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Distortions in Cognitive Maps

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Abstract: Cognitive maps refer to mental representations of maps or environments, as revealed in a variety of tasks. The simplest model of cognitive maps is that they are random degradations of real ones. Research using distance judgments, direction judgments, map recognition, map construction, and other information from memory for maps or environments suggests that distortions, rather than being random, are systematic. They result from cognitive organizing principles, such as hierarchical organization, perspective, reference points and frames, and other devices that facilitate memory and induce distortion at the same time. These distortions do not seem to be reconcilable in any simple way. There does not seem to be a single, coherent cognitive map that captures what we know about a particular map or environment.

Introduction

Physicians, engineers, mechanics and others use errors as signs of malfunctioning, that some system has broken down and is in need of repair. Not so for psychologists. Errors are viewed as natural products of the systems, and as such are clues to the way the system operates. Of course, I am using 'error' in two slightly different senses. In the sense of interest to psychologists, the errors people make are with respect to some true state of affairs.

The 'system' that I am interested in is cognitive maps, or mental representations for maps and environments. The nature of these representations is often revealed in errors of judgment and memory. I will first sketch three systematic errors well-researched in psychology. Then I will discuss in greater detail two related types of errors demonstrated by my own research, along with an analysis or theory of how the system produces the errors.

First, an aside, but an aside that makes a general point by comparison. Many of you have probably read that the National Geographic Society has recently changed the projection of the standard maps it uses. One problem faced by cartographers from Ptolemy to Mercator to this day is how to project a 3-D world onto a 2-D map. No matter what projection is used, there is bound to be distortion of shape, of size, and of spatial relations. The new map is an attempt to improve shape and size by sacrificing the readability of some spatial relations. But whatever the projection there is a mathematical formula that is followed and the true size, shape or position information can be recovered. In some sense, the human mind faces a similar problem—of mapping either an explored environment or an actual map onto a mental representation. The human mind, however, does not use a mathematical formula that takes a point on a map or in the world into a point in some mental representation of the map or environment. Rather, the human mind seems to reorganize the information entirely.

With that in mind, I turn to discuss three ways the human mind reorganizes spatial information, first through hierarchical organization or categorization, second through the use of perspective, and, third, through the use of landmarks or cognitive reference points.

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Hierarchical Organization

Some of the simplest evidence for reorganization of spatial information comes from studies demonstrating that spatial memory is hierarchical or categorical. Spatial information is grouped by states or countries, or in other ways, and comparisons of points, say cities, within a group are different from a comparison of equally spaced points between groups.

Let me try to make this clearer with some examples. The first example comes from a task developed by STEVENS and COUPE (1978) where subjects were asked to indicate from memory the direction from one American city to another by drawing a line in the proper orientation on a circle with north noted at the top. Viewed very generally, the direction estimates were not bad; however, there were several very interesting systematic errors. One of them was the direction from San Diego to Reno. Most people thought—incorrectly—that Reno was *east* of San Diego. Stevens and Coupe proposed that this sort of error occurs because of hierarchical reasoning. Instead of storing in memory the exact locations of every city, or instead of storing the relative locations of all cities, Stevens and Coupe argued that we store the relative locations of the states, and then store cities by the state that contains them. Thus, when asked to make direction judgments between cities, subjects do not compute them directly, but rather infer the relative locations of cities from the locations of the states they are in. Because California is generally west of Nevada, subjects make the incorrect inference that all cities in California are west of all cities in Nevada.

Subjects made a similar error in drawing the direction between the two Portlands, the one in Oregon and the one in Maine. The eastern Portland is actually quite a bit south of the western Portland, but most subjects thought the eastern Portland was north of the western one. Here the categorization is by country as well as state. Because Maine is on the Canadian border, but Oregon is a whole state away from the Canadian border, subjects thought that Maine was north of Oregon, and therefore Portland, Maine north of Portland, Oregon. Stevens and Coupe demonstrated that the same phenomenon occurs in properly constructed artificial maps learned by new subjects.

Another demonstration of hierarchical representation of spatial information comes from a task in which subjects, again, from memory, were asked to verify the truth of statements like 'Edinburgh is north of Sussex' or 'London is north of Liverpool.' These are easy questions, or at least they were easy for the British subjects in the experiments, so errors were not of interest in this task. What was of interest to psychologists was the reaction time to say whether the statements were true or false. In fact, when the two cities were in separate countries, that is, separate categories, the reaction times were faster than when the two cities were in the same country, even if the distance between cities was smaller between countries than within (WILTON, 1979).

A similar experiment assessed reaction time to verify statements about easterly or westerly directions of pairs of cities in North Dakota and Minnesota (MAKI, 1981). Here, the closer together the two cities, the longer it took to make the judgment, but only for cities in the same state. For cities between states, the judgments were in general fast, and did not depend on the distance between them. Being in separate states seemed to be sufficient grounds for answering the question.

The third example of hierarchical organization of spatial information uses yet another dependent measure, estimates of distance between locations, in this case, buildings in Ann Arbor, Michigan. HIRTLE and JONIDES (1985) found out how individual subjects grouped or organized some of the well-known landmarks in Ann Arbor. The groupings were partly by proximity and partly by similarity of function, for example campus buildings and commercial establishments were more likely to be grouped together. They also asked the same subjects to estimate the distances between the landmarks. The interesting finding was that distances between landmarks in the same group were underestimated relative to distances between landmarks in different groups. That is, the same real distance was remembered as smaller if it was between points in the same group but larger if it was between points in different groups.

Let me summarize the three effects of categorization or hierarchical organization. First, people group the cities on maps and the landmarks in their home towns into higher-order categories. Sometimes these are geographical categories such as states and countries, but sometimes they are conceptual categories, such as university buildings vs official city buildings vs commercial buildings. People then use these categories instead of or in addition to the Euclidean information in a map or environment, and the categories distort memory in various ways. People infer the direction of entities in a category from the overall direction of the category, thereby distorting the direction of cities in a state in the overall direction of the state. People are faster to make judgments of direction when cities are in two different states or categories than when they are in the same state. And when the two cities are in the same state, the farther apart they are, the easier it is to judge which is more north or east. Categorization also affects distance estimates. People estimate distances between entities in the same category as relatively smaller than distances between entities of different categories.

The distortions resulting from hierarchical organization have had a considerable impact on the way psychologists think about cognitive maps. This is partly because these distortions are such a clear violation of map-like properties, and thus an equally clear indication that cognitive maps are not like actual maps. That spatial information is hierarchically organized is also appealing because hierarchical organization is characteristic of memory for linguistic material, from words to text, so that it suggests a common basis for spatial and linguistic memory. Many others have explored or commented on hierarchical phenomena in cognitive maps, for example, CHASE (1983), HIRTLE and MASCOLO (1986), McNAMARA (1986), and McNAMARA *et al.* (1989).

Cognitive Perspective

A second factor leading to systematic errors in distance judgments is the perspective from which the judgment is made. Again, let me illustrate that phenomenon with an example from experiments, this time research by HOLYOAK and MAH (1982). These experimenters asked subjects, also from Ann Arbor, to judge the distances between pairs of American cities: San Francisco, Salt Lake City, Denver, Kansas City, Indianapolis, Pittsburgh, and New York City. Some of the subjects were asked to imagine themselves on the east coast when making those judgments and some of the subjects to imagine themselves on the west coast when making the judgments. Other subjects were given no specific reference point. In general, subjects exaggerated the distances between cities closer to their perspective relative to distances between cities farther from their perspective. Another way of putting this phenomenon is that we see more clearly more differences close to where we are than far from where we are. So the cartoons and posters that popularize the New Yorker's view of the United States or the New Englander's view of the United States are right, or at least psychologically right.

Holyoak and Mah, however, showed something that the cartoons and posters have not shown, and that is that reference points are flexible. Remember that the subjects in the experiment were living in Ann Arbor and randomly divided into east and west coast perspectives. Nonetheless, they were able to adopt either perspective, as indicated by distortions from either one.

Cognitive Reference Points

One very useful way to organize spatial information is around landmarks. For example, when asked where we live, we often say near the nearest landmark. When giving directions, we often start with a nearby landmark, and then give a detailed route. Thus, landmarks are implicitly or explicitly used to define neighborhoods. Landmarks are typically prominent and familiar structures in an environment. Many theories of acquisition of environments maintain that we first learn relative locations of landmarks, then we learn routes between them, and, finally, we fill in survey or distance information (despite their popularity, there are difficulties with such theories, including the present challenges to survey knowledge).

Perhaps for some or all of those reasons, landmarks apparently distort the space around them. SADALLA *et al.* (1980) selected a set of landmarks on the Arizona State campus from students' ratings of familiarity and location. They then asked students to estimate distances between pairs of campus locations, using either a landmark or a relatively unknown location as reference objects. They found asymmetries in distance estimates for the same pair of locations, depending on whether a landmark or an ordinary building was used as a reference object. When a landmark served as a reference, ordinary buildings were judged closer to it than vice versa.

Landmarks draw buildings closer to them, but ordinary buildings do not. Of course if the same person were asked both questions at the same time, there probably would not be any inconsistency or asymmetry in the distance estimates. People would impose symmetry on their distance estimates, knowing that distances must be symmetric. Like the effects of hierarchical organization and cognitive perspective, the distance asymmetries produced by landmarks are a clear violation of the true distance relations in the world, and another demonstration that cognitive maps are not veridical.

Other Causes of Distance Distortions

These three factors, hierarchical organization, perspective, and reference points, are by no means a complete catalog of factors leading to systematic errors in judgment of distance. Estimates of Euclidean distance between points are greater when a route has a barrier or detour than when a route is relatively direct (COHEN *et al.*, 1978; KOSSLYN *et al.*, 1974; NEWCOMBE and LIEBEN, 1982; THORNDYKE, 1981). Indeed, people do not seem to have direct perception of route distance, especially over distances that cannot be perceived at once. Rather, people seem to use a variety of surrogates in order to estimate distance, and these surrogates are not necessarily perfectly correlated with distance. Among the surrogates people have been demonstrated to use are: number of turns (SADALLA and MAGEL, 1980), number of nodes (SADALLA and STAPLIN, 1980b), amount of information remembered (SADALLA and STAPLIN, 1980a), and amount of clutter (THORNDYKE, 1981). BYRNE (1982) and GOLLEDGE (1978), among others, have used this sort of information in their models of cognitive maps.

Errors: Representation or Processing?

The term 'cognitive map' is one of those terms that is so useful that it is used in different ways for different people. Sometimes it carries with it the notion of an image, of a mental picture that can be internally consulted for information. Whether or not it is regarded as an image, it is usually thought to be a coherent whole. Here, I am using the term without either of those connotations and in a very broad sense, as whatever cognitive apparatus underlies the relevant behavior, be it recognition memory for maps or environments, distance estimates or direction judgments. In theory, underlying such behavior is both a mental representation and some sort of processing performed on it. In practice, however, it is difficult to distinguish what behavior is due to a mental representation and what behavior is due to processing. Thus, the distortions I am reviewing could be a product of a distorted representation or biased processing, or both. And from the way I have defined them, cognitive maps underlying such distortions may include both mental representations and mental processing.

Similar Distortions for Social Stimuli

So far, I have reviewed three cognitive processes that yield systematic errors in spatial cognition, categories or hierarchical organization, cognitive perspective, and cognitive reference points or landmarks. All of these processes are useful in organizing and remembering spatial information, but all distort that information, sometimes in subtle ways. Interestingly, these three sources of error appear not only in spatial cognition, but in judgment and thinking about other topics as well. People naturally form categories for all sorts of things, for example Swedes or Italians, or librarians or politicians, or chess players or movie actresses. We tend to perceive people in the same category to be more similar to each other even on irrelevant qualities than people in different groups, just as we think of cities in the same state as closer than cities in different states. We ourselves belong to social classes, our family, our college, our hometown team, our business, and our political party serve as our own cognitive perspective. We tend to see the differences in the members of our own group more readily than we see the differences among members of other groups (QUATTRONE, 1986). Instead, we lump *them*, the others, all together as liberals or conservatives, according to our own dispositions. This is analogous to taking a New Yorker's view of the United States, to seeing finer discriminations in the nearby territory than in the faraway territory. Finally, there are asymmetries in our social and political judgments that are analogous to the landmark asymmetries. People judge North Korea to be more similar to China than China to North Korea, or East Germany to be more similar to the Soviet Union than vice versa [or they did ten years ago (TVERSKY and GATI, 1978)]. So, these three principles for organizing information are pervasive in cognition, they have parallels in other domains of thought.

Faded Picture vs Constructionist View of Pictorial Memory

This view of cognitive maps stands in stark contrast to what might be termed a 'faded picture' view of memory for the visual world, that memory for the visual world is like snapshots that dim over time. If memory fades randomly, then memory errors would not be systematic. Instead, the view of memory for the visual world that the data seem to favor is a constructionist view, that representations of the visual world are constructed, and that systematic errors may be introduced in the construction of representations as well as in retrieval of information from them. On reflection, memory for the visual world would not be very useful if it consisted of unrelated snapshots. For example, we often perceive or explore a room or an environment from one particular point of view. But what we need to remember, and often seem to construct, is a more general representation of the spatial relations of the objects in the room or the landmarks in the environment. That way, if we encounter the environment from another point of view we may still recognize it or know how to navigate it. In fact, people appear spontaneously to integrate spatial material [e.g. MOAR and CARLETON (1982)] to make spatial inferences [e.g. LEVINE *et al.* (1982)]. So, although the faded picture point of view is implicit in much research and theory, it not only does not seem to be an efficient way to remember, but it also seems to be contradicted by the evidence.

A Theory of Map/Environment Comprehension and Memory

What follows is an analysis of the perceptual and conceptual processing that occurs when people comprehend a map or an environment (TVERSKY, 1981, 1991; TVERSKY and SCHIANO, 1989). This framework can account for some of the distorting factors and elucidates two additional ones. What people do and do not remember, is, for the most part, a consequence of that processing. One of the first processes in visual comprehension is distinguishing figures from backgrounds. Land masses, landmarks, and the like can be regarded as figures on backgrounds. Once distinguished, figures must be located, oriented, and identified. In the absence of a clear frame of reference, figures are difficult to locate. There is an old phenomenon in psychology known as the autokinetic effect. When people are seated in a dark room illuminated only by a tiny stationary light, that light appears to move. This is part of the reason that star-gazing is so difficult. Yet, assigning an orientation to a figure is an inseparable part of identifying the figure. This is why misoriented figures are so difficult to identify (ROCK, 1973; JOLICOEUR, 1985). What is more, figures that are not oriented tend to be unstable. ATTNEAVE (1971) has nicely demonstrated that with sets of triangles, which appear to be pointing first one way and then another way, and when the orientation appears to shift, it appears to shift for the whole set of triangles at once.

Figures, even nonsense figures, that have no assigned orientation may nevertheless have a natural orientation, that is, an orientation preferred by most observers (BRAINE, 1978). Braine showed stick and geometric figures to children and adults from many different cultures, and asked them which way was up. Some features determining orientation could be inferred from people's spontaneous orientations. They preferred to have focal features at the top, preferred vertical symmetry to horizontal symmetry, and vertical elongation to horizontal elongation. Of course, the very familiar real-world figure that has those properties is the human body.

Rotation

What happens when the natural orientation of a figure and its actual orientation conflict? One possibility is that the conflict between them is reduced by remembering the orientation of the figure as closer to the orientation of the frame of reference. This tendency was termed *rotation*, and is similar to the Gestalt organizing principle of *common fate*. In one task demonstrating rotation, students were given cut-outs of South America and a canonical frame of reference. They were asked to put South America in the frame of reference as it actually is with respect to north–south and east–west. Because the northern coast of South America is fairly straight but tilts upwards to the west and the southern tail also tilts westward, South America, in its proper north–south orientation, looks tilted. And, in fact, most of the subjects oriented South America as more upright than it really is. They rotated South America closer to an orientation where it would balance, that is, where a plane dividing it in half would be vertical.

Another task demonstrating rotation took advantage of the fact that the Bay Area surrounding Stanford is not naturally oriented in the north–south east–west frame of reference. Rather, the northern cities are far west of the southern cities, so much so that it is more accurate to say that the Bay runs diagonally northwest to southeast than to say that it runs north–south. In this task, borrowed from Stevens and Coupe, subjects were asked to draw the direction they would go in order to get from Stanford to Berkeley, for example, or from Palo Alto to Santa Cruz. Most of the subjects correctly indicated that Berkeley was north of Stanford, but they incorrectly indicated that Berkeley was east of Stanford. In fact, Stanford is slightly east of Berkeley (as anyone who knows the two universities knows). Similarly, most subjects knew that they needed to go south to get to Santa Cruz, but thought they should also go west, although Santa Cruz is actually east of Palo Alto. It is again as if people are mentally rotating the Bay Area to upright, thinking of the Bay as running north–south instead of at an angle.

Rotation was also demonstrated in memory for local environments, in particular rotation of streets towards right angles, in memory for artificial maps, and in memory for shapes not interpreted as maps. Other researchers have demonstrated rotation as well, notably BYRNE (1979), CHASE and CHI (1983), LLOYD (1989), LLOYD and HEIVLY (1987), and MOAR and BOWER (1983). These rotation phenomena may seem reminiscent of the landmark phenomena discussed earlier. It does seem that a similar process underlies both of them. In both cases, figures are remembered relative to a reference point or frame, with consequent distortions in memory, of distance in the case of landmarks, and orientation in the case of rotation.

Rotation was predicted from the analysis of perceptual processing. The idea was that figures are remembered with respect to a frame of reference, and that, when the orientation of the frame of reference and the natural orientation of the figure conflict, the figure's orientation will be remembered as closer to that of the frame of reference. Like cognitive reference points, cognitive frames draw other elements towards them.

Alignment

A second way to remember the location and orientation of figures is to remember one figure relative to another or several others. Again, it is the relative locations of objects in scenes that we try to remember, not the absolute locations as viewed from a particular place. This second organizing principle, which has been termed *alignment*, is related to the Gestalt organizing principle of grouping by proximity. The prediction is that two figures that are perceived as grouped together but are misaligned, that is, offset in one spatial dimension, are remembered as more aligned than they really are.

To demonstrate alignment, maps of the world were systematically altered in the direction of alignment, and subjects were asked to choose between the correct map and the altered map. In looking at the world map that adorns the walls of so many school classrooms, one natural east–west grouping is the United States with Europe and South America with Africa. However, on the real map, Europe is north of the United States and Africa is north of South America. That is, the east–west pairs are somewhat misaligned north–south. In the altered map, the Americas were moved northward relative to Europe and Africa. In fact, a significant majority of subjects chose the altered map as being closer to the true map. Another natural way to group countries on the world map is north–south. For the Western Hemisphere, North and South America are likely to be perceived as grouped. However, North America is for the most part west of South America. In the altered map of the Western Hemisphere, South America was moved westwards, making the two Americas more aligned than they really are. As before, a significant majority of subjects selected the incorrect, more aligned map as being closer to the true map. Other subjects were asked to indicate the directions of pairs of cities. Errors in the direction of alignment appeared. A majority of subjects thought that Rome was south of Philadelphia, Monaco south of Chicago, and Algiers south of Los Angeles, all of which are incorrect. East–west alignment errors were made between pairs of cities between North and South America. I do not think we can blame the U.S. eduction system for these errors. Again, they seem to be a natural consequence of perceptual processing. Alignment errors were obtained in other studies of memory for local environments, memory for artificial maps, and memory for meaningless shapes.

Alignment and rotation are consequences of the perceptual and conceptual processing done on the visual world as we experience and comprehend it. We isolate figures from a background, and then organize them by relating their locations and orientations to a frame of reference and to other figures. Both these organizational processes lead to systematic error. Like the effects of hierarchical organization and of cognitive reference points, the effects of alignment and rotation are to draw figures closer to them. In fact, it seems that all of these organizing principles reduce to a simpler one. We relate figures to referents, either on the same level of analysis, such as reference points or other figures, or at a superordinate level of analysis, such as reference frames or hierarchical category, and then remember the figures as closer to and/or more aligned with their referents. They are similar to anchoring or leveling phenomena in perception. These are not the only factors that lead to systematic errors in cognitive maps. The perspective distortion of HOLYOAK and MAH (1982), the distance distortions due to barriers, turns, and clutter, and the area distortions observed by KEMP (1988) are errors that do not fit easily into the framework of perceptual and conceptual processing in comprehension outlined above. These seem to be due to procedures invoked in judgment.

As we navigate an environment, or make inferences from memory of one, we draw on information from many different sources, from particular episodes in the environment and schematic knowledge of the environment, from verbal descriptions and visual experience, from information specific to the environment, and from general information about that kind of environment [see also KUIPERS (1978)]. When all that information is put together, it does not necessarily form a coherent picture, something that could be drawn on paper or modeled in three dimensions. On the contrary, the different bits and pieces may very well conflict with each other, something that would not be evident without an attempt to put them together. I end here as I did in 1981: cognitive maps may be impossible figures.

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