Research Article

SPATIAL SCALING IN YOUNG CHILDREN

Janellen Huttenlocher,[1] Nora Newcombe,[2] and Marina Vasilyeva[1]

[1]*University of Chicago and* [2]*Temple University*

Abstract—*This article examines the emergence of the ability to use a simple map to acquire information about distance in a larger space. It is commonly believed that scaling is a late achievement in childhood. The present study examined the origins of this ability by using the simplest of situations. In two experiments, we presented preschool children with a dot in a long thin rectangle, and asked them to use that representation to find an object in a corresponding location in a much larger sandbox. All 4-year-olds and a majority of 3-year-olds performed well on this task. We present a model that posits a simpler mechanism for scaling than that proposed in the existing literature.*

This article concerns the emergence of the ability to use maps in childhood. To be able to use a map, children must understand two kinds of correspondence between the map and the world: element-to-element correspondence and spatial-relational correspondence (Bluestein & Acredolo, 1979; Liben & Downs, 1989; Liben & Yekel, 1996; Presson, 1982). To understand correspondence of spatial relations requires scaling ability. Scaling, in turn, involves both an ability to code distance and an ability to understand how distance on a map corresponds to distance in the larger world. Scaling has been thought to be a late accomplishment, but in this article we show that the earliest emergence of the ability can be seen at 3 years of age. We propose that the mechanism required for scaling may be simpler than that posited in the existing literature.

The ability to recognize element-to-element correspondence, that is, to know that an item on a map stands for an object in the real world, is clearly the most basic component in map use. Earlier studies have shown that, initially, children have difficulty establishing element-to-element correspondences using models (three-dimensional representations), but that this competence is established over the age range of roughly 30 to 42 months as children acquire representational insight (DeLoache, 1990). Element-to-element correspondences using pictures (two-dimensional representations) appear at a similar age (DeLoache, 1990, 1994), even when the relation of elements in a two-dimensional representation to real objects is conventional rather than iconic (Dalke, 1998).

The ability to establish correspondence of spatial relations is a second essential component in using maps or models. Acquiring spatial information from a map requires the ability to accommodate to changes in scale. That is, to successfully use a map requires application of the principle that maps transform real-world distances into smaller ones, and that this principle applies to the judgment of real-world distances from distances on maps. Although such transformation is most accurately done with measurement devices such as rulers, it would seem that successful map use is possible without such precision, if the map user can carry out rough or intuitive scaling.

It has been assumed that scaling is a much later accomplishment than the representational insight regarding element-to-element correspondences. In fact, Piaget and Inhelder (1948/1967) argued that young children do not encode distance in establishing location at all, which would clearly preclude the ability to understand scaling of distance. Rather, young children's spatial representations were said to rely on topological features such as proximity and enclosure. Accurate assessment of distance was said to arise only as children become able to measure amount, at about 5 years of age. In addition, Piaget and Inhelder argued that proportional representation is involved in scaling and that this ability is not developed until the advent of formal operations at 10 to 12 years of age.

DISTANCE CODING

Recently, it has been found that distance coding actually emerges at a very early age. In a previous study (Huttenlocher, Newcombe, & Sandberg, 1994), we examined the emergence of distance coding in a simple situation, in which the location of an object had to be coded along a single dimension. A toy was hidden in a narrow, 5-ft long sandbox while a child watched. After a short delay during which the child was distracted, he or she indicated where the object had been hidden. The youngest children tested were 16 and 24 months old and able to walk; children of this age were quite accurate in pointing to the toy's location. Further work has shown that distance coding arises even earlier than 16 months. Bushnell, McKenzie, Lawrence, and Connell (1995) found distance coding in 12-month-olds. In this study, infants saw an object being hidden under one of a large array of identical pillows within a circular frame. They could find the pillow where the object was hidden. Most recently, using a somewhat smaller sandbox than in our toddler study, we found distance coding in 5-month-olds (Newcombe, Huttenlocher, & Learmonth, 1999). Infants saw an object hidden in a particular location several times. If the object that was hidden in that location was retrieved in a different location, the infants looked longer than if it was retrieved in its original location, indicating an ability to differentiate among locations in the box.

USING MAPS TO CODE DISTANCE

The existing literature shows that children have trouble on scaling tasks. For instance, when asked to reproduce configurations of objects learned from a map, 4- and 5-year-olds reconstruct angular relations accurately, but they are not very accurate on scale, showing both shrinkage and expansion relative to a correct layout (Uttal, 1996). Preschoolers are better at scale translation when the configurations of objects are symmetric (Uttal, 1996), but of course symmetry is uncommon on real maps. When shown pictures and photographs of places and asked to draw inferences about the actual spaces represented, preschoolers make errors such as rejecting depictions of roads as standing for actual roads because they are not "fat enough for two cars to go on" (Liben & Downs, 1989, p. 184). Preschoolers some-

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Address correspondence to Janellen Huttenlocher, University of Chicago, Department of Psychology, 5848 S. University Ave., Chicago, IL 60637; e-mail: hutt@ccp.uchicago.edu.

times even have difficulty establishing relations between familiar places and their symbolic representations. For instance, they are poor at metric placement of items on a map of a familiar classroom (Liben & Yekel, 1996). Furthermore, they may not transfer spatial-relational information (e.g., a stool is beside the dresser) from one model to another, even when the two models are identical in scale (Blades, 1991).

Difficulty in interpreting maps extends well into the elementary school years. Children as old as 7 years make substantial errors, usually of underestimation, when asked to use a map to place objects in a real space, and children through the age of 10 years perform worse than children of 11 to 13 years (Wallace & Veek, 1995). Liben and Downs (1989) argued that children "who have rudimentary map concepts show precisely the kinds of problems with map comprehension that one would predict from Piagetian theory" (p. 191). Although it is commonly believed that scaling itself remains difficult, it is at least possible that the map tasks that have been given to children are difficult not because they require scaling, but for other reasons. Map tasks may involve many spatial relations, thus placing too great a demand on memory (Uttal, 1996), or they may reveal irrelevant response preferences, such as a tendency to place items on specific symbols on maps rather than on empty spaces (Liben & Yekel, 1996).

THE EXPERIMENTS

Here, we report two experiments in which we used the simplest possible situation to examine the emergence of the ability to use a map to provide information about distance in a larger actual space. The task involved presenting an object in a location along the length of a map of a long, narrow rectangle. The map showed a rectangle drawn on a piece of paper. The actual space was the sandbox from our earlier distance-coding study. Children had to use object position on the map to determine the position of a hidden object in a larger space. In the first experiment, we evaluated the age at which children become able to obtain information about location from a map. In the second experiment, we examined this ability in more detail, evaluating the refinement with which they can differentiate different map locations.

Experiment 1

In this experiment, we made an initial determination of the age at which children become able to use distance in a small-scale space to provide information about distance in a larger-scale space. We used four different locations on our map and examined if children could point to the location in the sandbox indicated on the map. Our choice of age groups for this study was guided by DeLoache's (1990) finding that children under the age of 3 years fail to understand that a model or picture may stand for a real array.

Participants

Two age groups were used. The younger group included twenty-five 3-year-old children (15 boys, 10 girls; mean age = 44 months, range: 40–50 months). The older group included twenty-five 4-year-old children (12 boys, 13 girls; mean age = 55 months, range: 51–62 months). They were largely from middle-class families and attended nursery school on the University of Chicago campus. All children were tested individually in their school. Three additional children in the younger group and 1 child in the older group were excluded from the final analysis; 2 of the children refused to complete all experimental trials, and 2 others had difficulties understanding the task.

Materials

The sandbox was built out of plywood (60 in. long, 15 in. wide, 12 in. deep). The top 2 in. was filled with play sand. A pattern was created along the outside top edge of the box on the side away from the child but facing the video camera. The pattern consisted of marks placed every 3 in. along the length of the box. This pattern served as a scale for scoring the data. Small black disks (0.8 in. in diameter) were the objects that were hidden in the sandbox. The sandbox was located in the center of the room, separated from the child by a drawstring curtain. The curtain was closed during hiding of the object and open during finding of the object.

Maps were drawn on white paper (8.5 in. × 11.5 in.). They displayed a rectangular frame (8 in. long, 2 in. wide) representing the sandbox, with a dot inside the rectangle representing the location of the hidden disk along the length of the frame. Eight of these maps were used in the experimental trials, and two more were used during demonstration trials. The two maps that were used in demonstration trials displayed a dot 2.5 in. or 5.5 in. from the left end of the frame. The eight maps used in the experimental trials displayed a dot in one of four locations corresponding to hiding locations in the sandbox as shown in Table 1. (Locations reported in this and the following tables refer to distances from the left end of the frame.) A video camera and tripod stood facing the child and the side of the sandbox with the decorative pattern on it. All sessions were videotaped and were scored from the recordings, using the decorative pattern as the measuring device.

Design and procedure

Children were given eight experimental trials, two at each of four different locations on the map. The locations were defined as distances from the left end of the rectangle or sandbox. The ratio of the length of the rectangle to the length of the sandbox was 8 in./60 in.

After the child was familiarized with the experimental room and played with disks in the sandbox, he or she sat on a chair in front of the sandbox (about 15 in. from it), beside one of the experimenters (E1). The other experimenter (E2) was positioned at the opposite side of the sandbox. Two demonstration trials were conducted. In the beginning of each demonstration trial, the child was told that E2 was going to hide a disk in the sandbox and the child would have to help E1 find the hidden disk. Then the curtain was closed so that the child could not see where exactly the disk was buried. In 15 s, E2 said,

Table 1. *True locations and dot locations in Experiment 1*

True location in the sandbox (in.)	Dot location on the map (in.)
12	1.6
24	3.2
36	4.8
48	6.4

"Okay, it's hidden," opened the curtain, and handed the first map to the child. At this point, the child was told that this picture showed where the disk was located. E1 pointed to the correspondence between the big sandbox and its picture, emphasizing that the dot on the picture indicated where the disk was hidden.

The remaining part of the procedure was different for the first and second demonstration trials. In the first trial, E1 demonstrated how to locate the disk. She pointed to the dot on the picture, then looked at the sandbox and said, "This picture tells me that in the big sandbox, the disk is hidden right here," pointing to the correct location. The child was instructed to touch the sand in the place where the disk was buried. In the second demonstration trial, the child acted alone, which allowed the experimenters to check if he or she understood the procedure. If the child made a mistake (e.g., tried to dig up the disk instead of pointing to the location), or if the response was far from a hiding location, he or she was corrected. In the latter case, E1 could say, "Look at the picture again. It tells us that the disk is hidden over here."

Experimental trials were similar to the second demonstration trial except that the child did not receive any help from the experimenters. After the child pointed to the place where he or she believed the disk was hidden, the curtain was closed and a new trial began. The order of maps presented on the experimental trials was randomized across children. The only restriction in selecting the map order was that successively presented maps could not display a dot in the same location.

Results

The data were analyzed by comparing response locations and true locations. True location is the distance from the left side of the sandbox to the location that would be pointed to if both coding of distance and scale translation were exact. Response location is the distance from the same side of the sandbox to the location actually pointed to by the child. Eight response locations (two at each of the four true locations) were obtained for each child from the videotapes. Scoring was done using the "ruler" along the edge of the sandbox; increments for scoring responses were 1.5 in. A second observer rescored 15% of the data. The correlation between the two sets of scores was .98.

First, consider the metric accuracy of the 4-year-olds' responses. A two-way analysis of variance (ANOVA) was computed to determine the effects of position and gender on children's responses. True location was a significant factor, $F(3, 69) = 410.54$, $p = .0001$, but gender was not, $F(1, 23) = 0.016$, $p = .8998$. The mean responses and standard deviations for each of the four locations are shown in Table 2.

In addition to analyzing group results, we examined the patterns of individual responses of the 4-year-old participants. We determined if the order of the eight response locations matched the order of true locations, testing if both of each child's two responses to the left-most value were left of their two responses for the next value, and so on for the entire set of eight responses. Children who had at most one ordering error, involving adjacent locations, across the eight trials were judged to have preserved the order of true locations. According to this criterion, all twenty-five 4-year-old children preserved order on the eight experimental trials. Not only were their responses ordered in the same way as true locations, but their responses were near true locations. The average difference between children's responses and the corresponding true locations was 3.5 in.

Next, consider the 3-year-old group. A two-way ANOVA was computed to examine the effects of true location and gender on response locations. The results for true location were significant, $F(3, 69) = 30.805$, $p = .0001$. Gender was not a significant factor in children's performance, $F(1, 23) = 0.152$, $p = .7002$. Means and standard deviations of this group's responses are presented in Table 3.

As for the 4-year-olds, we examined the patterns of individual responses of 3-year-old participants. We sought to determine why the standard deviations of responses were much larger for this group of 3-year-olds than for the 4-year-old group (as can be seen by comparing Tables 2 and 3). The analysis of individual responses revealed two distinct groups of 3-year-old participants. One group performed similarly to the 4-year-olds. This group included 15 children who preserved the order of true locations according to the criterion of one ordering error. For these children, the placements were near the true locations; the average error in placement was 4.1 in. There were 10 children who failed to meet the criterion of correct ordering. This group provided little or no evidence of using the map at all. Six of the children pointed repeatedly to the same location in the sandbox, regardless of the dot location on the map. The other 4 children showed very large deviations from the true locations; their average error in placement was 14.6 in. This pattern of results for the 3-year-olds suggests an all-or-none character to the emergence of map use. That is, for 60% of the 3-year-old participants, performance was very much like that of 4-year-olds in terms of order and average accuracy. For the other 40% of the 3-year-old participants, there was no evidence that particular spatial locations were coded from the map at all.

Discussion

Our findings indicate that both 3-year-olds and 4-year-olds can use the simplest of maps, coding location along a single dimension. Although 15 of the twenty-five 3-year-olds were quite accurate, 10 provided no evidence of successful map use. All twenty-five 4-year-olds used the map accurately. However, because the task involved differentiating four locations falling in four different quadrants in the

Table 2. *Responses of 4-year-old children in Experiment 1*

True location (in.)	Response location (in.) Mean	Response location (in.) *SD*
12	10.4	3.0
24	22.6	4.0
36	34.9	5.7
48	48.7	3.1

Table 3. *Responses of 3-year-old children in Experiment 1*

True location (in.)	Response location (in.) Mean	Response location (in.) *SD*
12	16.1	10.5
24	28.4	11.4
36	36.3	7.4
48	42.6	10.6

larger sandbox, it could be argued that location might have been encoded categorically. We explored this issue in Experiment 2.

Experiment 2

In Experiment 2, we examined more closely than in Experiment 1 the refinement with which 4-year-olds can differentiate locations from a map. Our first study involved four locations on the map, two on either side of the center; the locations were 1.6 in. apart. Because, as we have noted, it is at least possible that the fact that dots were in different quadrants was important to success on this task, we used seven locations in the second study, three on either side of the center and one at the center; the locations were 1 in. apart.

Participants

Participants included twenty-six 4-year-old children (12 boys, 14 girls; mean age = 54 months, range: 48–59 months). They were from middle-class families and attended day-care centers in the Hyde Park area of Chicago and in Evanston, Illinois. All children were tested individually.

Materials

The actual space was presented by the same sandbox that was used in the previous experiment. A set of nine maps was constructed. Two of these were used on demonstration trials like those in Experiment 1. The seven other maps were used on experimental trials. These maps displayed the same rectangular frame as in Experiment 1 (8 in. long, 2 in. wide). In each map, a dot appeared in one of seven locations, as shown in Table 4. A video camera stood facing the sandbox and the child, and videotapes were used in scoring the data.

Design and procedure

The procedure was parallel to the procedure in Experiment 1. The difference was that children were given seven experimental trials, one at each location.

Results

Children's responses were compared with the true locations, as calculated from the location of the dot on the map. Seven response locations were obtained for every child. The responses were scored using the scale along the edge of the sandbox; increments for scoring were 1.5 in. A second observer rescored 15% of the data. The correlation between the two sets of scores was .98.

Table 4. *True locations and dot locations in Experiment 2*

True location in the sandbox (in.)	Dot location on the map (in.)
7.5	1
15	2
22.5	3
30	4
37.5	5
45	6
52.5	7

Table 5. *Responses in Experiment 2*

True location (in.)	Response location (in.)	
	Mean	*SD*
7.5	7.4	2.7
15	13.0	4.8
22.5	18.6	5.9
30	28.6	4.2
37.5	39.2	3.8
45	46.1	5.1
52.5	51.2	3.2

We compared the order of individual responses on the seven experimental trials with the order of true locations and found that all 26 participants met the order criterion established in Experiment 1: Either the order of their responses exactly matched the order of true locations or they had only one adjacent switch of locations across all responses. In other words, responses were in the correct order even though locations on the map were closer than in the previous experiment. The average error in placement was 3.4 in.

Mean responses and standard deviations about the means are presented in Table 5. To analyze the effects of true location and gender, we computed an ANOVA crossing these two factors. True location was a significant factor, $F(6, 144) = 418.29$, $p = .0001$; the effect of gender was not significant, $F(1, 24) = 0.006$, $p = .937$. The results indicate that children are sensitive to spatial information obtained from a map.

Discussion

In this experiment, we examined further the ability of 4-year-old children to use information from a map to establish location in a larger space. Our findings verified the conclusions drawn in our first experiment. That is, 4-year-olds can use a simple map to locate an object in a larger space. We found that children could differentiate locations that were closer than those in the first experiment, and that did not fall in different quadrants of the map.

OVERALL DISCUSSION

In the two experiments in the present study, all 4-year-olds and a majority of 3-year-olds could use a simple map to locate an object in a much larger actual space. Successful performance required recognizing a correspondence between the map and a sandbox of similar shape, and using the map to locate the object in the sandbox. These findings show that successful map use arises considerably earlier than has been reported in the literature. The map tasks used in previous studies were more complex than our task, but the difficulty of these tasks has been attributed, at least in part, to the necessity for scaling distance. Scaling is required on our map task as well, and thus scaling in a simple case can be accomplished earlier than previously believed.

It is often argued that scaling requires proportional reasoning. The claim is that a map is used to construct a fraction or ratio that can be applied to determine location in the larger actual space. That is, in the present case, the total length of the map can be treated as the denominator of a fraction, and the distance of the dot from one edge of the map can be treated as the numerator of that fraction. Then, the argument would continue, a second fraction is constructed from the sandbox, with the total length of the sandbox as the denominator and the unknown distance of the disk from the edge of the sandbox as the numerator. In this view, measurement units must be imposed by the child to determine the required distances; the location of the disk in the sandbox is found by adding units to determine distances and using those distances to form fractions and solve for the unknown numerator. Piaget and Inhelder (1948/1967) argued that proportional reasoning does not arise until 10 to 12 years of age. Their studies of the emergence of proportional reasoning involved tasks very different from map tasks, however. Children compared two sets of items, each set consisting of both red and green marbles, and indicated which set would be more likely to yield a red item if a random draw were made. The frequencies of the red and green marbles in each set were varied independently to ensure that the children had to make proportional judgments to obtain answers.

We propose that scaling does not require proportional reasoning in the same sense as in Piaget and Inhelder's task. In particular, we suggest that the explanation for early scaling ability lies in the nature of early distance coding. Success on a scaling task, as we have noted, presupposes an ability to code distance. Until recently, it was believed that distance coding was not possible for children until they became able to impose unit measures—at about 5 years of age, according to Piaget, Inhelder, and Szeminska (1960). Given this analysis of distance coding, together with the necessity of distance coding for scaling, scaling ability could not possibly emerge until after age 5.

Recently, however, it has been shown that distance coding occurs even in infants and toddlers. The processes involved in such coding have not yet been explored. It should be noted that in all of the studies in which early coding of location has been found, the tasks have involved enclosed spaces. These studies include our own sandbox experiments, Bushnell's study of location coding (Bushnell et al., 1995), and recent work by Hermer and Spelke (1996) in which toddlers used the relative lengths of the walls to differentiate corners in a room. We propose that location in enclosed spaces is special in that it can be established by relating visible distances to one another. For example, in our sandbox, the visible distances are from one edge of the box to the target and from the target to the other edge of the box. Because the distances are both perceptually present, they can be related to one another directly, without imposing measurement units. It is possible to determine, for example, that a location is two thumb lengths from one edge, that the entire box is five thumb lengths, and so on. If infants and toddlers can code location only by relating present distances to one another in this way, the early ability to establish location should be restricted to enclosed spaces and should not extend to tasks involving distal landmarks, because imposed measurement units must be used to establish distances in such cases. Several studies suggest that there is such a restriction (Newcombe, Huttenlocher, Drummey, & Wiley, 1998; Overman, Pate, Moore, & Peuster, 1996).

This proposed model of how infants and toddlers code location in enclosed spaces has implications for scaling tasks. That is, if location is coded by relating visible distances to one another rather than by imposing unit measures, the coding will directly preserve the relation between those distances. Such coding is applicable to spaces of varying size without requiring operations to transform scale. In this case, map tasks should be quite easy, as we have found. Even older children and adults may use this form of coding in interpreting maps, except when very precise locations are needed, in which case the use of unit measures can contribute to accuracy. Why, then, have map tasks been found to be difficult for young children? Our guess is that factors other than scaling may be critical. For example, the difficulty of such tasks may stem from having to find corresponding objects when several objects are present and having to realign spaces.

CONCLUSIONS

In the present experiments, we found an early ability to use maps. We propose that the 3- and 4-year-olds who participated in the experiments were successful because the coding of location in enclosed spaces preserves information about location in a form that is directly applicable to similarly shaped spaces regardless of size. If our hypothesis is correct, scaling may be achieved using two different sorts of procedures. One involves use of unit measures and formation of fractions, and the other involves comparison of perceptually present distances. The latter involves simple processes, which may explain both the early emergence of distance coding and the early emergence of scaling.

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REFERENCES

Blades, M. (1991). The development of the abilities required to understand spatial representations. In D.M. Mark & A.V. Frank (Eds.), *Cognitive and linguistic aspects of geographic space* (pp. 81–115). Dordrecht, The Netherlands: Kluwer Academic Press.

Bluestein, N., & Acredolo, L. (1979). Developmental changes in map-reading skills. *Child Development, 50,* 691–697.

Bushnell, E., McKenzie, B., Lawrence, D., & Connell, S. (1995). The spatial coding strategies of one-year-old infants in a locomotor search task. *Child Development, 66,* 937–958.

Dalke, D.E. (1998). Charting the development of representational skills: When do children know that maps can lead and mislead? *Cognitive Development, 13,* 53–72.

DeLoache, J. (1990). Young children's understanding of models. In R. Fivush & J.A. Hudson (Eds.), *Knowing and remembering in young children* (pp. 94–126). Cambridge, England: Cambridge University Press.

DeLoache, J. (1994). Early understanding of the representational function of pictures. *Cognition, 52,* 83–110.

Hermer, L., & Spelke, E. (1996). Modularity and development: The case of spatial reorientation. *Cognition, 61,* 195–232.

Huttenlocher, J., Newcombe, N., & Sandberg, E. (1994). The coding of spatial location in young children. *Cognitive Psychology, 27,* 115–147.

Liben, L., & Downs, R. (1989). Understanding maps as symbols. In H.W. Reese (Ed.), *Advances in child development and behavior* (Vol. 22, pp. 145–201). New York: Academic Press.

Liben, L., & Yekel, C. (1996). Preschoolers' understanding of plan and oblique maps: The role of geometric and representational correspondence. *Child Psychology, 67,* 2780–2796.

Newcombe, N., Huttenlocher, J., Drummey, A.B., & Wiley, J.G. (1998). The development of spatial location coding: Place learning and dead reckoning in the second and third years. *Cognitive Development, 13,* 185–200.

Newcombe, N., Huttenlocher, J., & Learmonth, A. (1999). *Spatial memory in 5-month-old infants.* Unpublished manuscript, Temple University, Philadelphia.

Overman, W.H., Pate, B.J., Moore, K., & Peuster, A. (1996). Ontogeny of place learning in children as measured in the radial arm maze, Morris search task, and open field task. *Behavioral Neuroscience, 110,* 1205–1228.

Piaget, J., & Inhelder, B. (1967). *The child's conception of space* (F.J. Langdon & J.L. Lunzer, Trans.). New York: Norton. (Original work published 1948)

Piaget, J., Inhelder, B., & Szeminska, A. (1960). *The child's conception of geometry.* New York: Basic Books.

Presson, C.C. (1982). The development of map reading skills. *Child Development, 53,* 196–199.

Uttal, D. (1996). Angles and distances: Children's and adults' reconstruction and scaling of spatial configurations. *Child Development, 67,* 2763–2779.

Wallace, J.R., & Veek, A.L. (1995, April). *Children's use of maps for direction and distance estimation.* Paper presented at the biennial meeting of the Society for Research in Child Development, Indianapolis, IN.

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