Structures of Mental Spaces

12

Barbara Tversky
Stanford University, USA

12.1

Keywords:
space, body, mental representation, spatial perception

Barbara Tversky
Professor, Cognitive Studies, Department of Psychology, Stanford University, Stanford CA
bt@psych.stanford.edu

How People Think about Space

Human activity takes place in space. Sometimes, interactions in space are explicit, as we grasp the things around us or find our ways inside and out. Other interactions are implicit, an awareness of where we are, where the things around us are. Still other spatial interactions are in imagination, when we estimate distances, or give directions, or describe a journey. To act effectively in space, humans need conceptions of space. We know about space and the things in it from looking, from hearing, from touching, from imagining, and from description. The knowledge obtained from these different sources is different; sometimes integrated and coherent, other times, not.

The mental representations that we form of space from these real and imagined interactions differ from the external representations of spaces of geometry or of physics or of maps. For geometry, physics, and maps, space is basic, metric, uniform, and unitary, and things are located in it. In human conceptions of space, the things in space are basic, and the qualitative spatial relations among them form a scaffolding. Which things and which spatial relations depend on the space. We interact with many spaces, the space of the body in eating or dancing, the space around the body in basketball or soccer, the space of navigation in wayfinding or estmating distances. Each of these spaces is represented schematically, in terms of the elements and spatial relations important to it.

The Space of the Body

The different spaces and their structure depend on and are distinguished by the functions they serve us. One space critical for human behavior is the space of the body. The body is naturally divided into parts, varying in size, perceptual prominence, functional significance. Which of these factors determine the importance of the parts? To answer that question, Morrison and I (1997) examined times to verify body parts named frequently across languages, head, arm, hand, chest, back, leg, foot. We presented either the name of a body part or a depiction of a body with a part highlighted paired with a comparison depiction of a body in a different posture with a part highlighted. The task of participants was to say whether the named part or first depicted part was the same as the comparison depicted part. On half the trials, the correct answer was "same;" on half, "different." The data of interest are the relative speeds of verifying the different parts. If large parts are the essential elements of the way we think about bodies, then parts like leg and back should be fastest. If, however, parts with greater functional significance are essential, then parts like head and hand should be fastest. One index of functional significance is the relative space allotted to the part by sensorimotor cortex. In fact, times to verify body parts were faster for the functionally significant parts and slower for the large parts. Functional significance turns out to correlate with another aspect of objects important in their recognition, a perceptual feature of objects, namely, contour discontinuity (Biederman, 1986; Hoffman and Richards, 1984; Tversky and Hemenway, 1984). The fact that perceptual features of objects and bodies correlate with more abstract, functional features is of fundamental importance, especially as it occurs in other domains. Because of this, humans can (and do) use perceptual salience as a sign of functional significance. For bodies as for many things, the correlation between contour discontinuity and functional significance is not perfect; for example, "chest" is a functionally significant part but does not have discontinuity with contour. Interestingly, perceptual salience predicts reaction times better for the body-body comparisons, which can be done without accessing the meaning of the visual stimuli. For name-body comparisons, functional significance accounts better for the verification times. Naming seems to evoke function.

12.2 The Space Around the Body

Another space with functional significance for human activity is the space around the body, the space of things that can be seen from the current vantage point. Franklin, Bryant, and I have investigated this space, initially using narratives, eventually using real scenes and diagrams and models of scenes. The narratives described "you" in an environment like a museum or a barn surrounded by objects in front, back, left, right, above, and below you (Bryant, Tversky, and Franklin, 1992; Franklin and Tversky, 1990). After learning an environment from description, participants were verbally reoriented to "face" another object in the scene and probed with direction terms for the identity of the objects currently found at the various directions from the body. The data of interest were the relative times to retrieve the names of the objects in the various directions from the body. The retrieval times differed systematically. They indicated that the space around the body is conceived of three-dimensionally from a coordinate system based on extensions of the three major body axes, head/feet, front/back, and left/right. The relative times to respond to each axis depended on asymmetries of the body and of the world. Times to report the objects to head and feet were fastest, presumably because the head/feet axis is asymmetric and is correlated with the only asymmetric axis in the world, the axis of gravity. Front/back was next, as it is an asymmetric axis of the body, but not correlated with an asymmetric axis of the world. Left/right is slowest as it lacks salient asymmetries and does not correlate with an asymmetric axis of the world. The situation changes slightly when "you," the observer in the situation, are described as reclining in the environment and turning from front to back to sides. In that case, no body axis is correlated with a salient axis of the world, so retrieval times depend only on the asymmetries of the body. Front/back is faster than head/feet for the reclining observer, presumably because the front/back axis is more salient than the head/feet axis; the front/back axis is not only asymmetric, it also separates the world that can be easily seen and manipulated from the world which cannot be easily seen and manipulated. The theory accounting for the pattern of reaction times has been termed the Spatial Framework Hypothesis. It reflects people's enduring conceptions of the spatial world that they inhabit, rather than momentary internalized imagery of the current scene.

Variations of this situation have been tried, with sensible variations in the patterns of reaction times. For example, the spatial framework pattern of retrieval times emerged when scenes were taught from diagrams, models, or real life instead of from description, when memory is tested (e. g., Bryant and Tversky, 1999; Bryant, Tversky, and Lanca, in press). When the environment was described as moving rather than the observer, the spatial framework pattern appeared once new viewpoints are adjusted to, but adjusting to new viewpoints took twice as long when the environment was described as moving (Tversky, Kim, and Cohen, 1999). This finding also illustrates the influence of enduring conceptions of the perceptual world on mental representations of the spatial world. In the world as experienced, from people's perspectives, it is they who move, not environments, save unusual circumstances such as earthquakes.

The Space of Navigation

The space of navigation is the space we explore, the space we inhabit as we move from place to place, typically a space too large to be seen at once. One remarkable feat of the mind is to conceive of some large spaces at once, as integrated, and not piecemeal as they are experienced. The critical elements of the space of navigation are landmarks and paths. Like the space around the body, spatial relations in the space of navigation are schematized to one or more of several references frames, primarily based on viewer, object, or environment (e. g., Taylor and Tversky, 1996). Directions and axes are not represented analogically, but rather at least somewhat categorically, not, for example, in exact degrees. It is this schematization, into elements and paths relative to reference frames, that allows integration of fragments into a whole. Importantly, both sketches and descriptions schematize environments in the same way (Tversky and Lee, 1998, 1999). Unlike the space around the body, the space of navigation is generally conceived of in two dimensions, rather than three. Another impressive feat of the mind is that it can convert a space experienced vertically as three surrounding dimensions to a space that is two-dimensional as if viewed from above.

The evidence that the space of navigation is schematized comes from systematic errors in judgements on remembered spaces. Large environmental features, such as roads or states or countries are not remembered at their correct angles relative to an environmental reference frame, nor as randomly different from the environmental frame, but rather as more north-south or east-west than they actually are (Tversky, 1981). In sketch maps, people draw roads running at odd angles as more perpendicular and parallel to the dominant road structure. When asked to place South America in a north-south east-west frame, people upright South America; in fact, it seems tilted with respect to the cardinal axes. This error, in which large environmental features are remembered as closer to the axes of the overall reference frame, has been termed *rotation*. It occurs in a variety of judgments on real and artificial environments, and on meaningless blobs as well.

Large environmental features are remembered relative to each other as well as relative to an encompassing frame of reference. When asked to choose which world map is correct, the correct map or one in which the Americas are moved northwards so that the U. S. is more aligned with Europe and South America with Africa, a significant majority of people select the incorrect, aligned map. Similarly, when South America is moved westwards to be more directly aligned with North America, more people select that as the correct map than the correct map (Tversky, 1981). This error, in which large environmental features are remembered as more aligned with each other, has been called *alignment*. It also appears in a variety of judgements on real and artificial environments and on meaningless blobs.

These are not the only systematic errors in memory for large spaces. Environments are organized around salient landmarks, such as the Eiffel Tower or Times Square. This leads to violations of metric assumptions in judgements; that is, people estimate distances from a landmark to an ordinary building to be less than distances from an ordinary building to a landmark (Sadalla, Burroughs, and Staplin, 1980). Imagined perspective also distorts judgements, much along the lines of the Steinberg cartoons in the New Yorker; nearby distances loom larger than faraway distances (Holyoak and Mah, 1982). Given this variety of systematic errors, there is no guarantee that our mental conceptions of large spaces are coherent. In wayfinding, memory, and judgement, we make use of a multitude of information, not just remembered experiences with environments or remembered maps of environments. We also use verbal information, such as route directions or political or geographic descriptions. Rather than "cognitive map," a more apt metaphor for people's mental representations of large spaces is "cognitive collage" (Tversky, 1993).

The Space of Graphics

Humans also create small spaces, such as maps, architectural drawings, charts, diagrams, and graphs as aids to human memory and thinking. Some of these, such as maps, are ancient and pervasive across the world; others, such as graphs that represent visually things that are not inherently visual, are modern inventions. Graphic displays reduce the load on working memory by externalizing memory and cognitive operations. They also use space in cognitively natural ways rendering them easy to interpret. They use spatial elements and spatial relations metaphorically to convey abstract elements and abstract relations, taking advantage of human facility in spatial thinking (Tversky, 1995, in press).

Multiple Spaces

Human activity occurs in a multitude of spaces. The space of the body, the space immediately around the body, the space of navigation, and the space of graphics are a few of them. Each space subserves different functions. Consequently, each has a different mental structure. The elements and spatial relations critical to each space are determined by the functions subserved by that space. Schematization both reduces memory load and allows integration of disparate bits of information; however, it also introduces conditions that produce error. Because these spaces are represented schematically and because the elements and spatial relations vary with the space, there is no guarantee that the spaces are coherent and consistent, either within a space or between spaces. Mental spaces are impossible figures.

References

Biederman, I. (1987). Recognition-by-components: A theory of human image understanding. *Psychological Review,* 94, 115-145.

Bryant, D. J., Tversky, B., & Franklin, N. (1992). Internal and external spatial frameworks for representing described scenes. *Journal of Memory and Language,* 31, 74-98.

Bryant, D. J. and Tversky, B. (1999). Mental representations of spatial relations from diagrams and models. *Journal of Experimental Psychology: Learning, Memory and Cognition, 25,* 137-156.

Bryant, D. J., Tversky, B., & Lanca, M. (In press). Retrieving spatial relations from observation and memory. In E. van der Zee & U. Nikanne (Eds.), *Conceptual structure and its interfaces with other modules of representation.* Oxford, Oxford University Press.

Franklin, N. and Tversky, B. (1990). Searching imagined environments. *Journal of Experimental Psychology: General,* 119, 63-76

Franklin, N., Tversky, B., and Coon, V. (1992). Switching points of view in spatial mental models acquired from text. *Memory and Cognition,* 20, 507-518.

Hoffman, D. D. & Richards, W. A. (1984). Parts of recognition. *Cognition,* 18, 65-96.
Holyoak, K. J. and Mah, W. A. (1982). Cognitive reference points in judgments of symbolic magnitude. Cognitive Psychology, 14, 328-352.
Morrison, J. B., & Tversky, B. (1997). Body schemas. In M. G. Shafto & P. Langley (Eds.), *Proceedings of the Meetings of the Cognitive Science Society.* (pp. 525-529). Mahwah, NJ: Erlbaum.
Sadalla, E. K., Burroughs, W. J., and Staplin, L. J. (1980). Reference points in spatial cognition. *Journal of Experimental Psychology: Human Learning and Memory,* 6, 516-528.
Taylor, H. A. and Tversky, B. (1996). Perspective in spatial descriptions. *Journal of Memory and Language,* 35, 371-391.
Tversky, B. (1981). Distortions in memory for maps. *Cognitive Psychology,* 13, 407-433.
Tversky, B. (1991) Spatial mental models .In G. H. Bower (Ed.), *The Psychology* of *Learning and Motivation: Advances in Research and Theory.*Vol. 27 (pp. 109-145). N. Y.: Academic Press.
Tversky, B. (1993). Cognitive maps, cognitive collages, and spatial mental models. In A. U. Frank and I. Campari (Editors*), Spatial information theory: A theoretical basis for GIS*. Pp. 14-24. Berlin: Springer-Verlag.
Tversky, B. (1995). Cognitive origins of graphic conventions. In F. T. Marchese (Editor). *Understanding images*. Pp. 29-53. New York: Springer-Verlag.
Tversky, B. (2000a). Levels and structure of cognitive mapping. In R. Kitchin and S. M. Freundschuh (Editors). *Cognitive mapping: Past, present and future*. Pp. 24-43. London: Routledge.
Tversky, B. (2000b). Remembering spaces. In E. Tulving and F. I. M. Craik (Editors), *Handbook of Memory*. Pp. 363-378. New York: Oxford University Press.
Tversky, B. (In press). Spatial schemas in depictions. In M. Gattis (Editor), *Spatial schemas and abstract thought*. Cambridge: MIT Press.
Tversky, B. and Hemenway, K. (1984). Objects, parts, and categories. *Journal of Experimental Psychology: Genera*l, 113, 169-193.
Tversky, B., Kim, J. and Cohen, A. (1999). Mental models of spatial relations and transformations from language. In C. Habel and G. Rickheit (Editors), *Mental models in discourse processing and reasoning*. Pp. 239-258. Amsterdam: North-Holland.
Tversky, B. and Lee, P. U. (1998). How space structures language. In C. Freksa, C. Habel, and K. F. Wender (Editors), *Spatial Cognition: An interdisciplinary approach to representation and processing of spatial knowledge*. Pp. 157-175. Berlin: Springer-Verlag.
Tversky, B. and Lee, P. U. (1999). Pictorial and verbal tools for conveying routes. In Freksa, C. and Mark, D. M. (Editors). *Spatial information theory: cognitive and computational foundations of geographic information science*. Pp. 51-64. Berlin: Springer.