COGNITIVE MAPS, COGNITIVE COLLAGES, AND SPATIAL MENTAL MODELS

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Abstract. Although *cognitive map* is a popular metaphor for people's mental representations of environments, as it is typically conceived, it is often too restrictive. Two other metaphors for mental representations are proposed and supported. *Cognitive collages* are consistent with research demonstrating systematic errors in memory and judgment of environmental knowledge. Yet, for some simple or well-known environments, people seem to have coherent representations of the coarse spatial relations among elements. These *spatial mental models* allow inference and perspective-taking but may not allow accurate metric judgments.

1 Introduction

1.1 Cognitive Maps

There is a popular view that people's mental representations of environments are embodied in "cognitive maps." Like many useful concepts, the term *cognitive map* has many senses, leading to inevitable misunderstandings. One prevalent sense is that cognitive maps are maplike mental constructs that can be mentally inspected. They are presumed to be learned by gradually acquiring elements of the world, first *landmarks,* pointlike elements, then *routes,* linelike elements, and finally unifying the landmarks and routes with metric *survey* information. The appeal of this view is manifold. As *cognitive,* they are presumed to differ from "true" maps of the environment. Social scientists from many disciplines would be quick to bring forth evidence for that. As *maps,* they are presumed to be coherent wholes that reflect spatial relations among elements. As mental constructs available to mental inspection, cognitive maps are presumed to be like real maps available to real inspection, as well as like images, which, according to the classical view of mental imagery, are like internalized perceptions.

1.2 Constructionist View

In this paper, I will present evidence not compatible with the view of mental representations of environments as cognitive maps. I will discuss two alternative *constructionist* views of the mental representations underlying people's knowledge of environments. According to the constructionist view, people acquire disparate pieces of knowledge about environments, knowledge that they use when asked to remember an environment, describe a route, sketch a map, or make a judgment about location, direction, or distance. The separate pieces include recollections of journeys, memories of maps, recall of verbal (aural or written) directions and facts, and more. As for any human memory task, it is possible that not all t he relevant stored information will be retrieved when needed.

1.3 Cognitive Collages

In many instances, especially for environments not known in detail, the information relevant to memory or judgment may be in different forms, some of them not maplike at all. Some of the information may be systematically distorted as well. It is unlikely that the pieces of information can or will be organized into a single, coherent maplike cognitive structure. In these cases, rather than resembling maps, people's internal representations seem to be more like *collages*. Collages are thematic overlays of multimedia from different points of view. They lack the coherence of maps, but do contain figures, partial information, and differing perspectives. In the second section, I will review some of the evidence for the notion that cognitive collage is often a more appropriate metaphor for environmental knowledge than cognitive map. That evidence shows that memory and judgment are systematically distorted and potentially contradictory, thus not easily reconcilable in a maplike structure.

1.4 Spatial Mental Models

In other situations, especially where environments are simple or well-learned, people seem to have quite accurate mental representations of spatial layouts. On close examination, these representations capture the categorical spatial relations among elements coherently, allowing perspective-taking, reorientation, and spatial inferences. In contrast to cognitive maps and cognitive collages, these have been termed *spatial mental models*. Unlike cognitive maps, they may not preserve metric information. Unlike cognitive collages, they do preserve coarse spatial relations coherently. These are relations that are easily comprehended from language as well as from direct experience. In the third section I will review some evidence for the success of language in inducing coherent mental representations of the categorical spatial relations in environments.

2 Systematic Errors in Memory for Environments

2.1 Hierarchical Representations of Space

When students at U.C. San Diego were asked to draw the direction between San Diego and Reno, they incorrectly indicated that San Diego was west of Reno [36]. Indeed, it is surprising to learn that Reno is in fact west of San Diego. After all, California is on the western coast of the United States, and Reno is far inland, in Nevada. A glance at a map reveals that the coast of California, far from running north-south, in fact cuts eastward as it cuts southward. Stevens and Coupe attributed their findings to hierarchical representations of space. People do not remember the absolute locations of cities. Instead, they remember the states cities are part of, and the relative locations of the states. Then they infer the relative locations of cities from the locations of their superset states.

Since this (shall I call it "landmark?") study, other evidence for hierarchical representations of geographic knowledge has accumulated. Hierarchical organization has been found to distort distance judgments as well as direction judgments [11].

Hirtle and Jonides asked one group of students at the University of Michigan in Ann Arbor to form subjective groups of buildings in town. They grouped the buildings according to function, commercial or educational. Another group of students was asked to judge distances between pairs of buildings. Distances between functional groupings were overestimated relative to distances within functional groupings. Chase found that a detailed hierarchical organization distinguished experienced taxi drivers from novices [4]. Other studies have demonstrated that people impose a hierarchy on what is in reality a flat two-dimensional display, and that that affects judgment and memory for environments [for example, 12, 23, 24, 25, 44; for a brief review, see 42 and 43]. Of course there are no hierarchies in maps, so this widespread cognitive phenomenon already introduces a distorting factor difficult to reconcile with maps.

2.2 Cognitive Perspective

Experienced hikers know that distances between nearby landmarks appear relatively larger than distances between faraway landmarks, though it is difficult to make adequate compensation for that. A similar phenomenon occurs in making distance judgments from memory. Holyoak and Mah [14] asked one group of students to imagine themselves on the East Coast of the United States, and another group to imagine themselves on the West Coast of the United States. Both groups were then asked to estimate the distances between pairs of U. S. cities along an east-west axis, for example, San Francisco and Salt Lake City, New York City and Pittsburgh. The students given a West Coast perspective overestimated the distances between the westerly pairs relative to the easterly pairs, and the students given an East Coast perspective did the opposite. Thus, the vantage point assigned for making the judgments systematically distorted the judgments.

2.3 Cognitive Reference Points

When I am out of state and asked where I live, I usually answer, "Near San Francisco." If I am closer to home, I will answer, "On Stanford campus," or "Off Stanford Avenue," or "Next door to the ----s." In other words, rather than giving an exact location, I convey where I live relative to a reference point [see 8] that I believe my questioner will know. Not only do we describe less-known locations relative to better-known landmarks, we also seem to remember them that way. As is often the case in memory, we describe situations to ourselves just as we would describe them to others.

Remembering less prominent locations relative to landmarks induces a distortion that is particularly intractable for metric maps, namely asymmetric distance. Sadalla, Burroughs, and Staplin [32] have found that people judge the distance from an ordinary building to a landmark to be *smaller* than the distance from a landmark to an ordinary building.

2.4 Alignment

Remembering one spatial location with respect to another leads to direction distortions as well. Two nearly-aligned locations tend to be grouped, in a Gestalt sense, in memory, and then remembered as more closely aligned than they actually were [41]. Students were given two maps of the Americas, one a correct map, and the other, a map in which South America was moved westward with respect to North America, so that the two Americas were more closely aligned. A significant majority of the students thought the altered map was the correct one. Another group of students selected a world map in which the Americas were moved northward relative to Europe and Africa in preference to a correct map of the world. In the preferred incorrect map, the United States was more closely aligned with Europe and South America with Africa.

Alignment errors in memory were also obtained for judgments of directions between cities, for example, students incorrectly thought that Boston was west of Rio de Janeiro and that Rome was south of Philadelphia. Alignment was also observed in memory for local environments most likely learned from navigation rather than maps, in memory for artificial countries and cities, and in memory for blobs not interpreted as maps.

2.5 Rotation

Remembering a spatial location relative to a frame of reference can also lead to direction distortions [41]. Think of a situation where the orientation of a land mass is not quite the same as the orientation of its frame of reference. A good example is South America, which appears to be tilted in a north-south east-west frame. In fact, when students were given cutouts of South America and asked to place them correctly with respect to the canonical directions, most students uprighted South America. Similar errors appeared for the San Francisco Bay Area, the environment immediately surrounding the students, and for artificial maps and blobs as well, in our work as well as that of others [4,21, 22].

2.6 Other Systematic Errors

This is by no means a complete catalog of systematic errors in memory and judgment of environments. Irregular geographic features may be regularized. For example, Parisians straighten out the Seine [27], and Americans seem to straighten out the Canadian border [36 as interpreted by 43]. Turns and angles are regularized to right angles [3, 13, 29, 34]. Distance judgments are arguably more complex than direction judgments. They are rarely known directly, so they seem to entail use of a number of surrogates that may yield distortions. Distances have been judged longer when a route has barriers or detours [7, 18, 30], when a route has more turns or nodes [33, 35], and when a route has more clutter [40].

2.7 Cognitive Collages

Thus, a number of different factors, hierarchical representations, cognitive perspectives, cognitive reference points, alignment to other locations, rotation to a frame of reference, regularization of geographic features, and more, can systematically distort memory and judgment of environments. On the whole, each empirical study has isolated the effects of a single factor, but in real cases, many factors may be operative. There is no guarantee that the distorting factors are consistent; in fact, it seems easy to construct cases where one factor would distort in one direction and another factor in another direction. The distortions alone are incompatible with a metric mental map, and inconsistent distortions make mental maps an even less satisfactory explanation. Of course, not all our spatial knowledge is distorted. Some of it may be quite accurate. But even so, it is unlikely to be complete, so that problems arise when trying to put it all together, especially if some of the information is erroneous and if the information from different sources is not compatible.

The inconsistencies, however, seem to provide a mechanism to reduce error. When subjects are asked for more information from an environment, it turns out that their judgments become more accurate [1, 2, 26]. This could happen because when confronted with their own inconsistencies, people retrieve additional information that allows them to reconcile the inconsistencies in the correct direction. It could also happen if there were a large number of unreliable judgments, with the majority going toward the correct. Figures can emerge from collages. In many real world situations, however, people are asked for partial information and may not use other information as a corrective.

2.8 Two Basic Relations

The situation is not always as chaotic as I've implied. Most of us manage to find our ways most of the time, either because an environment is familiar, or because we use maps or instructions or environmental cues or all of the above or more. For some well-learned environments, large-scale or small, people's knowledge can be well-organized and systematic. In those cases, the knowledge often has the form of locating elements relative to one another from a point of view or of locating an element relative to a higher order environmental feature or reference frame. Interestingly, the systematic errors described depend on these basic relations. The errors attributable to cognitive perspective, cognitive reference points, and alignment rest on representing landmarks relative to one another from a vantage point. The errors attributable to hierarchical organization and to rotation are based in representing a landmark relative to a higher order feature, a region or a frame of reference. Although much of human knowledge about space, including systematic errors, can be reduced to these two relations, some cannot.

These two simple relations can form a foundation for spatial knowledge from which memory and judgment are constructed. Although the relations can be quite coarse, they can also be refined by adding constraints imposed by other spatial relations. Significantly, these relations also form the basis for spatial language used in descriptions of environments. Because the spatial relations between elements or between an element and a reference frame can be expressed by the many disparate formats that convey environmental knowledge, the relations provide a means to integrate spatial information from different formats.

3 Spatial Descriptions

One of the major functions of language is to convey experience vicariously. Anyone who has laughed out loud reading a novel or felt their heart beat rapidly reading a mystery knows that. Describing space effectively must have been an early use of language, in order to tell others where to find food and where to avoid danger. Although modern-day spatial language can convey locations of landmarks with great accuracy using formal systems designed for that purpose, everyday spatial language is not very precise. Typical spatial expressions like "next to," "between," "to the left of," "in front of," "east of," and "on top of" describe spatial relations at coarse levels of precision, but their frequency in the language suggests that they are easily produced and readily understood. These expressions convey the relations between elements. Expressions like "within," "contains," "divides," "borders," and "curves" convey the relations between elements and reference frames. [For more discussion of spatial language, see for example, 6, 9, 15, 19, 28, 31.]

3.1 Comprehending Route and Survey Descriptions

Taylor and I have been interested in the nature of the spatial information that language alone can impart [37, 38]. Thus far, we have only investigated those spatial expressions that seem to be readily produced and understood. Spatial descriptions normally assume a perspective, explicit or implicit. An informal survey of guidebooks indicated that descriptions of environments take one of two perspectives. A *route* perspective takes readers on a mental tour of the environment, describing landmarks with respect to the (mentally) changing position of the reader in terms of the reader's front, back, left, and right. A *survey* perspective gives readers a bird's eye view, and describes landmarks relative to one another in terms of north, south, east, and west. These two perspectives have parallels with two major means of learning about environments, the first through exploration, and the second through maps. They also have parallels to a distinction made in knowledge representation that is both popular and controversial, namely, procedural and declarative.

Design. In our first set of experiments [38], students studied either a route or a survey description of each of four environments. Two of the environments were large-scale, one county-sized and the other a small town, and two were smaller, a zoo and a convention center. The environments contained about a dozen landmarks. After studying the descriptions, students responded true or false to a series of statements: verbatim statements taken from both the perspective read and the other perspective and inference statements from both perspectives. The inference statements contained information that was not explicitly stated in either text, but could be inferred from information in either text. If perspective was encoded in the mental representations, then inference statements from the read perspective should be verified more quickly than inference statements from the other perspective. After responding to the statements, students drew maps of the environments.

Results. From only studying the descriptions, students were able to produce maps that were nearly error-free, indicating that language alone was sufficient to accurately convey coarse spatial relations. The speed and accuracy to answer the true/false questions suggested that readers formed at least two mental representations of the text, one of the language of the text, and another of the situation described by the text, that is the spatial relations among the landmarks. We termed the latter a spatial mental model [cf. 16] to distinguish it from an image. Responses to verbatim statements were faster and more accurate than responses to inference statements. Presumably, verbatim statements were verified against a representation of the language of the descriptions, but inference statements had to be verified against a representation of the situation, a spatial mental model. Even though responses we refaster and more accurate to verbatim statements, the overall level of responding to inference statements was high. Subjects were able to verify spatial relations not specifically stated in the text, further support for the creation of spatial mental models. Responses to inference statements from the read perspective were neither faster nor more accurate than responses to inference statements from the other perspective, for both perspectives. This result was obtained in four separate experiments, including one where the students read only a single description and did not know they would be asked to draw maps.

Spatial Mental Models vs. Images. In this situation, where subjects studied coherent spatial descriptions of relatively simple environments, perspective did not seem to be encoded in the spatial mental models. Rather, the spatial mental models constructed seemed to be more abstract than either perspective. These spatial mental models appeared to capture the spatial relations among landmarks in a perspective-free manner, allowing the taking of either perspective with equal ease. As such, these spatial mental models are akin to an architect's model or a structural description of an object. They have no prescribed perspective, but permit many perspectives to be taken on them. Thus, spatial mental models are more abstract than images, which are restricted to a specific point of view [see 10, 17].

3.2 Producing Spatial Descriptions

Descriptions composed of the simple spatial relations between landmarks and between landmarks and reference frames were successful in inducing coherent spatial mental representations. It is then natural to ask what is the nature of the spatial descriptions that ordinary people spontaneously produce. In two experiments, Taylor and I [39] gave students maps to study, and asked them to write descriptions of the environments from memory. A compass rose appeared in each of the maps, allowing orientation with respect to the canonical axes, north-south and east-west. In a third stud y, we asked subjects to write descriptions of familiar environments they had learned from experience.

Survey, Route, and Mixed Descriptions. The descriptions subjects produced indicated that subjects regarded the maps as environments, and not as marks on pieces of paper. Perspective was scored using the definitions of route and survey described previously. As our intuitions suggested, descriptions used either route or survey perspectives, or a combination of both. No other style of description emerged. In the mixed perspective descriptions. either one perspective was used for parts of an environment and the other perspective for other parts, or both perspectives were used simultaneously for at least part of the descriptions. Across a wide variety of environments, survey, route, and mixed descriptions were obtained, their relative frequency depending in part on features of the environments. This was despite widespread claims that most spatial descriptions take a consistent perspective, specifically, a route perspective [for review, see 20]. The descriptions that subjects wrote from memory were quite accurate. They allowed a naive group of subjects to place nearly all the landmarks correctly [37].

Basic Relations and Coherence. A detailed analysis of the words, phrases, and clauses used in the descriptions revealed that the essence of a route description was describing the locations of landmarks relative to a single referent with a known perspective, in this case, the moving position of the reader. The essence of a survey description was describing the location of a landmark relative to the location of another landmark from a fixed perspective. These parallel the two basic relations described earlier. The situation is slightly more complex, however. In route descriptions, although the referent was constant, the orientation and location of the referent kept changing. Readers had to keep track of that orientation and location relative to the canonical frame of reference. Both our own and our subjects' route descriptions oriented readers with respect to north-south east-west. In survey descriptions, the referent kept changing, but the orientation was constant. Route descriptions, then, establish coherence by relating all landmarks to a single referent. They are complicated by the task of keeping track of the orientation of the referent. Survey descriptions establish coherence by using a single orientation, but they are complicated by changing the referent element. When either type of information is consistent and complete, as it was in the descriptions we wrote and in many of the descriptions subjects wrote, the individual pieces of information can be integrated into a coherent representation of the spatial relations among the landmarks independent of any specific perspective.

3.3 Spatial Mental Models

The integration of the relative locations of landmarks independent of perspective or orientation that occurs when people read spatial descriptions also seems to occur as people navigate the world. It would be inefficient to remember successive snapshots of the world because they would not allow recognition or navigation from other points of view. It makes more sense to isolate landmarks, and to remember their locations relative to one another and relative to a frame of reference so that recognition and way-finding are successful from different starting points. For simple, familiar environments, whether learned from direct experience, or learned vicariously through language, people can form coherent mental representations of the spatial relations among landmarks.

4 Conclusions

Despite its considerable appeal, as traditionally used, the "cognitive map" metaphor does not reflect the complexity and richness of environmental knowledge. That knowledge comes in a variety of forms, memory snippets of maps we've seen, routes we've taken, areas we've heard or read about, facts about distances or directions. It can also include knowledge of time zones and flying or driving times and climate. Even knowledge of historical conquests and linguistic families can be used to make inferences about spatial proximity. Some of that information may contain errors, systematic or random. When we need to remember or to make a judgment, we call on whatever information seems relevant. Because the snippets of information may be incomparable, we may have no way of integrating them. For those situations, *cognitive collage* is a more fitting metaphor for environmental knowledge.

Yet, there are areas that we seem to know quite well, either because they are familiar or simple or both. Even in those cases, metric knowledge can be schematic or distorted. What our knowledge seems to consist of in those cases is the coarse spatial relations among landmarks, what we have termed *spatial mental models*. Although spatial mental models may not allow accurate metric judgments, they do allow spatial perspective-taking and inferences about spatial locations. They are constructed from basic spatial relations, relations between elements with respect to a perspective or between an element and a frame of reference.

Those situations that are simple and that we know well are also easy to describe. Languages abound in expressions for categorical spatial relations. These expressions are readily produced and easily understood. Although many languages have adopted technical systems to convey metric information about location, orientation, and distance, this terminology is not widely used in everyday speech. When it is used in everyday situations, it is often used schematically. Apparently, descriptions using categorical spatial relations are sufficient for everyday uses.

Viewed as mental models or cognitive collages, environmental knowledge is not very different from other forms of knowledge. Just as for environments, there are areas of other knowledge where our information is consistent and integrated, but there are also areas where, because of incompleteness or incomparability or error, information cannot be consistent and integrated.

References

1. J. Baird: Studies of the cognitive representation of spatial relations: I. Overview. Journal of Experimental Psychology: General 108, 90-91 (1979)

2. J. Baird, A. Merril, J. Tannenbaum: Studies of the cognitive representations of spatial relations: II. A familiar environment. Journal of Experimental Psychology: General 108, 92-98 (1979)

3. R. W. Byrne: Memory for urban geography. Quarterly Journal of Experimental Psychology 31, 147-154 (1979)

4. W. G. Chase: Spatial representations of taxi drivers. In: Dr. R. Rogers, J. A. Sloboda (eds.): Acquisition of symbolic skills. New York: Plenum 1983

5. W. G. Chase, M. T. H. Chi: Cognitive skill: Implications for spatial skill in large-scale environments. In: J. H. Harvey (ed.): Cognition, social behavior, and the environment. Hillsdale, NJ: Erlbaum 1981

6. H. H. Clark: Space, time, semantics, and the child. In: T. E. Moore (ed.): Cognitive development and the acquisition of language. New York: Academic Press 1973, pp. 27-63

7. R. Cohen, L. M. Baldwin, R. C. Sherman: Cognitive maps of a naturalistic setting. Child Development 49, 1216-1218 (1978)

8. H. Couclelis, R. G. Golledge, N. Gale, W. Tobler: Exploring the anchor-point hypothesis of spatial cognition. Journal of Environmental Psychology 7, 99-122 (1987)

9. C. J. Fillmore: Santa Cruz lectures on deixis. Bloomington: Indiana University Linguistics Club 1975

10. R. A. Finke, R. N. Shepard: Visual functions of mental imagery. In: K. R. Boff, L. Kaufman, J. P. Thomas (eds.): Handbook of perception and human performance. New York: Wiley1986

11. S. C. Hirtle, J. Jonides: Evidence of hierarchies in cognitive maps. Memory and Cognition 13, 208-217 (1985)

12. S. C. Hirtle, M. F. Mascolo: The effect of semantic clustering on the memory of spatial locations. Journal of Experimental Psychology: Learning, Memory and Cognition 12, 181-189 (1986)

13. S. C. Hirtle, M. F. Mascolo: The heuristics of spatial cognition. Proceedings of the 13th annual conference of the cognitive science society. Hillsdale, N: Erlbaum 1992, pp. 629-634

14. K. J. Holyoak, W. A. Mah: Cognitive reference points in judgments of symbolic magnitude. Cognitive Psychology 14, 328-352 (1982)

15. R. Jackendoff, B. Landau: Spatial language and spatial cognition. In: D. J. Napoli, J. A. Kegl (eds.), Bridges between psychology and linguistics: A Swarthmore Festschrift for Lila Gleitman. Hillsdale, NJ: Erlbaum 1991), pp. 145-169

16. P. N. Johnson-Laird: Mental models. Cambridge, MA: Harvard University Press 1983

17. S. M. Kosslyn: Image and mind. Cambridge, MA: Harvard University Press 1980

18. S. M. Kosslyn, H. L. Pick, G. R. Fariello: Cognitive maps in children and men. Child Development 45, 707-716 (1974)

19. G. Lakoff: Women, fire, and dangerous things: What categories reveal about the mind. Chicago: University of Chicago Press 1987

20. W. J. M. Levelt: Speaking. Cambridge, MA: MIT Press 1989

21. R. Lloyd: Cognitive maps: Encoding and decoding information. Annals of the Association of American Geographers 79, 101-124 (1989)

22. R. Lloyd, C. Heivly: Systematic distortions in urban cognitive maps. Annals of the Association of American Geographers 77, 191-207 (1987)

23. R. H. Maki: Categorization and distance effects with spatial linear orders. Journal of Experimental Psychology: Human Learning and Memory 7, 15-32 (1981)

24. T. P. McNamara: Mental representations of spatial relations. Cognitive Psychology 18, 87-121 (1986).

25. T. P. McNamara, J. K. Hardy, S. C. Hirtle: Subjective hierarchies in spatial memory. Journal of Experimental Psychology: Learning, Memory, and Cognition 15, 211-227 (1989)

26. A. Merril, J. Baird: Studies of the cognitive representations of spatial relations: III. A hypothetical environment. Journal of Experimental Psychology: General 108, 99-106 (1979)

27. S. Milgram, D. Jodelet: Psychological maps of Paris. In: H. M. Proshansky, W. H. Ittelson, L. G. Rivlin (eds.): Environmental psychology. Second Edition. New York: Holt, Rinehart and Winston 1976, pp. 104-124

28. G. A. Miller, P. N. Johnson-Laird: Language and perception. Cambridge, MA: Harvard University Press 1976

29. I. Moar, G. H. Bower: Inconsistency in spatial knowledge. Memory and Cognition 11, 107-113 (1983)

30. N. Newcombe, L. S. Liben: Barrier effects in the cognitive maps of children and adults. Journal of Experimental Child Psychology 34, 46-58 (1982)

31. G. Retz-Schmidt: Various view on spatial prepositions. AI Magazine 9, 95-105 (Summer 1988)

32. E. K. Sadalla, W. J. Burroughs, L. J. Staplin: Reference points in spatial cognition. Journal of Experimental Psychology: Human Learning and Memory 5, 516-528 (1980)

33. E. K. Sadalla, S. G. Magel: The perception of traversed distance. Environment and Behavior 12, 65-79 (1980)

34. E. K. Sadalla, D. R. Montello: Remembering changes in direction. Environment and Behavior 21, 346-363 (1989)

35. E. K. Sadalla, L. J. Staplin: The perception of traversed distance: Intersections. Environment and Behavior 12, 167-182 (1980)

36. A. Stevens, P. Coupe: Distortions in judged spatial relations. Cognitive Psychology 13, 422-437 (1978)

37. H. A. Taylor, B. Tversky, Descriptions and depictions of environments. Memory and Cognition 20, 483-496 (1992)

38. H. A. Taylor, B. Tversky: Spatial mental models derived from survey and route descriptions. Journal of Memory and Language 31, 261-282 (1992)

39. H. A. Taylor, B. Tversky: Perspective in spatial descriptions (in preparation)

40. P. W. Thorndyke: Distance estimation from cognitive maps. Cognitive Psychology 13, 526-550 (1981)

41. B. Tversky, Distortions in memory for maps. Cognitive Psychology 13, 407-433 (1981)

42. B. Tversky: Distortions in memory for visual displays. In: S. R. Ellis (ed.), M. K. Kaiser, A. Grunwald (assoc. eds.): Pictorial communication in virtual and real environments. London: Taylor and Francis 1991, pp. 61-75

43. B. Tversky: Distortions in cognitive maps. Geoforum 23, 131-138 (1992)

44. R. N. Wilton: Knowledge of spatial relations: The specification of information used in making inferences. Quarterly Journal of Experimental Psychology, 31, 133-146 (1979)

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