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Chapter 8

The Development of Object Perception

Elizabeth S. Spelke, Grant Gutheil, and Gretchen Van de Walle

Although the environment can be described in many ways, we tend to perceive our surroundings as an arrangement of objects: from small bodies such as seeds and marbles, to medium-sized bodies such as dogs and chairs, to large bodies such as trains and houses. This tendency is reflected in our language. The simplest common nouns that apply to the scene in Figure 8.1, for example, refer to the kinds of objects it portrays: *orange, pitcher,* and *table*. More elaborate expressions are required to name the collection of objects on the table or one part of an object, such as the right back leg of the table. The tendency to perceive objects is reflected, as well, in our actions. If we attempted to transform the array in Figure 8.1, we would probably do so by manipulating one or more of the objects, not by manipulating the array in its totality or by moving a single object part.

8.1 Perceiving Objects

Perceiving objects makes sense, because a single object usually forms a more stable configuration than does a scene as a whole. If we follow the scene in the figure over time, the bowl and the table may part company, but the objects themselves are likely to persist. Although every momentary scene presents a new perceptual configuration, therefore, we can perceive scenes as familiar and meaningful by dividing them into objects of known kinds. Given these advantages, perhaps it is not surprising that adults perceive objects immediately and effortlessly, even in complex and cluttered environments, and that children appear to focus on objects as soon as they begin to talk about the world (Markman 1989) and act upon it (see below). What is surprising is how difficult a feat object perception turns out to be.

8.1.1 Problems of Object Perception

In apprehending objects, our perceptual systems solve two general problems. One is the problem of *parsing*, of carving up perceptual arrays into

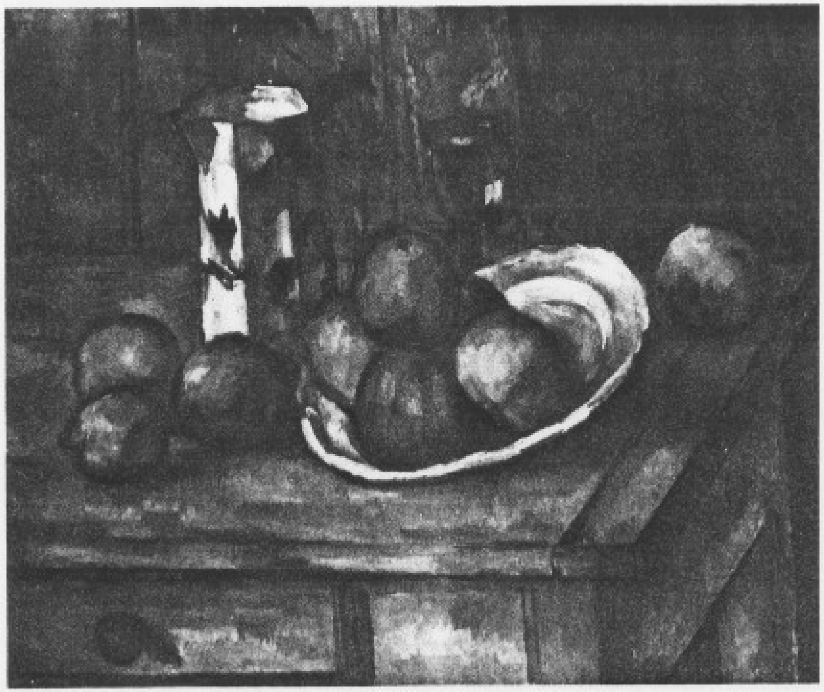

Figure 8.1
"Still Life," by Paul Cezanne. (Reprinted by permission of the National Gallery, Washington D. C.)

regions that correspond to the bodies that the scene contains. The other is the problem of *recognition*, of perceiving each body as an entity of a known kind. The recognition problem has been studied intensively and is discussed in a number of the chapters in this volume (see the chapters by Biederman, Farah, Goodale, Nakayama, He and Shimojo, and Pashler). Here, we focus primarily on the parsing problem, discussing object recognition only insofar as recognition processes enter into the parsing of scenes.

The parsing problem has two aspects. First, perceivers must apprehend the boundaries of objects in the surface layout that surrounds them at any given time, deciding what parts of the layout belong to the same or different bodies. In philosophy, this task forms part of the general problem of *individuation*, determining what in our surroundings counts as a single entity; in computational vision and perceptual psychology, this task forms part of the general problem of *unit formation*, dividing visual arrays into the entities that receive further processing. Second, perceivers must apprehend the persistence of objects over successive encounters, determining when something viewed at one time is the same body as something viewed at another time. Philosophers discuss this task as part of the general problem of *identity*: determining which of our experiences or descriptions of the world pertain to a single entity. For students of psychophysics and computational vision, this task presents one aspect of the general *correspondence problem*: the problem of determining what elements in multiple visual representations pertain to a single entity in the scene represented. At first glance, both these tasks appear simple, because we normally solve them so effortlessly. Even after centuries of study by philosophers and intense recent work by psychologists, computer scientists, and linguists, however, no simple procedure for accomplishing either task has been found.

Imagine first an ideal perceiver with full information about the layout of surfaces in a scene: not just the surfaces visible from one point of observation but all the hidden surfaces and their hidden connections as well. Because each object in the scene rests upon other objects, and because distinct objects can be complexly intertwined, it is extremely difficult to state criteria by which such a perceiver could decide where one object ends and the next begins. Philosophers have puzzled over such everyday cases as that illustrated in Figure 8.2: Why do we describe the array in this figure as "a car and trailer" but not "a bumperless car-trailer and bumper," viewing the front bumper but not the trailer as part of the car? Moreover, how should we describe an event in which parts of the car are replaced? Does the car persist over the replacement of one fender? Does it persist over the replacement of all its original parts? What is the status of a second car, composed entirely of the original parts of the first car? (For a discussion of these and other problems, see Hirsch 1982.)

The problems of object perception are compounded when we consider the task faced by an actual perceiver, who does not have access to complete information about objects and their connections. Objects are not fully visible from any one point of observation: the back of every opaque object is hidden, and the front surfaces of many objects are partly occluded as well. In Figure 8.1, for example, only one lemon and a few oranges present front surfaces that are fully in view. Moreover, the connections and separations among adjacent surfaces in a scene are not themselves visible. No visual information clearly indicates, for example, that the bowl and the stem of the glass are parts of a single connected body whereas the dish and the pitcher are not. Finally, objects are frequently obscured from view by movements—the perceiver's, the object's itself, or those of other objects. In these cases, perceivers have no direct information about what might have occurred while objects were occluded and must decide, from

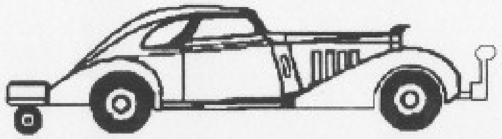

Figure 8.2
A puzzle of individuation: a car and a trailer (after Hirsch, *The concept of identity*, 1982, Harvard University Press.)

highly incomplete information, whether something seen now is the same object as something seen in the past.

Cognitive scientists do not agree about how these problems are solved. Controversies concern such fundamental questions as these: (1) What is an object for a human perceiver? Is there one basic level at which we divide up the world (singling out, perhaps, such entities as a person and a house), or do we divide scenes into objects at multiple levels with equal facility (singling out a hand and a family as well as a person, and a kitchen and a village as well as a house)? (2) At what point or points in perceptual analysis does object perception occur, and on what information is it based? Do perceivers organize arrays into objects early in visual analysis or only after extracting considerable information about perceived scenes? (3) What is the relation between our ability to detect object boundaries over space and our ability to trace the identity of an object through time? (4) What is the relation between our ability to perceive objects in real time and from limited sensory information, and our ability to form judgments about the unity and identity of objects in real or hypothetical situations in which time pressures and perceptual limitations are minimized? Is object perception guided by common principles in all these cases? (5) On what processes does object perception depend? In particular, we may distinguish two different classes of procedures by which arrays could be divided into objects both over space and over time: those employing principles that apply to all objects and those employing knowledge of the properties and behavior of objects of particular kinds.

8.1.2 General and Kind-Based Approaches to Object Perception

It is possible that humans perceive objects in accord with a set of rules or principles that apply to any objects and scenes that we might encounter. The most well-known proposal of this sort comes from Gestalt psychology, a theoretical and experimental approach to perception and other psychological phenomena that developed near the beginning of this century and generated ideas that remain influential today. The Gestalt psychologists suggested that perceivers inherently tend to organize the surrounding layout into the simplest, most regular units. This tendency can be expressed as a set of principles such as *similarity* (surfaces lie on a single object if they share a common color and texture), *good continuation* (surfaces lie on a single object if their edges lie on the same line or smooth curve), *good form* (surfaces lie on a single object if their edges can be joined to form a region with a symmetrical shape), and *common fate* (surfaces lie on a single object if they move together). In Figure 8.1, for example, the principles of similarity, good continuation, and good form serve to group together all the visible regions of the dish and to single out the dish as separate from the oranges. Gestalt principles of organization were also thought to underlie perception of object identity over successive encounters. When an object appears successively in different locations, perceivers were said to perceive a single, persisting body by grouping its appearances into the simplest patterns of motion and change (Michotte 1963).

Considerable evidence appears to favor the Gestalt theory. Presented with meaningless arrays of unfamiliar forms, adults organize the arrays into units that are maximally simple and regular (Figure 8.3a), even when their knowledge about the objects in those arrays contradicts this organization (Figure 8.3b). In addition, this theory provides a natural account of how children develop the ability to perceive objects. If one set of general principles serves to organize the layout into objects, then children who are endowed with some or all of these principles would be able to perceive and direct their actions to objects before they have acquired any specific knowledge about the kinds of objects that surround them. By perceiving and acting on objects, children could learn to recognize, categorize, and talk about the objects they encounter, and they could learn to make inferences about the distinctive properties and behavior of objects of particular kinds.

General theories of object perception, nevertheless, have been subjected to serious criticism within philosophy, psychology, and computational vision for a simple reason: no set of general principles has yet been found that singles out objects under all and only the conditions that human perceivers do. To see the difficulties faced by any theory of object perception based on general principles, consider again the example in Figure 8.2. Why do we perceive a car and a trailer, instead of a front bumper and a bumperless car-trailer? Gestalt principles do not distinguish between these two organizations. Different sets of general principles, focusing perhaps on the material composition or the mode of connection of the car and the trailer (e.g., Palmer and Rock 1994), do not appear more promising, because our perception of the objects in this scene does not appear to change if we imagine that the trailer and the bumper are composed of the same substance and are connected to the car body in the same manner. Examples such as the disassembled car present similar problems for any general

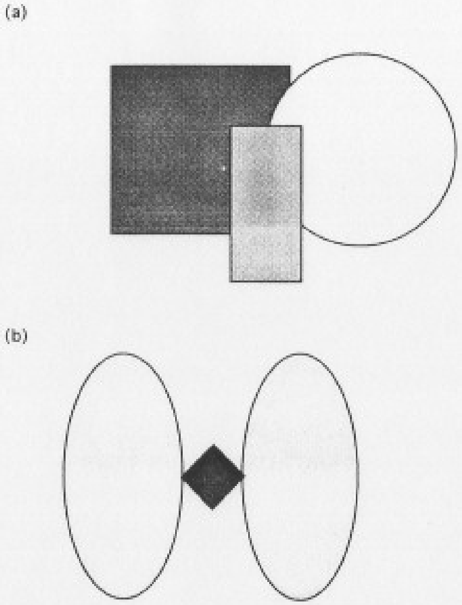

Figure 8.3
Some illustrations of the Gestalt principles of organization: In (a), we group lines into figures with smooth, symmetrical shapes and uniform textures; in (b), this grouping takes precedence over recognition of the letters *M* and *W* (after Wertheimer 1923).

account of perception of object identity. For example, no general principles readily explain why we are inclined to judge that a car persists when its transmission is replaced, but would be less inclined to judge that a dog persists if its central nervous system were replaced. These examples, and similar examples that have been discussed within computational vision (see Marr 1982), appear to defy any general theory of object perception.

Faced with these problems, many cognitive scientists have proposed that object perception depends on the ability to recognize objects of particular kinds and to apply knowledge about those objects' properties and permissible transformations. Object perception may depend on processes of object recognition, which depend in turn on the perceiver's vocabulary of internal representations, or models, of the kinds of objects that furnish our surroundings.

More specifically, the processes by which perceivers recognize part of a visual scene as a car or a tree may operate on an unparsed representation of that scene. Models of visible objects may be applied everywhere to the scene, irrespective of the actual boundaries of objects (which, by hypothesis, the perceiver does not yet represent). When a sufficiently good match

is found between an object model and a region of the scene, an object of the kind that corresponds to the model is recognized. Once an object is recognized, perceivers can apply their knowledge of the properties and the behavior of that kind of object both to perceive the object's boundaries in the visual scene and to trace the object's identity through time. Because we know that cars have bumpers but not trailers as proper parts, we perceive a car but not a bumperless car-trailer in Figure 8.2. Because we know that dogs but not cars have behavioral and mental capacities supported by certain internal structures, we consider certain transformations of dogs to be more radical than other, superficially similar transformations of cars.

Studies in computational vision and perceptual psychology provide support for the plausibility of model-based unit formation. A variety of mechanical recognition schemes have been devised that operate on input representations that have been parsed into elementary edges and features but not into objects (see Ullman 1989). Moreover, recent experiments provide evidence that human perceivers can recognize objects before they have divided a scene into units. Before the visual system determines whether the white regions in Figure 8.4 are objects or a shapeless background, for example, recognition processes appear already to have categorized the region as a person (Peterson 1995). Processes of object recognition, therefore, could provide a feasible basis for object perception.

Nevertheless, kind-based approaches to object perception have certain limitations. First, they do not provide a natural account of our ability, under certain circumstances, to perceive that a "thing" has appeared without perceiving what that thing is, or our ability to change how we categorize an object while perceiving the object to persist over this change (see Kahneman and Treisman 1984). Second, kind-based approaches provide no natural account of the development of object perception in young children. If processes of object recognition underlie perception of the boundaries and identity of objects, then one can perceive objects only if one has a vocabulary of object models. But how do children develop this vocabulary? Because it is hardly likely that humans possess innate knowledge of the visual appearance of cars and trailers, children must have the means to learn about these objects as they encounter them. As the Gestalt psychologists emphasized, however, it is not at all obvious how one can learn about the appearance of a car or trailer if one does not first have the means to single out these entities as units in a visual scene. Because every visual scene presents a novel arrangement of objects, a perceiver who possesses neither a rich store of object models nor a set of general principles for organizing arrays into units seems doomed to experience a meaningless succession of novel arrays. Cars and trailers might populate these arrays and travel through them in a predictable fashion, but children with no

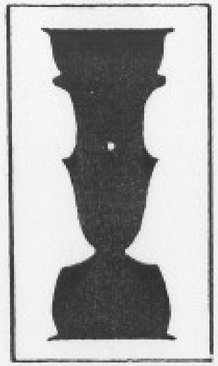

Figure 8.4
A reversible figure-ground display (after Peterson, 1994). When the black region is perceived as figure, the white regions appear to be indefinite in form and to continue behind the figure. Nevertheless, subjects who experience the black region as figure may activate representations of people in the region perceived as background. Evidence for these representations comes from the finding that this figure undergoes a reversal faster than an otherwise comparable figure-ground display in which the background has no meaning, and from the finding that subjects presented with this background are slower to identify a subsequently presented figure with the same shape. (Redrawn by permission from M. A. Peterson, Object recognition processes can and do operate before figure-ground organization, 1994, *Current Directions in Psychological Science*.)

means to perceive such objects would not experience their presence or learn from their predictable behavior.

In summary, neither general theories nor kind-based theories appear to provide a complete account of human perceivers' abilities to apprehend the boundaries and the persistence of everyday objects. Whereas some evidence suggests that object perception depends on general principles that override knowledge of the recognizable objects in a scene (e.g., Figure 8.3b), other evidence suggests the reverse (e.g., Figure 8.2). Moreover, each class of theory appears to have inherent limitations: general theories do not do justice to the richness and specificity of mature object perception, and kind-based theories do not appear to support an account of how object perception develops.

These observations raise the possibility that object perception depends both on a small set of general principles and on a much larger body of kind-specific knowledge. General principles of object perception may serve to organize the perceptible surface layout into bodies in the absence of any knowledge of the kinds of objects that visual arrays contain. These principles may be available to children early in development; they may serve as a basis for the development of kind-specific knowledge; and they may underlie adults' ability to perceive the boundaries and persistence of objects that we fail to recognize or that we categorize differently at different times. Kind-specific knowledge could supplement the general principles of object perception, accounting for our fine-tuned perceptions of and intuitions about the boundaries and persistence of familiar things.

8.2 Infants' Perception of Object Boundaries

If mature object perception depends both on general and on kind-specific processes, then the general process may be difficult to discern in adults, who possess a vast store of knowledge of object kinds. This process may be studied more easily in people whose knowledge is less extensive. Studies of object perception in infancy might reveal what the basic process for perceiving objects is and how it becomes extended and changed by the growth of knowledge.

In the sections that follow, we ask whether and how infants perceive the unity and boundaries of objects in momentary scenes and the persisting identity of objects over successive encounters. We consider both the nature and the limits of infants' perception of objects in hopes of shedding light on the process by which infants organize perceptual arrays. After exploring this process in infancy, we consider its possible relation to processes of object perception in adults. Our primary focus concerns the roles of general principles and kind-specific knowledge in object perception. We will see, however, that studies of early perceptual development also bear on the other questions about object perception with which we began, concerning the nature of the objects perceivers apprehend, the nature of the information on which object perception depends, the relation between perception of object boundaries and perception of object identity, and the relation between immediate perception of objects, and intuitive judgments about them.

8.2.1 Figure-Ground Organization

Adults perceive objects as separate from whatever stands behind them, and we perceive the border between an object and its background as bounding the object, not the ground. Psychologists have studied the development of perception of these figure-ground relationships by presenting infants with simple scenes such as those illustrated in Figure 8.5 and observing infants' patterns of reaching for the displays.

To reach for and pick up an object effectively, the hand must be directed to the object's external boundaries (see Chapter 5). This ability, in turn, depends on the ability to perceive the object as distinct from the objects and surfaces around it. Experiments from a number of laboratories provide evidence that at the age when infants begin reaching for objects (about

(a)

(b)

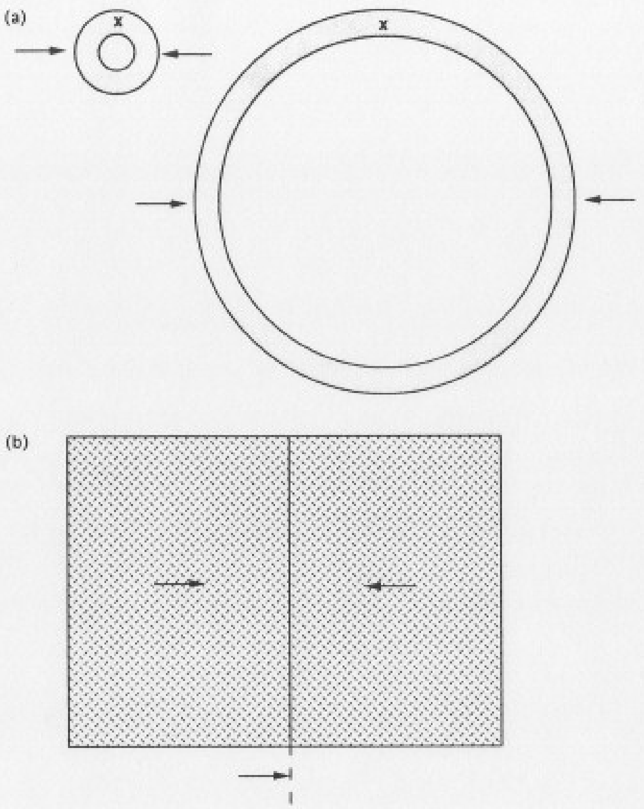

Figure 8.5
Schematic depictions of displays for studies of infants' perception of an object as separate from its background. In (a), the location of a sound source is indicated by the *x*; frequent points at which the reaching hands contact the object are indicated by arrows (after Clifton et al. 1991). In (b), arrows indicate the direction of motion of each of the two regions at one point in time (over time, the regions reverse direction). Infants reach for the region that moves together with the border—in this case, the region on the left (after M. E. Arterberry, L. G. Craton, and A. Yonas, Infants' sensitivity to motion-carried information for depth and object properties, 1993, in C. E. Granrud, ed., *Visual perception and cognition in infancy*, vol. 23, Carnegie-Mellon Symposia on Cognition, L. Erlbaum.)

four-and-a-half months), they reach for object boundaries. For example, Clifton et al. (1991, Figure 8.5a) presented six-month-old infants, in alternation, with a large and a small ring within reaching distance. Infants reached for each object by directing their hands to its borders, aiming at different spatial locations for the different objects. These reaching patterns suggest that infants perceived each object as separate from the background surface behind it and represented, with some accuracy, the location of each object's boundaries. Interestingly, infants' representations of object boundaries appeared to persist in the absence of visual information, because their reaching was also directed to the borders of the objects when the lights were extinguished and reaching took place in the dark.

What information do infants use to perceive the boundaries of a visible object? Experiments by Yonas and colleagues suggest that infants perceive object boundaries by detecting the relative motion patterns of surfaces and edges (Arterberry, Craton, and Yonas 1993). When a surface and its borders move as a unit relative to surrounding surfaces, infants perceive the surface as a bounded object (see Figure 8.5b). Such motions are normally produced when an object moves against a stationary background or when a stationary object stands in front of its background and is viewed by the baby with a moving head.

According to the Gestalt psychologists, the simplest example of figure-ground organization occurs in displays containing no motion or depth changes: static, two-dimensional displays consisting of two regions of different brightness or color (e.g., Figure 8.4). Perception of these displays as containing a bounded figure in front of an unbounded ground was thought to depend on the same organizational principles as perception of objects in moving, three-dimensional arrays. Research with infants casts doubt on this view: Infants do not appear to reach for the borders between the two regions in a two-dimensional figure-ground display (Spelke 1988; Arterberry et al. 1993). They appear to perceive figure-ground relations by analyzing the three-dimensional spatial arrangements and motions of surfaces but may not organize surfaces into regions of a common brightness and color.

8.2.2 Perception of Object Boundaries in Scenes of Multiple Objects

Infants rarely encounter objects in the simple arrays studied above because the objects in natural scenes stand upon, beside, and in front of other objects. Can infants perceive the boundaries of objects in these more complex situations? Some experiments have approached this question by presenting infants with displays containing two objects that touched or overlapped in depth, and investigating infants' patterns of reaching for the displays.

(a)

(b)

(c)

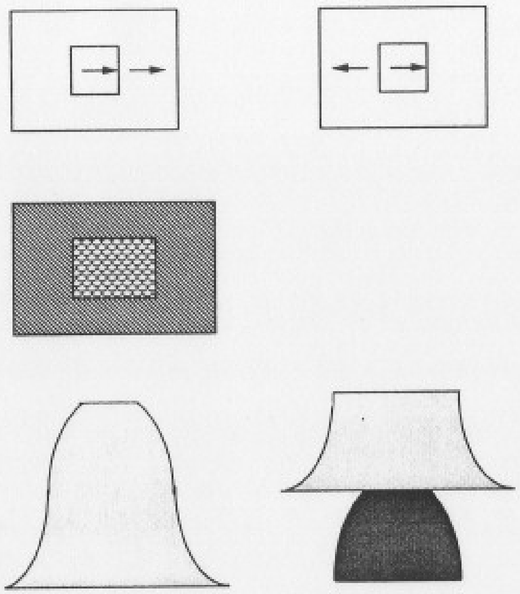

Figure 8.6
Schematic depictions of displays for studies of infants' perception of the boundaries of objects in two-object arrays. (Redrawn by permission from C. von Hofsten and E. S. Spelke, Object perception and object-directed reaching in infancy, 1985, *Journal of Experimental Psychology: General* 114, 198–212; R. Kestenbaum, N. Termine, and E. S. Spelke, Perception of objects and object boundaries by three-month-old infants, 1987, *British Journal of Developmental Psychology* 5, 367–383; and E. S. Spelke, K. Breinlinger, K. Jacobson, and A. Phillips, Gestalt relations and object perception: A developmental study, 1993, *Perception* 22, 1483–1501.)

For example, infants have been presented with one object that was small and close to them and a second object that was larger and more distant (Hofsten and Spelke 1985; Figure 8.6a). A variety of observations indicate that infants tend to reach for the object that is closest (Yonas and Granrud 1985). If infants perceived the two objects as distinct, therefore, they were expected to reach for the borders of the small object. If infants perceived the two objects as a single unit, in contrast, they were expected to reach primarily for the borders of the larger object, because it provided most of the external borders of the display. Infants reached for the borders of the small object when the objects were spatially separated, either vertically or in depth, and when the objects moved relative to one another. In contrast, they reached for the two objects as a single unit when the objects were stationary and adjacent in depth and when the objects moved together. Like the studies of one-object arrays, these studies suggest that infants

perceive objects by detecting surface arrangements and motions, grouping together all surfaces that are adjacent and undergo no relative motion.

The above studies suggest that infants perceive objects by analyzing the three-dimensional arrangements and motions of surfaces, not by analyzing motions and configurations in the visual representations that precede the recovery of depth information (see Chapter 1). Consider, for example, the display in Figure 8.6a, in which two objects that are arranged in depth undergo a rigid translatory motion. Because the objects are at different distances from the infant, they undergo different two-dimensional displacements in the infant's visual field: The closer object is displaced at a greater speed and to a greater extent than the more distant object. If object perception depends on an analysis of two-dimensional patterns of image displacement, infants should perceive these two objects as separate units, because the images of the two objects undergo different retinal motions. Contrary to this prediction, infants perceived a single object in this display. This and other findings (e.g., Kellman et al. 1987) provide evidence that infants' perception of objects occurs relatively late in visual analysis, after the recovery of information about the arrangements and motions of surfaces in depth.

In all the above studies, infants' perception of object boundaries has been inferred from patterns of reaching. Further studies have investigated object perception in infancy by focusing on infants' visual attention to displays of objects. If infants are presented repeatedly with a single visual display, the time they look at the display tends to decline over successive presentations. If a new display is presented subsequently, their looking time increases. This pattern of preferential looking at novel displays has provided psychologists with a different method for assessing infants' perception of object boundaries. Infants are first familiarized with an array of two objects and then presented with new arrays in which either both objects appear in new locations—but with the same internal arrangement—or one object appears in a new location, changing the objects' arrangement. If infants perceive the objects as separate units, we would expect them to see the array in which both objects are displaced together as more novel and, therefore, to look at it longer. If infants perceive the objects as a single unit, they should look longer at the array in which one object is displaced relative to the other.

The findings of experiments using this preferential-looking method converge closely with the findings of experiments using reaching methods. In particular, preferential-looking experiments provide evidence that infants perceive objects as separate units if the objects are separated visibly or in depth (Kestenbaum et al. 1987; Figure 8.6b). In contrast, the experiments provide evidence that infants perceive two stationary, adjacent objects as a single unit, even if the objects differ in color, texture, and shape and their edges are not aligned (Kestenbaum et al. 1987; Spelke et al. 1993; Figure 8.6c).

The above studies support the Gestalt thesis that perceivers have an early-developing, general process for organizing arrays into objects, but they cast doubt on the Gestalt psychologists' characterization of that process. Infants do not appear to perceive object boundaries by organizing visual scenes into units that are maximally homogeneous in color and texture and maximally smooth and regular in shape. For a young infant, the relatively complex objects in Figure 8.6c appear to be perceived as units just as readily as the simpler objects. Infants' failure to perceive object boundaries in accord with the Gestalt principles cannot be explained by failures to perceive the colors or shapes of surfaces, because studies of infants' sensitivity to color and pattern suggest that these properties are detectable (see, for example, Teller and Bornstein 1987). Further studies suggest that infants use such properties as lightness similarity and good continuation to group together closely spaced elements on a single surface (Quinn, Burke, and Rush 1993; Van Giffen and Haith 1984). Infants appear to detect Gestalt relationships and to use them to perceive surface textures, but they do not appear to use these relationships to perceive the boundaries of objects.

These studies suggest that infants would perceive the display in Figure 8.2a as a single object: a "car-trailer," rather than a car and a trailer. A final preferential-looking experiment has tested this suggestion quite directly (Xu and Carey 1994). Ten-month-old infants were presented with two toys—for example, a yellow rubber duck and a red metal truck—arranged so that one toy stood on top of the other. In one condition, the duck moved back and forth on top of the truck, remaining in contact with the truck throughout the motion; in the other condition, the two toys were stationary. After familiarization with one or the other of these displays, infants viewed two test events in which a hand entered the display, grasped the duck, and lifted it into the air. In one event, the duck moved separately from the truck; in the other event, the duck and truck moved together. Infants who had been familiarized with the duck and truck undergoing relative motion looked longer at the second event, suggesting that they had perceived the two toys as separate objects and expected them to move independently. In contrast, infants who had been familiarized with the duck and truck without motion looked longer at the first event, suggesting that they had perceived the two toys as a single object. This study provides further evidence that infants fail to perceive object boundaries in accord with the Gestalt principles of similarity, good continuation, and good form. In addition, it suggests that ten-month-old infants failed to perceive the object boundaries by recognizing the toy duck and the toy truck as objects of distinct kinds.

All the findings discussed in this section suggest that infants perceive objects through a general process for grouping surfaces into units by analyzing their three-dimensional arrangements and motions, irrespective of their colors, textures, or shapes. Similar conclusions emerge from studies focusing on infants' perception of objects that are partly hidden.

8.2.3 Perception of Objects over Occlusion

Because almost every object in a natural visual scene is partly hidden by parts of itself or by other objects, perceiving object boundaries requires that we represent the connections among parts of objects that are occluded. Research with infants has investigated infants' perception of partly hidden objects under a variety of circumstances in which the visible parts of an object appear at spatially separated places or at different times.

For example, researchers have familiarized infants with an object whose top and bottom are visible but whose center is occluded and tested their perception of the connectedness and the shape of the partly occluded object by comparing looking times to subsequent fully visible displays (Figure 8.7a). If the visible ends of the center-occluded object moved together, four-month-old infants subsequently looked longer at a fully visible display in which the ends were separated by a gap than at a fully visible display in which the ends were connected. Because infants tend to look longer at displays they perceive as more novel, this preference provides evidence that the infants perceived the original center-occluded object as connected behind the occluder (Kellman and Spelke 1983; S. Johnson and Nanez, in press; Slater, et al. 1990). Infants did not show this preference when the entire display was stationary, when the ends of the center-occluded object were stationary and the occluder moved, or when one end of the object moved while the other did not (Kellman and Spelke, 1983). These findings suggest that infants perceive the unity of a center-occluded object by detecting the common motion of its visible surfaces.

Further experiments provided evidence that perception of the unity of a center-occluded object was unaffected by the color and form relations among its visible surfaces (Kellman and Spelke 1983, Figure 8.7b), suggesting that Gestalt relations such as similarity, good continuation, and good form do not influence infants' perception. Moreover, experiments provide evidence that Gestalt relations do not dictate the forms of the objects that infants perceive. Infants' perception of the form of a moving center-occluded object was investigated by familiarizing infants with the occlusion display and then presenting fully visible objects that differed in form (Figure 8.7c). Infants were found to look equally at displays presenting the simple and regular form perceived by adults and at displays presenting

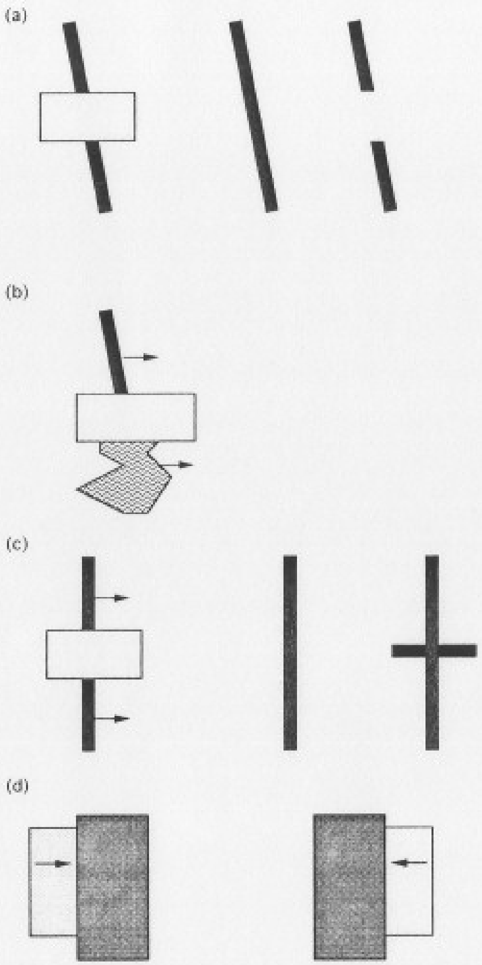

Figure 8.7
Displays for studies of infants' perception of partly occluded objects. (Redrawn by permission from P. J. Kellman and E. S. Spelke, Perception of partly occluded objects in infancy, 1983, *Cognitive Psychology* 15, 483–524; L. G. Craton and R. Baillargeon, personal communication; and G. Van de Walle and E. S. Spelke, L'intégration spatio-temporelle dans la perception des objets chez le bébé, 1993, *Psychologie française* 38, 75–83.)

a more complex form (Craton and Baillargeon, personal communication, December 1991). This finding suggests that whereas infants perceive the connectedness of a moving center-occluded object, they have no definite perception of its shape.

Finally, experiments have investigated infants' perception of objects whose parts become visible only over time (Figure 8.7d). In one study, five-month-olds were familiarized with an object that moved laterally behind one large occluder such that its center was always hidden, and its left and right sides underwent the same motion and were visible in immediate succession. After this familiarization, infants were presented in alternation with a connected object and with the two previously visible parts separated by a gap. Infants looked longer at the latter display, suggesting that they perceived the visible parts in the original occlusion display as a unitary object (Van de Walle and Spelke 1993). In other experiments presenting objects with successively visible parts, however, infants were found not to perceive properties of an object such as its overall form (see Arterberry, Craton, and Yonas 1993). The ability to perceive the form of an object whose parts appear in succession appears to develop over the second half of the first year. At younger ages, infants appear to perceive the unity and boundaries of such an object but not its shape.

Recently, a number of investigators have explored the early development of the ability to perceive the unity of a moving, partly occluded object. Experiments with infants from birth to four months suggest that this ability emerges at about two months of age. Newborn infants who are familiarized with a center-occluded object subsequently look longer at a fully visible display containing one connected object than at a display containing the two visible parts of the original object separated by a gap: the opposite looking pattern from that shown by four-month-old infants (Slater et al. 1990). At two months of age, infants show no preference between these two displays when the occluder is large (S. Johnson and Nanez, 1995); they look longer at the display with the gap when the occluder is reduced in size (Johnson and Aslin, in press). Two-month-old infants, therefore, perceive the unity of a center-occluded object under some but not all of the conditions that are effective at four months.

These findings suggest that a developmental change in object perception occurs over the first four months. At this writing, the nature of this change is not clear. It has been suggested that the change depends on the maturation of the neural systems underlying the perception of coherent motion and the control of attention to spatially separated parts of the visual field (M. Johnson 1990). Alternatively, the change may depend on developmental changes in visual resolution, allowing greater access to information about surfaces and their arrangement (S. Johnson 1994; see Banks and Shannon, 1993). Finally, the change may reflect the emergence, through learning or maturation, of the system for perceiving objects itself (Slater et al. 1990; Smith and Katz, in press).

8.2.4 Principles of Object Perception

Although the above studies cast doubt on the thesis that infants perceive objects in accord with Gestalt principles such as similarity and good continuation, they do suggest that infants organize the three-dimensional surface layout into objects on some basis. Two- to four-month-old infants appear to perceive objects by relating the motions of surfaces to the arrangement of surfaces in the following ways. First, when they are unable to see a spatial separation between two stationary surfaces, infants infer that the surfaces consist of a single object, regardless of differences in color and texture. This inference accounts for infants' tendency to reach for adjacent objects as one unit and to dishabituate to changes that alter the perceived boundaries of such an array. Two surfaces that are spatially separated, in contrast, are perceived as two distinct objects, despite similarities in color and texture. This inference accounts for infants' tendency to reach for surfaces separated by a visible gap as independent units and to generalize habituation to displays in which such objects change position with respect to one another. Third, when infants observe two surfaces that undergo a common rigid motion, they infer that the surfaces are connected, provided that this interpretation is not inconsistent with the perceivable layout (i.e., the surfaces are not separated by a visible gap). This inference accounts for infants' perception of the connectedness of the visible portions of a moving partly occluded object. Finally, when infants observe two surfaces that move relative to one another, they infer that the surfaces belong to two separate objects. This inference accounts for infants' tendency to reach for adjacent objects undergoing independent motion as separate units.

Taken together, infants' inferences about surface arrangements and motions appear to reflect two fundamental properties of inanimate, material objects. First, objects are cohesive: they are internally connected and externally bounded entities that maintain both their connectedness and their boundaries over time and space. Second, objects influence one another's motions if and only if they touch. These object properties have led us to propose that object perception initially accords with two principles: the principles of *cohesion* and *contact* (Spelke and Van de Walle 1993; see Figure 8.8a and 8.8b).

8.3 Infants' Perception of Object Identity

When an object disappears from view and later returns to view, are inexperienced perceivers ever able to recognize that the two appearances in-

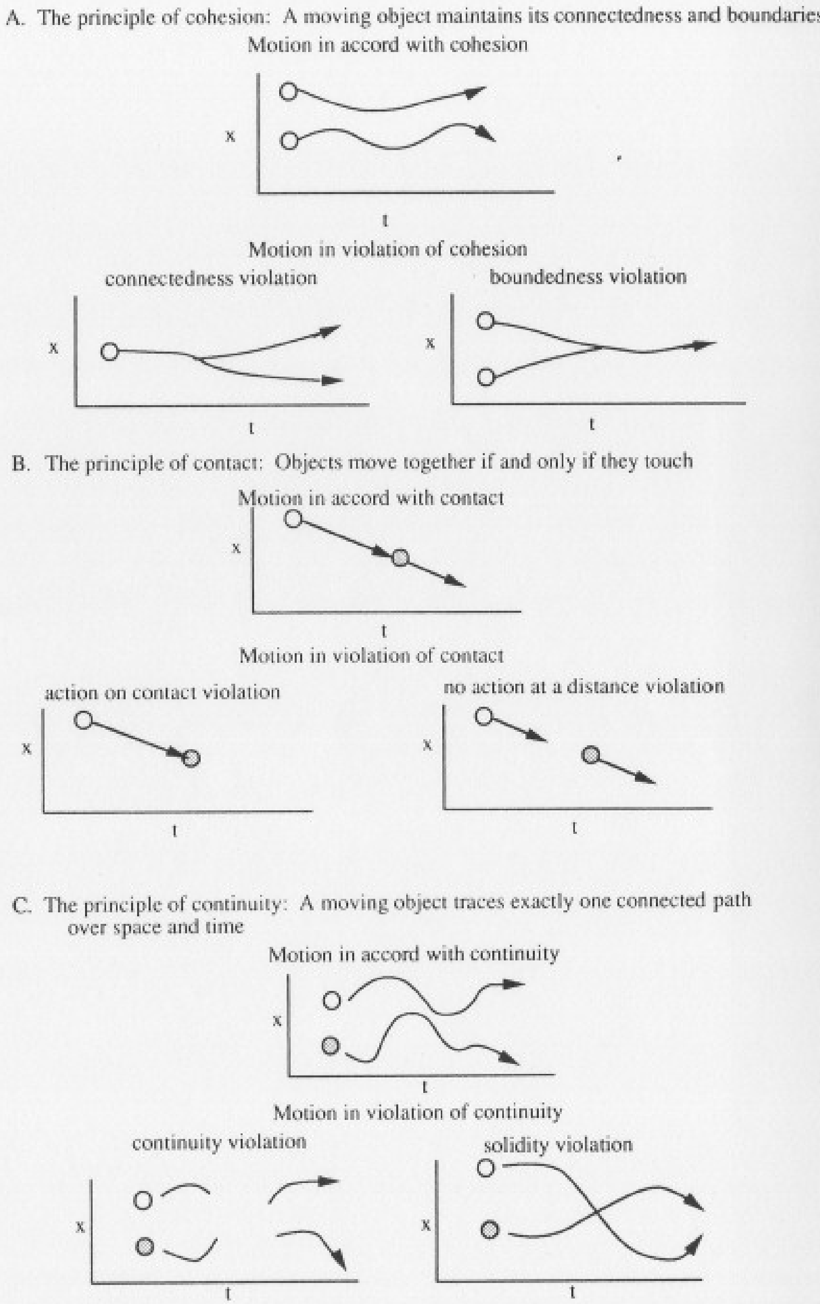

Figure 8.8
Three proposed principles of object perception in infancy.

volve a single, persisting object? Studies of infants have addressed this question through preferential-looking methods similar to those described above.

8.3.1 Perceiving Objects over Successive Encounters

One series of experiments investigated whether young infants perceive the identity or distinctness of objects by analyzing the spatiotemporal continuity or discontinuity of object motion: a factor that strongly influences adults' intuitions about object persistence and change (Spelke et al. 1995). Separate groups of four-month-old infants were familiarized with one of two events involving objects that moved in and out of view (Figure 8.9a). In one event, one object moved at a constant speed behind two spatially separated occluders. Because the occluders were almost as narrow as the object, the motion in this condition appeared to be continuous. In a second event, the same object motions occurred on the far sides of the two occluders, but no object was seen to move in the space between the two occluders. The visible paths of object motion therefore were discontinous. To assess infants' perception of the identity or distinctness of the objects in these events, experimenters tested all the infants with fully visible displays containing one or two objects. The infants who had been familiarized with the two-screen event involving continuous motion showed a greater preference for the two-object event than those who had been familiarized with the two-screen event involving discontinuous motion. This finding provides evidence that infants' perception of the number of objects in the occlusion events was influenced by the apparent continuity or discontinuity of object motion. Whereas infants presented with continuous motion appeared to perceive a single object that moved in and out of view, those presented with discontinuous motion appeared to perceive two distinct objects.

Following the ideas of the Gestalt psychologists, Michotte (1963) proposed that perceivers apprehend the identity of objects through time by organizing events so as to maximize the smoothness of object motion. Experiments tested whether infants exhibit this tendency by comparing infants' perception of object identity over occlusion events in which objects either undergo smooth motion or motion that changes in speed (Spelke et al., in press). They presented four-month-old infants with events in which two objects moved in succession behind one large occluder (Figure 8.9b). In one event, the objects' visible speed and the duration of occlusion gave rise, for adults, to the impression that one object moved in and out of view at a constant speed. In two further events, the objects moved at speeds and with occlusion times that suggested an abrupt change in object motion behind the occluder. After familiarization with any of these events, infants showed no consistent looking preferences

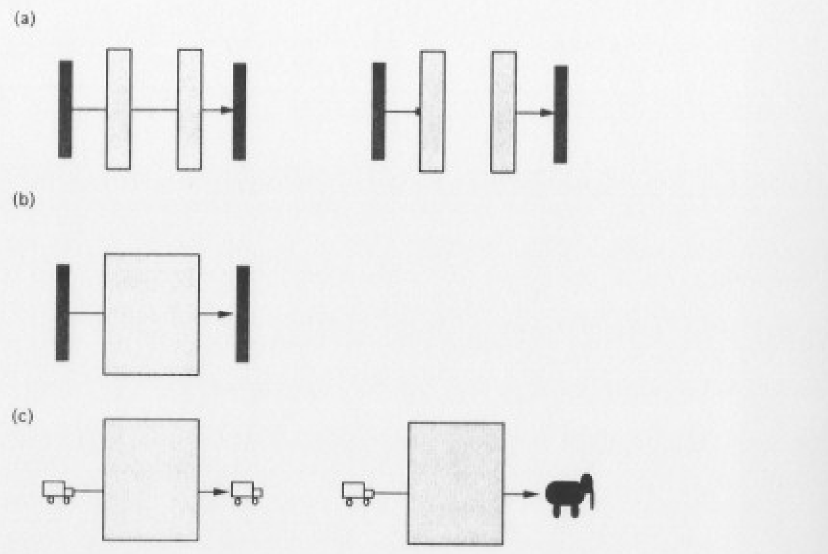

Figure 8.9
Displays for studies of infants' perception of the identity of objects over successive encounters. (Redrawn by permission from E. S. Spelke, R. Kestenbaum, D. Simons, and D. Wein, Spatio-temporal continuity, smoothness of motion, and object identity in infancy (1995), *British Journal of Developmental Psychology*, F. Xu and S. Carey, Infants' metaphysics: The case of numerical identity (in press), *Cognitive Psychology*.

between displays of one versus two objects. These findings cast further doubt on the Gestalt thesis that object perception depends on a general tendency to organize the perceptual world in to the simplest and most regular units. Infants' perception of object identity did not appear to be influenced by the apparent smoothness of object motion.

Further preferential-looking experiments have investigated whether infants perceive the identity of objects over successive appearances by analyzing properties of objects such as surface color and shape or by taking account of object kind (Xu and Carey, in press, Figure 8.9c). In these studies, two objects moved into view, in succession, on the opposite sides of a single, wide box. In one condition, the objects were visually indistinguishable and from the same category. In a second condition, the objects differed in color, texture, and shape, and were members of different categories (for example, a red metal truck and a blue rubber elephant). Infants' perception of object identity was also tested under conditions in which the spatiotemporal discontinuity of object motion specified that the objects were distinct: Two toys appeared on the opposite sides of two narrow, spatially separated boxes, or they were visible on the two sides of the wide box simultaneously. In all cases, perception of object identity was tested by familiarizing ten-month-old infants with one occlusion event and then comparing their looking times to fully visible displays of one versus two objects.

Once again, infants' perception of identity was influenced by information for the spatiotemporal continuity or discontinuity of object motion. Infants familiarized with two spatially separated objects that were visible simultaneously, or with two objects whose successive visible motions were separated by a visible gap, looked longer at the fully visible display containing only one object. In contrast, infants' perception of identity did not appear to be influenced either by such perceptible properties of the objects as their color or shape or by object kind. When objects appeared in succession from within a single box, infants' perception of the identity or distinctness of the objects appeared to be indeterminate, and equally so, regardless of whether or not the objects differed in color, shape, and kind.

In the situation studied by Xu and Carey, ten-month-old infants' perception of object identity appears to differ dramatically from the perceptions of adults. When adults view a toy elephant and a toy truck that emerge from a box in succession, they are strongly inclined to view the second object as distinct from the first. Young infants, in contrast, appear to be uncommitted as to the identity or distinctness of the objects. What accounts for this difference?

One might propose that infants failed to perceive object identity by taking account of the perceptible differences between the elephant and the truck because they failed to detect these differences. The best evidence against this possibility comes from Xu and Carey's own experiments. In one study, they presented infants with an occlusion event in which one object appeared and disappeared on the left side of the box and then a second object (that either was featurally indistinguishable from the first object or came from a different category) appeared on the right side of the box and remained in view for as long as the infant looked at it. The infants who viewed two featurally distinctive objects looked longer at the second object than those who viewed two featurally indistinguishable objects. This preference provides evidence that infants detected the featural differences between the former pair of objects. Nevertheless, infants in both conditions showed the same indeterminate perception of the number of objects participating in the event. Ten-month-old infants evidently detected differences between a toy elephant and a toy truck, but they did not infer from these differences that the elephant and truck were numerically distinct objects.

Following philosophers such as Wiggins (1980) and Hirsch (1982), Xu and Carey suggest that adult perception of the distinctness of the elephant and truck depends on the knowledge that elephants and trucks are different sorts of things. Perception of object identity depends, in their view, on knowledge of object categories. Xu and Carey's research suggests that conceptual categories such as *elephant* do not guide ten-month-old infants' perception of object identity. Instead, infants may view the elephant/truck event in the way that many adults would view temporally separated appearances of a chrysalis of one species and a mature moth of a different species. Although a naturalist might draw on knowledge of insect kinds to perceive the first object as numerically distinct from the second, most of us would note the property differences between the chrysalis and the moth and yet be uncertain as to the identity or distinctness of the objects.

8.3.2 More Principles of Object Perception

In summary, infants appear to share some, but not all, of adults' abilities to perceive the identity of objects over successive encounters. Like adults, young infants perceive object identity by analyzing the positions and motions of objects. When infants view an event in which two successive encounters with objects can be seen to be connected by a single path of motion, they infer that a single object participated in the event. Conversely, when infants view an event in which they can see that no continuous path of motion connects two object appearances, either because two successive object motions are separated by a gap or because two objects are visible simultaneously in distinct locations, then infants infer that two distinct objects participated in the event. Unlike adults, young infants do not appear to perceive object identity by analyzing the smoothness of object motion, by analyzing the constancy or change of objects' perceptible properties such as shape, color, and texture, or by recognizing objects as instances of familiar kinds.

These findings suggest that there exists a basic process for perceiving object identity that is independent of knowledge of the kind of object under consideration. Contrary to Gestalt theory, this process does not appear to depend on a general propensity to organize events into units that are maximally simple and regular. Rather, infants appear to perceive object identity in accord with the principle that objects exist continuously and move on paths that are connected over space and time (see Figure 8.8c). This principle of *continuity* appears to operate prior to the emergence of knowledge of many object kinds. It may form part of the initial capacities that make possible the development of the latter knowledge.

Putting together the findings from studies of perception of object boundaries and studies of perception of object identity, young infants appear to organize visual arrays into bodies that move cohesively (preserving their internal connectedness and their external boundaries), that move together with other objects if and only if the objects come into contact, and that move on paths that are connected over space and time.

Cohesion, contact, and continuity are highly reliable properties of inanimate, material objects: objects are more likely to move on paths that are connected than they are to move at constant speeds, for example; and they are more likely to maintain their connectedness over motion than they are to maintain a rigid shape. Infants' perception appears to accord with the most reliable constraints on objects.

8.4 Developmental Changes in Object Perception

The principles of cohesion, contact, and continuity, nevertheless, leave many object boundaries unspecified. They fail to specify the border between two stationary objects that touch, the connectedness of a stationary object whose center is occluded, or the distinctness of moving objects that emerge from the same place at different times. Given that adults usually perceive object boundaries under these conditions, object perception must undergo developmental change, but the nature of that change is unclear. It is possible that adults perceive objects in accord with further general principles, such as the Gestalt principles of good continuation, similarity, and good form. Alternatively, adults may perceive objects by recognizing objects of known kinds. For example, adults may perceive the bowl in Figure 8.1 as complete and bounded, not by organizing the scene into the simplest shapes but by recognizing the bowl as a familiar object with a known shape.

Studies of the development of object perception might serve to distinguish between these possibilities. If adults perceive objects in accord with a single, general tendency to confer the simplest organization on perceptual experience, then there may be a single time in development when this tendency emerges. In contrast, if the organizational phenomena that Gestalt psychologists described depend on processes of object recognition, then these phenomena should appear earlier in development when children are presented with objects that are more common and familiar.

Studies of developmental changes in perception of stationary, adjacent objects provide preliminary support for the latter view. In three experiments, infants of different ages were presented with adjacent objects that differed in color, texture, and form (Figure 8.10). The objects in one experiment included a solid block; infants evidently perceived it as distinct from the object adjacent to it by eight months of age (Needham and Baillargeon 1994). Infants may have perceived two objects in this study, because blocks come to be recognized early in development. The objects in a second study were toy animals and vehicles; infants began to perceive them as distinct objects between ten and twelve months (Xu and Carey 1994). Infants may have perceived two objects in this study when categories such as *truck* and *duck* (or, perhaps *toy vehicle* and *toy animal*) emerged (see Mandler and McDonough 1993). The objects in a third study had simple, smooth conical shapes but were not clearly recognizable; the ability to perceive their distinctness began to emerge between three and five months but was not complete at nine months: nine-month-old infants' perception of the boundaries of the two-object display appeared to be indeterminate (Spelke et al. 1993). Because the shapes bore a weak resemblance to a number of objects that may be familiar to infants but no strong resemblance to any one object kind, the developmental change in perception in this study may have occurred over a protracted period, with considerable variability across infants. At any given age, therefore, some infants may perceive the conical objects as familiar whereas others do not.

Our interpretations of the above studies are tentative, for no experiment has tested directly the effect of familiarization with an object category on perception of object boundaries. These studies nevertheless give

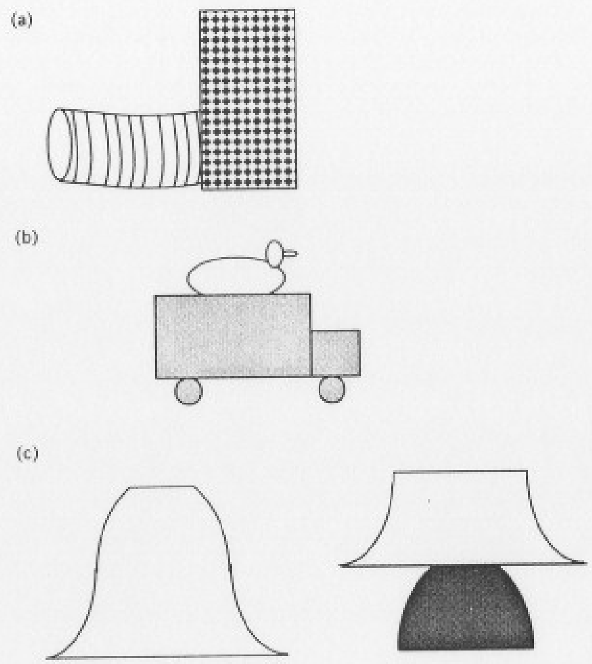

Figure 8.10
Displays for studies of infants' perception of adjacent objects. (Redrawn by permission from A. Needham and R. Baillargeon, Object segregation in eight-month-old infants, 1994, manuscript submitted for publication; F. Xu and S. Carey, Infants' ability to individuate and trace the identity of objects, 1994, paper presented at the International Conference on Infant Studies, Paris, June; and E. S. Spelke.)

some plausibility to the view that perception of objects in accord with Gestalt relations depends, at all ages, on object recognition. Adults may appear to apply Gestalt principles to unfamiliar arrays of objects because our vocabulary of object models is sufficiently extensive to encompass displays designed to be unfamiliar as well as those composed of familiar objects. Processes of categorization may underlie the organizational phenomena that the Gestalt psychologists described.

Little is known about infants' abilities to recognize objects. Although a wealth of research provides evidence that they are capable of a variety of perceptual categorizations (e.g., Quinn, Eimas, and Rosenkrantz 1993), this research does not reveal whether infants view the members of a single perceptual category as different individuals of the same kind (for discussion, see Mandler and McDonough 1993). Despite a paucity of evidence, however, it is highly likely that infancy and early childhood are the times when we acquire the bulk of our knowledge of object kinds and the corresponding visual representations by which we recognize each kind of object. Studying the processes by which infants come to recognize objects may shed light on the nature of object recognition processes: processes that have received extensive study in other areas of cognitive science (as this volume attests) but rather less attention from students of perceptual development.

8.5 From Infants to Adults

Studies of infancy suggest a picture of the origins and development of object perception. In infancy, object perception is a late perceptual process taking as input a representation of three-dimensional surface arrangements and motions. Surfaces are grouped into objects, over both space and time, in accord with principles capturing three fundamental properties of material bodies: Such bodies are cohesive, they interact only on contact, and they move on connected paths. By applying these principles to visible surface layouts, infants perceive objects as distinct from the surfaces behind them, as separated from the objects they touch, as continuing in places where they are hidden, and as existing and moving continuously between successive perceptual encounters.

In each case we have considered, we have found limits to infants' abilities to perceive objects, and these limits appeared to be overcome during development by developing abilities to recognize objects of known kinds. Processes of object recognition may allow older infants to perceive object boundaries where younger infants fail to find them, and they may allow infants to trace object identity in circumstances that, for young infants, are ambiguous. These findings suggest that general principles of object perception become enriched by kind-specific principles as infants grow. We close by asking whether the same general and kind-specific processes underlie object perception in adults.

8.5.1 Core and Peripheral Processes of Object Perception

Although existing studies of adults are open to multiple interpretations, a number of hints suggest that adults' perception depends on the same general and kind-based processes we find in infants. One hint comes from the studies of object perception we reviewed in the introduction: Neither general principles of perceptual organization nor kind-specific processes of object recognition appear to provide a complete account of adults' perception of objects. Further hints come from two sources we have not yet considered: chronometric studies of attention and visual representation and interview studies of intuitions about object persistence and change.

8.5.2 Visual Attention and Object Representations

Although this chapter cannot do justice to the extensive literature on the time course of the processes by which we construct and act on visual representations (see Chapter 2), one series of studies is especially relevant to the problem of object perception. When an event suddenly occurs in the visual field, human perceptual systems appear to make a very rapid decision: Has a new object appeared, or has a previously visible object changed state or position? Studies using a variety of methods focusing on the speed with which we can identify an object or indicate its location have explored the nature of this decision process. Because these studies typically use two-dimensional displays of alphabetic characters, their findings cannot be compared directly to the findings of studies of infants' perception of the identity of real objects moving through three-dimensional scenes. The convergence between the findings of these very different studies is nonetheless striking: adults appear to identify objects in rapidly changing displays by taking account of relations such as cohesion and continuity, and not by taking account of relations such as sameness in color and form.

In an experiment by Kahneman, Treisman and Gibbs (1992; Figure 8.11), for example, a letter appeared in one of eight stationary boxes, and subjects named it quickly. Immediately before this event, the letter to be named and a different letter appeared in two boxes. Subjects named the target letter more slowly if a different letter previously occupied its box, providing evidence that a representation of the earlier display influenced processing of the target display. This effect was then used to investigate subjects' representations of displays of moving boxes. When the boxes moved between the two letter presentations, subjects were slower to name

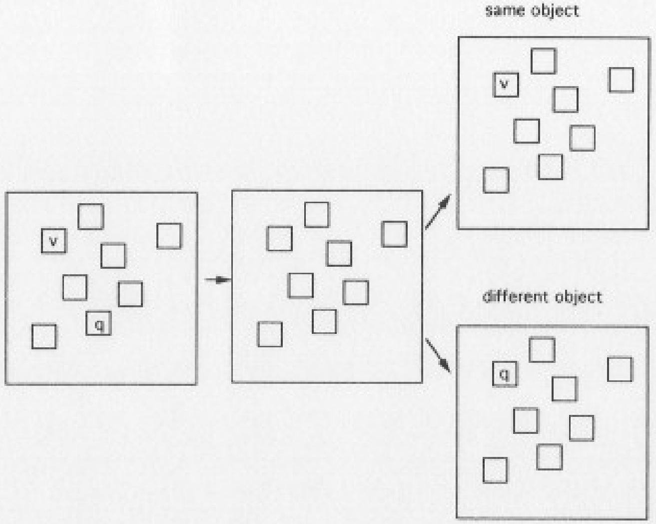

Figure 8.11
Displays and events in two conditions of a study of rapid identification of object identity and change. (See Kahneman et al. 1992, for a description of the complete study).

the target letter if a different letter previously occupied the target's box than if a different letter previously occupied a different box at the same distance from the target. A representation of the persisting box evidently influenced subjects' responding.

Kahneman et al. (1992) next used this procedure to assess the factors that influence adults' representation of identity and change over space and time. Like infants, adults' representation of identity was influenced by information about the cohesiveness and continuity of object motion and not by the constancy or change of an object's shape, color, or category membership. When a set of visual elements appeared or moved continuously together, adults saw them as a single unit. Experiments using other chronometric methods suggest that such object representations survive periods of occlusion (Tipper, Brehaut, and Driver 1990), as do the object representations studied in infants. These experiments suggest that a basic process for representing the boundaries of objects and for tracing object identity through time exists in adults, independent of processes for categorizing objects as instances of known kinds. This process bears some resemblance to the process by which infants perceive objects.

8.5.3 Intuitions about Identity

The most extensive discussions of human intuitions about object boundaries and persistence have taken place within philosophy and linguistics.

These discussions appear to pose serious problems for the view that mature apprehension of objects depends on any general process.

Consider, for example, Cornell University. Much of the university is located in Ithaca, but its medical school is in New York City. Because Cornell is located both in Ithaca and in New York City but not along any route that connects these places, it is not a cohesive object. (Neither is the United States.) Consider, next, a church that occupies an old building at one time and then moves to a new building (Hume 1739). Because no continuous motion connects the old building to the new, the church is not a spatiotemporally continuous object. (Neither is Estonia.) Consider, finally, a duck. Like all animals, a duck can direct its motion from within, guided by its perception of objects at a distance. At the level of perceptible objects, therefore, the duck's motion is not subject to the contact principle.

These and other examples suggest that concepts such as *university*, *church*, and *duck* come to influence our intuitions about object persistence and change, overcoming in some cases the principles of cohesion, continuity, and contact. It is possible, however, that the latter principles continue to guide our intuitions about objects as well. In learning new categories of objects, we may be strongly predisposed to single out, as potential category members, things that are cohesive, continuous, and subject to the constraints of contact mechanics. Moreover, our intuitions about the boundaries and persistence of objects in any category may continue to be influenced by these principles: we may tend to conceive of physical bodies as persisting as long as they maintain their cohesiveness, continuity, and powers to act on contact with other objects, and we may overcome this predisposition only with difficulty and in special cases.

A recent study provides support for this view (Gutheil, Spelke and Hayes, 1995). College students read scenarios in which a table or a ship was introduced and then a transformation of the object was described. In different scenarios, the transformation changed the object's appearance (for example, the table's shape was changed from rectangular to round), its function (for example, the table was used as a piano bench) or its cohesiveness (for example, the table was cut into pieces and then reassembled). A number of questions probed subjects' intuitions about the effect of each transformation on the object's existence and category membership.

Although judgments about the persistence of an object sometimes coincided with judgments about its category membership, these judgments diverged in many cases. For example, 60 percent of the subjects judged that the table that emerged from the disassembly/reassembly process was not the same object as the original table, whereas less than 5 percent of the subjects judged that it was not the same kind of object. Conversely, 76 percent of the subjects judged that the table-turned-piano bench was no longer a table, whereas less than 5 percent judged that it was no longer the same individual. These findings suggest that mature, commonsense intuitions about object persistence are not inextricably tied to intuitions about object kind.

Further findings from this experiment suggest that the cohesion principle is central to intuitions about object persistence. A majority of subjects judged that the table or ship no longer existed after transformations that destroyed its cohesiveness. Over the set of transformations tested in these studies, loss of cohesion led to more frequent judgments that the object ceased to exist than did loss of original shape or function. These findings are consistent with the thesis that a general conception of objects as cohesive bodies underlies many of our intuitions about object persistence and change. Common principles, therefore, may guide representations in infants and adults, and common processes may underline both immediate perceptions and reflective judgments of object identity.

8.5.4 From Perceptual Development to Cognitive Science

Object perception is a wonderful subject for studies in cognitive science because of the long and intense tradition of work on this problem within philosophy, computer science, linguistics, and psychology. Studies of object perception in these disciplines have often proceeded independently of each other: For example, philosophers concerned with the metaphysical question of what a physical body is, or with the epistemological question of how we perceive and gain knowledge of objects, have rarely consulted research on mechanical systems for parsing visual scenes, or the reverse. The problem of how we conceive of object persistence and change has seemed quite different from the problem of how we perceive objects in immediately visible scenes.

Research on the early development of object perception is beginning to suggest, however, that philosophical investigations assessing common sense intuitions about object persistence and change, linguistic analyses of the primitive notions underlying the meanings of words and expressions, chronometric experiments probing the extremely rapid processes by which we detect changes in objects, and psychophysical and computational studies of image segmentation and object recognition may reveal common cognitive capacities. All of these abilities may be rooted in a single system of knowledge that emerges early in human infancy and underlies our first perceptions of objects. Studies within all these disciplines, in concert with studies of early perceptual development, may serve to probe the nature of this knowledge system.

Suggestions for Further Reading

An excellent introduction to the philosophical problems of object perception is provided by Hirsch 1982, who proposes a solution to the problem of physical identity that combines

general rules and category-based perspectives. For a briefer introduction to this and other problems of metaphysics from a cognitive science perspective, see Goldman 1993.

On the problem of dividing the world into objects from the perspective of computational vision, see Marr 1982 (Chapter 3). Marr suggests that the parsing problem is solved by processes of model-based object recognition; general discussions of such procedures can be found in Lowe 1985 and Ullman 1989. For rule-based approaches to the parsing problem similar to the approach of the Gestalt psychologists, see Witkin and Tenenbaum 1983 and Palmer and Rock 1994.

A good original source on Gestalt psychology is Koffka 1935. Excellent modern discussions of the Gestalt approach to object perception are provided by Hochberg 1974 and Rock 1983. For an example of a contemporary approach to perception within the Gestalt tradition, see Kanizsa 1979. Hatfield and Epstein 1985 provide a general discussion of the Gestalt simplicity principle.

Atkinson and Braddick 1989 provide a good introduction to the development of basic visual functions in infancy, including sensitivity to contrast and color, binocularity, and eye movement control. A collection of recent papers on perceptual and cognitive development in infancy can be found in Granrud 1993. In particular, the chapter by Kellman discusses the early development of perception of objects and motion, and the chapter by Arterberry, Craton, and Yonas discusses intriguing recent work on perception of depth and occlusion. On infants' sensory and perceptual capacities, see Salapatek and Cohen 1987. On methods of studying perception in infancy, see Gottlieb and Krasnegor 1985.

Although our chapter focused exclusively or perception of inanimate objects, considerable research has investigated infants' perception of human faces. Johnson and Morton 1991 discuss this research from both biological and cognitive science perspectives.

It is likely that early-developing abilities to perceive objects underlie the child's earliest learning of words for objects. For research on early word learning that addresses this possibility, see Markman 1989. For analyses of the conceptual primitives underlying mature language, see Jackendoff 1983 and Volume 1 of the present series.

Problems

8.1 Some investigators have proposed that young infants learn to see partly occluded objects as continuing behind their occluders by repeatedly experiencing visual arrays in which objects move in and out of view (e.g., Edelman 1987; Smith and Katz, in press). What preexisting capacities must an infant have, in order for such learning to be possible? How could one study whether these experiences are necessary?

8.2 Just as a major task of the young child is to acquire the lexicon of his or her language, a major task of early childhood is to acquire a vocabulary of object categories and models for object recognition. How could one investigate when children begin to develop models of objects, and (more important) the nature of the models they develop? Note that demonstrations that children respond to a given array as familiar, or that they respond to a group of arrays as similar to one another, are not sufficient to establish that children carve the arrays into objects and categorize each object as a member of a certain kind.

Questions for Further Thought

8.1 Goodale (in Chapter 5) discusses two distinct visual pathways involved in the representation of objects. Which of these pathways do you think might underlie infants' perception of objects? How could the functional separation of the pathways underlying object recognition and object-directed action be investigated further with infants? How might the general process for perceiving objects, independently of processes of object recognition, be studied with neurologically impaired patients?

8.2 Studies of normal and neurologically impaired adults suggest that face recognition depends on distinct mechanisms from other forms of object recognition (Chapter 3). Would you expect infants to show the same perceptual abilities (and limitations) perceiving faces as they show perceiving inanimate objects?

8.3 Pashler (in Chapter 2) discusses evidence that in certain situations people divide attention more easily among two features of one object than among two features belonging to two different objects. What do you think defines a single *object* in these experiments? For example, suppose subjects were presented with a map of the world and asked to detect events that could occur in either of two places. Would attention divide as easily between events in Hawaii and California as between events occurring in two equally distant parts of the continental United States? Which pair of events would be detected faster: events in Washington and Alaska, or events in Washington and British Columbia?

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Chapter 9

Meaningful Perception

Fred Dretske

One can perceive an object without knowing or understanding what it is. One sees, one might even taste, a poisonous mushroom without realizing that it is poisonous—perhaps even without knowing it is a mushroom. Nonetheless, despite such ignorance, despite not perceiving *what* it is, one still perceives (sees and tastes) it. The poisonous mushroom is the object one perceives.

Meaningful perception refers, not to the objects one perceives, but to *how* one perceives them. It is perception that embodies a judgment or belief, some degree of recognition or identification of what one is perceiving. Meaningful perception requires more than good eyesight. It requires the kind of conceptual skills needed to classify and sort perceptual objects into distinct categories. At the most basic level, it involves perceiving that one thing is, in certain respects, the same as another. Even the ignorant can see poisonous mushrooms. What they cannot do is what experienced observers can do: see that they are poisonous or (at a more basic level) that they are mushrooms or (a a yet more basic level) that they are the same kind of thing as those other objects.

We begin by distinguishing perception of objects (mushrooms) from perception of facts about these objects (that they are mushrooms). The perception of objects—what I will call *sense perception*—is that early phase of the perceptual process that culminates in sense experience (visual, auditory, tactile, etc.) of the object. Perception of facts about these objects, on the other hand—that which constitutes *meaningful perception*—is a more inclusive process. Besides sense perception, meaningful perception includes a knowledge (at least a judgment or belief) about the object being experienced.

9.1 Perceiving Objects and Perceiving Facts

When they speak of visual perception, it seems reasonable to suppose that cognitive scientists are referring to something we normally use the verb *to see* to describe. Seeing the cat on the sofa is to visually perceive the cat on the sofa.