Navigating by Mind and by Body

Barbara Tversky[1]
Stanford University
Department Of Psychology
420 Jordan Hall
Stanford, Ca 94305
{bt@psych.stanford.edu}

Abstract

Within psychology, at least two research communities study spatial cognition. One community studies systematic errors in spatial memory and judgement, accounting for them as a consequence of and clue to normal perceptual and cognitive processing. The other community studies navigation in real space, isolating the contributions of various sensory cues and sensori-motor systems to successful navigation. The former group emphasizes error, the latter, selective mechanisms, environmental or evolutionary, that produce fine-tuned correct responses.

How can these approaches be reconciled and integrated? First, by showing why errors are impervious to selective pressures. The schematization that leads to errors is a natural consequence of normal perceptual and cognitive processes; it is inherent to the construction of mental spaces and to using them to make judgments in limited capacity working memory. Selection can act on particular instances of errors, yet it is not clear that selection can act on the general mechanisms that produce them. Next, in the wild, there are a variety of correctives. Finally, closer examination of navigation in the wild shows systematic errors, for example, over-shooting in dead reckoning across species. Here, too, environments may provide correctives, specifically, landmarks. General cognitive mechanisms generate general solutions. The errors inevitably produced may be reduced by local specific sensori-motor couplings as well as local environmental cues. Navigation, and other behaviors as well, are a consequence of both.

1. Two Research Communities in Psychology

Yes, the title evokes the mind-body problem. However one regards the venerable monumental mind-body problem in philosophy, there is a contemporary minor mind-body problem in the psychological research on spatial cognition. While the major problem is how to integrate the mind and the body, an additional minor problem in spatial cognition is how to integrate the approaches—and the researchers—on the mind and on the body. The community studying spatial judgments and that studying wayfinding rarely interact. Or have rarely interacted. These conferences of minds may be a meeting point and a turning point.

The two communities, the mind community, and the body community, differ in their agendas and differ in the tools to carry out them out. The mind community studies spatial judgments: what is the direction between San Diego and Reno? How far is Manchester from Glasgow? Manchester from Liverpool? The Eiffel Tower to Jacque's house? How do I get to San Marco? The questions are cleverly chosen. They are designed to yield errors. The design works because the errors are a consequence of the way spatial information is represented and used. In fact, one goal of this approach is to reveal those cognitive representations and mechanisms, many of which appear not only in spatial judgments, but in other domains as well (e. g., Tversky, 1993; 2000a; 2000b).

In contrast, the body community studies the cues, visual, auditory, kinesthetic, vestibular, that people and animals use to arrive at their destinations. The research reduces the sensory input and diminishes the environmental richness in order to isolate the role of a particular cue or system in guiding the organism. In many cases, the goal is to reveal the elegant fine-tuning of a particular cue or sets of cues or sensory-motor systems to specific aspects of environments (see, for examples, Gallistel, 1990 and papers in the volume edited by Golledge, 1999, especially the paper by Berthoz, Amorim, Glassauer, Grasso, Takei, and Viaud-Del,mon and Loomis, Klatzky, Golledge, and Philbrick).

To caricature the approaches, the emphasis of the mind community is to reveal the systems generating error and the emphasis of the body community is to reveal the systems generating precision.

No wonder the community of mind and the community of body pass each other by like the proverbial ships in the night. They differ in the tasks they give, in the responses they collect, in the processes they propose to account for the responses to the tasks. And, perhaps most significantly, they differ philosophically, in their fundamental attitudes toward human nature. For the mind group, being human is fundamentally about limitations, limitations in representations and in processing, in capacity and in computation. Those limitations can be revealed in errors. The errors provide clues to normal operations. For the body group, being human is fundamentally about evolution and learning, about selection and adaptation, pressures toward perfection. Again, these are caricatures of the positions, hence not attributed to any of the fine reasonable people in the fields, but caricatures that are close enough to the truth to warrant further discussion. And perhaps, rapprochement, even integration, of the approaches.

Neither evolution nor adaptation are doubted. Both communities believe that organisms have evolved in and continue to live in environments, and that the environments have selected successful behaviors across the millennia through evolution and across the lifespan through learning. So the real puzzle is not why some spatial behaviors are exquisitely precise and fine-tuned, but rather why systematic errors persist. Before that question can be addressed, a review of some of the documented errors is in order. Then these errors must be accounted for by an analysis of the general mechanisms that produce and maintain them

2. Systematic Distortions of Distance and Direction

2.1 Errors of Distance.

First, what errors do we mean? Errors of distance estimates, for one. They are affected by irrelevant factors, such as hierarchical organization. Elements, like cities or buildings, within the same group are perceived as closer than those in different groups. The groups might be states or countries. The groups need not be geographic; they can be functional or conceptual. Distances between a pair of academic buildings or a pair of commercial buildings in Ann Arbor are perceived as shorter relative to distances between an academic and a commercial building (Hirtle and Jonides, 1981). Arabs perceive distances between pairs of Arab settlements to be smaller than distances between an Arab and a Jewish settlement; similarly, Jews perceive distances between Jewish settlements to be shorter than distances between an Arab and a Jewish settlement (Portugali, 1993). Grouping is reflected in reaction times to make distance estimates as well; people are faster to verify distances between geographic entities such as states or countries than within the same entity (e. g., Maki, 1981; Wilton, 1979). Another factor distorting distance estimates is the amount of information along the route. Distance judgments for routes are judged longer when the route has many turns (e. g., Sadalla and Magel, 1980) or landmarks (e. g., Thorndyke, 1981) or intersections (e. g., Sadalla and Staplin, 1980). Similarly, the presence of barriers also increases distance estimates (e. g., Newcombe and Liben, 1982). Most remarkably, distance judgements are not necessarily symmetric. Distances to a landmark are judged shorter than distances from a landmark to an ordinary building (Sadalla, Burroughs, and Staplin, 1980; McNamara and Diwadker, 1997). Similar errors occur for prototypes in similarity judgments: people judge atypical magenta to be more similar to prototypic red than red to magenta (Rosch, 1975). Landmarks seem to define neighborhoods and prototypes categories whereas ordinary buildings and atypical examples do not. Ordinary buildings in the vicinity of a landmark may be included in the neighborhood the landmark defines.

2.2 Errors of Direction.

Systematic errors occur for judgments of direction as well. Hierarchical organization is again a factor. For example, the overall direction between pairs of states appears to be used to judge the direction between pairs of cities contained in the states. The example so famous that it has become a Trivia Pursuit question is the direction between San Diego and Reno. Students in San Diego erroneously indicated that San Diego is west of Reno (Stevens and Coupe, 1978). That is, the overall direction of the states is used to infer the directions between cities within those states. But errors of direction occur within groups as well, for example, informants incorrectly report that Berkeley is east of Stanford (Tversky, 1981). This error seems to be due to mentally rotating the general direction of the surrounding geographic entity, in this case, the south Bay Area to the overall direction of the frame of reference, in this case, north-south. In actuality, the south Bay Area runs nearly diagonally with respect to the overall frame of reference, that is, northwest to southeast. Geographic entities create their own set of axes, typically around an elongated axis or an axis of near symmetry. The axes induced by the region may differ from the axes of its' external reference frame. Other familiar cases include South America, Long Island, Japan, and Italy. In this error of rotation, the natural axes of the region and those of the reference frame are mentally brought into greater correspondence. Directions also get straightened in memory. For example, asked to sketch maps of their city, Parisians drew the Seine as a curve, but straighter than it actually is (Milgram and Jodelet, 1976). Even experienced taxi drivers straighten the routes they ply each day in the maps they sketch (Chase and Chi, 1981).

2.3 Other Errors.

These are not the only systematic errors of spatial memory and judgment that have been documented; there are others, notably, errors of quantity, shape, and size, as well as errors due to perspective (e. g., Tversky, 1992; Poulton, 1989). Analogous biases are found in other kinds of judgements: for example, people exaggerate the differences between their own groups, social or political, and other groups, just as they exaggerate the distances between elements in different geographic entities relative to elements in the same geographic entity. The errors are not random or due solely to ignorance; rather they appear to be a consequence of ordinary perceptual and cognitive processes.

3. Why do Errors Exist?

3.1 Schematization Forms Mental Representations.

A number of perceptual and cognitive processes are involved in establishing mental representations of scenes or depictions, such as maps. Isolating figures from grounds is one of them; figures may be buildings or roads, cities or countries, depending on what is represented. Figures are then related to one another and to a frame of reference from a particular perspective (e. g., Tversky, 1981; 1992; 2000a). Natural as they are, essential as they are, these perceptual organizing principles are guaranteed to produce error. They simplify, approximate, omit, and otherwise schematize the geographic information. Schematization thereby produces error.

How does this happen? Consider these examples. Relating figures to one another draws them closer in alignment in memory than they actually are. Evidence comes from a task where students were asked to select the correct map of the Americas from a pair of maps in which one was correct and the other had been altered so that South America was more aligned with North America. A majority of students selected the more aligned map as the correct one (Tversky, 1981). The same error was obtained for maps of the world, where a majority preferred an incorrect map in which the U.S. and Europe were more aligned. Alignment occurred for estimates of directions between cities, for artificial maps, and for blobs. Relating a figure to a reference frame yields the rotation errors described in the section on errors of direction. Like alignment, rotation occurs for directions between cities, for artificial maps, and for blobs.

3.2 Schematization Allows Integration.

Many environments that we know, navigate, and answer questions about are too large to be perceived from a single point. Acquiring them requires integrating different views as the environment is explored. Even perceiving an environment from a single point requires integration of information, from separate eye fixations, for example. How can the different views be integrated? The obvious solution is through common elements and a common reference frame. And these, elements and reference frames, are exactly the schematizing factors used in scene perception. To make matters more complex, knowledge about environments comes not just from exploration, but from maps and descriptions as well, so the integration often occurs across modalities. Again, the way to link different modalities is the same as integrating different views, through common elements and frames of reference.

3.3 Schematization Reduces Working Memory Load. A third reason for schematization is that the judgments are performed in working memory, which is limited in capacity (e. g., Baddeley, 1990). Providing the direction or distance or route between A and B entails retrieving the relevant information from memory. This is unlikely to be in the form of a prestored, coherent memory representation, what has been traditionally regarded as a cognitive map. More likely it entails retrieving scattered information and organizing it. Moreover, whatever is stored in memory has already been schematized. All this, and the judgment as well, is accomplished in working memory. Like mental multiplication, this is burdensome. Anything that reduces load is useful, and schematization does just that. This is similar to reducing bandwidth by compression, but in the case of constructing representations in working memory, the compression is accomplished by schematization, by selecting the features and relations that best capture the information

3.4 Spatial Judgments are Typically Decontextualized. Unlike navigation by the body, navigation in the mind is without support of context. This is in sharp contrast to the spatial behaviors that are precise, accurate, and finely-tuned, such as catching balls, playing the violin, wending one's way through a crowd, finding the library or the subway station. Context provides support in several ways. First it provides constraints. It excludes many behaviors and encourages others. The structure of a violin constrains where the hands, fingers, chin can be placed and how they can be moved. The structure of the environment constrains where one can turn, where one can enter and exit. The world does not allow many behaviors that the mind does. Second, natural contexts are typically rich in cues to memory and performance. For memory, contexts, like menus on computer screens, turn recall tasks into recognition tasks. A navigator doesn't need to remember exactly where the highway exit or subway entrance is as the environment will mark them. The presence of context means that an overall plan can leave out detail such as exact location, direction, and distance. In fact, route directions and sketch maps leave out that level of detail, yet have led to successful navigation across cultures and across time (e. g., Tversky and Lee, 1998, 1999). For performance, context facilitates the specific actions that need to be taken. In the case of playing the violin, this includes time and motion, the changing positions of the fingers of each hand. In the case of wayfinding, this also includes time and motion of various parts of the body, legs in walking, arms, hands, and feet in driving.

4. Why do Errors Persist?

4.1 Rarely Repeated.

Context and contextual cues provide one reason why spatial behaviors by the body may be highly accurate and spatial behaviors by the mind biased. Contexts constrain behaviors and cue behaviors. Contexts are also the settings for practice. As any violin player or city dweller knows, the precise accurate spatial behaviors become so by extensive practice. The efforts of beginners at either are full of false starts, error, and confusion. Practice, and even more so, practice in a rich context supporting the behavior, is the exception, not the rule, for navigation by the mind, for judgements from memory. Indeed, for the judgments that we are called upon to make numerous times, we do eventually learn to respond correctly. I now know that Rome is north of Philadelphia and that Berkeley is west of Stanford.

4.2 Learning is Specific, not General.

But knowing the correct answer to a particular case corrects only that case, it does not correct the general perceptual and cognitive mechanisms that produce schematizations that produce the errors. Knowing that Rome is north of Philadelphia doesn't tell me whether Rome is north of New York City or Boston. Knowing that Rome is north of Philadelphia doesn't inform me about the direction from Boston to Rio either. Learning is local and specific, not general and abstract. Immediately after hearing an entire lecture on systematic errors in spatial judgments, a classroom of students made exactly the same errors.

The mechanisms that produce the errors are multi-purpose mechanisms, useful for a wide range of behaviors. As noted, the mechanisms that produce errors derive from the mechanisms used to perceive and comprehend scenes, the world around us. The schematizations they produce seem essential to integrating information and to manipulating information in working memory. In other words, the mechanisms that produce error are effective and functional in a multitude of ways.

4.3 Correctives in Context.

Another reason why errors persist is that they may never be confronted. Unless I am a participant in some abstruse study, I may never be asked the direction between Rome and Philadelphia, from Berkeley to Stanford. Even if I am asked, I may not be informed of my error, so I have no opportunity to correct it. And if I am driving to Berkeley, my misconception causes me no problem; I have to follow the highways. Similarly, if I think a particular intersection is a right-angle turn when in fact it is much sharper, or if I think a road is straighter than it is, the road will correct my errors, so I can maintain my misconception in peace. In addition, these errors are independent of each other and not integrated into a coherent and complete cognitive map, so there is always the possibility that errors will conflict and cancel (e. g., Baird, 1979; Baird, Merril, and Tannenbaum, 1979). Finally, in real contexts, the extra cues not available to working memory become available, both cues from the environment, like landmarks and signs, and also cues from the body, kinesthetic, timing, and other information that may facilitate accuracy and overcome error. In short, schematic knowledge, flawed as it is, is often adequate for successful navigation.

5. Systematic Errors in the Wild

Now the caricature of the communities that has been presented needs refinement. Despite millennia of selection by evolution and days of selection by learning, navigation in the wild is replete with systematic errors. One studied example is path integration. Path integration means updating one's position and orientation while navigating according to the changes in heading and distances traveled, the information about one's recent movements in space (Golledge, 1999, p. 122). A blindfolded navigator traverses a path, turns, continues for a while, and then heads back to the start point. How accurate is the turn to home? Ants are pretty good, so are bees, hamsters, and even people. But all make systematic errors. Bees and hamsters overshoot (Etienne, Maurer, Georgakapoulus, and Griffin, 1999). People overshoot small distances and small turns and undershoot large ones (Loomis, Klatzky, Golledge, and Philbeck, 1999), a widespread error of judgment (Poulton, 1989). But the situation that induced the errors isn't completely wild; critical cues in the environment have been removed by blindfolding or some other means. In the wild, environments are replete with cues, notably, landmarks, that may serve to correct errors.

6. Implications

How do people arrive at their destinations? One way would be to have a low-level, finely-detailed sequence of actions. But this would only work for well-learned routes in unchanging environments; it wouldn't work for new routes or vaguely known routes or routes that encounter difficulties, such as detours. For those, having a global plan as well as local actions seem useful. These are global and local in at least three senses. Plans are global in the sense of encompassing a larger environment than actions, which are local. Plans are also global in the sense of being general and schematic, of being incompletely specified, in contrast to actions, which are specific and specified. Plans are global in the sense of being amodal, in contrast to actions, which are precise movements of particular parts of the body in response to specific stimuli. A route map is a global plan for finding a particular destination, much as a musical score is a global plan for playing a particular piece on the violin. Neither specifies the exact motions, actions to be taken.

Several approaches to robot navigation have recommended the incorporation of both global and local levels of knowledge (e. g., Chown, Kaplan, and Kortenkamp, 1995; Kuipers, 1978, 1982; Kuipers and Levitt, 1988). The current analysis suggests that global and local levels differ qualitatively. The global level is an abstract schematic plan, whereas the local level is specific sensori-motor action couplings. Integrating the two is not trivial.

The gap between the mind navigators and the body navigators no longer seems so large. True, the focus of the mind researchers is on judgments and the challenge is to account for error and while the focus of the body researchers is on behavior and the challenge is to account for success. Yet, both find successes as well as systematic errors. And in the wild, the correctives to the errors are similar, local cues from the environment.

Systematic errors persist because the systems that produce them are general: they are useful for other tasks and they are too remote to be affected by realization of local, specific errors. Spatial judgment and navigation are not the only domains in which humans make systematic errors. Other accounts have been made for other examples (e. g., Tversky and Kahneman, 1983). It makes one think twice about debates about the rationality of behavior. How can we understand what it means to be rational if under one analysis, behavior seems replete with intractable error but under another analysis, the mechanisms producing the error seem reasonable and adaptive.

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