Book Review

Making sense of the development of spatial cognition

Making Space: The Development of Spatial Representation and Reasoning
by Nora S. Newcombe and Janellen Huttenlocher, MIT Press, 2000. £25.95 / $37.95 (xii + 262 pages) ISBN 0 262 14069 1

Spatial cognition is fundamentally important, both in its own right and because it can provide a window onto many other psychological processes. For example, Tolman's classic work on cognitive mapping in rats challenged traditional notions of the bases of learning[1].

Making Space by Newcombe and Huttenlocher highlights even more clearly the centrality of spatial cognition in experimental and developmental psychology. This is a remarkable book, not only for the contribution that it makes to studies of spatial cognition but also because it offers a new perspective on cognitive development.

The book is comprehensive in its scope, covering not only developmental but also cognitive and neuropsychological approaches to spatial cognition. Indeed, it is worth buying for its encyclopedic reference section alone. Yet the text is always accessible and interesting. Moreover, unlike many modern books in psychology, this book is not simply a review of the authors' research program. Instead, the book brings a new, synthetic perspective to many lines of research.

The concept of flexibility in spatial representation lies at the core of the authors' theory. Many different organisms, ranging from bees to humans, rely on multiple cues to keep track of their location in space. This redundancy had important evolutionary advantages because organisms are not dependent upon only a single cue to location. For example, bees can find their way back to their hives even on cloudy days when solar cues are not available[2], and people can find their way in a city using routes, landmarks, or cognitive maps[3–5].

But such flexibility also comes with a potential cost: organisms must learn to use the right cues in the right context. Using the wrong cues can lead to systematic errors. The challenge of learning when to use and when to ignore different cues to location is the centerpiece of development in Newcombe and Huttenlocher's theory. In the authors' words, 'development consists of changes in the importance attached to different types of spatial information as they come into conflict.' (p. 49). Young infants might possess the ability to code spatial information in multiple and sophisticated ways, but they do not always use the appropriate cues or representations in the appropriate circumstances. As children develop, they learn to weight different kinds of information in increasingly larger spaces.

The authors' perspective helps to integrate the findings of several bodies of research. These include children's performance in Piaget's A/not B task, the cognitive bases of children's recognition of map-features, and the encoding of space in terms of categorical relations. In every case, the authors argue persuasively that what develops is a systematic re-weighting of the environmental features to which children must attend. For example, consider the well-known demonstration that infants tend first to use only egocentric, response-based learning to remember the location of hidden objects[6,7]. After rotation, 9–12-month-old infants fail to return to the correct location; instead they respond with the same behavior (e.g. going to the location on their right) that was correct before rotation. Older infants are more likely to rely on external cues in the environment; these allocentric reference frames allow the child to perform well after movement or rotation. Newcombe and Huttenlocher argue persuasively that this development is not a qualitative change but rather a re-weighting of the relevant cues to location. For an infant just beginning to crawl, response learning works well most of the time. But increasing mobility necessitates the use of another encoding system that will work regardless of the relation of the infant's body to the locations. In combination, the results of prior studies reveal that infants possess the ability to encode space egocentrically or allocentrically, but infants come to favor allocentric cues only when movement makes the egocentric cues less reliable.

More generally, *Making Space* makes an important contribution to meta-theoretical issues in developmental psychology. The authors' perspective goes beyond the dated but still popular nature–nurture controversy[8–10]. Children acquire many of the basic building blocks of spatial representation at an early age, but this is far from the end of the developmental story. Newcombe and Huttenlocher suggest that the most important developmental question is not what infants are born with but when, how, and why they apply these abilities in different contexts. The authors therefore do not emphasize either innate predispositions or the influence of environmental factors. Rather, they consider how the unique constraints of the environment and of what children do in those environments influence the use and weighting of different cues. In the final chapter, the authors demonstrate that their perspective on development applies not only to spatial cognition but also to other important domains, including language, number, and theory of mind.

A hallmark of a good theory is that it highlights gaps in our knowledge. Like the periodic table, theories help us to know where to look for additional information. The contribution of Newcombe and Huttenlocher's thesis is remarkably clear in this regard. A good example is research on the encoding of continuous distance in young children. Their theory predicts that the ability to code distance in continuous space is one of the basic building blocks of spatial thought. However, very little research had addressed the early development of the ability to encode continuous space. The authors therefore undertook a series of studies that supported their hypotheses. Likewise, their theory predicts specific kinds of changes in the ability to encode space categorically, and they have demonstrated that although basic categorization of space

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emerges at an early age, children learn to subdivide space into increasingly finer categories.

In summary, Newcombe and Huttenlocher have presented not only a theory of the development of spatial cognition but also a theory of cognitive development in general. Readers are encouraged to make space for *Making Space* on their shelves and desktops.

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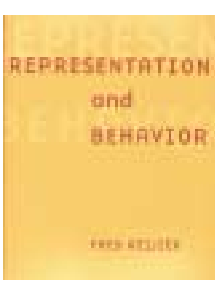
Making space for embodiment

Representation and Behavior
by Fred Keijzer, MIT Press, 2001. £27.50 / $40.00 (xi + 276 pages) ISBN 0 262 11259 0



Fred Keijzer's *Representation and Behavior* makes several important contributions to the recent push toward embodiment in cognitive science. Unfortunately, these contributions are at the end of a book whose early chapters are sufficiently mis-shapen that they will probably deter many readers from getting to the contributions. The problems with these early chapters stem from the fact that Keijzer is a philosopher. (I can say this: I'm a philosopher too.) You see, philosophers typically feel the need to 'make space' for their ideas by arguing that someone else's ideas are wrong. Granted, this sort of thing keeps philosophers in business, but space-making does little to help move science along. And, worse, much of Keijzer's space-making is questionable or misguided. This is especially frustrating because it is so unnecessary: the attractions of Keijzer's non-representational framework for explaining behavior stand on their own.

The purpose of Keijzer's space-making arguments is to establish that representational, computational approaches in cognitive science are inadequate as explanations of behavior. Keijzer begins with an outline of what he calls 'agent theory' (AT), a re-formulation of computational cognitive science so that it is a framework for explaining behavior (rather than cognition, planning, etc.). AT is a straw man: Keijzer admits that it is his invention, and moreover that no one actually believes it. Thus when Keijzer evaluates AT's ability to account for real-time, embodied activity, it is, unsurprisingly, found wanting.

In judging AT (and hence computational cognitive science) by its ability to explain the cases farthest from its central focus, Keijzer has performed what post-modern types call a 'reversal'. Reversals, non-post-modern types realize, are inherently unfair in science, because in science, theories are always works in progress. They start by explaining their central phenomena, and then perhaps later, if all goes well, move out from there to the more difficult cases. Keijzer's reversal is similar to finding fault with embodied, non-representational frameworks for their perceived inability to account for so-called 'higher cognition'. (This does happen[1], but it's still unfair[2].)

Keijzer's attacks on the straw man AT are an unfortunately long – but, fortunately, skippable – prelude to the truly rewarding part of the book: Keijzer's non-representational framework for explaining behavior. In the book's final two chapters, Keijzer outlines what he calls behavioral systems theory (BST), which is a commitment to two theses:

(1) Behavior results from dynamical interactions among a nervous system, a sensory-musculo-skeletal system, and an environment.

(2) Behavior does not result from internal representations.

If these two dicta look a lot like the sort of claims made by dynamical systems theorists, they should[3]. BST is essentially a refinement and extension of the explanatory structure of dynamical systems theory (DST).

Keijzer argues that BST is importantly different from DST, though, and better. The difference is that some dynamical-systems theorists tend to call for internal representations when the going gets tough, in what Clark and Toribio call 'representation-hungry' cases[4]. But BST is explicitly opposed to representations. It is, therefore, crucial that BST be able to account for the tough cases without mental representations.

To make the case that it can deal with the representation-hungry cases, Keijzer suggests that an extension of BST is in principle sufficient to account for 'anticipatory behavior', behavior in service of long-term goals and for which current sensory information is insufficient. Keijzer accounts for anticipatory behavior within BST by drawing a detailed and extraordinarily rich analogy between the generation of behavior and morphogenesis.

Here, very briefly, is how it goes: both morphogenesis and the generation of behavior are the result of interacting dynamical systems at multiple levels. In morphogenesis, there are inter- and intra-level couplings among genes, cytoplasm and larger-scale factors; in the generation of behavior, there are inter- and intra-level couplings among the CNS, body and aspects of the environment. The key addition here is the inclusion of *between*-level couplings, which are typically missing from dynamical explanations in cognitive science. Keijzer suggests that in both morphogenesis and behavior generation, the final product (an organism; an appropriate series of actions) is the result of complex, sometimes unpredictable, interactions between micro- and macro-level dynamical systems.

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