Vasiliev, I., Freundschuh, S.M., Mark, D.M., Theisen, G.D. and McAvoy, J. (1990) What is a map? *The Cartographic Journal*, 27, 119–23.
Zubin, D. (1989) Oral presentation, NCGIA Initiative 2 Specialist Meeting, Santa Barbara, CA. Reported in Mark, D. (ed.), *Languages of Spatial Relations: Researchable Questions and NCGIA Research Agenda*, NCGIA Report 89–2A, NCGIA.

9 Cognitive mapping in childhood

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Introduction

In the span of a few years, children go from being immobile to freely navigating in a host of environments. The developmental changes in mobility are accompanied by changes in children's ability to keep track of locations. Children must learn the layout of their homes, their neighbourhood, their schools, and many other environments. Most children learn all of these environments with apparent ease. However, that police in almost all urban districts devote substantial effort to finding lost children demonstrates the importance of children forming accurate cognitive maps (Cornell *et al.*, 1996).

The focus of this chapter is on the development of children's conceptions and mental representations of environments. Our chapter is organized like the others in this book; we review the past and present of cognitive mapping research and discuss possible directions for future work. However, before beginning our review, we discuss briefly our perspective on two themes that are of central importance in much research on the development of cognitive mapping: scale and representation.

Scale and the development of cognitive mapping

People possess knowledge of spaces of a variety of sizes or shapes, ranging from table-tops through continents. However, much of the research in spatial cognition has focused on relatively small-scale spaces, such as rooms or experimental laboratories (although there are important exceptions that are discussed in this chapter). One obvious reason for the focus on relatively small spaces is that it is very difficult to study children's knowledge of larger spaces. Children are exposed to large-scale spaces in numerous ways, and each child's knowledge of, and exposure to, the environment will vary. It is far easier, and more scientifically controlled, to investigate children's knowledge of small-scale environments that can be systematically controlled and manipulated. However, many researchers have challenged the focus of research on people's knowledge of relatively small-scale spaces. For example, behavioural geographers and environmental psychologists have stressed that the perceptual and cognitive processes that are used in large-scale space may differ fundamentally from those that are used in small-scale space (see Acredolo, 1981; Hart, 1979; Siegel and White, 1975; Montello, 1993; Montello and Golledge, 1999 for a discussion of these issues).

Because our focus is on children, we review work that has been conducted in a variety of different sized spaces. This is appropriate because the scale of space in which children navigate changes dramatically with development (e.g., Acredolo, 1981; Herman and Siegel, 1978; Weatherford, 1985). For example, the sizes of the spaces that toddlers know well are likely to be much smaller than those that elementary school children know well. Hence, most of the work on very young children has been conducted in what geographers would consider to be very small spaces. By the pre-school years, children begin to explore and know the environment beyond their homes, and consequently, the focus of research shifts from the home to the neighbourhood and school.

Representation

The second theme that plays a prominent role in much research on the development of cognitive mapping is *representation.* We use this term in two distinct ways. First, we refer extensively to *mental* representations of space. By this we mean how information about space is coded in the mind. For example, people may encode information in multiple ways – in terms of landmarks, routes, or a map-like survey of the environment. Most theories of the development of cognitive mapping have couched their work in terms of changes in the way in which children mentally represent spatial information.

The second sense of representation is *external*, symbolic representations of space, such as maps and scale models. Much of the information that people know about very large-scale environments would be difficult, if not impossible, to acquire from direct experience navigating in the world. For example, we could not easily learn the locations of several cities in Europe without looking at a map. Acquisition of knowledge of the large-scale environment therefore requires that people understand and use the information that maps can provide. We therefore have included discussion of the development of children's understanding of maps and models.

The past

Research on the development of cognitive mapping began in the early years of the twentieth century, although there were not consistent programmes of research until the late 1960s and early 1970s. Trowbridge (1913) conducted the earliest research on the development of cognitive mapping in childhood. He suggested that there were important similarities between

the spatial strategies of young children and those of adults in 'primitive' (i.e., non-western) cultures for representing the large-scale environment. Both groups tended to represent the environment more in terms of relatively simple routes rather than in terms of integrated, survey-like maps. Although many of Trowbridge's ideas have since been discredited, his seminal work nevertheless was important because it foreshadowed the central theme of much research on the development of cognitive mapping: that changes in how children mentally represent large-scale space may be the mechanism of developmental change.

By the 1940s and 1950s, there were extensive studies of children's knowledge of both small and large-scale environments. Perhaps the most notable were those of Piaget (Piaget and Inhelder, 1956; Piaget *et al.*, 1960). Piaget claimed that there was a developmental progression in children's representation information. For example, the pre-operational child's mental representations of spatial relations were based solely on *topological* relations, which maintain only relations of grouping and order. A pre-operational child did not mentally represent spatial locations in terms of distance or angle.

Piaget also investigated children's knowledge of relatively large-scale spaces, such as the layout of their town. In these studies (Piaget *et al.*, 1960), the children were asked to make miniature models of the layout of their town. Piaget claimed that children's constructions of the layouts of their home area reflected how they mentally represented spatial information. For example, children younger than approximately six or seven tended to conflate Euclidean distance with other measures of similarity or interest. For example, one child placed a store that sold candies and toys much closer to his school than it was in actual Euclidean distance. Until approximately age nine, children's constructions failed to show a systematic integration of the locations into an organized form.

A noteworthy characteristic of Piaget's work was that he did not make a fundamental distinction between children's conceptions and representations of small- and large-scale environments. In both cases, the pre-operational child's representation of space was primarily topological. The child captured in his or her mental representation only the relative ordering of locations; he or she did not think about spatial relations in terms of the metric properties (distance and angle of the space).

Research on the development of cognitive mapping burgeoned in the late 1960s and early 1970s. Converging movements in geography and psychology led to heightened interest in how people, and particularly children, represent the large-scale physical environment (see Appleyard, 1970; Downs and Stea, 1977; Kosslyn *et al.*, 1974; Wohlwill, 1970). The most influential work within this tradition was Siegel and White's (1975) theory of the development of children's mental representations of large-scale environments. They proposed that children of different ages mentally represented locations in the environment in fundamentally different ways. Young children (pre-schoolers) tended to focus more on landmarks. For example, they might represent the location of a building only as 'near the school.' These landmark-based representations did not capture information about the spatial relations among the different landmarks.

By the latter pre-school years, children began to augment their representations to include linkages between landmarks; these linked representations are *route* representations. A route-based representation includes several locations, but it does not include information about the spatial relations among these locations. In essence, route-based representations are *ordinal*; they encode locations in an inmutable order but they do not encode the distance between these locations or the spatial relations among them.

The final stage in Siegel and White's theory of the development of cognitive mapping was *survey knowledge*. Survey knowledge encodes locations from an overhead or oblique view, and includes knowledge of the multiple spatial relations among multiple locations (Levine *et al.*, 1982). Survey knowledge involves abstracting one's thoughts about space from direct space; the knowledge, and its representation, is no longer tied to travel or finding one's way. Survey representations are akin to maps (Tversky, 1996), but this does not mean that the survey representation is a map in the head (Downs, 1981). Under some specific circumstances, survey knowledge allows the child to think abstractly about multiple relations and multiple landmarks, and to behave *as if* he or she had a 'map in the head', albeit with distortions and severe limitations.

Siegel and others tested this theory in many different contexts, including children's classrooms, neighbourhoods, and school grounds (Cousins *et al.*, 1983; Herman and Siegel, 1978; Siegel and Schadler, 1977). In general, their theory provided an adequate description of how children of different ages thought about large-scale space. However, subsequent research has revealed some limitations. For example, researchers have disagreed substantially on what is and is not a landmark (Presson and Montello, 1988; Newcombe, 1988) as well as on exactly what constitutes survey knowledge (Kitchin, 1996). Nevertheless, Siegel and White's work continues to stand out as the most comprehensive and generative theory of how children learn and mentally represent the large-scale environment.

Infancy

Another important development in the 1970s was the emergence of research on the development of cognitive mapping in the first two years of life. Much of the early research on the development of cognitive mapping in infancy focused on how very young children code spatial locations. Young infants tended to code locations in terms of egocentric relations, that is, in terms of their own bodies. Consequently, if an experimenter moved the infant, they would often not be able to keep track of the location of a hidden object. Older infants were more likely to use allocentric codings, which involve external reference frames that are not linked to the infants' own bodies (Acredolo, 1981 Bremner, 1978). Some studies suggested that the onset of allocentric coding was tied to the emergence of mobility. That is, the learning to crawl or creep affects children's representation of the environment. As children become mobile, they can no longer rely exclusively on their own bodies as the basis for coding locations because the relation between their bodies and the locations is constantly changing (see Bai and Bertenthal, 1992; Bremner, 1978; Bremner and Bryant, 1977).

Other studies investigated the emergence of detour behaviour in one- and two-year-olds. A fascinating demonstration in this regard was Rieser *et al.*'s (1982) investigation of the effects of exposure to the overhead view on very young children's ability to navigate a detour in a simple maze. The children (ages nine to twenty-five months) were asked to navigate through the maze to find their mothers. Some of the infants were first raised to chest height to provide an overall, aerial view of the maze and of their mother. The children were then placed on the ground inside the maze. The dependent variable was whether they would go around a barrier to reach their mother, who the infants could not see from the ground-level perspective. Exposure to the overhead view facilitated the 25-month-olds' performance. This study thus demonstrates the importance of thinking about space from an aerial perspective, even for very young children.

The present

Space constraints do not permit us to provide a detailed review of current research in cognitive mapping. In this section, we instead highlight some key findings of ongoing research to indicate what kinds of questions are being addressed. We have selected these issues because of their current influence in the field and their relation to the classic themes of representational change that emerged in the early history of cognitive mapping research.

Infants and toddlers

Reflecting a general interest in infancy in cognitive development work, there is substantial current interest in the development of cognitive mapping in very young children. This work is especially important because it can help to shed light on the developmental origins of the abilities that have typically been studied in older children and adults. For example, Hermer and Spelke (1994, 1996) have conducted a series of studies on the emergence of the use of landmarks by very young children. The basic question that motivated this work was whether very young children (ages eighteen to twenty-four months) and adults would attend to the presence of a landmark that was placed in one corner of a rectangular-shaped room. There was a panel in each corner of the room, behind which a toy could be hidden.

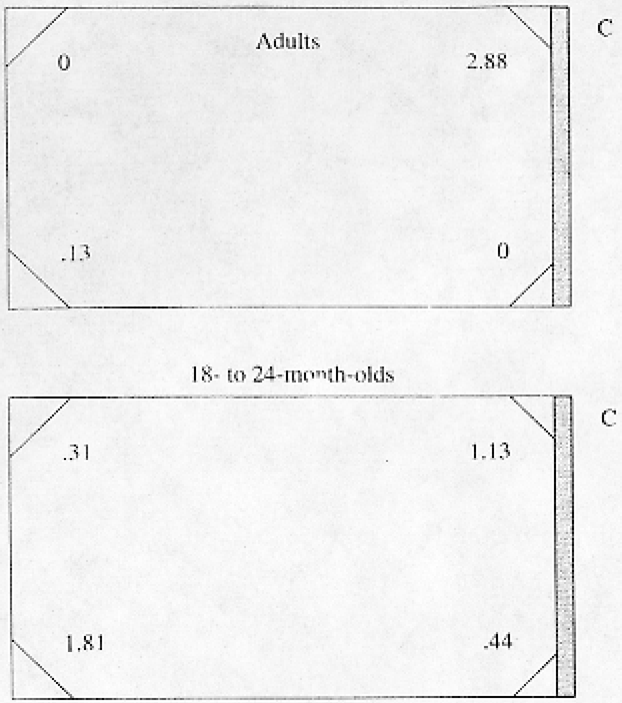

Figure 9.1 The design and results of Hermer and Spelke's (1996) studies. The numbers represent the average number of trials (out of four) on which subjects searched in each corner. The letter C represents the correct corner.

In the control conditions, all walls of the room were identical (other than their length). In the experimental conditions, one of the walls was covered entirely with blue fabric, as shown in Figure 9.1.

There were two important aspects of this design. First, because the room was rectangular, there were two sets of geometrically identical corners. That is, a short wall and a long wall connected in the same way in two sets of corners. Second, at least ostensibly, the presence of the blue curtain would seem to differentiate the two sets of corners. For example, although there were two corners in which a person could stand with a long wall in front and a short wall to the right, only one of the two corners would have had the blue curtain nearby. The critical question was whether children and adults would use the blue wall as a cue to differentiate the two sets of geometrically identical corners.

On each trial, participants in Hermer and Spelke's research observed as the toy was hidden in one of the four corners. Then, to disorient them, the

participants were then asked to cover their eyes and turn around several times. The participant was then asked to uncover his or her eyes and to find the toy.

As shown in Figure 9.1, the young children did not use the landmark to differentiate the corners. They searched at the correct corner and at the geometrically equivalent corner almost equally, even though the blue curtain was placed near the correct corner. In contrast, adults were nearly perfect when the blue curtain was available, although they often searched at the geometrically identical corners when the blue curtain was not available. Follow-up studies showed that children could remember, point out, and describe the blue wall; nevertheless, they continued to fail to use it as a landmark to search for the toy.

Why would young children fail to use what would seem to be such an obvious landmark, especially when doing so would lead to near-perfect performance? Hermer and Spelke suggested a fascinating answer to this question: After they are disoriented by being turned several times, young children fall back to an evolutionary primitive strategy of relying on the shape of the environment. Previous work (e.g., Cheng, 1986; Gallistel, 1990) had shown that rats rely exclusively on the shape of the environment to find their way after disorientation. Hermer and Spelke suggested that the young children shared this evolutionary primitive cognitive 'module' (Fodor, 1983) that encodes *only* the shape of the environment. This cognitive module does not include any other information, such as the location or relevance of landmarks. In most situations, this strategy will work well; the shape of the environment is usually a reliable and stable cue that organisms can rely on when they are disoriented. However, in a perfectly rectangular space, children (and rats) cannot distinguish two of the four corners, and hence their searches are split equally between the correct corner and the geometrically identical corner. Development may therefore consist of learning when (and how) to ignore evolutionary primitive strategies in favour of using the cues that are best suited to the particular environment (Hermer and Spelke, 1996).

Other researchers are investigating the development of representation of distance information in infancy. For example, Bushnell *et al.* (1995) found that twelve-month-olds could find an object that was hidden under one of more than fifty irregularly shaped cushions in a large, circular, hiding space. Curtains were placed around the border of the search space and, consequently, there were no salient landmarks that the children could use as cues to the location of the object. The children were very good at finding the toy. These and similar results (e.g., Newcombe *et al.*, in press) have been difficult to explain without claiming that the children have accurately encoded (metric) distance information that specifies the location in terms of a specific distance (Bremner, 1993).

Maps and cognitive mapping

Until about fifteen years ago, almost all research on spatial cognition and cognitive mapping had focused on children's *mental* representations of spatial relations. However, in the past decade, researchers have devoted substantial attention to children's understanding of maps, scale models, and other external representations of space. For example, DeLoache and colleagues (DeLoache, in press, 1987, 1989, 1991, 1995; DeLoache and Burns, 1994; Marzolf and DeLoache, 1994; Uttal *et al.*, 1995) have focused on the emergence of the ability to use external representations (photographs, scale models, and simple maps) to find a hidden toy. In the basic version of this task, the child watches as the toy is hidden in the scale model (or as the location is indicated on a photograph). He or she is then asked to find the hidden toy in the corresponding location in the larger room.

In general, these studies have demonstrated that there is a dramatic improvement in children's ability to understand the relation between these external symbolic representations and the spaces that they represent. For example, in the standard scale model task (DeLoache, 1987), two-and-a-half-year-olds fail; their performance is at near-chance levels. In contrast, three-year-olds perform far better. These results have been interpreted (DeLoache, 1995; DeLoache and Smith, 1999) as indicating that the ability to understand external symbolic representations emerges sometime around the end of the third year. However, this does not mean that children of this age have a full understanding of the representational functions of maps. Studies that have investigated children's use of more complicated external representations indicate that the development of an understanding of maps and map-like representations continues well into the pre-school year. For example, when children look at 'real' maps, they often make errors that seem to reveal they do not fully grasp that the map is a *representation* of a geographic area. For example, one kindergartener said that a red line on a map (which indicated a road) could *not* represent a road because there are no red roads in the world (Liben, 1999). Additional experimental work supports some of these claims. For example, Liben and Yekel (1996) found that not until the latter elementary school years could children use the unique spatial position of an object on a map to disambiguate the locations of objects within their classroom (see also Blades and Cooke, 1994; Blades and Spencer, 1994; Liben and Downs, 1993). These results thus suggest that learning to use the *spatial* information that maps can provide may be a particularly difficult hurdle for young children. The question of how much young children know about the relations between maps and the spaces that maps represent continues to be a topic of substantial controversy (see Blaut, 1997; Downs and Liben, 1997; Liben, 1999; MacEachren, 1995).

Another line of research is investigating factors that may help children cope with the extra demands of using the spatial information available on

maps. Since the time of the Gestaltists, psychologists have stressed that the interpretation of spatial stimuli is not merely a process of keeping track of individual locations. Instead, people often interpret individual locations as part of an organized or meaningful structure. A classic example is the constellations; ancient navigators organized and described the locations of sets of stars into meaningful patterns. This higher level of organization facilitates memory for and communication of locations. For example, it is easier to remember the location of a star if we can recall that it is in the handle of the Big Dipper.

Maps and map-like representations such as astronomical charts may play an important role in facilitating the construal of locations in terms of an organized or meaningful pattern. Because (most) maps represent spatial information from a plain or oblique perspective and at a relatively small scale, they can afford a fundamentally different way of perceiving and thinking about spatial information than can be gained from direct experience in the world. For example, it is easier to conceive of a set of stars as forming a constellation if we first see the locations on a chart.

In several recent studies, we (Uttal *et al.*, 1999) have investigated the development of the ability to use this function of maps. We have asked whether, and how, four- and five-year-old children can use maps to help them think about spatial information in ways that extend beyond the characteristics of individual locations. In this research, the children were asked to use a simple map to search for a sticker hidden under one of twenty-seven paper coasters that were distributed across the floor in the pattern shown in Figure 9.2. The overall configuration of objects formed the outline of a dog. Half of the children, the *lines* group, were informed that the locations could be interpreted as forming the outline of a dog; these children used the lines map shown in Figure 9.3. The remaining children, the *no lines* group, used the no lines map. There were no lines in the actual space

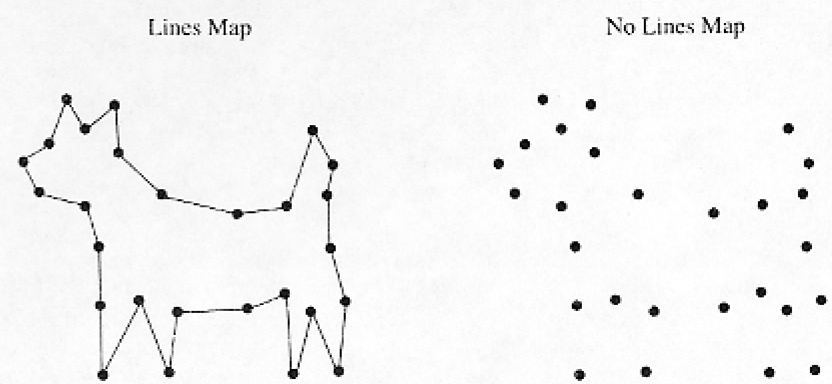

Figure 9.2 The 'dog' figure used by Uttal *et al.* (1999).

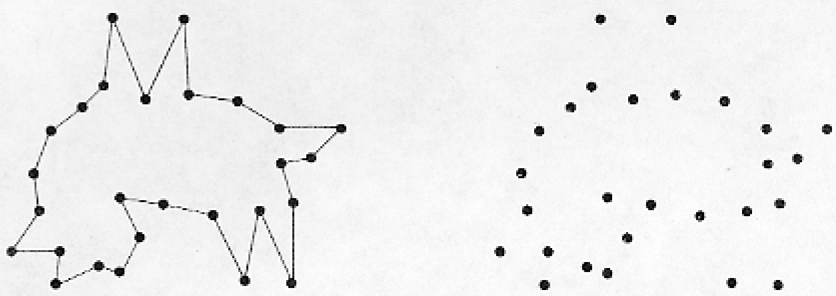

Figure 9.3 The alternate, meaningless figure used by Uttal *et al.* (1999).

in which the children searched. Thus the only difference between the two groups was the presence or absence of lines on the maps.

As predicted, the lines group performed substantially better than the no lines group. Analysis of children's errors revealed that knowledge of the dog pattern helped the children on difficult trials that required them to discriminate one search location from many others.

A follow-up study indicated that these effects could not be attributed simply to the addition of lines. We scrambled the dog to form the pattern shown in Figure 9.3. This alternate figure contained individual parts that were similar; however, the alternate figure lacked the systematic, overall organization of the dog figure. As in the original studies, half of the children saw a map on which the individual locations were connected with lines. In this case, adding lines to the figure made no difference in children's performance. These results suggest that it is the unique configuration of the locations – to form a meaningful pattern – which was responsible for the advantage that was observed in the first set of studies. Interestingly, however, we (Tan and Uttal, in preparation) have recently shown that children can perform well using the 'scrambled dog' pattern *if* they are first given prior experience in using the dog pattern. The children transferred what they learned about the dog pattern to the new pattern, which other children did not recognize as a meaningful shape. This result supports the claim that construing locations in terms of organized or meaningful patterns can be an important influence on the development of spatial cognition and map use.

Categorical representations of spatial locations

Another area of current interest concerns the development of *categorical* representations of space. When adults talk and think about the locations of

objects in large-scale space, we often do so in terms of distinct categories (Allen, 1981; Huttenlocher *et al.*, 1994; McNamara, 1986; Sandberg *et al.*, 1996; Stevens and Coupe, 1978). We might say, for example, that Edinburgh is in Scotland or that Los Angeles is in California. These distinctions reflect a tendency of adults to break the world up into smaller units. We do this at many levels; we may think about particular locations within a neighbourhood, within a county, within a state, etc. Categorical representations are important because they allow us to know something about the location of a particular place without knowing the precise location. For example, if a person knows that a particular city is in California, then he or she knows some general information about the location of city, regardless of whether he or she knows the precise location. Of course, categorical representations can lead to systematic errors (McNamara, 1986; Stevens and Coupe, 1978), but they nevertheless provide important information in the absence of completely accurate information.

Several programmes of research are investigating the development of the ability to subdivide space into categories. For example, Huttenlocher *et al.* (1994) have investigated the emergence of the ability to subdivide a small-scale space into distinct regions or categories. Across several studies, Huttenlocher *et al.* tested very young children (ages sixteen to twenty-four months), pre-schoolers (ages four to five), first graders (age six to seven) and fifth graders (ages ten to eleven). The child's task was to search for a toy that was hidden in a five feet long, narrow sand box. The experimenter asked the child to turn around while an assistant hid a small toy in the sand. The child was then turned back to face the sand box and was allowed to search in the sand for the toy. A video recording was used to determine where the child searched in the sand.

The results revealed developmental differences in how younger and older children subdivided the sand box to remember the location of the toy. The youngest children (ages eighteen to twenty-four months) formed fewer spatial categories than did the older children and adults. This result was revealed in the pattern of children's errors. Specifically, the 18- to 24-month-olds' responses were biased toward the middle of the sand box. In other words, when the toy was hidden to the left of the centre of the sand box, these children tended to search somewhat to the right of the correct location. Likewise, when the toy was hidden to the right of the centre of the sand box, children's errors usually involved searching to the left. In contrast, the older children and adults demonstrated different patterns of bias. Their errors were biased towards the centre of the two *halves* of the sand box, suggesting that they had categorized the sand box as having two separate sections.

These results highlight the possibility of developmental change in the formation and use of spatial categories. An important aspect of development may involve learning to subdivide spaces into categories and to use those categories to facilitate memory (Huttenlocher *et al.*, 1994) communication (Plumert *et al.*, 1995), and map use (Acredolo and Boulter, 1984).

Studies of real world environments

Researchers are continuing to study the development of children's conceptions and mental representations of large-scale environments. One area of central interest concerns the development of flexible use of spatial information. Before approximately age twelve, children appear to have difficulty in choosing landmarks that will provide consistent and reliable cues to aid navigation. For example, twelve-year-olds are more likely to use distal and stable landmarks, such as tall buildings, as landmarks when learning the layout of a university campus (Cornell *et al.*, 1989; Cornell *et al.*, 1992; Heth *et al.*, 1997). Thus, even though young children can navigate successfully, children continue to fine tune their skills throughout the elementary school years (Allen and Kirasic, 1988; Pick and Lockman, 1981).

The work of Cornell, Heth and colleagues provides a good example of current approaches to the development of cognitive mapping in real world environments. Cornell *et al.* (1994) investigated how six-, and twelve-year-olds differed in their response to suggestions to use strategies to facilitate recall of landmarks while learning a new environment, the layout of a university campus. The experimenter led children on a route across the campus and then asked them to lead the way back. Different groups of children were given different instructions before they began the tour of the campus. Specifically, there were four conditions. In the *uninformed* condition, the children were not told that they would need to lead the way back. In the *generally informed* condition, the children were told only that they would be asked to lead the experimenter back to the starting point and that they should generally pay careful attention. Children in the third and fourth conditions were given more specific instructions that included information about the use of landmarks. In the *near landmark* condition, the experimenter stopped the children near two landmarks along the path and told them that the landmark might be useful for remembering the way back. For example, the experimenter pointed to a telephone booth and said, 'See this telephone booth? This telephone booth might be a good thing to remember for the way back' (p. 757). In the *far landmark* condition, the experimenter pointed to landmarks on the horizon rather than to landmarks on the path. The experimenter pointed to the tallest building on the skyline and said, 'See the tallest brick building? That's where we just came from.' The experimenter then turned and pointed to another building at the opposite end of the skyline and said, 'See that smokestack? That's where we are going?' (p. 757).

Children in all four conditions took a walk with an experimenter across the campus, following a standard route. At the end of the walk, the experimenter told the child that he or she would be the 'leader' for the return trip. The experimenters then assessed how far children travelled during the return trip, and how much of the total distance was spent on and off the original path. In general, the six-year-olds performed poorly, and they

responded only to instructions to use the near landmarks. In contrast, the twelve-year-olds were able to use the distal landmarks to find their way back to the path when they deviated from it.

These results highlight the importance of learning to use the appropriate landmarks to keep track of one's location. Young children may be able to navigate successfully in environments with which they are familiar, but they have trouble keeping track of their location when they deviate from a known path. The results also have important practical locations for assessing and predicting the behaviour of lost children (Cornell *et al.*, 1996).

The future

In this final section, we consider what we believe to be the key issues that will receive attention in the coming decades. Some of these predictions reflect ongoing trends in research, and others reflect the likely influences of emerging technologies both on how children learn about environments and on the ability of researchers to study this development.

Relations between the cognition of small- and large-scale space

We believe that there are important similarities between the perceptual and cognitive processes that have been investigated in small-scale, laboratory tasks and those that exist in large-scale space. We foresee increasing collaboration between researchers who have studied small- and large-scale space. Accordingly, we expect to see an increasing number of studies that focus specifically on the relation between what is known about the development of cognition of small-scale space and the processes that develop in the cognition of large-scale space.

One example topic that could be investigated concerns the development of categorical representations of large-scale space. As discussed above, researchers (e.g., Huttenlocher *et al.*, 1994; Plumert *et al.*, 1995) have documented important developmental change in how children form spatial categories and use these categories to remember or communicate the location of objects. Almost all of these studies have been conducted in small-scale space, but we believe that the results may have important implications for research on the development of conceptions of large-scale environments. People often think about large-scale environments in terms of both formal (e.g., counties, states, countries, etc.) and informal (e.g., neighbourhoods, shopping districts, etc.) (Lynch, 1960). We know very little about the emergence of children's conceptions of these geographical scale spatial categories (although see Spencer *et al.*, 1989). A fruitful area of research would involve linking the emergence of children's categorical representations of small-scale space with their understanding of categorical representation in large-scale environment.

Emerging technologies and research on the development of cognitive mapping

We believe strongly that emerging technologies will play an increasingly important role in research on the development of cognitive mapping. We forecast a substantial increase in the use of two technologies that have recently become practical and inexpensive, virtual reality and electronic tracking systems. Each has substantial potential to contribute to research on the development of children's experience of large-scale environments.

Virtual reality technologies have received considerable attention in research on adult spatial cognition (e.g., Loomis *et al.*, in press), but there has been relatively little virtual reality research with children. We expect this to change quickly. Virtual reality will allow researchers to expose children to many of the features of a realistic, large-scale environment while simultaneously maintaining experimental control. Researchers then can ask, and answer, many of the questions that have remained difficult to address in real world environments. For example, in a virtual environment, it should be possible to control precisely when and how children are exposed to different kinds of landmarks. This would allow the researcher to examine when, and how, children begin to integrate knowledge of these landmarks into survey-like representations.

Electronic tracking systems have been available for many years, but recent advances in global positioning systems (GPS) and related technologies has made them affordable. It is now relatively easy to keep track of a person's location at any moment. This technology could allow researchers to investigate how children travel in familiar environments and how they explore unfamiliar environments. This new data, in combination with appropriate sampling procedures (see Csikszentmihalyi, 1992) could be very useful in answering basic questions that thus far have received surprising little attention. For example, we know very little about how children's home ranges change with development, and whether there are sex differences in how boys and girls explore new environments (see Hart, 1979).

In sum, virtual environments and tracking technologies can facilitate research on the development of cognitive mapping in two related ways. First, it can allow us to know more about how children actually experience real environments, and second, it can allow us to simulate and control children's experience of environments. In combination, these two technologies will provide important insights into questions that previously were intractable.

What causes development?

Although research on cognitive mapping and spatial cognition has increased substantially in the past ten years, almost all research has focused on the *description* of developmental change. Very little work has attempted to explain

how or why these changes occur. The focus on description of change rather than on explanation reflects the general focus of cognitive development work (see Siegler, 1996). However, in recent years, developmental scientists have begun to address in earnest the process and mechanisms of change. For example, developmental psychologists have studied the specific mechanisms of change in many domains, ranging from early motor development (Thelen and Smith, 1994) to the acquisition of strategies for solving mathematics problems (Siegler, 1996).

We predict that there will be an increase in research on the mechanisms of change in the development of cognitive mapping. A good example of the kind of work that we foresee concerns the influence of the onset of mobility on infants' representations of space (Bremner and Bryant, 1977; Bai and Bertenthal, 1992). This work illustrated that becoming mobile contributed to developmental change in children's ability to represent locations in space. We believe that there will be more studies of this type, involving intensive, short-term longitudinal (i.e., microgenetic) investigation of the process of change. One example concerns the acquisition of survey knowledge of large-scale environments. By testing children several times as they learn the layout of a new environment, researchers could gain insight into the process by which routes or landmarks are integrated into a more cohesive, integrated representation (see Uttal, 1999).

Conclusions

Although research on the development of cognitive mapping has grown and changed substantially in its eighty-year history, some core themes have remained constant throughout. For example, much of the research has focused, and will continue to focus, on how children's mental representations of the environment change with age. Although descriptions of both the form and content of these representations varies substantially from theory to theory, almost all researchers view the development of cognitive mapping as an interaction between the child's developing mental representations and the environments to which they are exposed.

Perhaps the most important question that researchers will face in the future concerns the nature of the environments that children will be asked to learn. It is important to note that the environments to which children are exposed will change dramatically in the future. So-called virtual environments will become as much a part of the child's everyday experience as the typical real world environments in which they navigate. Navigating on the World Wide Web or in other computer-mediated environments may become as important of an environmental experience as navigating in the home environment. Research will need to keep pace with changes in children's environments as they study how children's conceptions of these environments change.

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References

Acredolo, L.P. (1981) Small- and large-scale spatial concepts in infancy and childhood. In Liben, L.S., Patterson, A.H. and Newcombe, N. (eds), *Spatial Representation and Behavior across the Lifespan*. New York: Academic, pp. 63–82.

—— and Boulter, L.T. (1984) Effects of hierarchical organization on children's judgement of distance and direction. *Journal of Experimental Child Psychology*, 37, 409–25.

Allen, G.L. (1981) A developmental perspective on the effects of 'subdividing' macrospatial experience. *Journal of Experimental Psychology: Human Learning and Memory*, 7, 120–32.

—— and Kirasic, K.C. (1988) Young children's spontaneous use of spatial frames of reference in a learning task. *British Journal of Developmental Psychology*, 6, 125–35.

Appleyard, D. (1970) Styles and methods of structuring a city. *Environment and Behavior*, 2, 100–17.

Bai, D.L. and Bertenthal, B.I. (1992) Locomotor status and the development of spatial search skills. *Child Development*, 63, 215–26.

Blades, M. and Cooke, Z. (1994) Young children's ability to understand a model as a spatial representation. *Journal of Genetic Psychology*, 155, 201–18.

—— and Spencer, C. (1994) The development of children's ability to use spatial representations. In Reese, H.W. (ed.), *Advances in Child Development and Behavior*, 25, San Diego, CA: Academic, pp. 157–99.

Blaut, J.M. (1997) Piagetian pessimism and the mapping abilities of young children: A rejoinder to Liben and Downs. *Annals of the Association of American Geographers*, 87, 168–77.

Bremner, J.G. (1978) Egocentric versus allocentric spatial coding in 9-month-old infants: Factors influencing the choice of code. *Developmental Psychology*, 14, 346–55.

—— (1993) Spatial representation in infancy and early childhood. In Pratt, C. and Garton, A.F. (eds), *Systems of Representation in Children: Development and Use*. Chichester: Wiley, pp. 211–34.

—— and Bryant, P.E. (1977) Place versus response as the basis of spatial errors made by young infants. *Journal of Experimental Child Psychology*, 23, 162–71.

Bushnell, E.W., McKenzie, B. E., Lawrence, D.A. and Connell, S. (1995) The spatial coding strategies of one-year-old infants in a locomotor search task. *Child Development*, 66, 937–58.

Cheng, K. (1986) A purely geometric module in the rat's spatial representation. *Cognition*, 23, 149–78.

Cornell, E.H, Heth, C.D. and Broda, L.S. (1989) Children's wayfinding: Response to instructions to use environmental landmarks. *Developmental Psychology*, 25, 755–64.

—— , —— , Alberts, D.M. Place recognition and wayfinding by children and adults, *Memory and Cognition*, 22, pp. 633–43.

—— , —— Kneubuhler, Y. and Sehgal, S. (1996) Serial position effects in children's route reversal errors: Implications for police search operations. *Applied Cognitive Psychology*, 10, 301–26.

—— , —— and Rowat, W.L. (1992) Wayfinding by children and adults: Response to instructions to use look-back and retrace strategies. *Developmental Psychology*, 28, 328–36.

Csikszentmihalyi, M. (1992) Validity and reliability of the Experience Sampling Method. In deVries, M. (ed.), *Investigating Mental Disorders in their Natural Settings*. Cambridge: Cambridge University Press, pp. 43–57.

Cousins, J.H., Siegel, A.W. and Maxwell, S.E. (1983) Wayfinding and cognitive mapping in large-scale environments: A test of a developmental model. *Journal of Experimental Child Psychology*, 35, 1–20.

DeLoache, J.S. (1987) Rapid change in the symbolic functioning of very young children. *Science*, 238, 1556–7.

—— (1989) Young children's understanding of the correspondence between a scale model and a larger space. *Cognitive Development*, 4, 121–39.

—— (1991) Symbolic functioning in very young children: Understanding of pictures and models. *Child Development*, 62, 736–52.

—— (1995) Early symbolic understanding and use. In Medin, D. (ed.), *The Psychology of Learning and Motivation*, 33. New York: Academic, pp. 65–114.

—— (in press). Dual representation and young children's use of scale models. *Child Development*.

—— and Burns, N.M. (1994) Early understanding of the representational function of pictures. *Cognition*, 52, 83–110.

—— and Smith, C.M. (1999) Early symbolic representation. In Sigel, I.E. (ed.), *Development of Mental Representation: Theories and Applications*. Mahwah, NJ: Erlbaum, pp. 61–86.

Downs, R.M. (1981) Maps and mappings as metaphors for spatial representations. In Liben, L.S., Patterson, A.H. and Newcombe, N. (eds), *Spatial Representation and Behavior across the Lifespan*. New York: Academic, pp. 143–66.

—— and Liben, L.S. (1997) The final summation: The defense rests. *Annals of the Association of American Geographers*, 87, 178–80.

—— and Stea, D. (1977) *Maps in Mind: Reflections on Cognitive Mapping*. New York: Harper and Row.

Fodor, J. (1983) *Modularity of Mind: An Essay on Faculty Psychology*. Cambridge, MA: MIT.

Gallistel, C.R. (1990) *The Organization of Learning*. Cambridge, MA: MIT.

Hart, R. (1979) *Children's Experience of Place*. New York: Irvington.

Herman, J.F. and Siegel, A.W. (1978) The development of cognitive mapping of the large-scale environment. *Journal of Experimental Child Psychology*, 26, 389–406.

Hermer, L. and Spelke, E. (1994) A geometric process for spatial reorientation in young children. *Nature*, 370, 57–9.

—— and —— (1996) Modularity and development: The case of spatial reorientation. *Cognition*, 61, 195–232.

Heth, C.D., Cornell, E.H. and Alberts, D.M. (1997) Differential use of landmarks by 8- and 12-year-old children during route reversal navigation. *Journal of Environmental Psychology*, 17, 199–213.

Huttenlocher, J., Newcombe, N. and Sandberg, E. (1994) The coding of spatial location in young children. *Cognitive Psychology*, 27, 115–48.

Kitchin, R.M. (1996) Methodological convergence in cognitive mapping research: Investigating configurational knowledge. *Journal of Environmental Psychology*, 16, 163–85.

Kosslyn, S.M., Pick, H.L. and Fariello, G.R. (1974) Cognitive maps in children and men. *Child Development*, 45, 707–16.

Levine, M., Jankovic, I.N. and Palij, M. (1982) Principle of spatial problem solving. *Journal of Experimental Psychology*, 111, 157–75.

Liben, L.S. (1999) Developing an understanding of external spatial representations. In Sigel, I.E. (ed.), *Development of Mental Representation: Theories and Applications*. Mahwah, NJ: Erlbaum, pp. 297–321.

—— and Downs, R.M. (1993) Understanding person-space-map relations: Cartographic and developmental perspectives. *Developmental Psychology*, 28, 739–52.

—— and Yekel, C.A. (1996) Preschoolers' understanding of plain and oblique maps: The role of geometric and representational correspondence. *Child Development*, 67, 2780–96.

Loomis, J.M., Blascovich, J.J. and Beall, A.C. (in press) Immersive virtual environments as a basic research tool in psychology. *Behavior Research Methods, Instruments, and Computers*.

Lynch, K. (1960) *The Image of the City*. Cambridge, MA: Technology.

MacEachren, A.M. (1995) *How Maps Work: Representation, Visualization and Design*. New York: Guilford Press.

McNamara, T.P. (1986) Mental representations of spatial relations. *Cognitive Psychology*, 18, 87–121.

Marzolf, D.P. and DeLoache, J.S. (1994) Transfer in young children's understanding of spatial representations. *Child Development*, 65, 1–15.

Montello, D.R. (1993) Scale and multiple psychologies of space. In Frank, A.U. and Campari, I. (eds), *Spatial Information Theory: A Theoretical Basis for GIS*. Berlin: Springer-Verlag, Lecture Notes in Computer Science 716, pp. 312–21.

—— and Golledge, R.G. (1999) Scale and detail in the cognition of geographic information. Report of Specialist Meeting of Project Varenius held 14–16 May 1998, in Santa Barbara, CA, University of California at Santa Barbara, http://www.ncgia.org.

Newcombe, N. (1988) The paradox of proximity in early spatial representation. *British Journal of Developmental Psychology*, 6, 376–8.

—— Huttenlocher, J., Learmonth, A. and Wiley, J. (in press) Spatial memory in 5-month-old infants. *Developmental Psychology*.

Piaget, J. and Inhelder, B. (1956) *The Child's Conception of Space*. New York: Norton.

—— , —— and Szeminska, A. (1960) *The Child's Conception of Geometry*. New York: Norton.

Pick, H.L. and Lockman, J.J. (1981) From frames of reference to spatial representations. In Liben, L.S., Patterson, A.H. and Newcombe, N. (eds), *Spatial Representation and Behavior across the Lifespan*. New York: Academic, pp. 39–62.

Plumert, J.M., Ewert, K. and Spear, S. (1995) The early development of children's communication about nested spatial relations. *Child Development*, 66, 959–69.

Presson, C.C. and Montello, D.R. (1988) Points of reference in spatial cognition: Stalking the elusive landmark. *British Journal of Developmental Psychology*, 6, 378–81.

Rieser, J.J., Doxsey, P.A., McCarrell, N.S. and Brooks, P.H. (1982) Wayfinding and toddlers' use of information from an aerial view of a maze. *Developmental Psychology*, 18, 714–20.

Sandberg, E.H., Huttenlocher, J. and Newcombe, N. (1996) The development of hierarchical representation of two-dimensional space. *Child Development*, 67, 721–39.

Siegel, A.W. and Schadler, M. (1977) Young children's cognitive maps of their classroom. *Child Development*, 48, 388–94.

—— and White, S.H. (1975) The development of spatial representations of large-scale environments. In Reese, H. (ed.), *Advances in Child Development and Behavior*, 10, New York: Academic, pp. 9–55.

Siegler, R.S. (1996) *Emerging Minds: The Process of Change in Children's Thinking*. New York: Oxford University Press.

Spencer, C., Blades, M. and Morsley, K. (1989) *The Child in the Physical Environment: The Development of Spatial Knowledge and Cognition*. Chichester: Wiley.

Stevens, A. and Coupe, P. (1978) Distortions in judged spatial relations. *Cognitive Psychology*, 10, 422–37.

Tan, L.S. and Uttal, D.H. (in preparation). From dog to hedgehog: Transfer in children's use of a meaningful patterns for maps.

Thelen, E. and Smith, L.B. (1994) *A Dynamic Systems Approach to the Development of Cognition and Action*. Cambridge, MA: MIT/Bradford Books.

Trowbridge, C.C. (1913) Fundamental methods of orientation and imaginary maps. *Science*, 38, 888–97.

Tversky, B. (1996) Spatial perspective in descriptions. In Bloom, P., Peterson, M.A., Nadel, L. and Garrett, M.F. (eds), *Language and Space: Language, Speech and Communication*, Cambridge, MA: MIT/Bradford Books, pp. 463–91.

Uttal, D.H. (1999) Seeing the big picture. Map use and the development of spatial cognition. Unpublished manuscript.

—— Gregg, V., Tan, L.S., Chamberlin, M. and Sines, A. (1999) Connecting the dots: Children's use of a meaningful pattern to facilitate mapping and search. Unpublished Manuscript.

—— Schreiber, J.C. and DeLoache, J.S. (1995) Waiting to use a symbol: The effects of delay on children's use of models. *Child Development*, 66, 1875–89.

Weatherford, D.L. (1985) Representing and manipulating spatial information from different environments: Models to neighborhoods. In Cohen, R. (ed.), *The Development of Spatial Cognition*. Hillsdale, NJ: Erlbaum, pp. 41–70.

Wohlwill, J.F. (1970) The emerging discipline of environmental psychology. *American Psychologist*, 25, 303–12.