Spaces of Thought

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Abstract

People inhabit a variety of spaces, the space of the body, the space around the body, the space of navigation. They also create spaces to promote cognition, communication, and collaboration. People's mental representations of each of these spaces differ, and differ systematically from Euclidean space. Instead people's conceptions reflect their perception of and action in each space.

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Multiple Mental Spaces

Space is special. It is essential to survival. Without conceptions of space we would have a hard time getting food to our mouths or finding our way home at night. It is one of the earliest forms of knowledge. We act in space even before birth, and learn about space soon after, if not before. It is multimodal. We keep track of space with vision, but also with hearing, kinesthesis, smell, and touch. Spatial knowledge is fundamental to other forms of knowledge. We speak in spatial metaphors, think in spatial metaphors, and act in spatial metaphors. Somebody's at the top of the heap and someone else has fallen into a depression; we look forward to celebrations and back on fond memories.

Our conceptions of space are not like those of physicists or surveyors where spatial coordinates come first and things are located with respect to them. For the mind, objects come first, and spaces are constructed from them. Spaces, in plural, because we inhabit several spaces, and our conceptions derive from our perception and action in each space, the space of the body, the space around the body, the space of navigation, and the spaces we create to improve our well-being.

Fundamental to spatial thinking are our bodies and the surrounding world. Our bodies have three essential axes, a head-foot axis that is asymmetric; a front-back axis that is asymmetric; and a right-left axis that is nearly symmetric. The world, too, has three axes, two horizontal axes that are orthogonal with respect to some arbitrary point, often that of our body, and one vertical asymmetric axis defined by gravity. Gravity affects action—what we can or cannot do with ease—as well as perception—how things look. These inexorable facts about the body and the world affect our conceptions of each of these spaces.

Space of the Body

In many ways, bodies are like objects, which are recognized by their contours or their parts in the proper configuration. But, unlike objects, bodies are experienced from the inside. The insider's view includes somatic sensations and kinesthetic feedback, stimuli that provide information about behaviors and functions of the body over and above the perceptual information available for objects. Does this insider view affect mental representations of the space of the body? To investigate this question, Julie Morrison and I used a body part verification task. Participants in the body-body experiment saw pairs of profiles of bodies in different orientations each with a body part highlighted with a uniform-sized dot. Their task was to respond "same" if the same body part was highlighted in both bodies, or "different" if different body parts were highlighted. Participants in the name-body experiment saw a name of a body part followed by a picture of a body with either the same or a different body part highlighted. The parts highlighted were frequent ones, those typically named by primary morphemes across languages: head, chest, back, arm, hand, leg, and foot. The parts vary in size, contour distinctiveness, and functional importance.

Three theories were considered to account for the reaction times to judge whether the parts were the same or different. According to the *Imagery Theory*, derived from research on visual imagery, larger parts should be verified fastest. According to the *Part Distinctiveness Theory*, parts that emerge from the object's contour, that are readily segmented, should be verified fastest. According to the *Functional Importance Theory*, parts that have greater functional importance should be verified fastest. The latter two theories are correlated, both for bodies and objects; that is, parts that have contour distinctiveness, such as head and hand, are also rated as more functionally important. For bodies, chest was the only part that lacked contour distinctiveness (these were men) but was rated highly important, possibly because it is the front of the body, the direction of movement and perception, as well as enclosing important internal parts, like heart and lungs.

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The Imagery Theory was soundly rejected by the data from both experiments. Large parts, notably leg and back, were the slowest parts to be verified, not the fastest. For the body-body comparisons, parts high on Contour Distinctiveness were fastest, notably head and hand, probably because the task can be done on a purely perceptual basis, and parts that extend from the contour are perceptually salient. By contrast, the name-body comparisons seemed to entail thinking about the meaning of the name of the body part, and that apparently aroused function because for this task, parts high on Functional Significance, head and chest, were verified fastest. Names not only eliminate visual information they also arouse functional information, apparent in many other tasks as well. The space of the body, then, is thought of in terms of not size of parts, but rather, for perceptual tasks, in terms of contour distinctiveness and for conceptual tasks, in terms of functional significance, a view informed by our insider's perspective on bodies. Extending this thinking metaphorically to corporate or geopolitical bodies, it is not physical size but rather functional significance that appears to dominate our thinking.

Space Around the Body

The space around the body is the space that can be reached or seen without moving, the space surrounding the body in three dimensions. A major way to keep track of that space is with reference to the body, primarily the three axes, front/back, head/feet, and left/right. As noted earlier, the first two, front/back and head/feet have salient asymmetries, the third, left/right, not. When the body is upright, head/feet is reinforced by its alignment with the only asymmetric axis of the world, that defined by gravity.

In order to assess how people think about the space around the body, Nancy Franklin, David Bryant, and I turned again to a task for which participants first read narratives describing them in spaces, such as opera houses or museums, with objects located beyond their head, feet, front, back, left, and right. The narratives then turned them to face various directions, and queried them for the objects now located in those positions, each in turn. The data of interest are the times to access objects in each location with respect to the body. Three theories were considered. According to the *Equiavailability Theory*, reaction times to all positions should be equal as no location is privileged. In fact, the locations were chosen randomly. According to the *Imagery Theory*, participants form mental images of the situations described in the narratives. Then imagine themselves in those settings and when probed, imagine themselves looking for the object in that direction. If so, retrieval times to front should be fastest, followed by retrieval times differing by 90 degrees from front, that is, left, right, head, and feet. Responses to back should be slowest as, according to the model, those require a mental turn of 180 degrees. The data of more than a dozen experiments rejected both those theories. The data supported the *Spatial Framework Theory*, according to which participants construct a mental spatial framework out of the three axes of the body. The accessibility of each axis depends on its asymmetries, which confer distinctiveness and consequent discriminability on the axis, as well as alignment with an asymmetric axis of the world. Thus, when the character in the narrative is upright, head/feet should be fastest, followed by front/back, and then left/right. For a reclining character, no body axis is correlated with gravity. In that case, front/back was fastest, presumably because that axis separates the world that can easily be perceived and acted on from the world that cannot.

The Spatial Framework analysis has been extended to and supported by many variants of the described spatial scenarios. Along with other work, in our lab with Taylor, but also in other labs, these studies demonstrate that people can construct and update elaborate spatial models in their imaginations, simply from language.

Space of Navigation

What we are calling the space of navigation is too large to be viewed at a glance. It is typically acquired in pieces, and from many sources, from experience, perhaps from different times and different views, from descriptions, from maps. The relevant information could be from perception, from language, from somatic responses. Piecing the different sources, views and modalities together to create a coherent mental model is a challenge. Evidence suggests that that integration is not always done, partly because the information may be incomplete but also because the information may be distorted by the way it is coded and represented. Persistent and systematic errors of memory, overviewed below, attest to many distortions.

Hierarchical Organization An early cognitive process in any domain is categorization, treating similar things as the same. Categorization is crucial to successful interactions in the world, recognizing that different views and experiences with a person are generally the same person, recognizing that tables generally support objects and are at a convenient height for sitting, and so on. One consequence of categorization is treating the things within a category as more similar to each other than to things not in the category. This holds for geographic categories as well, so that pairs of cities within the same state are regarded as closer to each other than pairs of cities that are actually closer but in different states are judged to be relatively farther. Hierarchical inferences affect judgments of direction as well as distance, and affect judgments of distance and similarity for social and other categories as well as geographic ones.

Perspective In viewing a complex scene, objects that are closer to the viewpoint are easier to distinguish whereas distant objects seem to be compressed and overlap. Distance estimates are consequently distorted, so that near objects seem farther apart from one another than distant ones. An analogous process occurs in memory. When people imagine themselves at one position in space, their distance judgments to other positions are compressed with distance, just as in Steinberg's famous New Yorker covers.

Landmarks Landmarks are salient (conceptual) points in environments, perhaps physically salient, perhaps central to interactions. They often define conceptual neighborhoods; people say they live near the Eiffel Tower or the Empire State Building. Landmarks also distort geographic information (as well as conceptual information): people judge ordinary buildings to be closer to landmarks than landmarks to ordinary buildings, a violation of any Euclidean model of mental spaces.

Alignment Spaces, environments, geographic regions, maps, have things in them, figures on backgrounds. The mind has no direct way of imposing measurements on viewed or remembered scenes to record where the objects are. Instead, the mind locates objects with respect to other objects with respect to reference frames. Because different the different remembered fragments may include some of the same objects and allow determining changes in perspective or reference frame, common objects and transformed reference frames provide the links among the fragments.

Other objects and reference frames, then, are critical to forming mental representations of spaces. However, mental estimates using them are just that, estimates, and prone to error. In particular, objects are remembered as more aligned with each other with respect to reference frames, a phenomenon we have termed *alignment.* Evidence for alignment comes from remembered real maps, from remembered artificial maps, from remembered abstract depictions, from memories established by exploration. For example, more people select a map in which Europe and the US are more aligned east-west or a map in which the Americas are more aligned north-south than the correct maps. Errors are also evident in judged directions: people incorrectly judge Philadelphia to be north of Rome and Boston to be east of Rio.

Rotation Objects induce their own reference frames, along an axis of elongation and its perpendicular. The induced reference frame of the object and the external reference frame, say of the page, or of north-south-east-west, are then rotated closer together in memory. As for alignment, evidence comes from real and artificial maps, from abstract visual displays, from exploration. When provided with a cut-out of South American and asked to place it in a north-south-east-west frame, people upright South America; otherwise, it seems tilted, out of balance.

It should be clear by now that people's memories of geographic regions, even ones they know well, are simplified and distorted. People do not seem to have files of ready-made mental representations of the various spaces they navigate, even successfully navigate. Rather, they seem to construct ad hoc and incomplete representations as they need them, from scattered bits and pieces of information; that the store they are looking for was north of town, was around the third or fourth right turn from the court house on the main street, that it had a green or blue awning, that it smelled like pizza from a restaurant near by. A better metaphor for geographic, indeed spatial, knowledge than cognitive map is *cognitive collage*.

Spaces People Create

In common with other animals, people create artifacts and tools to improve their physical well-being; for example, primates use or fashion thin sticks to extract insects from logs or use them to build nests. Humans, however, are unique in creating artifacts and tools to increase their cognitive well-being, to augment memory and information processing, to communicate and collaborate with others, and to promote inference and discovery, from ancient cave paintings and trail markers to the latest technology.

Although cognitive tools take many forms, the paradigmatic external cognitive tool can be regarded as a page with marks on it. Each of these can convey meanings directly. The meanings they convey are not as specific as symbols like *shoe* or *diploma*, but they are comparable to symbols like *field* or *relationship*, or even *head*. In addition they are similar to spatial expressions and to gestures in space.

Place on a Page. In a large study, children from pre-school through university were asked to place stickers on square pieces of paper to express spatial, temporal, quantitative, and preference relations. For example, they were asked to place stickers for breakfast, lunch, and dinner. Or they were asked to place a sticker for a TV show or food that they loved, one that they were indifferent to, and one that they disliked. All the children were able to place stickers to represent the relative positions of small dolls. For the more abstract problems, some of the youngest children placed the stickers haphazardly or on top of each other, representing the concepts categorically. However, most of them put the stickers in a row or column, using the line so formed to represent the relationship ordinally. A separate study assessed interval representations, for example, time for breakfast, morning snack, and dinner. Preserving interval relations would mean placing the sticker for morning snack closer to that for breakfast than to that for dinner. Only at about 11 years were children able to spontaneously represent interval on the page. Thus, with age, children come to use space to reflect increasingly quantitative aspects of abstract relations, but even preschoolers could use space to categorize and even order things on abstract dimensions.

Children and adults used direction on the page to convey abstract meanings. Participants were drawn from cultures in which language is written left to right as well as cultures in which reading and writing proceed from right to left. Increases in quantity or preference were equally often plotted left to right and right to left, irrespective of reading order, or down to up. Plotting increases starting at the top and going down was avoided. In language and gesture, more, good, powerful and the like are associated with

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upwards. To go upwards means overcoming gravity, taking strength and power. People and plants grow stronger as they grow taller, piles of money get higher. The vertical axis is loaded in language and gesture as well; we give thumbs up, we say someone has reached the heights of their abilities and someone else is the bottom of the pack.

The horizontal axis is more neutral, though affected by reading order (and handedness). Time increased from left to right for those with left to right languages but from right to left for those with right to left languages. Gestures used to describe temporal events do the same. Perhaps because most languages follow subject-verb-object order, perceived agency also follows reading order.

Space is spontaneously used to convey meaning even at a young age. Proximity and order in space indicate proximity or order on abstract dimensions. Direction in space conveys a range of abstract concepts, time, quantity, preference, power, agency, and more.

Marks on a Page Marks on a page can convey meanings iconically, by resembling what they mean to convey. They can also convey meaning by figures of depiction, by associations to what they mean to convey, like scales of justice or a trashcan in a computer interface. However, a third way they can convey meanings directly is by their gestalt or geometric properties. Lines, for example, are links; they indicate a relationship between the things they link. Arrows are asymmetric lines, indicating asymmetric relations. Boxes contain. These meanings, like the associated words, relationship, field, point, area, are approximate, and become clearer in context.

Some meanings of these simple geometric forms, or glyphs, have been demonstrated in paired studies, comparing production and comprehension. In one, students were asked to interpret either a line graph connecting A to B, where B was higher than A or a bar graph showing the same "data." Lines connect, indicating that there is an underlying dimension, and that A and B have different values on the same dimension. Bars contain and separate, indicating that there are a bunch of A's and a bunch of B's and they are different. This led to the prediction that line graphs should be interpreted as trends and bars as discrete comparisons, a prediction held up by the data. Conversely, students given statements of trends and asked to produce a graph made line graphs whereas students provided with discrete comparisons made bar graphs. The visual display even overrode the content, so that some people interpreted a line graph of height of women and men as "as you get more male, you get taller."

Another set of experiments examined meanings of arrows. Students were asked to interpret a diagram without arrows of a mechanical system, a car brake, a pulley system, or a bicycle pump, gave structural descriptions, of the parts and their spatial relations. Diagrams with arrows elicited functional descriptions, the behavior and consequences of the systems one step at a time from "beginning" to end. This kind of linear thinking, imposing a beginning on a continuous process and proceeding step by step might be one reason that linear diagrams were more frequent than circular ones when participants were asked to diagram cyclical processes, like cell division, the rock cycle, the seed cycle, the seasons. Circular diagrams were interpreted well, but by imposing a start point and proceeding clockwise.

Meaningful interpretations of glyphs that are modulated by context have been shown in other domains, such as route maps, which consist primarily of links and nodes. A line in a route map has a different meaning from a line in a bar graph underlying both is a relationship. These spontaneous interpretations can have both benefits and costs. For example, in diagrams of computer networks, interconnected computers are depicted as if hanging from a clothesline probably because showing that each is connected to each other would clutter a diagram, making it hard to read. However, this convention leads to misinterpretations. Students in information design, for example, often incorrectly think that information has to go from one computer to another along the path of the "clothesline." Diagrams, like categories, schemas, and other knowledge structures, can be effective ways to reduce information effectively, retaining important features and eliminating irrelevant and distracting features. Reducing and recoding information can sometimes have costs, even it usually has benefits.

Diagrams, unlike purely symbolic words, can convey a range of meanings quite directly, by using the page and marks on it. For the space of the page, proximity, position, and direction in space have concrete, e. g., quantitative, and abstract meanings, as do the marks made on the page. The well-practiced spatial reasoning skills can then be applied to comprehending and making inferences to abstract—and concrete—relations expressed spatially, making diagrams a powerful tool for conveying and reasoning, as well as insight and discovery.

Perception, Action, and Thought in Space

Every mobile creature interacts with space. Humans interact with many spaces: the space of the body, the space around the body, reachable by eye or hand, the space of navigation, constructed from multiple sources, the spaces people create. Perception and action in each space determine the conceptions of each space. To conduct our lives, we also organize and reorganize the spaces we inhabit. We place together things that look similar or serve similar functions into groups or piles or drawers or shelves. We order things in rows or columns, the ingredients for a recipe or the towels in the linen closet in order of use. The canned goods on the shelves or the dairy in the refrigerator are grouped by kind as well as ordered by date. We make one-to-one correspondences when we set a table or distribute a birthday cake. Homes and stores are lined up along streets, with driveways for each and streetlights and cross-streets distributed evenly. These spatial groupings and orderings, piles and rows, reflect abstract thinking, categories, themes, orders, and correspondences. Because they are not random, because they are simply and systematically patterned, the spatial arrays suggest that they were intentionally created. They serve as signals to ourselves and to others that the spatial patterns are meaningful, that there is an organizing principle or principles behind them, and that the meaning, the reason for the pattern, can be discerned. They groupings and orderings and correspondences create spatial patterns that are good gestalts, groups, piles, lines, correspondences. Those spatial patterns form the visual basis for diagrams, lines and boxes and tables. Our everyday actions in space, then, are communicative.

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References

Tversky, B. (2001). Spatial schemas in depictions. In M. Gattis (Ed.), *Spatial schemas and abstract thought*. Cambridge: MIT Press.

Tversky, B. (2005a). Functional significance of visuospatial representations. In P. Shah & A. Miyake (Editors.), *Handbook of higher-level visuospatial thinking*. Cambridge: Cambridge University Press.

Tversky, B. (2005b). Visualspatial reasoning. In K. Holyoak and R. Morrison, (Editors). *Handbook of Reasoniong* .Cambridge: Cambridge University Press.

Tversky, B. (2008). Spatial cognition: Situated and embodied. In P. Robbins and M. Aydede (Editor). *Cambridge handbook of situated cognition.* Cambridge: Cambridge University Press.

Tversky, B. (In press). Visualizations of thought. *TopiCS in Cognitive Science.*

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