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COMMENTARY AND REPLY

The proper placement of uniform connectedness

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In this journal, Palmer and Rock (1994) articulated a principle of perceptual organization called *uniform connectedness* (UC); and they contended that previous investigators of perception had failed to realize the need for this organizing principle. The authors outlined a theory of perceptual organization that "places the principle of UC at center stage" (p. 38) in that UC was assigned the two privileged roles of (1) forming the fundamental units for later perceptual processes, and (2) yielding the postconstancy regions that correspond to environmental surfaces. In this commentary, I argue that the proposed theory entails a serial ordering of perceptual processes that is inconsistent with current evidence regarding figure–ground organization, stereo fusion, and object recogntion. In addition, I point out that Kurt Koffka (1935) recognized the need for a principle of unit formation similar to the one proposed by Palmer and Rock.

In a recent article in this journal, Palmer and Rock (1994) articulated a principle of perceptual organization called *uniform connectedness* or, simply, *connectedness*. Uniform connectedness entails that "a connected region of uniform visual properties—such as luminance or lightness, color, texture, motion, and possibly other properties as well—strongly tends to be organized as a single perceptual unit" (p. 30); in the authors' view, connectedness operates similarly in these various domains. According to Palmer and Rock, connectedness yields the elementary units over which other processes, such as figure–ground organization, Gestalt grouping laws, stereo fusion, and constancy mechanisms, operate. Thus, connectedness has the privileged position of defining *the first fundamental units* for perceptual organization. The authors imply that neither the Gestalt psychologists nor more recent perception theorists grasped the profound point that the primitive units over which Gestalt laws of grouping operate are not simply given in the retinal image, but must be the result of some organizing process.

In addition to proposing that connectedness operates as the first stage of perceptual organization, Palmer and Rock maintain that connectedness operates again in a postconstancy representation—that is, after stereo fusion and constancy have been achieved. The repeated application of the principle of connectedness ensures that connected regions correspond not only to the primitive units of perceptual organization, but also to the surfaces of real objects and their parts.

This commentary is organized into two parts. In the first part, I point out severe problems that ensue from assigning the principle of uniform connectedness the two privileged roles of forming the fundamental units for later processes of organization and of yielding the postconstancy regions that correspond to environmental surfaces. In the course of this discussion, I show that the arguments advanced by Palmer and Rock lead to a serial ordering of perceptual processes, as is shown in Table 1. Next, I discuss theoretical arguments and empirical evidence that undermine two aspects of this serial ordering: (1) the allocation of figure–ground organization and stereo fusion to different stages of processing, and (2) the assumption that figure–ground organization must precede the operation of contour-parsing mechanisms and object recognition processes. In this context, I briefly discuss my own work, showing that some object recognition processes (Stage 7 in Table 1) operate before figure–ground organization (Stage 2 in Table 1 and in Palmer & Rock's Figure 13). In the second part of the commentary, I argue that, contrary to Palmer and Rock's contention, other perception psychologists have realized that more fundamental organizing processes operate before the Gestalt laws of grouping. Particular emphasis is placed on the writings of Koffka (1935).

What is "Early" and What is "Late" in Perceptual Organization?

Palmer and Rock acknowledge that the principle of connectedness alone yields a mosaic-like representation of the visual field. In a mosaic, all connected regions would be equivalent; no subset would be defined as ele-

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ments or units. According to Palmer and Rock, the regions that are determined to be figures by a process of figure–ground organization become the *entry-level units* for later organizing processes. Thus, Palmer and Rock place figure–ground organization as the second stage of perceptual organization, immediately following the formation of connected regions. Palmer and Rock place parsing processes after figure–ground organization, as many others have done (e.g., Hoffman & Richards, 1985).

Figure–ground organization and stereo fusion. The ordering of the first four stages illustrated in Table 1 is clearly spelled out in Palmer and Rock's Figure 13. I have constructed the ordering of the next three stages from discussions of stereo fusion and object perception distributed throughout their text. For example, I have placed stereo fusion after parsing, because of the interpretation Palmer and Rock ascribe to their Figure 8 (reproduced here as Figure 1). Palmer and Rock presented this figure to demonstrate that "UC [uniform connectedness] should not be identified *solely* with 2-D image processing" but "must also be influenced by relatively late perceptual processes" (Palmer & Rock, 1994, p. 37).

Figure 1 demonstrates that stereo fusion operates on units smaller than those defined by uniform connectedness. But that is potentially troublesome for Palmer and Rock's view. It implies one of the following:

1. Some process other than connectedness provides the elementary units over which fusion operates. If this were the case, it would undermine Palmer and Rock's claim that "UC [uniform connectedness] occupies a privileged position in perceptual organization by virtue of defining the primary or *entry-level* units on which further organizational processes operate" (Palmer & Rock, 1994, p. 38).

2. Uniform connected regions have already been parsed into subunits before stereo fusion processes operate. Palmer and Rock state clearly that parsing processes cannot operate until after figure–ground organization has occurred. Thus, a necessary assumption of this second interpretation is that stereo fusion processes operate after figure–ground organization, after the isolation of entry-level units, and after the parsing of those units into subunits.

Palmer and Rock seem to favor the second interpretation. They espouse the view that some organization occurs before stereo fusion (Palmer & Rock, 1994, p. 37–38, 45, and 49), and write that "depth information at a later stage of processing overcomes an initial organization in terms of UC [uniform connectedness]" (p. 45). Although Palmer and Rock never explicitly order the stages beyond the first four in Table 1, their interpretation of the demonstration reproduced in Figure 1 entails both that figure–ground organization occurs and that parsing processes operate before stereo fusion. Consequently, I have placed stereo fusion at Stage 6 in Table 1.

What is wrong with allocating figure–ground organization to an earlier stage of processing than stereo fusion? Why not suppose that figure–ground organization refers to two-dimensional (2-D; monocular) input only, not to three-dimensional (3-D; binocular) input, and therefore that figure–ground organization can be accomplished before the inputs from the two eyes are combined? There are many reasons for rejecting this notion. One reason is that it is remarkably inefficient. Figure–ground organization entails depth segregation; it is the process of segregating *figures from their backgrounds*. Following figure–ground organization, figures appear to be interposed *in front of* grounds and to have a definite shape, whereas grounds appear to be shapeless near the border they share with figures (Rubin, 1915/1958).

Table 1
The Ordering of Perceptual Processes Stated or Implied by Palmer and Rock (1994)

Stage	Process
1	operation of uniform connectedness
2	figure–ground organization
3	isolation of entry level units
4	parsing of entry level units into subunits
5	stereo fusion
6	reapplication of uniform connectedness to bind together only those uniform connectedness regions that lie in the same depth plane
7	shape/object recognition

Palmer and Rock wonder whether "the initial organization of the 2-D representation is carried over into the later 3-D representation in some way as the 'default' organization" or whether "organizational processes are simply started afresh." They favor the latter view, which seems to be inconsistent with modern research and theory. It is generally accepted by current investigators of depth perception that perceived relative depth relies on the computation and combination of both monocular and binocular depth cues (Bruno & Cutting, 1988; Bülthoff & Mallot, 1988; Dosher, Sperling, & Wurst, 1986; Hochberg, 1971; Landy, Maloney, & Young, 1990; Ramachandran, 1988). I have proposed that other variables should be introduced into this list, including the Gestalt configural cues, such as symmetry, convexity, and relative area (Peterson, 1994; Peterson & Gibson, 1994a), and object recognition inputs (see below). In all likelihood, uniform connectedness should be included as well.

The idea that connected regions are *detected* before depth segregation and figure–ground relationships are determined is consistent with the theory proposed by Palmer and Rock (1994) as well as with the alternative one-of-many cues view sketched above. When connectedness is considered to be one of many cues, however, the conundrum of how connectedness can operate to yield both the fundamental units for perception and the surfaces of perceived objects does not arise. Consequently, one would not have to demonstrate that connectedness operates both early and late in processing, and one would not be forced into the sequential view of

A
B
C

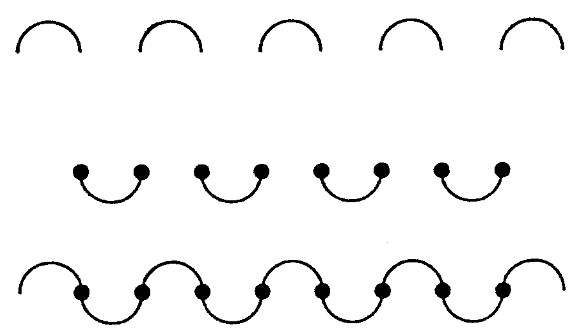

Figure 1. This figure is reproduced from Palmer and Rock's (1994) Figure 8. To experience the demonstration, Palmer and Rock advise the reader to trace the arcs in A onto a clear plastic transparency and to slide that transparency over the display in B so that the pattern looks like C. When this is done, the dots do not selectively group with either the upright-U shapes or the inverted-U shapes, because all are connected by the initial application of the principle of uniform connectedness. However, the authors advise the reader to lift the transparency above the page to see that the final perception of connected regions occurs after stereoscopic depth perception. From "Rethinking Perceptual Organization: The Role of Uniform Connectedness," by S. Palmer and I. Rock, 1994, *Psychonomic Bulletin & Review, 1,* p. 37. Copyright 1994 by the Psychonomic Society, Inc. Reprinted by permission.

perceptual organization implied by Figure 1 (their Figure 8) and illustrated in Table 1.

I am not proposing that there are no stages in visual processing; some processes *must* follow others. Nor am I implying that none of the cues that contribute to figure–ground organization depend on the prior computation of any of the others. For example, global symmetry, a configural cue discussed by the Gestalt psychologists, may rely on the prior computation of uniform connectedness. But the detection of uniform connectedness may not be necessary for the computation of all the cues discussed above. For instance, Stevens and Brookes (1988) have shown that a *local* measure of contour convexity is an effective determinant of figure–ground organization. The prior detection of uniform connectedness may not be required for the operation of contour-parsing mechanisms either. I turn to a discussion of this point in the next section, in the context of addressing the question of whether or not figure–ground organization must precede shape recognition.

Figure–ground organization, contour-parsing mechanisms, and object recognition. One factor that has long been excluded from the list of variables thought to determine candidate objects and their relative depths has been some index of familiarity or recognizability. Most theories of perception have been grounded on the assumption that regions must be registered as figures before they can be matched to representations of objects in memory (e.g., Biederman, 1987; Gottschaldt, 1929; Kosslyn, 1987; Marr, 1982; Rock, 1962, 1975; Wallach, 1949). This assumption entails that (1) regions in the visual field have no shape until after figure–ground relationships have been established, at which point only figures have shape, (2) it is impossible to access representations of objects (or shapes) in memory before shaped regions in the visual field have been separated from shapeless regions, and (3) figure–ground organization must depend only on variables that can be computed from the current stimulus array ("bottom-up" variables) and must precede any contributions from memory or other "top-down" processes.

Palmer and Rock favor the assumption that figure–ground organization occurs before object recognition and the corollary assumption that contour-parsing processes cannot operate until after figures have been distinguished from grounds. This corollary assumption is grounded on the notion that the parts for recognition are delimited between successive concave cusps along a contour. The segments of a contour that are concave from one side are convex from the other side. Therefore, contour-parsing mechanisms using concave cusps will identify different parts (and hence, different objects) along the two sides of a contour. For this reason, it has been thought that a side of origin must be specified before contour-parsing mechanisms operate; it has been assumed that figure–ground organization serves this function (Hoffman & Richards, 1985). Although it is certainly true that contour extrema of curvature exhibit different polarities on the opposite sides of a contour, this fact need not entail that figure–ground organization must precede the operation of contour-parsing mechanisms.

Contrary to the accepted notion that figure–ground organization must precede the operation of contour-parsing mechanisms and subsequent object recognition processes, my students and I discovered that outputs from representations of shapes in memory can contribute to figure–ground organization, implying that some object recognition processes[1] must operate before figure–ground organization. The first indication that some object recognition processes might be operating before figure–ground organization was obtained in an experiment in which observers viewed 2-D figure–ground stimuli for long durations and reported about reversals of perceived figure–ground organization (Peterson, Harvey, & Weidenbacher, 1991). Since that initial discovery, we have replicated these effects on numerous occasions (e.g., Peterson & Gibson, 1993, 1994b); we have extended our reversal findings to 3-D displays (Peterson & Gibson, 1993), and we have found evidence that object recognition influences extend to initial perceived organization as well as reversal (Gibson & Peterson, 1994; Peterson & Gibson, 1991, 1993, 1994a). Rather than describing the results of those experiments in more detail here, I will discuss our proposal regarding how object recognition processes can operate before figure–ground relationships have been established, because that proposal is most relevant to the question of whether or not contour parsing procedures *must* follow the determination of figure–ground relationships.

We have proposed that the object recognition processes that contribute to figure–ground organization and depth segregation operate on edges per se, and not necessarily on the edges of regions already (partially or fully) determined to be figure. We propose that these "prefigural recognition processes" carve the edges that can be detected early in visual processing into parts *from both sides simultaneously*, therefore indicating different sets of parts along the edge's two sides. These different part sets are used to access in parallel the representations of different objects in memory that best fit the opposite sides of an edge or a contour. Outputs from these activated representations in object memory serve as input to figure–ground computations, along with outputs from processes assessing Gestalt configural cues and depth cues of both the monocular and binocular variety. Thus, the outputs from object recognition processes combine with configural cues and classic depth cues to determine depth segregation (Peterson, 1994; Peterson & Gibson, 1993, 1994a).

The notion of edge-based recognition is not new (e.g., Biederman, 1987; Hoffman & Richards, 1985; Marr & Nishihara, 1978). Our account is unique in permitting some object recognition processes to operate on *edges* per se and not necessarily on the edges of *regions* already determined to be figure. Consistent with our view, we have found that when a recognizable object is depicted by only part of the bounding contour of a (uniform connected) region, object recognition inputs to figure–ground organization are localized only in the vicinity of the depictive part of the contour and do not extend across the entire luminance bounded region (Peterson & Gibson, 1993, Experiment 3).

We interpret our results to imply that some object recognition processes occur earlier than has been thought, *not* that figure–ground organization occurs later than has been thought; the latter is Palmer and Rock's interpretation (1994, pp. 36–37). We have proposed that "prefigural" shape recognition processes can proceed in parallel with other processes that contribute to figure–ground organization only by operating on edges that are detected quite early in processing. Experimental results reveal evidence that prefigural shape recognition processes can operate on luminance edges, on outlines, and on subjective contours (Peterson & Gibson, 1994b), but not on stereo-only edges (as in random-dot stereograms; Peterson & Gibson, 1993); the latter are available only following figure–ground organization and, hence, cannot serve as a platform for processes that contribute to figure–ground organization or reversal (Peterson & Gibson, 1993).

Thus, the results of the experiments conducted in my laboratory indicate that outputs from representations of objects in memory must be included in the list of cues weighed by the visual system in producing perceived depth. Therefore, they form a body of empirical evidence contesting serial views of organization, such as the one espoused by Palmer and Rock (1994) and by others before them (e.g., Marr, 1982). Our research shows that figure–ground computations take converging inputs from many processes, including stereo fusion and object recognition. Investigators of visual perception have noted that none of the depth cues is infallible. Thus, perceived depth is not dominated by any one depth cue, be it monocular or binocular; rather, it reflects some combination of the various cues. Consistent with the findings regarding the traditional depth cues, we have found that inputs from prefigural recognition processes do not dominate the depth segregation process. This is as it should be, as prefigural recognition processes are not infallible either. For instance, although it may be unlikely for a familiar object to be sketched out along the converse side of the edge of an object, it is not impossible, as both 2-D and 3-D versions of the Rubin vase/face stimulus attest. Likewise, although it may be unlikely for a single uniform connected region to map onto different objects, or for different objects to map onto a single uniform connected region, it is not impossible, as Palmer and Rock point out. Therefore, in order to ensure that perception is as close to accurate as possible, it would be sensible for depth computations to consider each of these cues in parallel rather than in sequence. In that way, the percept receiving the most support from the largest number of cues will be seen, and that percept will be the most likely to be veridical. Furthermore, when perceptual organization is construed as a more parallel process, certain conundrums that provide some difficulty for Palmer and Rock would never arise (e.g., How much organization is completed before stereo-fusion–based constancy? Is that organization undone following stereo-fusion–based constancy? See Palmer & Rock, 1994, p. 49).

A Prior Argument for Uniform Connectedness

Palmer and Rock's central point is that one cannot simply argue that the fundamental units (primitives) over which later perceptual processes operate are given in the retinal image; rather, some perceptual processes are required to make them explicit. Even if Max Wertheimer were guilty of committing the "experience error" (see Palmer & Rock, 1994, note 1) in believing this, the prominent Gestalt psychologist Kurt Koffka was not.[2] Koffka (1935) argued that perceiving a spot (blot) of ink on a piece of white paper as unitary required some force of organization:

> Let us look at any such spot, produced, for instance, by splashing ink on a white piece of paper. We see the ink blot: no problem seems to be contained in this simple case. There is the ink blot and we see it.... But.... There is a very real problem here which is concealed only by the fact of the universality of such experiences.... To see an ink blot is the result of an organization.
>
> **The two problems involved in this case. (1) Unit formation.** In the first place, then, our blot is seen as a unit, segregated from the rest of the field.... Why is the blot a unit; how does it become segregated from its surroundings? The answer seems obvious: because it is differently coloured. Certainly this is the right answer if one gives the

Wallach, H. (1949). Some considerations concerning the relationship between perception and cognition. *Journal of Personality*, **18**, 6-13.

NOTES

1. I refer to these processes as "object recognition processes" because they appear to access representations of objects in memory. These representations specify both the typical or canonical orientation of the depicted object and the proper spatial relationships between the parts of the object (Gibson & Peterson, 1994; Peterson et al., 1991; Peterson & Gibson, 1994a, 1994b). Additional reasons for referring to shape recognition processes per se and not simply to familiarity or meaningfulness are discussed elsewhere (e.g., Peterson & Gibson, 1993). Our proposal that some object recognition processes operate prefigurally does not entail that the entire object recognition process is completed before figure–ground organization.

2. I am indebted to my colleague, William Ittelson, for pointing out these passages from Koffka during my preparation of this commentary.

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