contours are organized as though they were closed.

The likelihood principle handles closure as follows. Three-dimensional objects by definition are closed. Exceptions (stimuli such as the circle with the gap) are not representative of objects likely to be encountered in the environment. Unlike the figure region, the ground need not be closed. The ground often is shapeless, with its proximal shape reflecting only the regions that happen to remain unoccluded by the figures lying in front of it.

The prägnanz explanation for closure works well for Figure 36.7a because a circle is a simpler configuration (in almost any descriptive system) than an hourglass. However, most textbook demonstrations of closure help the phenomenon along by confounding closure with good configuration, good continuation, and convexity, as in the parenthesis example. To test the prägnanz account of closure, we must find whether *any* set of elements will form a simpler configuration when the elements are closed. Figure 36.12 shows a set of figures (Street, 1931) that may be used to test for closure (or "figural completion"). At a minimum, the fragments in each of the patterns of Figure 36.12 appear to form a crude whole or aggregation (Metelli, 1982); but that much would be expected on the basis of proximity and similarity alone (cf. the distinction between grouping and emergent features in Rock, Chapter 33, and in Section 1.2.2).

Does grouping (or mere aggregation) simplify the perception of these patterns as compared with the perception of ungrouped fragments? If only the global outlines of these patterns (and not the internal details) were represented in perception, clearly these outlines could be described more briefly than could the actual stimuli. Indeed, internal details are often missing from our perception of (or at least memory for) complex patterns (Rock, Halper, & Clayton, 1972). But this economy of description is achieved only at the expense of discarding potentially valuable information about the stimulus. *Any* organizational scheme could achieve an economical description by simply deleting information from the stimulus.

One measure of closure (as distinct from aggregation) is whether observers can correctly identify the objects that the fragmented images portray. For three of the four stimuli in Figure 36.12, identification is easily achieved; for the fourth, taken from Attneave (1967), it is not. Thus we can say that closure is achieved for three of the patterns, but only aggregation, not closure, occurs for the fourth. The three that do show closure do not become simpler in any geometric sense; that is, they are

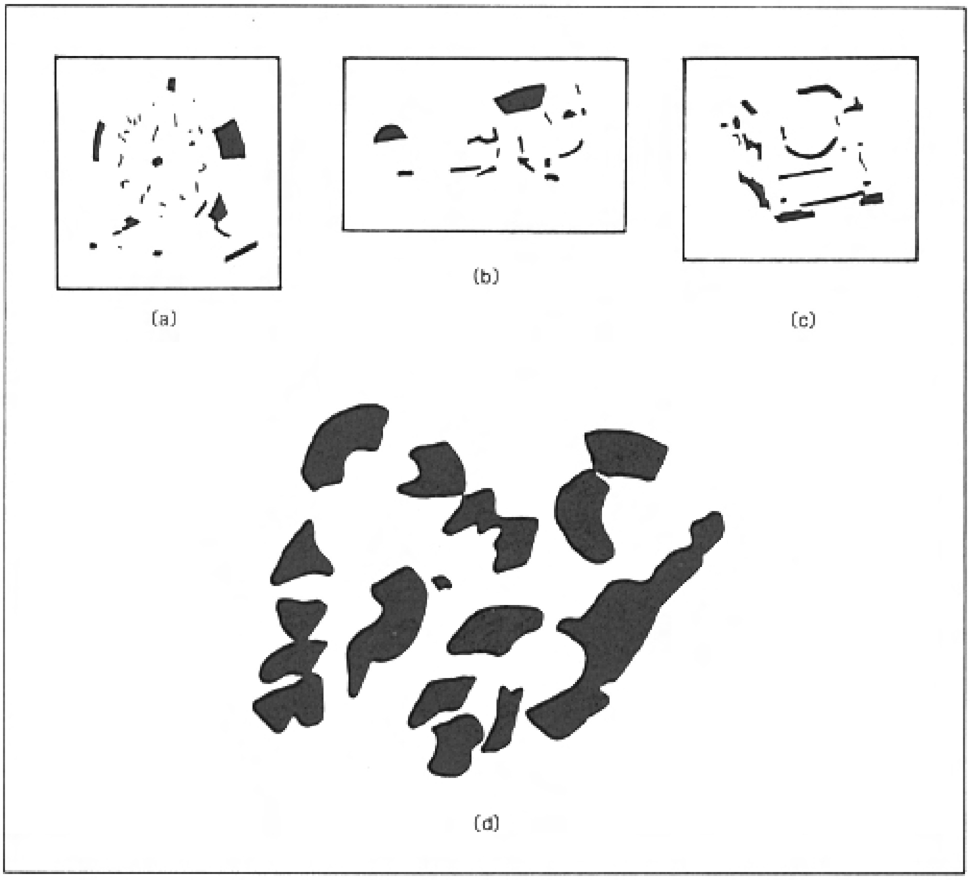


Figure 36.12. The Street figures. With a little effort, the scattered black patches of (a), (b), and (c) can be closed perceptually to reveal familiar (albeit somewhat dated) depictions of a fan, an airplane, and a typewriter. Closure is difficult if not impossible to achieve in (d). [From R. Leeper, A study of a neglected portion of the field of learning—The development of sensory organization. *Journal of Genetic Psychology*, 1935, 46. Reprinted with permission of the Helen Dwight Reid Educational Foundation. And (a–c) from R. F. Street, *A Gestalt completion test: A study of a cross section of intellect*. AMS Press, 1931. Reprinted with permission. (d) From F. Attneave, Criteria for a tenable theory of form perception. In W. Wathen-Dunn (Ed.), *Models for the perception of speech and visual form*. M.I.T. Press, 1967. Reprinted with permission.]

not like the Ames trapezoid, which becomes more regular when seen as a rectangle. They become "simpler" only in the sense that they can be matched into learned perceptual categories. The situation is in some ways analogous to a string of letters seeming simpler when the letters spell a familiar English word, but this simplification will be enjoyed only by a perceiver who has learned English.

In summary, closure is among the weakest and most vague of the Gestalt laws. To date, we lack any robust demonstration of closure that is free from confounded effects of other Gestalt laws. However, what few phenomena that do exist and that do appear to result from the law of closure seem better explained by the likelihood principle than by prägnanz.

4.4. Good Continuation

Fourth, consider the law of good continuation, which is absent from Table 36.1 but is demonstrated in Figure 36.13. The X-shaped pattern in (a) is usually perceived as two wavy diagonal lines that cross, not as two V-shaped patterns that happen to be abutted at their vertices. Good continuation is an important factor in hidden figures (Gottschaldt, 1926) and other forms of camouflage, as with the hidden digit 5 in (b). It is a powerful law that can easily override the law of closure as in (c), where a sine wave is seen as superimposed on a square wave; closure would predict that we should see the organization shown in (d) (Hochberg, 1978, p. 138). In fact, good continuation, coupled with interposition cues for depth (discussed later) can lead to closure, as is demonstrated with Bregman's (1981) B's in Figure 36.14. The block letter B's are difficult to perceive in (a), but when occlusion information is added in the form of an amorphous ink blot, the collinearity of the B's contours precipitates rapid closure. Figure 36.13*e*, taken from Kanizsa (1979, p. 101), shows five separate crosses. When they are made contiguous at their vertices in (f), the cross becomes harder to perceive. A centrally located square becomes perceptually prominent and is seen as superimposed on the four odd-shaped block figures in the corners. Although the stimulus as a whole retains its global symmetry with this new organization, its regularity or simplicity is diminished; one no longer sees five identical and symmetrical crosses. Thus this figure demonstrates the power of good continuation overriding symmetry in determining perceptual organization.

The prägnanz explanation of good continuation is straightforward: a line or contour whose direction remains constant through an intersection can be described more simply than one

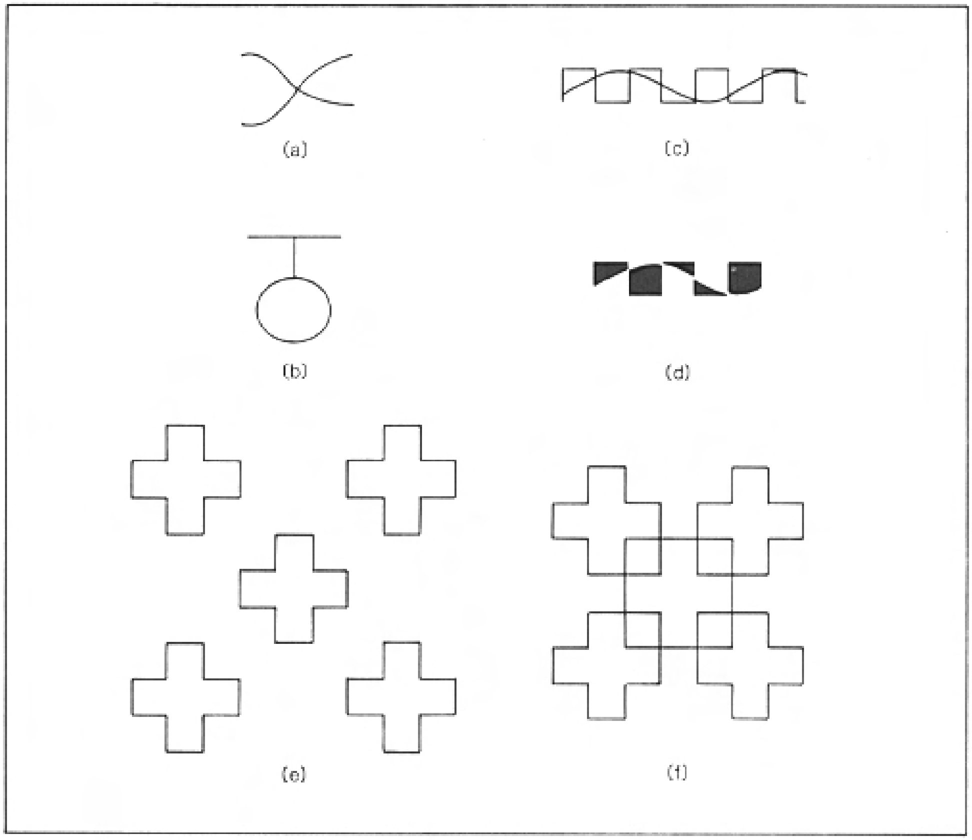


Figure 36.13. Demonstrations of the Gestalt law of good continuation. In (a) the observer is more likely to perceive two smoothly curved lines that cross than to perceive lines containing sharp bends or four lines meeting at a central point. (b) How good continuation can be used to camouflage a familiar figure (the digit 5). (c) Good continuation overcoming closure; the pattern is seen as a sine wave superimposed on a square wave, rather than as a set of adjacent, closed figures as suggested in (d). (e, f) How good continuation can overpower other organizational laws: in (f) the five crosses of (e) have been brought together so they touch each other at their vertices; as a result, the symmetric and identical crosses are no longer seen as primary perceptual units. (From G. Kanizsa, *Organization in vision*. Copyright 1979 by Gaetano Kanizsa. Reprinted with permission of Praeger Publishers.)

whose direction changes or than one that terminates at the intersection and is replaced by another line or contour. Note that in this account prägnanz is applied at a local level, namely, the intersection of lines or contours, with little regard for the consequences at more global levels, as we saw with Kanizsa's crosses. Thus this explanation runs counter to the Gestalt view because prägnanz is supposed to operate at a global level.

The likelihood principle explains good continuation as follows. Given the lines that cross in Figure 36.13a, it is far more likely that the distal stimulus is actually two wavy yet roughly straight lines (or cracks or strings) that intersect than two wavy, V-shaped strings that (1) just happen to have spatially coincident vertices and (2) just happen to be oriented so that the contours of the different strings are roughly collinear at the intersection. To accept both of these coincidences simultaneously would exceed the limits of reasonable doubt.

Figure 36.15 (Kanizsa, 1979, p. 103) appears to demonstrate good continuation even though none of the lines maintains its precise direction through the intersections. Observers tend to organize the pattern in (a) into the two overlapping figures shown in (b) rather than into the two abutting figures in (c). The law of good continuation might be rephrased accordingly to state that when two lines intersect, each continues through the intersection along the path that requires the *smallest change of direction*. However, this reformulation does not favor either prägnanz or likelihood. Given that a line changes its direction abruptly at an intersection, why would a smaller change be simpler than a larger one? Clearly *no* change represents a major simplification, but it is less clear that a change of 60° is more complex geometrically than one of 10°.

How would likelihood handle the smallest-change-of-direction rule for good continuation? Are smaller changes of angle more likely in the environment? The burden of proof falls on the Helmholtzeans to demonstrate this in an ecological survey.

A more promising explanation would claim that Figure 36.15 has nothing to do with good continuation but instead is a demonstration of the law of convexity (in the next section). This law states that convex regions of the field are more likely to be seen as figure than are concave ones. An example is given in Figure 36.16, which is usually seen as a disk on top of a square. Alternatively, it could be seen with the square as figure, containing a round hole (i.e., as a nut), but this is less frequent. Convexity, rather than good continuation, could explain why Figure 36.15a is organized as in part (b) rather than (c), since one of the two component figures in (c) has a substantial concave component.

Thus the law of good continuation need not be modified to include a bias for perceiving small changes of direction over large changes, at least not given the evidence now available. The law need state only that no change is preferred over change. Both the prägnanz and the likelihood principles can handle this law satisfactorily. This in no way implies that both principles are correct; it merely indicates that no experimental method has yet been devised that discriminates between the two principles on this score.

4.5. Convexity

Fifth, what can be said about the law of convexity, which appears to account for Figure 36.15? This law seems to apply only in the plane perpendicular to the line of sight, not in depth, since otherwise we would see dents in surfaces as bumps (holding constant the direction of illumination). The law is further demonstrated in Figure 36.17 (Kanizsa, 1979, p. 112) which shows that convexity is powerful enough even to override the effects of symmetry (Section 4.6). Thus we see the dark, asymmetric regions as figure rather than the light, symmetric ones, because

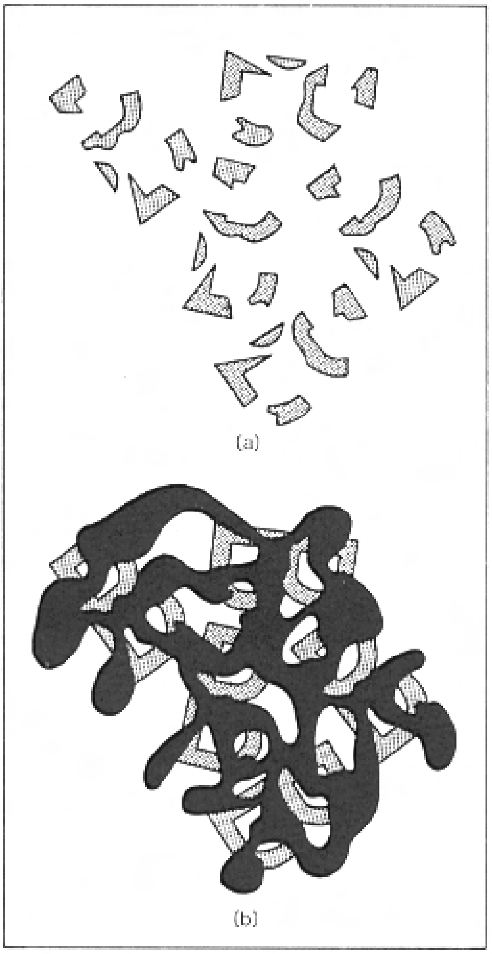


Figure 36.14. Bregman's B's. (a) A seemingly random scattering of irregular shapes that fail to group into meaningful configurations. (b) These same fragments are left intact but an amorphous blob is added that provides clues to occlusion. As a result, it becomes fairly easy to perceive the five B's. This figure thus demonstrates the role of good continuation and of interposition cues in grouping. (From A. S. Bregman, Asking the "What for" question in auditory perception. In M. Kubovy & J. R. Pomerantz (Eds.), *Perceptual organization*. Lawrence Erlbaum Associates, 1981. Reprinted with permission.)

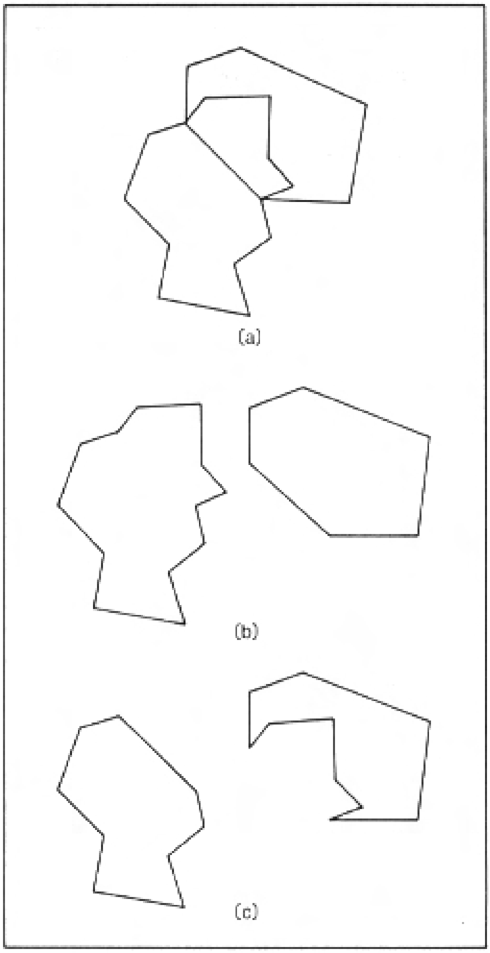


Figure 36.15. Good continuation or convexity? The pattern in (a) is perceptually organized as two superimposed figures as in (b) or, less often, as two figures contiguous at their vertices (c). Although the figure might seem to be a demonstration of the law of good continuation, it is probably a demonstration of the law of convexity, as explained in the text. (From G. Kanizsa, *Organization in vision*. Copyright 1979 by Gaetano Kanizsa. Reprinted with permission of Praeger Publishers.)

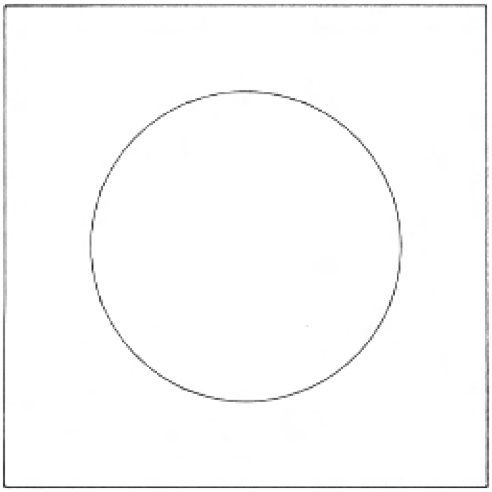


Figure 36.16. A demonstration of the Gestalt law of convexity. This figure is most often perceived as a circle inside of or on top of a square. Alternatively, it could be seen as a square with a circular hole (e.g., a square bolt), but this would require perceiving the circular contour as concave rather than convex.

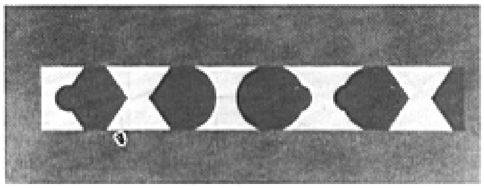


Figure 36.17. A demonstration of the Gestalt law of convexity prevailing over the law of symmetry. Although the white regions define symmetrical figures, the black regions are more often perceived as figure. Thus the law of symmetry, which has been regarded as the most central to the Gestalt principle of prägnanz, has less effect on perceptual organization than the law of convexity, which is unrelated to prägnanz. (From G. Kanizsa, *Organization in vision*. Copyright 1979 by Gaetano Kanizsa. Reprinted with permission of Praeger Publishers.)

the former are convex whereas the latter are concave. (Note that the areas of the two regions have been equated so the law of area cannot explain the effect; neither does it matter which regions are dark and which are light.) The prägnanz principle would appear hard-pressed to explain the perception of Figure 36.17: the less-favored organization involving symmetrical figures is clearly simpler than the favored one because symmetrical figures are simpler than asymmetric ones.

The likelihood principle fares better than prägnanz with the law of convexity. No ecological survey is required to show that convex edges are more common in the environment than concave ones. Many natural stimuli (the moon, an orange, a smooth stone, etc.) are completely convex, but few if any objects are totally concave. Figure 36.18a shows a figure that is almost fully concave; it resembles little that occurs in nature, save perhaps for a starfish. Moreover, this figure is convex in a net, global sense (in that the figure, not the ground, is on the inside of the contour), although locally it is always concave. Figure 36.18b shows that this shape can readily be seen as figure against a circular background. This suggests that the law of convexity applies to global, not just to local regions, since otherwise the cusped shape should appear as ground. Apertures in surfaces such as a slice of Swiss cheese produce large amounts of concave contour, but even here the outermost contour is usually convex and may be longer than the inner, concave contours. In sum, the law of convexity is not explained well by prägnanz; the likelihood principle provides a more plausible account.

4.6. Symmetry

Sixth and last, consider the law of symmetry, listed tenth in Table 36.1. Boring's (1942) description reads as follows: "A form tends toward symmetry, balance, and proportion. Many of the geometrical 'illusions' illustrate this principle" (p. 254). Beyond this, we may add that, according to this law, elements are likely to group if they are arrayed symmetrically, and symmetrical regions of the field tend to be perceived as figure. Symmetry is a key element in pattern goodness (Garner, 1970); further, there may be specialized detector systems in the nervous system that register symmetry directly (Julesz, 1971). Symmetry exists in a variety of forms distinguished by mathematicians, including axial (symmetry about an axis), rotational (a form can be rotated into itself), and translational (a form is repeated in the visual field). These three classes are not all equally conspicuous to perception (e.g., axial symmetry is more readily detected than translational), nor are the effects of symmetry constant within a class (symmetry is more readily noticed about vertical and horizontal rather than oblique axes, as noted by Mach, 1906/1959 and Rock, 1975).

The law of symmetry is usually demonstrated with stimuli containing alternating symmetric and asymmetric columns. Such figures were first devised by Bahnsen (1928), a student of Rubin (as cited in Kanizsa, 1979, p. 108). An example is shown in Figure 36.19 (Rock, 1975, p. 263) in which the white and black columns have been equated for area, convexity, and other potentially confounding factors. In both panels of this figure, the symmetrical columns tend to be seen as figure, with the asymmetrical ones constituting the ground.

Although symmetry is usually regarded as a preeminent law of organization that stems directly from prägnanz (Koffka, 1935/1963, p. 195), it can be overpowered by other laws, such as convexity and good continuation in Figure 36.20a and b (from Kanizsa, 1979, p. 100). These demonstrations serve as much to reveal the power of good continuation and convexity as to downplay the importance of symmetry. In both cases we perceive two overlapping, asymmetrical figures rather than two abutted, symmetrical ones. The same holds true in Figure 36.21 (Kanizsa, 1979, p. 96, Fig. 5.3c) where a square is perceived as occluding a less symmetrical object rather than dovetailing with a more symmetrical one. Of course all the Gestalt laws refer to tendencies, not absolutes, and they apply only within certain boundary conditions. However, the fact that symmetry

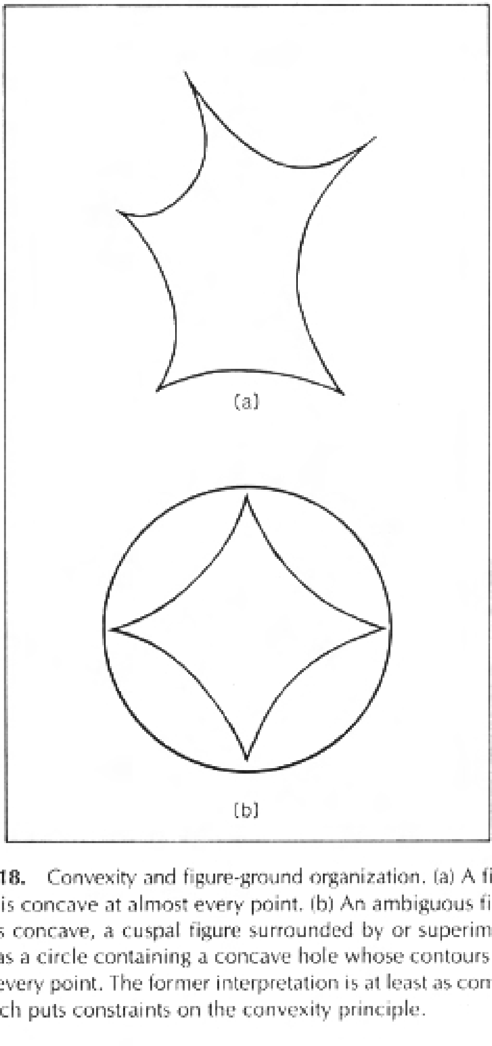


Figure 36.18. Convexity and figure-ground organization. (a) A figure whose perimeter is concave at almost every point. (b) An ambiguous figure: it can be seen as concave, a cuspal figure surrounded by or superimposed on a circle, or as a circle containing a concave hole whose contours are convex at almost every point. The former interpretation is at least as common as the latter, which puts constraints on the convexity principle.