Journal of Experimental Child Psychology **78**, 84–97 (2001)
doi:10.1006/jecp.2000.2604, available online at http://www.idealibrary.com on IDEAL®

Separating Processes in Object Perception

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In this article, I consider research by Needham and colleagues examining the role of object knowledge on infant's segregation of scenes into objects. I suggest that research in this area would benefit from closer connections to computational, psychophysical, and neurophysiological research on adult perceptual segmentation and grouping. I sketch a framework for understanding the components of object perception and apply it to the paradigm and displays used by Needham. This analysis suggests two ideas. First, it would be valuable to demonstrate the role of object knowledge in cases that are less impoverished in terms of perceptual information for segregation and more typical of object arrangements in ordinary scenes. Second, some method is needed to distinguish whether infants' object knowledge affects *perceptual* organization of new scenes or produces specific beliefs, inferences, or expectations about particular objects and scenes. As a specific example of the benefits of connecting developmental and adult research, some recent research in adult perception is described. The research indicates that in adult object segregation, two types of processes may be distinguished: basic perceptual processes of object segregation and more cognitive processes involving recognition. I suggest that Needham's research may be revealing the developmental origins of the latter processes.

Key Words: object perception; segmentation; grouping; perceptual organization.

In 1926, Gottschaldt studied the issue of whether familiarity with a form affects the segmentation of arrays containing that form. He gave observers extensive experience with particular outline forms and then embedded these in more complex configurations. His results suggested that observers' familiarity with specific forms did not affect their segregation of more complex arrays. Object segregation is governed instead by basic perceptual rules of segmentation, such as edge continuity (Gottschaltdt, 1926).

Needham's (2001, this issue) article "Object Recognition and Object Segregation in 4.5-Month-Old Infants" (along with other recent work, e.g., Needham & Baillargeon, 1998) takes up Gottschaldt's questions with human infants. Using an elegant paradigm, the studies suggest that when an object is first presented alone, it may later allow segregation of an array that would otherwise

The author gratefully acknowledges support from National Science Foundation Research Grants SBR-9496112 and SBR-9720410.

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0022-0965/01 $35.00

have appeared ambiguous or indeterminate. Several experiments probe the limits of this effect in terms of the required similarity of the previously exposed object and the object in the target array.

These studies, old and new, address a crucial problem. Our partitioning of the world into objects is basic for both action and thought; accordingly, understanding object segregation abilities, their development, and the role of experience with objects are fundamental concerns in perception and cognitive development.

In this article, I focus on one overriding theme. There is a need, I believe, to connect the type of research reported by Needham more closely to computational analyses and psychophysical research with adult humans on processes of segmentation and grouping. The benefits of doing so go in both directions. On one hand, analyses of computational tasks, information, processes, and mechanisms have advanced considerably in research on adult perception. In some developmental research, these advances are not used as a starting point or even a reference point. That is unfortunate, inasmuch as these other lines of research provide an important source of hypotheses and interpretations for the developmental study of processes and mechanisms. Going in the opposite direction, developmental results such as those offered by Needham can shed light on our general understanding of perceptual processes. Infant research may be especially useful in helping to distinguish separate processes that may jointly contribute to perceptual organization and in revealing the role of learning. Such impact will not occur, however, unless investigators make clear the relation of their experiments to nondevelopmental research.

In this article, I aim to advance these connections by sketching a framework, from current research in adult perception, of the tasks and information involved in human object segregation. Then I attempt to interpret Needham's displays and results in that framework. In the latter portion of my comments, I will illustrate the value of connecting adult and developmental research by describing some particular recent developments in adult object perception research that may converge with Needham's findings in supporting the idea that object segregation responses may reflect at least two distinct levels of processing.[1]

A New Theoretical Context?

Needham's article sets out some context for the present research. She notes that research on infant object segregation with adjacent and partly occluded objects has supported several conclusions:

1. For "information present within the display, common motion and spatial separations are the most useful kinds of information for young infants to accurately determine object boundaries . . ." (p. 4).

[1] As the author mentions, there are possible interpretations of the looking patterns in these studies other than the interpretation in terms of object segregation. I concur, but assume along with the author that these discussions have taken place elsewhere. In my comments, I more or less assume Needham's interpretation that the looking time differences reflect either perception or belief (although these may be quite different) of separate or connected objects in an array.

2. “ . . . featural information is used by infants as young as 4 months of age, provided that (a) more reliable information, such as common motion and spatial separations, is not available (Needham & Baillargeon, 1997; Needham & Kaufman, 1997) and (b) the objects’ features are not too complex (Needham, 1998, 1999; see also Johnson, 1997)” (p. 4).

3. “Infants also use knowledge about particular objects or kinds of objects to form interpretations of displays” (p. 4).

More theoretical background is given in earlier work by Needham, Baillargeon, and Kaufman (1997). They set forth a taxonomy of information, consisting of *configural*, *physical*, and *experiential* cues: “Configural knowledge refers to adults’ expectations about how objects typically appear . . .” with the general idea being that “adults tend to group surfaces that present the same featural properties . . . “ (Needham, Baillargeon, & Kaufman, 1997, p. 3). Physical knowledge “refers to adults’ beliefs about the lawful ways in which objects can move and interact, such as the beliefs that objects cannot remain stable without support . . . “ (p. 3). Finally, experiential knowledge “corresponds to adults’ knowledge of what specific objects, or types of objects, exist in the world” (p. 3).

Neither the background in the current article nor the taxonomy elaborated earlier makes any direct contact with computational, psychophysical, or neurophysiological work on segmentation and grouping processes in adult perception. Research on perceptual organization is a scientific enterprise that has been proceeding continuously since even before Gottschaldt (1926), and it has made much progress at all levels in recent years (for reviews, see Kellman, 2000; Kellman & Shipley, 1991; Palmer, 1999; Rock, 1986).

There are many problems in constructing a theoretical framework *de novo*. This research project seeks to describe the contributions of object knowledge to scene interpretation above and beyond what is given by basic perceptual processes. The effort is not likely to succeed if the basic perceptual processes are poorly understood or misconstrued. Needham, Baillargeon, and Kaufman (1997) argue that object knowledge in segregation is crucial because “spatial information” cannot segregate any adjacent objects, and they give examples. But “spatial information” means “spatial separation” (Needham, 2000, p. 4); these investigators assume that spatial information for segregation consists of the idea that spatially continuous surfaces belong to the same object and spatially discontinuous surfaces do not (Needham et al., 1997). The assumption is simply incorrect. To motivate their approach, Needham et al. (1997) present a number of examples of adjacent objects that they claim would be perceived as unitary according to spatial information. Without exception, all would be correctly segmented into two objects by human adults, according to both traditional and contemporary accounts of perceptual processes (Kanizsa, 1979; Kellman & Shipley, 1991; Marr, 1982; Michotte, Thines, & Crabbe, 1964; Wertheimer, 1923/1958). These accounts depend not on familiarity with specific objects, but on segmentation and grouping principles that work on unfamiliar objects (Kellman & Shipley, 1991), are innate in some other species (e.g., Regolin & Vallortigara, 1995), and now appear to depend on basic interactions of orientation-sensitive units in early visual cortical areas (Field, Hayes, & Hess, 1993; Gilbert et al., 1996; Polat & Sagi, 1993). Similarly, the idea that adult unit formation can be summarized as the grouping together of surfaces with the same featural properties simply does not characterize current models in any reasonable way (for discussion of the role of featural similarity in models of object segregation and grouping, see Yin, Kellman, & Shipley, 1997).

Another question that needs to be considered in greater depth is the distinction between perceptual knowledge and other sources of belief. Needham (2001, this issue) and Needham, Baillargeon, and Kaufman (1997) argue that infants are not "modular processors" (Needham et al., 1997, p. 39), but that they "take advantage of all of their knowledge . . . to make sense of the world." It is not clear what evidence or argument against dedicated perceptual mechanisms for object segregation the authors believe they have assembled. I suppose one source of this belief might be the difficulty of determining from infants' looking times whether these are based in a given case on perceptual organization or on specific expectations, beliefs, or inferences. Yet the inability of a dependent variable to sort out the contributions of separate processes does not provide any evidence against the possibility of modular perceptual processes.

In perception research, it has often been argued that we can and should distinguish processes of perceptual organization from other influences (cf. Fodor, 1983). Going back at least to the Gestalt psychologists (e.g., Gottschaldt, 1926; Koffka, 1935; Wertheimer, 1921), there is evidence that perceptual processes in human object segregation are relatively unaffected by beliefs, expectations, or specific experience. The view would seem to receive additional support from the finding that some of the basic segmentation processes, such as completion of partly occluded objects based on edge continuity, are demonstrably innate in some other species (e.g., Regolin & Vallortigara, 1995). Moreover, several investigators, such as Kanizsa (1979) and Michotte, Thines, and Crabbe (1964), explicitly studied cases where perceptual organization and beliefs or knowledge about specific cases of segmentation conflicted. They concluded that the former obey rather rigid rules and constraints. They also showed that it is completely possible for an observer to *know* that a display is organized a certain way even though they *see* it some other way.

Some attempt to grapple with prior work would benefit this research. Not all distinctions between perceptual knowledge and other sources of belief are clear, but some are. I may believe that the car is in the garage because I see it there, or because I watched it go in yesterday, or because you tell me that it is in there. These cases are all different; they use different cognitive processes and follow different rules. Investigators such as Kanizsa (1979) and Michotte et al. (1964) have worked hard to consider these issues and their arguments are convincing (or at least worth considering).

Infants may also form beliefs from different sources. A difficult question in Needham's research is how we might decide whether a pattern in infants' looking times tells us about perceptual organization, about specific expectations for a previously viewed object, or about some scene representation to which both contribute. I may see that the magician's assistant has disappeared but I would not be willing to bet against her reappearance. Infants at 4.5 months of age may also have percepts, beliefs, and inferences. How can we draw conclusions from this sort of data about whether perceptual organization is modular?

I do not mean to place this burden uniquely on the present research; it is a difficult and general problem. Given, however, that different bases for belief about object segregation are well established in research with adults (e.g., in the analyses and evidence given by Kanizsa (1979) and Michotte et al (1964)), it surely means that we are uncertain of the meaning of the infant data in Needham's experiments. Note that the situation is clearer for paradigms in which the infant's segregation of a display occurs *without* prior object familiarization. As Needham indicates, findings are clear in showing that certain spatial and motion relationships are used by perceptual segregation processes in infancy. This conclusion is far easier to reach than the conclusion that specific object experience affects *perceptual* segregation of displays. The point may be especially important when the basic case chosen for study may be a fairly unique one (see below).

A Perceptual Analysis of Segregation Information

The study of the perceptual processes for grouping and segmentation in adult perception and computational vision is far advanced. Optimally, developmental research provides an important input to the understanding of these processes but only if it is informed by and interpreted relative to accumulated knowledge in this area. Here we set out some of the computational tasks and, in sketchy fashion, some relevant points of current models.

Psychophysical research and computational modeling suggest several components of object perception. Moreover, each poses questions at several levels of analysis. This framework can help to guide experiments and their interpretation in perceptual development research. A taxonomy of these components (Kellman, 1995; see also Kellman & Banks, 1997) derives from many lines of research involving the various components, such as edge detection (Marr, 1982), edge classification (e.g., Gilchrist, Delman, & Jacobsen, 1983), boundary assignment (e.g., Nakayama, Shimojo, & Silverman, 1989), unit formation (Kellman & Shipley, 1991), and so on. The components are (1) edge detection, (2) edge classification, (3) boundary assignment, (4) unit formation, (5) form perception, and (6) perception of other object properties (e.g., size and substance).

These are initially formal distinctions; that is, they refer to separable computational problems being solved by visual processes. They may also represent distinct processes and mechanisms in the visual system. However, it is not clear that this must be the case for all of the components listed. Also, the list does not imply that the various processes necessarily proceed sequentially in time.

For each component, there is more than one level at which they must be explained (Gibson, 1966, 1979; Marr, 1982). For edge detection or unit formation or any of these abilities, we may ask (a) What is the information available in reflected light that allows the task to be performed? (And what constraints or assumptions about the way the world is can be used to make the computation tractable?), (b) What representations and processes are used to do the task?, and (c) What neural mechanisms carry out the computations?

For further discussion of these levels and their roles in infant perception research see Kellman and Arterberry (1998). In the current context, the goals of Needham's research seem to lie primarily in characterizing the information used in object segregation and perhaps shedding some light on processes used.

If information is our main concern, we must add that for most or perhaps all of the components of object perception, there appear to be multiple forms of information for doing the task (Kellman & Arterberry, 1998). With our focus on information and process, let us take a closer look at the various components of object perception.

Edge detection refers to the finding of significant discontinuities in the optic array. The ecological constraint underlying this first component is that objects tend to be relatively homogeneous in the luminance and spectral composition of light they reflect as well as in depth and texture. These various properties make possible various kinds of information. Discontinuities in luminance, e.g., the boundary between a black and white surface, are available in static scenes, as are discontinuities in texture. Depth discontinuities between different objects make available discontinuities in stereoscopic disparity maps across a scene as well as in optic flow maps given to a moving observer.

In Needham's research, edge detection is largely (and appropriately) presupposed. In the first place, other research suggests that even from birth, infants detect significant edges in visual displays (Kellman & Arterberry, 1998). Also, I believe it would be hard to make sense of Needham's data (and prior data by Needham & Baillargeon, 1998) if infants lacked basic edge detection abilities.

Edge classification refers to identifying which edges are boundaries of surfaces or objects as opposed to shadows or textural markings. There are several edge classification issues implicit in the present research. A primary question is whether or when a visible contour will be classified as an object boundary. There are other embedded classification questions, such as whether the squares painted on the box are taken to be objects.

Edge classification may be possible from multiple sources of information. Two that appear to function early in infancy are use of motion (accretion-deletion of texture) information and depth information (Kellman & Arterberry, 1998). Needham's research converges with earlier results in suggesting that the use of luminance or color edges to segregate adjacent objects, i.e., classification of the edges as object boundaries, appears to be a relatively late developmental achievement (e.g., Hofsten & von Spelke, 1985).

When an edge is classified as an occluding edge, it bounds only one of the surfaces adjacent in the retinal projection. Determining which is called *boundary assignment*. Boundary assignment is a good example of why these components of object perception might not be fully separate or sequential in actual processing. When depth or motion information is available, it may produce edge detection, classification, and boundary assignment all together (see Kellman & Arterberry, 1998, for elaboration of this idea).

In Needham's experiments, motion and stereoscopic depth discontinuities are available to segregate the object when it is moved by the hand in the familiarization part of the experiment. Thus, the issue in the test concerns how knowledge representations obtained from this perceptual processing affect expectations about an array presented later, which I will call the target array. For segmenting static scenes, a great deal of information is carried by contour junctions (Barrow & Tenenbaum, 1986; Heitger et al., 1993; Kanizsa, 1979; Nakayama, Shimojo, & Silverman, 1989; Shipley & Kellman, 1990). Especially powerful are "T" junctions. T's are a reliable cue to occlusion in the environment. This fact seems to be reflected in perception: The contour forming the stem of the T is ordinarily seen as going behind the surface bounded by the "roof" of the T. Peculiarities of the presence and absence of T junctions are interesting features of the target display in these experiments (see below).

Unit formation involves the determination of contour and surface connections in the array. An important and frequently studied case is the connecting of spatially separate visible regions, but unit formation also involves the segmentation or grouping of adjacent displays. In adult perception of stationary arrays, crucial information involves contour junctions and contour continuity. These are really complementary notions, expressing a general constraint, incorporated into perceptual machinery, that object boundaries tend to be smooth (Marr, 1982). Contour junctions, which come in many types, are all tangent discontinuities in that there is no unique edge orientation at these points (Heitger et al., 1993; Kellman & Shipley, 1991). Continuity of a contour as an important grouping factor was first described by Wertheimer (1923/1958) as the Gestalt factor of good continuation. In more recent accounts, it has been formalized mathematically as involving at least first-order (first-derivative) continuity, i.e., the absence of tangent discontinuities. This relationship, which with a couple of other formal constraints is known as *relatability*, is crucial in accounting for unit formation across gaps, as in perception of objects under occlusion and perception of illusory contours (Kellman & Shipley, 1991). The case of unbroken contours is really the case of relatability with gap size zero: thus, a contour continuing through a junction is seen as belonging to one object (Kanizsa, 1979; Kellman, 2000).

Analyzing the Target Display

The preceding framework is relevant to many general issues in understanding in object segregation. A few comments relating specifically to understanding the displays used in Needham's research (and in prior work by Needham & Baillargeon, 1998) may be useful.

To anticipate the conclusion: the display is a special and potentially misleading case if we are trying to understand the determinants of object segregation.

The target array in these experiments is shown in Needham's Fig. 1. From the standpoint of perceptual information, it is a very special case. The typical (generic) case for two objects that are separate in the world but appear adjacent in the retinal projection is that at least some boundaries of the further object will form stems of T-junctions (see, e.g., Barrow & Tennenbaum, 1986; Kellman & Shipley, 1991). In the display used here, the objects are positioned so as to be adjacent. This is not an impossible case in natural scenes, but it is relatively rare (as one can verify by looking around a room trying to spot such cases). Accordingly, it is not clear how much about object segregation in general we would want to infer from studies of this special case. At the very least, we should identify it as a special case.

What junctions do appear? The upper contour intersection is not a T, but a K junction. The K junction is a quite rare and puzzling case, notable in that it provides little useful information for segmentation (see Barrow & Tennenbaum, 1986). The lower junction appears to be a T junction. But it is an exceptionally interesting T junction! Ordinarily, the stem of a "T" is an edge of an object that goes behind another object at the intersection. The "roof" of the T is ordinarily an occluding edge of a single object, and the result of T junctions in adult perception is that the occluding edge will reliably be perceived as such.

From the appearance in the figure, the objects have been placed adjacently in a way that gives the unique result that there is apparent continuity of their contours along the ground surface. This accident makes for a *misleading* T junction—one in which the continuous boundary indicates connection of the two objects. Also, taken alone, this T junction might specify that the surface of the table is an occluding edge, which it is not.

In short, this junction is highly nongeneric. The problem is partly that objects often do terminate on a common ground surface (a fact that presents some interesting issues in analyzing junctions), but it has most to do with the fact that the objects have been placed adjacent to each other in special way.

The exact implications of this stimulus choice for Needham's research depend on the intent and interpretation. The fact that the target array is informationally impoverished and atypical for natural scenes does not invalidate the experiments, but it is crucial to understanding what they do and do not tell us. It would be nice to test whether specific object knowledge can affect displays for which perceptual organization provides a clear answer. Compounding the questions here is uncertainty about what aspects of segmentation processes based on edge continuity and junction analysis are operational in the 4.5-month-old human infant (Johnson & Aslin, 1996, 1998; Kellman & Spelke, 1983; Yonas & Arterberry, 1994).

Finding that object knowledge may tip the balance for a case that is borderline or indeterminate to begin with may not tell us much about the general significance of the process, especially if the indeterminate case is atypical in ordinary scenes. Interestingly, Gottschaldt's (1926) conclusion that familiarity makes little difference came from displays that incorporated robust information usable by perceptual processes. Future research might profitably address these questions by systematically manipulating the perceptual information in the displays. Furthermore, if the relevant processes are maturating in human infancy (see discussion in Kellman & Arterberry, 1998, pp. 161–163), then studies at later ages may be important, and the question of the relative roles of the different influences on object segregation will bear reexamination

To sum up this section, three ideas are clear. First, computational and empirical analyses have established that there are multiple information processing tasks and multiple sources of information involved in object segregation. To maximize the impact of research with infants, it would be helpful to locate particular procedures, displays, and hypotheses within this space of tasks and information. Second, the relative importance of infants' object knowledge and dedicated perceptual processes cannot be assessed without understanding the latter in more detail. In particular, we need to know as much as possible about the stimulus relationships in our displays, and we need to consider systematically the perceptual information in the scene and the infant's developing abilities to use it.

Finally, there is the sticky problem of untangling processes. If infants have some knowledge representations that derive from perceptual segmentation processes, and they also have some specific expectations tied to specific objects or object types, how can we learn about both types of processes? The same question, I believe, poses a challenge in research on adult perception. Some paradigms reveal processes of segmentation and grouping that clearly do not involve any potentially familiar objects at all (e.g., Field et al., 1993). Others, such as priming experiments, seem to show effects of global symmetry on object perception (e.g., Sekuler, Palmer, & Flynn, 1994). Needham's research on object knowledge may be revealing the origins of these latter effects, as we consider in the next section.

Separating Processes in Object Perception and Cognition

Much of the above analysis has stressed the importance of placing object segregation in an appropriate general framework. In this section, I grapple with one specific issue on which Needham's research converges and may help explain recent results in adult research. Specifically, Needham's research suggests that knowledge about particular objects can influence expectations about object segregation. Moreover, if experiences with objects can lead to relatively generic expectations (Needham, Dueker, & Lockhead, 2000), this research may help us to understand more global influences in adult object perception (e.g., Sekuler, Palmer, & Flynn, 1994).

A continuing puzzle in research on segmentation and grouping in adult perception concerns the roles of local and global determinants. Research on relatively local determinants, such as edge relatability and surface spreading, suggests that these processes follow determinate rules and that, in the case of edge processes, they may map onto basic neurophysiological interactions quite early in the cortical visual pathway.

Some other research, however, suggests that more global influences, such as the notion that objects are symmetric, may influence object perception. For example, Sekuler, Palmer, and Flynn (1994), using a priming paradigm, suggested that partly occluded figures are completed in accordance with global symmetry. Other reports suggest that priming can produce either global or local completions (Sekuler, 1994; van Lier, van der Helm, & Leeuwenberg, 1995). This kind of effect seems to be related to the category of configural cues described by Needham et al. (1997). Moreover, an intriguing hypothesis in the present research is that from experiences with particular objects, some general knowledge about objects emerges and comes to affect object segregation. In other words, use of global shape variables, such as symmetry, may arise from experiences with particular objects.

The idea that both relatively autonomous and local perceptual processes, as well as more global influences involving familiarity and symmetry, affect object processing is theoretically challenging. Are these influences all contributing to a single process of perceptual organization? If so, it would be a complex process indeed and nearly intractable to characterize precisely. For example, efforts to connect perceptual segmentation and grouping processes to early interactions in the visual pathway would seem to be misguided, as information from higher areas having representations of object shape would be used together with local information in some scheme. Alternatively, both global and local effects may exist, but they may reflect separable processes. This latter idea could be true but nevertheless difficult to discover from experiments using dependent variables such as infants' looking times or adults' priming data, as both of these might well be affected by local perceptual processes as well as more global cognitive ones.

Some recent research sheds light on this situation. It points to the conclusion that basic perceptual processes for object segmentation may be distinguishable from higher level cognitive determinants. Needham's research may be revealing the origins of these latter inputs to object representation. Although Needham's current article involves segregation of adjacent displays and the line of research I discuss involving adults involves partially occluded ones, the two levels of processing we examine probably encompass both kinds of situations.

Kellman, Shipley, and Kim (1996) suggested that results from different paradigms in object perception might reflect two distinct categories of processing. One is a bottom-up, relatively local process that produces representations of boundaries according to the geometry of edge relatability. This process is *perceptual* in that it appears to be a modular process that takes stimulus relationships as inputs and produces boundaries and forms as outputs. The other process is more top-down, global, and cognitive, coming into play when familiar or symmetric forms can be recognized. We have labeled it *recognition from partial information*.

One factor supporting this distinction is the *identity hypothesis* in unit formation (Kellman, Yin, & Shipley, 1998; Ringach & Shapley, 1995; Shipley & Kellman, 1992). The identity hypothesis states that the a common contour connecting process governs unit formation phenomena that look quite different, notably partly occluded objects (what Michotte et al. called *amodal* completion) and illusory contours and objects (*modal* completion in the terminology of Michotte et al.). A variety of logical and empirical considerations support the identity hypothesis (Kellman, Yin, & Shipley, 1998; Ringach & Shapley, 1995). There is, however, an apparent problem. Global completion phenomena are sometimes reported in occlusion cases, and global influences can be seen in some priming data with occluded displays. Yet, global completion phenomena are never observed in illusory object displays (see Kellman, 2000, for more detailed discussion).

The paradox can be resolved as follows. The identity hypothesis applies to the perceptual process of contour and surface interpolation, but not to recognition from partial information. Although the basic interpolation mechanisms may be shared, there is a crucial difference in terms of higher level visual cognition between an occluded surface and an illusory one, i.e., one that is nearest to the observer in some visual direction. The crucial difference is this: An observer viewing an occluded display is aware that part of the object is hidden from view. This allows certain kinds of reasoning and responses that are not sensible when no part of an object is occluded. Despite any local completion process, the observer may notice in an occluded display whether the visible parts are consistent with some familiar or symmetric object.

As a concrete example, if I see under a pile of papers only a corner of a uniquely purple-colored book, I know the book is there. In this case, the particular contours and surfaces of the hidden parts are not given perceptually. A stored representation of the book may be activated and a belief about the presence of the book may be formed. But this recognition from partial information differs from perceptual processes that actually specify the positions of boundaries and surfaces behind an occluder.

Although the specifics are a bit different, I suggest that Needham's research may be revealing the same duality of perceptual and recognition processes. In arrays lacking usable perceptual information for segmentation, infants appear to use specific object knowledge. Moreover, as Needham suggests, familiarity with many objects (especially artifacts, which tend to be symmetric) may lead to expectations about global symmetry. These expectations about global symmetry may be the bases of effects found in priming paradigms with partly occluded displays. The idea is especially plausible given the known sensitivity of priming to high-level cognitive influences as well as to basic perceptual ones (e.g., Kawaguchi, 1988).

So far this separation of processes is a hypothesis. It would be useful to know about separate processes, if they exist, as it would allow researchers to characterize the inputs and workings of each as well as explore their relationships and interactions. Is there any way to separate the processes empirically?

We believe there is. To test the possibility of different processes, Kellman, Palmer, and Kim (1996) developed a new paradigm. We reasoned that perceptual processes of contour completion lead to specific perceived boundaries (under occlusion or as illusory contours). Recognition from partial information, on the other hand, because it may work through activation of stored information, might not produce very specific representations of the locations of occluded boundaries. To measure the precision of boundary location, we used a dot localization paradigm in which an occluded display is presented, followed by a brief probe dot in front of the occluder, after which the display is masked. Subjects' were instructed to respond on each trial whether the probe dot fell inside or outside the occluded object's boundaries (i.e., whether the projection of the occluded object to the eye would or would not encompass the dot).

We used an adaptive staircase procedure. In this procedure, stimulus values change over trials depending on the subject's responses. Systematic changes allow estimation of a single point on the subject's psychometric function. For each display, we used two staircases: a "two-up, one-down" and a "one-up, two-down" staircase, estimating the .707 probability of seeing the dot as outside the boundary and .707 probability of seeing the dot inside the boundary (= .293 probability of outside) respectively. *Precision* was measured as the reciprocal of the *difference* between these estimates, and accuracy as their *mean*. We interleaved staircases for several stimulus patterns, and screen position varied randomly.

Occluded displays similar to those used in priming research (e.g., Sekuler, Palmer & Flynn, 1994) were tested (Kellman, Palmer, & Kim, 1996; Kellman, Temesvary, Palmer, & Shipley, 2000). Different groups of subjects were instructed that the occluded display should be completed globally or locally. Instructing the subjects in this way made the task an objective performance task. The prediction was that boundaries created in perceptual representations by contour interpolation processes would support precise boundary localization, whereas those suggested by global recognition processes would not.

These predictions were confirmed in all displays. Localization of boundaries in displays where completion was predicted by contour relatability was very precise and accurate. Where completion was predicted to follow global symmetry, a different outcome occurred. Precision was nearly an order of magnitude worse than for local completions. Moreover, the accuracy of localization for the boundaries predicted by global processes was very poor. A number of issues are still under investigation in this research. It is already clear, however, that global recognition processes may be separated from local boundary perception processes on the basis of the sorts of representations they create. Precise spatial positions of object boundaries are created in representations derived from latter process but not the former. These outcomes are consistent with the idea of separate perceptual completion and more cognitive recognition processes. They are also consistent with neurophysiological hypotheses (e.g., Goodale & Milner, 1992) about separate visual processing streams for recognition (the ventral stream, leading from early visual cortical areas to temporal areas) and for precise spatial representations (the dorsal stream, leading from early visual cortex to parietal areas).

In sum, Needham's work may be helping to illuminate the developmental origins of processes that use object knowledge to form expectations about the boundaries of objects in scenes, especially where perceptual information is indeterminate. Both the existing developmental research and research with adults suggest that dedicated perceptual processes use certain stimulus relationships to parse scenes into objects. These perceptual processes exploit general ecological regularities rather than familiarity with specific objects. Both Needham's studies and results in adult perception indicate that coexisting with basic perceptual processes are more cognitive expectations about objects, perhaps derived from specific experiences or generalizations of these.

These ideas are tentative, and many questions remain. Progress in answering them will depend on utilizing to the fullest connections between developmental research and computational, psychophysical and neurophysiological explorations of perception and visual cognition.

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Received February 20, 2000; revised September 13, 2000