6 Is Cognitive Modularity Necessary in an Evolutionary Account of Development?

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Our species has many distinctive characteristics, including upright posture, opposable thumbs, large brains, language, tool use, and many others. Arguably, one of the key characteristics of *Homo sapiens* is a developmental one: the extended proportion of our life span that comes before sexual maturity (Gould 1977). One of the crucial adaptive functions of this lengthy childhood is to allow for cognitive development. When a young organism must fend for itself, its interactions with the environment must be "good to go," and hence relatively preformed and inflexible. By contrast, human young can take their time, while protected by adults, to adapt to the environment in which they find themselves and to learn from the innovations and insights of prior generations. The same is true, albeit perhaps to a lesser extent, for other species in which there is a juvenile period before sexual maturity that is spent with mother, parents, or a band of adults.

Viewing it in this way, one might assume that an evolutionary approach to cognitive development would stress plasticity and learning, and might seek to relate interspecies differences to differences in the length of the juvenile age period. However, in reality, characterizing the nature of cognitive development has involved a repetitive struggle between nativism and empiricism, in which nativism has lately had a fairly dominant hand. For a while, Piaget's constructivism seemed to provide a way out of this opposition, but as Piaget's influence waned in the late 1970s and early 1980s (Gelman and Baillargeon 1983), a new nativism became the predominant mode of theorizing (e.g., Spelke et al. 1992). Alternative approaches appearing in the 1990s (Elman et al. 1996; Karmiloff-Smith 1992; Siegler 1998; Thelen and Smith 1994) may collectively be called emergentist theories because all of them suggest that there is significant developmental change, although there are differences as well as similarities among them (see chapters in Spencer et al., in press). However, nativism (under the banner of "core knowledge") has continued to be an attractive option for many cognitive developmentalists into the twenty-first century (Dehaene et al. 2006; Spelke 2000; Spelke and Kinzler 2007).

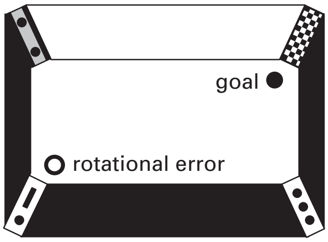
The persistence of nativism is a curious situation; all concerned, including individuals seen by others as unvarnished proponents of one side or the other, have professed support for the notion of *interactionism,* the idea that genetics and environment interact in complex and bidirectional ways to lead to development (Marcus 2004). However, nativism benefits from several advantages in the ongoing nature-nurture controversy. Chief among these advantages is the fact that it provides a simple and elegant story about how development and evolution fit together. In this way of thinking, adaptive pressures operate on a modular cognitive architecture (Cosmides and Tooby 1992). This brand of evolutionary psychology has in fact argued that evolution could *only* work if our cognitive organization is modular, because otherwise there would be no distinct target for adaptive pressures. For example, the adaptive value of fluently recognizing others leads to selection for modular face recognition abilities, the fact that living in social groups demands attention to equity in exchange leads to selection for a cheater detection module (Cosmides and Tooby 1989, 1992), and so on. Although modularity does not, strictly speaking, entail nativism (Barrett and Kurzban 2006; Fodor 2000; Karmiloff-Smith 1992), the two concepts are deeply intertwined in theorizing of this sort. In addition, innate origins are identified with modularity because they were in fact explicitly advanced as an attribute of a cognitive module in Fodor's original (1983) formulation of modularity.

The innate-module approach to the evolution and development of cognition is dramatically exemplified in recent proposals of an encapsulated geometric module that guides reorientation (Hermer and Spelke 1994, 1996). We are normally oriented to our spatial environment as we move through it, maintaining awareness of our position using both internal tracking mechanisms and relations to external landmarks. However, if we pass through a dark cave, or tumble down a hill, we may look around with very little idea of where we are, and need to reorient. Clearly, reorientation is an adaptive problem—the person who does not solve it will be unable to get home, avoid dangers, or find food. Experiments originally done with rats (Cheng 1986) and later done with human toddlers (Hermer and Spelke 1994, 1996) showed that reorientation was accomplished using information about the geometric shape of an enclosure. For example, in a rectangular space, after disorientation, searches for food or other objects concentrate on two geometrically congruent corners, for example, "long wall to left of short wall" (figure 6.1).

This pattern shows that geometric information is used to constrain likely search locations. Dramatically, when a prominent feature such as a colored wall or a corner panel potentially allows picking the correct spot, search remains evenly divided between the two geometrically congruent corners. The features are easy to notice and are used to guide search when there has been no disorientation. Hence, it seems that using geometric information to reorient is not only modular in the sense of making use of distinctive information uniquely relevant to the problem at hand (functional specialization) or in the sense of utilizing a specialized brain area (although there is some evidence there may be such an area; Epstein and Kanwisher 1998). Rather, it seems that this was a module in a very strong sense: encapsulated and unable to accept functionally relevant information.

Human adults, however, do use nongeometric information to reorient (Hermer and Spelke 1994, 1996). The transition from nonuse to use of nongeometric information, which

(a) Performance on task



(b) Geometric information

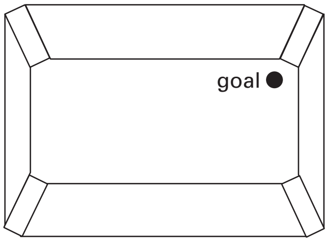


Figure 6.1
Geometric and featural (nongeometric) information in the relocation task (a) The task in a rectangular arena as seen from above. In attempting to relocate the goal after disorientation, subjects frequently commit the rotational error. This is the location at 180-degree rotation through the center from the correct location. (b) The geometric information is contained in the broad shape of the arena. The featural information is what is not shown: patterns on the panels, different brightnesses of walls, smells in the corner, and the like. When a “map” is used containing only geometric information, the goal and the rotational error cannot be distinguished. Adapted from Cheng and Spetch (1998).

takes place between the ages of five and six years (Hermer-Vazquez et al. 2001), poses an interesting issue for a nativist approach to cognition: How to account for developmental change? This challenge was answered by the suggestion that human language provides the tool for alteration of what would otherwise be a fundamental constraint on thought. When children acquire productive control of the terms “left” and “right,” they become able to conjoin geometric and nongeometric information in a fashion unavailable in the absence of a symbolic system (Hermer-Vazquez et al. 2001). Interestingly, this research has been cited enthusiastically by proponents of culture- and language-based approaches to cognitive development (Haun et al. 2006; Levinson 2003).

The module-plus-language approach is, however, not the only way to conceptualize the evolution and development of a capacity for spatial reorientation. There are several difficulties with the hypothesis, including the facts that many nonhuman animals actually can use nongeometric information to reorient (see review by Cheng and Newcombe 2005), that human toddlers can use nongeometric information to reorient in larger and more ecologically valid spaces than those used in the original research (Learmonth et al. 2001, 2002), and that language does not appear to have a unique role in adult use of nongeometric information to reorient (Ratliff and Newcombe 2008). The main purpose in this chapter is to explore the promise of a different view of the relation of evolution and development, one more in the tradition of the plasticity-due-to-neoteny way of thinking. We argue both for a different view of orientation and reorientation and, more generally, for a different view of the relation between evolution and development than the currently popular one.

In the first section of the chapter, we outline an *adaptive combination* approach to spatial cognition and spatial development, and in the second section we review recent findings that support it (see Newcombe and Huttenlocher 2000, 2006, for more extended reviews of spatial development and this approach to it). In the third section, we critique two recent arguments for innate geometry: a demonstration that features alone cannot be used to reorient (Lee et al. 2006), and data on geometric concepts in the Munduruku (Dehaene et al. 2006). In the concluding section, we place the adaptive combination view in the framework of a prepared-learning approach to cognitive development and of an evolutionary approach to psychology that does not require cognitive modularity.

Adaptive-Combination Approach to the Development of Reorientation

People are frequently confronted with questions that require spatial estimation, such as "Which way should I head to get home from the library?" or "Where did I leave my cell phone?" There is considerable evidence for the use of multiple sources of information when we answer such questions. Cheng and colleagues (2007) review this evidence and theorizing, which includes several Bayesian models that show that such combination frequently maximizes the average accuracy of responses. Cheng and colleagues structure their review around three kinds of situations in which combination occurs, including when two or more currently available metric estimates (such as visual and haptic information; Ernst and Banks 2002) are combined, when current information is combined with the average of past experience (Kersten and Yuille 2003), and when current information is combined with categorical information that may or may not derive from past experience (Huttenlocher et al. 1991, 2000).

The overall thrust of the Cheng et al. (2007) review is that spatial conclusions are typically supported by various information sources whose use derives at least in part from experience. For example, recalibration of the relation of optic flow to distance traveled occurs when the relation is changed because one is walking on a treadmill that is itself moving, for example, pulled by a tractor (Rieser et al. 1995). Learning may work in one of two ways. First, it sometimes determines the relative weighting of the various information sources, with weightings affected by several factors, including the reliability of the source, how variably or inexactly it is coded, how perceptually salient it is, and how frequently it has been used in the past (e.g., Wang et al. 2005). Second, when two information sources lead to incompatible responses, learning may determine which of the sources will be preferentially relied on, in other words, it may shape a hierarchy of responses to be tried sequentially rather than production of an integrated estimate. In sum, the adaptive-combination approach involves the propositions that there are multiple sources of spatial information and that those sources are either integrated using weighting mechanisms or are hierarchically arranged in order of preference, and that those weightings and orderings are, at least in part, learned in the course of interaction with the spatial environment.

What happens when two information sources provide redundant information? In some cases both are learned, but in other cases, one of the two is ignored, or it is learned less easily or thoroughly than it would have been when presented alone. Classically, this phenomenon has been described either as *blocking* (when one information source has already been learned and prevents learning of a second source) or as *overshadowing* (when the two sources are presented concurrently, and the learning of either or both may be affected). Blocking and overshadowing seem to contradict the idea of adaptive combination, in that an information source is ignored even though it might contribute to increased precision of spatial estimation or even provide a way of estimating location when it would be otherwise impossible (as when the first source becomes perceptually unavailable, or unreliable). In addition, in terms of the geometric module hypothesis specifically, there are findings that show that learning distinctive features that mark a goal does not block learning of the geometry of an enclosure (Hayward et al. 2003; Pearce et al. 2001; Wall et al. 2004). One conclusion that could be drawn from such a lack of blocking effects is that the featural and geometric information are processed separately, perhaps in a fashion that might be called modular.

However, Miller and Shettleworth (2007) provide a nonmodular account of these findings on overshadowing and blocking, as well as one consistent with the adaptive combination approach. In doing so, they also bring order to the literature by explaining other findings that seem contradictory to overshadowing and blocking, in which learning one kind of information is easier or quicker or more robust when the other kind is present (e.g., Pearce et al. 2006) or in which blocking or overshadowing are sometimes observed (e.g., Gray et al. 2005). Miller and Shettleworth (2007) present an operant model related to the Rescorla-Wagner associative-learning model. In this account, features and geometry are both encoded on every trial, and the contingencies of one kind of information influence learning of the other kind and vice versa.

In summary, although many issues remain to be worked out in detail, there is growing evidence that spatial behavior typically depends on combining information from a variety of sources. This kind of theorizing is very different from that sometimes espoused in the literature, as, for example, when Wang and Spelke (2002) postulated that spatial behavior is determined completely by the geometric module for coping with reorientation, coupled with memory for viewpoint-specific representations of local sections of the environment that are related to each other through egocentric spatial updating. In fact, a recent critique of the Wang and Spelke argument by Burgess (2006) shows that egocentric and allocentric spatial representations coexist and interact in supporting spatial behavior, in general accord with the adaptive-combination point of view.

Recent Findings Supporting an Adaptive Combination to Reorientation

In this section we argue that the coexistence and interaction of various kinds of spatial information for reorientation, as postulated by the adaptive-combination view, is necessary to explain the data on development of the ability to reorient. Specifically, use of geometric and nongeometric information to reorient fluctuates systematically as a function of variables that affect the certainty with which the two kinds of information are encoded, their salience, and their cue validity. Such fluctuation could not be predicted by a modular theory. First, we examine fluctuation as a function of size of the enclosed space. Second, we discuss recent work on rearing and training effects. Third, we look at the effects of full enclosure as compared with a geometric outline that is only suggested by separated environmental elements, an issue that has the potential to shed light on the modularity issue but whose status is not yet empirically clear.

Room-Size Effects

In the literature on reorientation in human children, the first demonstration that very young children do sometimes use features as well as geometry to reorient, came from experiments by Learmonth and colleagues (2001). The contrast between the Learmonth et al. findings and those of the Spelke group were quickly shown to be due to the fact that the Learmonth et al. experiments were done in a room with quadruple the area of the Spelke group's experiments (Learmonth et al. 2002). The two papers by Learmonth and colleagues provide three challenges to the geometric module approach to the development of reorientation. First, children are using features as well as geometry by eighteen months, well before they control production of the terms "left" and "right" (and recall that acquisition of these linguistic terms is the only developmental mechanism postulated by the Spelke group). Second, a geometric module that only operated in extremely small spaces would not be very useful in our environment of adaptation; in fact, even the larger room used by Learmonth is quite small by the standards of the real world. Third, the modularity view cannot provide a cogent account of why the size of the space matters. The size of the experimental enclosure also appears to have a profound effect on nonhuman species, who have also shown a preference for using geometric information in small spaces but relying on nongeometric featural cues during reorientation in larger spaces (Sovrano et al. 2005; Vallortigara et al. 2005).

How does the adaptive-combination view account for the room-size effect? According to an adaptive-combination view, geometric information would be expected to predominate in studies where room shape is easily encoded with great certainty and low variability, as is true in most work so far, which has used fully enclosed spaces with a simple regular geometric shape such as a rectangle, triangle, or rhombus (an issue discussed in a later section of this chapter). In contrast, the nongeometric features are often likely encoded variably and with lower salience, for example, if they are small and mobile (Hermer and Spelke 1996, see experiments 3, 4 and 6; Gouteux et al. 2001). In terms of the room-size effect, an important variable is likely to be whether the features are distal or proximal. The further away a feature is located from an organism the greater the strength of encoding. Imagine movement around a local area. This movement creates very large variability in the location of a proximal feature. In contrast, movement creates only small variability in the location of distal features, according to an adaptive combination model (Nadel and Hupbach 2006; Newcombe and Ratliff 2007; O'Keefe and Nadel 1978).

Learmonth and colleagues (2008) explored how landmark proximity affects search patterns to produce the differences found between room sizes. They also examined the effect of the relative ease of moving around a space; smaller spaces constrict movement, which is known to lead to reduced spatial coding (for rats, see Foster et al. 1989; for children, see Acredolo 1978; Acredolo and Evans 1980; McComas and Dulberg 1997).[1] Children between three and six years of age performed the reorientation procedure of searching for a toy hidden in one of the four corners of a larger 8 × 12 foot rectangular room with one colored wall. Some of the children had their movements restricted by being placed within a small, centrally located 4 × 6 foot unfeatured rectangular area located within the larger room.

The results showed that at least three factors affect the age at which features are used to reorient. First, when the colored wall was more distal than it could be in the small room, children succeeded in using the feature to guide search at four years instead of six years, even when their movement was restricted. Second, the ability to move freely in the larger room also has an impact. When action is restricted, using features to reorient does not appear until four years, as compared to eighteen months when active movement is allowed (Learmonth et al. 2001). Third, when the toy was hidden in a corner of the unfeatured central enclosure—close to the child but far from the landmark—successful orientation did not occur until six years of age as compared to four years old when targets were placed adjacent to the distal colored-wall landmark. These variable ages of transition in use of a nongeometric feature suggest the overall inadequacy of a modularity-plus-language view.

Size of the experimental enclosure also changes reorientation strategies when a nongeometric feature, such as a colored wall, is displaced during testing from the location learned during training. When the learned geometry and feature locations are placed in conflict, fish (Sovrano et al. 2007) as well as chicks (Chiandetti et al. 2006; Sovrano and Vallortigara 2006) reorient by the geometry of a small enclosure, but the animals switch their search strategy in the larger spaces, relying on the current location of the nongeometric feature to reorient. Applying this conflict paradigm to identify the hierarchy of spatial cues used during adult reorientation, Ratliff and Newcombe (in press) found that the adults used geometric information to a greater degree in a small (4 × 6 foot) room whereas adults reoriented by the location of a feature in a larger (8 × 12 foot) room. Additionally, when training and testing occurred in rooms that were geometrically equivalent but of different sizes (the ratio of long to short walls remained constant although the room areas were different sizes, either large or small), reorientation behavior was consistently dominated by the feature location rather than the geometric shape of the room. Such search patterns suggest an adaptive approach to reorientation by means of integrating geometric and nongeometric information, depending on the certainty of encoding, reliability, and salience of the two types of spatial cues.

Effects of Training and Rearing

A core element of the adaptive-combination approach is the idea that spatial coding will be dynamically affected by experience—both recent experience (training effects) and early experience in a juvenile period (rearing effects). By contrast, the modularity-plus-language position has little room for such ideas, proposing instead that a fixed innately determined module can be changed only by the human capacity for linguistic encoding that can override the outputs of the module. There is considerable evidence for training effects, however, and some accumulating evidence for rearing effects. In this section we look at both issues.

Training Effects

Many training experiments have shown that flexibility of cue use can be achieved with both mature and juvenile participants, both human and nonhuman, if they have had the appropriate experience.

Pigeons Pigeons flexibly use feature and geometric information, depending on the initial training experience (Kelly et al. 1998). All pigeons in these experiments were trained to find a hidden food source in an enclosed rectangular environment. One group of pigeons was trained with only geometric information while the other group was also trained with distinct feature information at each corner. The pigeons that had been initially trained with only geometric information were then retrained with the same feature information as the first group. During the test phase, the features were rotated 90 degrees so that the correct-feature corner was now in an incorrect geometric location. The pigeons that had been initially trained with features mainly selected the featurally correct corner, whereas the pigeons that had been initially trained with geometry divided the choices between the two geometrically correct corners and the correct-feature corners.

Pigeons and human adults To extend this work, Kelly and Spetch (2004a, 2004b) trained pigeons and human adults with a two-dimensional schematic form of the reorientation task. A rectangle appeared with four landmarks at each corner of a computer screen. The pigeons and adults were divided into two groups; half were trained first only with geometric information, followed by geometric and feature information. The other half was trained first only with feature information, followed by geometric information. In the conflict trials, all of the adults chose the featurally correct corner, so the order of training had no effect. Thus, for schematic diagrams, feature information may be more salient than geometric information for human adults. For pigeons, in contrast to Kelly et al. (1998), the training order did not influence the choice on the conflict trials. All of the pigeons divided the search equally between the geometrically correct corners and the correct-feature corner., However, there was a difference in the training procedure. The pigeons in Kelly et al.'s (1998) experiment only received the feature and geometry training before the conflict trial. The pigeons in Kelly and Spetch's (2004b) experiment received the feature and geometry training followed by a geometry-only training session before the conflict test. One dose of geometry training, either before or after feature training, was enough to boost the use of geometric information for pigeons. Thus, it appears that the relative weightings of feature and geometry cues for pigeons can be quite malleable.

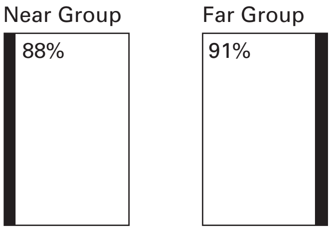
Human children It also appears that the relative weighting of geometric and nongeometric information for children can be influenced by experience. As mentioned earlier in the chapter, children below the age of six are not normally able to use nongeometric cues to reorient in a small 4 × 6 foot room (Hermer and Spelke 1994, 1996). However, when given practice using nongeometric information, four- and five-year-old children can succeed at the task in the same size of enclosure (Twyman et al. 2007). These children were asked to practice the reorientation task in an equilateral triangle that had no distinctive geometric information. Each of the walls was a different color, so the children were given practice using nongeometric cues to reorient. Children were then tested in the small rectangular room and were able to reorient using both geometric and nongeometric cues. When children were given practice in the standard small rectangular room with the feature wall, a more subtle feature training task, these children were also able to conjoin geometric and nongeometric cues after a relatively small number of trials. Moreover, Learmonth and colleagues (2008) found that three-year-old children needed only four trials in a larger room with a feature—a situation in which they naturally use features as well as geometry—to show use of features in the small room, in which without prior experience they do not use features. Thus, it appears that practice with nongeometric cues, both salient and subtle, can influence the use of geometric and nongeometric information.

Rearing

Rearing experiments take the principles of training experiments one step further and dramatically display the flexibility of cue use. One of the first studies to demonstrate this flexibility was with wild-caught mountain chickadees (Gray et al. 2005). These birds live in forested areas lacking salient geometric cues, in contrast to the standard rearing environment in a lab. The chickadees were trained to find food in the corner of an enclosed rectangle with one blue wall as the salient feature wall. When the target corner was adjacent to the feature wall, the chickadees did not encode the geometry of the enclosure. However, when the target corner was away from the feature wall, the chickadees did encode the geometry (figure 6.2). Thus, the use of geometric and nongeometric information depended on the proximity of the nongeometric, or featural, information to the target corner.

To further understand the effects of rearing, two groups of researchers used a laboratory version of the wild-caught chickadee experiment. Brown and colleagues (2007) reared convict cichlids *Archocentrus nigrofasciatus* in either a circular (lacking geometry) or rectangular tank (salient right angles). Unlike the chickadees, all of the fish encoded the geometry of the rectangle. However, there were still differences between the groups. Fish that had been reared in the circular tank more rapidly learned to use features than fish that had been reared in the geometry-rich rectangular tank. Further differences were revealed on conflict trials, where the feature wall was moved from a short wall to a long wall or vice versa, placing the learned geometry in conflict with the feature location. A conflict task reveals the hierarchy structure of the cues. Fish that had been reared in the circular

(a) Control Tests



(b) Geometry Tests

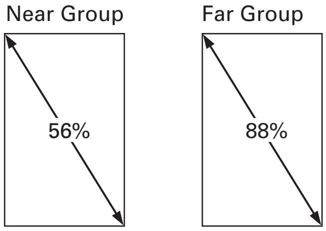


Figure 6.2
In this figure the data are presented as an average, with the correct corner in the top left position. From panel (a), both groups accurately selected the correct corner on probe trials where reinforcement was not available. The crucial test is in panel (b). Here, the near-feature group failed to encode geometry as they selected a geometrically equivalent corner at chance (50 percent). In contrast, the far-feature group encoded the geometry of the apparatus, performing above chance. Adapted from Gray et al. (2005).

tank chose the featurally correct corner more often than their rectangular-reared counterparts who more often chose a geometrically correct corner. Thus, the use of geometric and nongeometric information was influenced by the rearing environment of the convict cichlids.

Chiandetti and Vallortigara (2008) examined the influence of rearing environment on the performance of chicks in the reorientation task. This particular species is quite precocial, and hence experience might have less of an impact on the weighting of reorientation cues, compared to species with longer developmental periods. After hatching, chicks were placed in either a rectangular or circular cage for two days before training began on the third day of life. Whether training occurred in the presence or absence of features, all chicks encoded the geometry of the environment. But because the crucial conflict tests were not conducted, it remains unknown whether there may be a hierarchy of spatial cues related to rearing environment.

At this point we are just starting to understand some of the differences in the flexibility of use of geometric and nongeometric cues. There may be species-specific reasons why malleability is found in some cases, such as the children or the mountain chickadees, whereas a more crystallized pattern is found in other cases, such as the chicks or fish. It is also possible to look at these data as they relate to the developmental period. If one looks at the spectrum from precocial to altricial, it is possible that the amount of flexibility within the adaptive combination model may depend on where on this spectrum an organism lies. At the precocial end, we may find the chicks are "good to go" as soon as they hatch, indicating that their spatial navigation system may be crystallized early on. At the other end of the spectrum we might find that altricial species, such as humans, elephants, and hippopotamuses, with an elongated period of development, may be able to support a more flexible cognitive system, including spatial navigation as one example. Future research on species differences could prove to be worthwhile.

Inferred Geometric Information

Natural environments do not typically contain fully enclosed regular geometric spaces. The appeal of the geometric module hypothesis rests in part on the proposition that geometric aspects of the environment such as cliff faces and river courses are unlikely to change, whereas the coloration or texture of cliffs or rivers may change with the season or the weather (Gallistel 1990). Even though cliff faces or river courses are extended in space, however, they rarely delineate more than a portion of the area surrounding a person or animal, and what is delineated is done so in a complex and irregular way. In addition, many natural environments, such as open savannah areas, are fairly uniform except for discrete landmarks (Poucet 1993). These observations have several implications for the geometric module hypothesis. First, they suggest that the typical experiment conducted so far tests the role of geometry in reorientation at "industrial strength," namely when there is minimal uncertainty regarding the shape and when the geometry can easily be encoded from the ratio of long and short sides meeting at a right angle. Second, and following from the first point, they suggest that a crucial test of the geometric module hypothesis in an evolutionary-adaptive context is whether geometry can be used in cases where it must be inferred from fragmentary information, and if so, whether its strength is reduced when this is the case.

It appears that human adults can use geometry that is only suggested by the presence of separated landmarks marking the vertices of a geometric figure (Gouteux and Spelke 2001; Kelly and Bischof 2005), as can rats, as shown by Gibson and colleagues (2007b), although note that they changed the position and orientation of the arrays rather than disorienting the rats. However, nutcrackers do not use geometry defined in this way (Kelly 2005), which is a puzzling finding given that animals able to fly would appear to be particularly advantaged in discerning overall relations among separated aspects of the environment.

Kelly and Bischof (2005) have conducted several studies to examine the relative use of partial versus fully specified geometry. Human participants were presented with a nonimmersive three-dimensional-reorientation computer task. A rectangular room was displayed on the screen with uniquely colored and shaped landmarks in each corner. This environment contains two types of geometric information: fully specified surface information and partial information from a configuration of objects. The walls of the rectangle create a surface geometry. The relation between the landmarks also creates a rectangle and thus could be classified as configuration geometry. The weighting of surface and configuration geometry depended on the initial experience. Participants were trained with either surface geometry or configuration geometry, or both. At test, the surface and configuration geometry were placed in conflict (see figure 6.3). Participants who were presented with only one useful type of geometry weighted that category of geometry more heavily than the other type. For participants trained with both types of geometry, the searches were divided equally between surface and configuration geometry. Thus, the hierarchy of surface and configuration geometry depends on experience for adults, in accord with the adaptive combination view, but it was not clear that there was a preference for fully specified information over the configuration. However, this fact may be specific to use of human adults, of computerized testing, or of the training regime.

Do human children use geometry when overall shape is only partially specified? The answer to this question is not yet clear. Gouteux and Spelke (2001) found that children of three and four years need at least a set of partial extended surfaces, although not necessarily a closed figure, to use geometric information. Lee and Spelke (2008) found, similarly, that closed figures were necessary for four-year-olds to use geometric information, finding additionally that figures formed by flat lines were not used. In a series of investigations involving the use of maps (and so not directly relevant to the disorientation paradigm, although arguably still suggestive), Vasilyeva and Bowers (2006) found that the ability to infer geometric information from partial information improves markedly between the ages

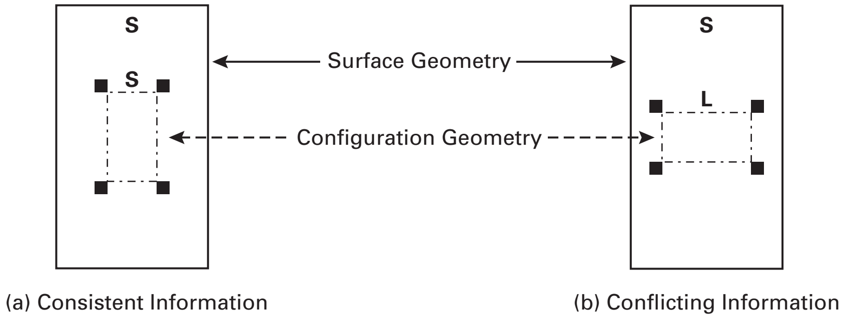


Figure 6.3
Surface and configuration geometry. In the diagram, the large rectangle represents the fully specified surface geometry. The squares represent possible response locations. Imagine a rectangle connecting these points. Here, a second geometric relationship exists and this is called configuration geometry, as indicated by the dashed line. In panel (a), the two types of geometry agree with each other so that the small, S, and long, L, sides of the rectangles match. In panel (b), the relationship is now conflicting. Through this type of trial, the participant's bias for either surface or configuration geometry is revealed. For example, a participant may have been asked to learn that the top left square was correct in panel (a) during training. At test, in panel (b), the participant is asked to make a choice. If the preference is for surface geometry, then the participant will select the top left box. However, if the bias is for configuration geometry, then the participant selects the bottom left box. Original figure and caption, Kelly and Bischof (2005).

of three and six years. Similarly, Gibson et al. (2007a) found that children could not use the geometry of separated points on a computer screen to locate targets until six years of age. On the other hand, Garrad-Cole and colleagues (2001) found that children as young as eighteen to twenty-four months succeeded in using the geometry of four separated objects to define search (as well as in using featural information when available). Further studies using looking paradigms rather than search techniques showed sensitivity to the distances separating discrete objects in children as young as twelve to eighteen months (Lew et al. 2006) and even six to twelve months (Lew et al. 2005).

If one sets aside the studies of mapping or search on computer monitors and the studies using looking techniques, as being not directly relevant to search following disorientation, there is a straightforward contradiction between the studies of Gouteux and Spelke (2001) and Lee and Spelke (2008) on the one hand and that of Garrad-Cole et al. (2001) on the other hand. Cheng and Newcombe (2005) suggested two points of contrast: the use of a reference-memory task (Garrad-Cole et al. 2001) vs. a working-memory task (Gouteux and Spelke 2001), and the fact that experimental procedures with children were conducted by parents in Garrad-Cole et al.'s study. There may well be other differences, including the placement of the boxes with respect to a larger enclosing space (Lew et al. 2006). The whole question deserves a closer look, not only at methodological variables that might account for the discrepancy but also at the extent to which partial geometry is relied on compared to fully specified geometry and to features. The latter issue is key to the theoretical debate, because the adaptive-combination position clearly predicts that use of geometry should be weakened when its encoding would be expected to be more uncertain, and might strengthen as children learn more about the usefulness of such partial information.

Two Recent Arguments for Innate Geometry

So far, most of this chapter has concentrated on the adaptive-combination view of how organisms perform spatial reorientation tasks. Such a view is consistent with what we know about spatial functioning more generally—mobile animals seem to navigate using a wide variety of sources of relevant information. It is also consistent with plasticity approaches to evolution and development, as we discuss in more depth in the next and last section. However, the innate modularity approach to the evolutionary and developmental issues has maintained its popularity, despite critiques and empirical disconfirmations of many of its findings or predictions. In particular, two recent articles have advanced arguments for retaining this approach to spatial development. The first is directly relevant to the geometric module debate; the second is only indirectly relevant but is discussed here because of the considerable attention it received when it appeared.

Can Features Alone Be Used to Reorient?

Lee and colleagues (2006) asked what role landmarks might serve in four-year-olds' reorientation. Specifically, they asked whether landmarks would serve as reorientation cues or as beacons for an object's location. In order to probe this question, they placed three containers in an equilateral-triangle configuration in the center of a circular room. For the majority of their experiments across a series of trials they used two blue boxes (the indistinct containers) and one red cylinder (the distinct container) in which they hid a sticker. Their logic was that if children directly associated landmarks to locations, then they should only succeed when the object was hidden at the distinctive container. Children correctly found the target sticker when it was hidden at the cylinder whereas their searches were at chance when either of the two identical boxes covered the sticker (or stickers). From these search patterns, they concluded that children used the red cylinder only as a direct cue to an object's location. From their findings, they propose that "behavior following reorientation depends on two distinct processes: a modular reorientation process that is sensitive only to geometry and an associative process that directly links landmarks to goal locations" (p. 581).

These bold assertions are not, however, clearly supported by the experiments that Lee and colleagues conducted. Newcombe and colleagues (2007) pointed out that the small, movable landmarks placed on top of the targets used in Lee et al. may not be used because they lack the trustworthiness of large, stable landmarks and that, in addition, the area they defined was quite small. They suggested an alternative way to examine the use of features to reorient when associative processes can be ruled out, using an octagon with alternating short and long sides. If the octagon contains one colored wall, one examines the children's ability to discriminate among boxes located at three all-white corners that are geometrically congruent.

The first step is to examine reorientation in an octagonal space in which all of the walls are white, because no prior research has used such a complex geometry. Newcombe and colleagues (2006) found that two- and three-year-old children used the geometry of the space to guide their searches. Children were reliable in choosing boxes that bore a geometrically equivalent relationship (for example, long wall on the left connected to a short wall on the right) to the box where the target object, a toy duck, was hidden. These results provided the foundation for the critical test; reorienting in the octagon with one feature, a long red wall.

In the octagon with the red wall, Newcombe and colleagues (2007) found that three- and five-year-old children were able to reliably choose the correct corner in the cases in which children searched for the target in the unmarked, all-white corners (the target box did not border the red wall). Their correct searches were significantly greater than the average of the two other geometrically correct corners that bordered white walls. These results demonstrate that children in fact use features to reorient in a relatively large complex environment in a nonassociative fashion.

Geometric Principles among the Munduruku

The Munduruku are an Amazonian group who live in isolated villages and have little access to schools. Their language is reported to have few words for geometric or spatial concepts, they do not possess instruments for spatial measurement, and they do not use or draw maps to any great extent. Thus, if cultural or linguistic transmission were essential to the formation of basic geometric concepts, the Munduruku would be expected to perform poorly when asked about such fundamental concepts as parallelism or congruence. On the other hand, if the human mind comes equipped with the prerequisites for spatial thought, they would be expected to be able to recognize such concepts. Dehaene and colleagues (2006) evaluated geometric thinking among Munduruku children and adults by showing participants panels of six figures (using a solar-powered laptop). Five figures shared a key geometric characteristic that the other one lacked. For instance, there might be five pairs of parallel lines and one pair of nonparallel lines. Crucially, the five sets of parallel lines varied in several ways, such as their orientation and the distance between the paired lines. When asked to point out the "weird" or "ugly" image, the Munduruku reliably chose the geometrically odd figure, such as the nonparallel lines, as predicted by the "core knowledge" position (see figure 6.4a).

The results seem to show strong support for a hard-wired view of human cognitive ability, as was heavily stressed in media coverage of the study by outlets such as the *New York Times* (Bakalar 2006). However, some aspects of the data support plasticity (Newcombe and Uttal 2006). First, Dehaene and his colleagues tested American children and

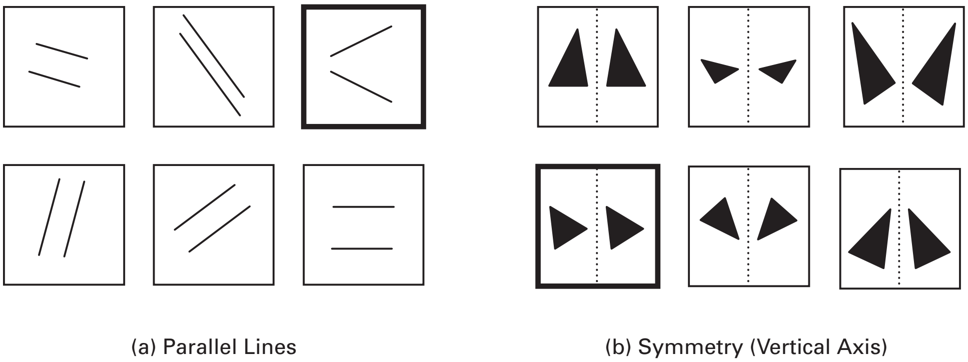


Figure 6.4
Geometric principles among Americans and the Munduruku: perception of incongruent patterns. From among six images, participants select the incongruent tile (indicated here with a heavy border). In panel (a) both Americans and the Munduruku select the pair of lines that do not run parallel. In panel (b), there is a cultural difference for symmetry across a vertical axis. The above-chance performance of the Americans, as indicated by the heavy border, is not matched by the Munduruku. Adapted from Dehaene et al. (2006).

adults as a comparison group for their Amazonian sample, and they repeatedly found that American adults did better than Munduruku of any age, as well as better than American children. This improved performance shows us that culture, language, or education likely helps us build a more robust edifice on the foundation of our core intuitions. Second, the Munduruku performed particularly poorly on items involving geometric transformations (see figure 6.4b); the fact that American adults can cope well with such items is noteworthy because this ability is likely of practical importance to performance in science and technical disciplines. Third, Dehaene and colleagues also note, though they did not test, that it is possible that the geometric intuitions they assessed are acquired progressively during the first six years of life, that is, at ages younger than those they studied. Finer-grained study of geometric intuitions and mapping ability in Munduruku infants and very young children might show a progression of success, as has been found in previous studies of American infants and preschoolers, who often do *not* seem able to cope with some of the concepts with which the older American and Munduruku children showed success.

Plasticity and Modularity in Cognitive Development

Must we choose between plasticity and innate modularity, in an only slightly refreshed version of the nativist-empiricist debate? Perhaps not. Evolution and development have recently come together in the modern study of biology, in the form of evolutionary developmental biology, sometimes called evo-devo. The main ideas of this line of research are said to be innovation, modularity, plasticity, emergence, and inherency (Müller 2005).

This list of traits, and in particular the inclusion of modularity along with plasticity and emergence, points to the potential of this conceptual framework for allowing the formulation of integrated accounts of cognitive development that get beyond old dichotomies. Similarly, Barrett and Kurzban (2006) provide a road map to rapprochement when they write, “Emergentism should not be viewed as an alternative to an evolutionary approach. . . . In particular, the error is the view that proximate and ultimate causation are competitors” (p. 637). In other words, the ultimate causation created by adaptive pressures can be executed proximately in a variety of ways, and in particular, by endowing young organisms with prepared learning propensities rather than explicitly preformed representations (Greenough et al. 1987).

Consider the research area in which the notion of prepared learning was first proposed—the example of taste aversion and specific hungers. Some pairings of stimuli and consequences are far more easily learned than others. For example, specific tastes are more easily paired with nausea than with shock and audiovisual stimuli are more easily paired with shock than with nausea (Garcia and Koelling 1966). Conditioned taste aversion can be established even when there are long delays between the taste and the nausea (Garcia et al. 1966). These discoveries put learning in an evolutionary context without undermining the fact that real learning is occurring. Furthermore, the findings allow for specification of what initial structure really means. When investigators noted that rats deficient in some essential nutrient, such as thiamine, preferred to eat thiamine-rich diets to their usual fare, it was initially natural to postulate a “wisdom of the body” that recognized specifically what was lacking and sought it out. However, Rozin and Kalat (1971) showed that a general aversion to diets that create illness, such as those caused by vitamin deficiency or poisonous substances, leads to a general preference for novel food items in situations where only long-familiar foods are being consumed. There is no specific recognition of what substance is needed. Thus, an evolutionarily important goal (avoiding illness) can be reached by the provision of a general rule (try new foods if you feel bad when eating the usual ones) rather than specific knowledge (look for thiamine).

A similar but more recent example of the role of learning in understanding the evolution of development comes from Dukas’s work on perceptual learning (see chapter 8, this volume). Whether or not it pays for an organism to specialize in recognizing camouflaged food items depends on the variety of foods in the environment: if food is plentiful and much of it is easily identified, then an investment in the perceptual learning required to find such food is ill advised. However, when camouflaged foods are the predominant sources of nutrition, perceptual learning is beneficial. In addition, when several camouflaged food sources are available, which prey a predator learns to recognize is a matter of chance, with the beneficial effect that specializations will vary across predators so that no one food source is as likely to be exhausted. In this case, an evolutionarily important goal (feeding) can be reached by the availability of a capacity for perceptual learning that occurs only in certain environments.

Is modularity required for a prepared-learning approach to cognitive development? The answer depends on one's definition of modularity. The kind of modularity that Müller had in mind when he included it on his list of attributes of an evo-devo approach is quite different from the kind of modularity stressed by Fodor (1983). As originally proposed by Fodor (1983), modularity was a strictly defined concept requiring the demonstration of several attributes, notably encapsulation from other informational sources and associated resistance to change, and was said to characterize sensory input more than central processes. However, the term "modularity" quickly came to refer simply to the idea that there may be neural and functional specialization for processes such as face or place recognition (Epstein and Kanwisher 1998; Kanwisher et al. 1997) and that evolution worked by selection pressure on such specializations (Cosmides and Tooby 1992). Unfortunately, subsequent authors have often been quite unclear about what they have in mind when they use the term. Newcombe and Ratliff (2007) argued that encapsulation is central to a clear definition of modularity and that when researchers simply mean neural specialization, they should say so, rather than using one term to mean many different things. Barrett and Kurzban (2006) disagree, saying that encapsulation as well as various other criteria are unimportant to modularity, and instead suggest that "module" is one way of talking about the simple fact of functional specialization.

In summary, we have argued in this chapter against the idea that evolution can only work to create cognitive advances by affecting selection for innately based and encapsulated modules. It might do so, but it need not. Instead, and more consistent with the existence of a lengthy juvenile period that itself may have overall evolutionary value, our species may have been subject to selection pressures for prepared learning that enables flexible accommodation to the vast array of environmental niches in which we have been able to live successfully. Such preparation would include starting points for learning as well as powerful learning algorithms, and that initial equipment may lead to emerging cognitive and neural specialization.

Note

1. Foster and colleagues (1989) found that completely preventing movement of the rats affected place cell firing. However, place cells do fire in the absence of self-motion when rats are moved passively (Gavrilov et al. 1998), which disrupts proprioceptive cues but leaves vestibular signals as the only reliable cue (Stackman et al. 2003).

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