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COMMENTARY ON "A LAW OF NUMERICAL/OBJECT IDENTITY"
(F. L. BEDFORD)

Object identity: A developmental perspective

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Bedford describes many situations in which one is required to make decisions about the numerical identity of objects. She then argues that five geometries, nested one within the other, can be used to solve the identity problem in each of these situations. In her approach, Bedford focuses on transformations of form, specifying the conditions under which form transformations will signal the presence of numerically distinct objects or, alternatively, be integrated into a single object representation. She makes three important points. The first is that there is probably a *general solution*, or framework, by which the problem of object identity is solved, regardless of the modality or situation. According to Bedford this is, of course, geometry. The second and third points have to do with how geometries are used. She suggests that (a) geometries are *hierarchically organized* and identity is resolved based on the lowest level available and (b) *solutions are flexible*, whereby sometimes a transformation will signal the presence of two objects and sometimes it

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will not. The strength of this approach is that it is probabilistic: the greater the transformation, the more likely it is that two samples will be judged as two separate and distinct objects. As many have argued (including myself), object individuation is not an all-or-none process, but is instead dependent upon the situation and information available.

There are two places, however, where Bedford's theory runs into some difficulty. The first has to do with the role that spatiotemporal information plays in the individuation process. The second has to do with where to place other, non-geometric, properties within this conceptual framework. I will discuss each in turn, drawing on developmental research.

Infancy research: Basic paradigm and relevant findings

Most research on object individuation in infancy has been conducted within the context of occlusion events. In a typical experiment, infants see an event in which an object disappears behind one edge of an occluder and then an object appears at the other edge of the occluder. Test trials are designed to assess whether infants perceive the object that reappeared from behind the occluder as the same object, or a different object, from the one that disappeared earlier. Visual attention measures (i.e., infants' looking times to events) are used to infer infants' interpretation of such events.

Spatiotemporal information and object individuation

There is evidence that spatiotemporal information[1] is fundamental to the individuation process. From a very early age, infants interpret spatiotemporal discontinuities as signaling the presence of distinct objects.

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1. By spatiotemporal information I mean the location or trajectory (path and speed of motion) of an object. I would argue that spatiotemporal information is embedded within a larger body of knowledge: physical knowledge. For it is expectations about the way objects should move and interact (e.g., objects follow spatiotemporally continuous paths) that lead one to individuate objects based on spatiotemporal criteria.

For example, when shown an event in which an object disappears behind the first of two spatially separate screens, and then emerges from behind the second screen without appearing between the two screens, infants as young as 3.5 months are led by the discontinuity in path to conclude that two distinct objects are involved in the event (Aguiar & Baillargeon, in press; Spelke, Kestenbaum, Simons, & Wein, 1995; Wilcox & Schweinle, in press). Likewise, when presented with an event in which an object disappears behind one edge of a wide screen and then reappears immediately at the other edge, 3.5-month olds take the discontinuity in speed to signal the presence of two objects (Wilcox & Schweinle, 2001). Spatiotemporal information is the first source of information for which infants demonstrate sensitivity, and both infants and adults use it reliably and consistently to individuate objects (Aguiar & Baillargeon, in press; Burke, 1952; Michotte, Thinès, & Crabbé, 1991; Spelke et al., 1995; Wilcox & Schweinle, in press, 2001; Xu & Carey, 1996).

These findings prove difficult for Bedford's theory in the follow way. They suggest that spatiotemporal information is as important, if not more important, as information about object form. Furthermore, spatiotemporal discontinuities make strong predictions about object identity. To illustrate, consider the discontinuity in path research described above. Both infants and adults are led by their knowledge that moving objects follow connected unobstructed paths to conclude that two objects are present in the event: one object that moves behind the first screen and a second identical object that moves behind the second screen. The discontinuity in path clearly signals the presence of two objects; no further analysis is required. In fact, in situations like this object form is irrelevant: we would conclude that two objects are present regardless of whether the objects differed, or were similar, in their form.

According to Bedford's theory, spatiotemporal discontinuities set the stage for object individuation, but they do not guarantee the decision that there are two objects. For example, a discontinuity in path raises the possibility of two objects by introducing two samples. To determine if those two samples represent two distinct individuals, the geometries of the two samples are compared. If little or no difference between the geometries is perceived, the two samples will be integrated into a single object representation. If the geometries are viewed as sufficiently distinct, they will be seen as two objects. Of course, this occurs along a continuum: the smaller the difference the more likely it is that the two samples will be perceived as instances of a single object. This approach predicts that it would be unlikely that two objects that are identical in appearance and occupy different spatiotemporal coordinates would be perceived as two distinct entities. Yet, infants and adults make a two-object decision in situations like this quite easily.

Bedford's theory does, however, account for situations where spatiotemporal information is degraded or ambiguous. When spatiotemporal information does not clearly specify how many objects are present, one must draw on other sources of information to make decisions about object identity. As will become evident in the next section, infancy research supports the notion that form transformations play an integral role in this process.

Featural information and object individuation

There are many situations in which spatiotemporal information is not sufficient to establish that two objects – two separate and distinct entities – are present. Consider, for example, the following scenario: a ball disappears behind one edge of a screen and, after an appropriate interval, reappears from behind the other edge. In the absence of information about the path that the ball traced behind the screen, it is difficult to determine whether the ball that disappeared and the ball that reappeared were one and the same ball. When spatiotemporal information is ambiguous, one way to make an identity decision is to compare the featural properties of the objects seen to each side of the screen. When the features are identical, we typically conclude that one object is involved in the event; when the features are different, we typically conclude that two objects are present.

Object features can be grouped into two general categories: those that specify three-dimensional form and those that constitute surface properties. Wilcox (1999) systematically investigated 4.5- to 11.5-month olds' sensitivity to two form features (i.e., shape and size) and two surface features (i.e., pattern and color) when faced with an occlusion event like that described above. (Bedford also describes this work.) In these experiments, infants saw a test event in which an object moved behind the left edge of a screen and then a featurally distinct object appeared at the right edge. The second object then reversed direction to return behind the screen, and the first object emerged and returned to its starting position. This entire sequence was repeated until the end of the trial. The objects seen to each side of the screen varied on only one feature dimension at a time. For half the infants, the test screen was sufficiently wide to occlude the two objects simultaneously (wide-screen event); for the other infants, the test screen was too narrow to occlude both objects at the same time (narrow-screen event). If infants (a) are led by the featural differences between the two objects to view them as two distinct objects; (b) correctly judge that the two objects could be occluded simultaneously by the wide but not the narrow screen; and (c) are puzzled or intrigued when this last expectation is violated, then they should look longer at the narrow- than wide-screen event. In contrast, if infants fail to use the featural differences to individuate the objects, the size of the screen should not matter (i.e., the narrow screen was wide enough to hide any one of the objects alone). Hence, infants should look equally at the two events.

The results revealed that when the objects seen to each side of the occluder differed in shape (i.e., a green ball and a green box) or size (i.e., a large ball and a small ball), 4.5-month olds used the difference to conclude that two distinct objects were involved in the event: they looked reliably longer at the narrow- than wide-screen event. In contrast, when the objects seen to each side of the screen differed in their pattern (i.e., a dotted and a striped ball) or their color (i.e., a green and a red ball), infants were less likely to succeed: it was not until 7.5 months that infants used the pattern difference, and 11.5 months that they used the color difference, to reason about the number of objects present in the event. It is noteworthy that similar developmental trends have been observed in object segregation experiments. Needham (1999) reported that 4-month olds use shape but not pattern information to segregate stationary adjacent displays and Craton, Poirier, and Heagney (1998) found that 7- but not 4-month olds use pattern to parse partly occluded displays.

Why do infants demonstrate sensitivity to form features before surface features? One possibility is that suggested by Bedford: "geometry is the most primitive, basic, and core factor in object identity" (p. 158). In most physical situations, form features are more important than surface features for predicting the outcome of events. For example, in containment events, the shape and size of an object relative to that of a container determine whether the object can fit into the container; in support events, the dimensions and placement of an object relative to a supporting surface determine whether the object will remain supported or fall to the ground; and in collision events, the size of a moving object determines, at least in part, how far a stationary object will be displaced on contact. Because surface features are rarely crucial to making predictions about physical events, they are assigned little importance. In other words, as infants attempt to makes sense of the world as it unfolds before them, they are biased to attend to those features - in this case, form features - that are most relevant.

There is evidence, however, that other physical properties are also important for individuating objects. This evidence has led me to think about object identity within the context of the physical reasoning system, a system that draws on many different sources of information as it attempts to trace the identity of objects through space and time.

Other non-geometric object properties and object individuation

Like Bedford, we recognize that object individuation is a process that is not unique to the visual system. In recent experiments, we explored infants' ability to use auditory information to individuate objects in occlusion events. For example, in one experiment (Wilcox, Tuggy, & Napoli, 2001), we investigated 4.5- and 7.5-month olds' sensitivity to two kinds of auditory information: natural and artificial sounds (Walker-Andrews, 1994). *Natural* sounds are produced in accordance with the structure and the substance of an object and are unique to that object (e.g., the sound a jar of marbles makes when it is shaken or the sound of a wooden ball as it hits a solid surface). In contrast, *artificial* sounds are neither naturally occurring nor intrinsic to an object (e.g., the sounds electronic toys make or tones produced by a music box). From a physical reasoning perspective, we expected that infants would be more sensitive to natural than artificial sounds. Natural sounds are inherent to an object, reflect an object's physical make-up, and, in general, provide more relevant information about an object. In addition, because natural sounds are unique to specific objects, they are a more reliable source of information for keeping track of the identity of objects as they move about in the world.

To test this hypothesis, infants were presented with an event in which they heard two different sounds, separated by a temporal gap, from behind a screen. The two sounds were either natural (i.e., produced by shaking a papier-mache egg filled with either uncooked rice or small bells) or artificial (e.g., tones, produced by an electronic keyboard, that differed in pitch and timbre; the tones emanated from speakers inside the papier-mache eggs). The screen was then lowered to reveal a single object (i.e., a papier-mache egg) on the platform. When the sounds were natural, the infants responded as if they had concluded that two objects were present in the event and were surprised to see only one object when the screen was lowered. In contrast, when the sounds were artificial the infants responded as if they had failed to draw a conclusion about the number of objects present in the event.

It is difficult to imagine how a theory that focuses on geometric transformations could account for these results. In contrast, a conceptual framework that focuses on information processing biases within the context of physical events can explain infants' use of auditory information, as well as many other non-geometric object properties, as the basis for individuating objects.

Final comments

I heartily agree with Bedford that a *general solution* to object identity is called for. What I am left wondering is whether a theory of five nested geometries will suffice, or whether a broader conceptual framework is needed. From a developmental perspective, geometric transformations are certainly important to object individuation, but they do not appear to stand alone at the core of object identity. For example, the first source of information that infants demonstrate sensitivity to is spatiotemporal information, at 3.5 months. By 4.5 months, infants reliably use form features and natural sounds to individuate objects. One way to account for these results is to consider object identity within the context of the physical reasoning system. Within this system, each source of information is *hierarchically organized* (e.g., form features are used before surface features; natural sounds are used before artificial sounds) and there is *flexibility in the solutions* that are used (e.g., Wilcox, Schweinle, & Chapa, in press; Needham & Baillargeon, 2000). However, geometric information is just one of several sources of information that are fundamental to the individuation process.

REFERENCES

Aguiar, A., & Baillargeon, R. (in press). Developments in young infants' reasoning about occlusion events. *Cognitive Psychology*.

Burke, L. (1952). On the tunnel effect. *Quarterly Journal of Experimental Psychology, 4,* 121-138.

Craton, L., Poirier, C., & Heagney, C. (1998, April). Perceptual completion and object segregation in infancy. Presented at the International Conference on Infant Studies, Atlanta, GA.

Michotte, A., Thinès, G., & Crabbé, G. (1991). Amodal completion of perceptual structures. In G. Thinès, A. Costall, & G. Butterworth (Eds.), *Michotte's experimental phenomenology of perception*. Hillsdale, NJ: Lawrence Erlbaum Associates. (Original work published in French in 1964.)

Needham, A. (1999). The role of shape in 4-month-old infants' segregation of adjacent objects. *Infant Behavior and Development, 22,* 161-178.

Needham, A., & Baillargeon, R. (2000). Infants' use of featural and experiential information in segregating and individuating objects: A reply to Xu, Carey, and Welch (2000). *Cognition, 74,* 255-284.

Spelke, E. S., Kestenbaum, R., Simons, D. J., & Wein, D. (1995). Spatiotemporal continuity, smoothness of motion and object identity in infancy. *British Journal of Developmental Psychology, 13,* 113-143.

Walker-Andrews, A. (1994). Taxonomy for intermodal relations. In D. J. Lewkowicz & R. Lickliter (Eds.), *The development of intersensory perception: Comparative perspectives*. Hillsdale, NJ: Lawrence Erlbaum.

Wilcox, T. (1999). Object individuation: Infants' use of shape, size, pattern, and color. *Cognition, 72,* 125-166.

Wilcox, T., & Schweinle, A. (in press). Object individuation and event mapping: Infants' use of featural information. *Developmental Science*.

Wilcox, T., & Schweinle, A. (2001). Infants' use of speed information to individuate objects in occlusion events. Manuscript submitted for publication.

Wilcox, T., Schweinle, A., & Chapa, C. (in press). Object individuation in infancy. To appear in F. Fagan & H. Hayne (Eds.), *Progress in infancy research*, Vol. 3. Mahwah, NJ: Lawrence Erlbaum Associates.

Wilcox, T., Tuggy, L., & Napoli, R. (April, 2001). Young infants' use of auditory information to individuate objects. Presented at the biennial meeting of the Society for Research in Child Development, Minneapolis, MN.

Xu, F., & Carey, S. (1996). Infants' metaphysics: The case of numerical identity. *Cognitive Psychology, 30,* 111-153.