Some Ways that Maps and Diagrams Communicate

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Abstract. Since ancient times, people have devised cognitive artifacts to extend memory and ease information processing. Among them are graphics, which use elements and the spatial relations among them to represent worlds that are actually or metaphorically spatial. Maps schematize the real world in that they are two-dimensional, they omit information, they regularize, they use inconsistent scale and perspective, and they exaggerate, fantasize, and carry messages. With little proding, children and adults use space and spatial relations to represent abstract relations, temporal, quantitative, and preference, in stereotyped ways, suggesting that these mappings are cognitively natural. Graphics reflect conceptions of reality, not reality.

1 Introduction

One candidate for an intellectual achievement separating humankind from other kinds is the creation of cognitive artifacts, of external devices that extend the human mind. They range from using fingers for counting or fashioning bends in trees to mark trails to powerful computers or global positioning systems. Cognitive tools augment the mind in two major ways: they reduce memory load by externalizing memory, and they reduce processing load by allowing calculations to be done on external rather than internal objects and by externalizing intermediate products. Of course, external representations have other benefits as well. They take advantage of people's facility with spatial representations and reasoning, they are more permanent than thoughts or speech, they are visible to a community (cf. Tversky, in press, b). Written language is prominent among useful cognitive tools, but graphics of various types preceded written language and serve many of the same functions. What renders graphics privileged is the possibility of using space and elements in space to express relations and meanings directly, relations and meanings that are spatial literally as well as metaphorically.

Early graphics, found in cultures all over the world, include not only lines on paper or bark, but also inscriptions on trees, paintings in caves, incisions in bones, carvings in wood, scarifications on bodies, and more. They portrayed things that took up space, animals, objects, and events, actual or imagined, or spaces, the prime example being maps. It was only in the late 18th century that graphics began to be used, in the West, to portray non-spatial, abstract information, most notably, economic data, such as

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balance of trade over time (Beniger and Robin, 1958; Tufte, 1990). I will first characterize ways that graphics convey the essentially visual through a discussion of maps, the prime example of these graphics. Then I will characterize ways that diagrams visualize the non-visual.

2 Characterizing Maps

One of the most typical and ubiquitous of graphics is a map. Nowadays, when people think of maps, they think of the world map in school classrooms or the road map in the glove compartment of the car or the city map in the tourist guide. Yet the maps that have been invented across cultures throughout human existence are both far more and far less than these. They seem to share two features, though by no means strictly. Maps typically portray an *overview,* and they reduce and roughly preserve *scale.* As we shall see, in practice, maps are not limited to overviews, and scale is not always consistent. Here, we analyze those maps, characterize what they do and do not do, and bring those insights to the study of diagrams in general.

2.1. Maps are Two-Dimensional

Although the worlds that maps typically represent are three-dimensional, maps are typically two-dimensional. This is for a number of converging reasons. Obviously, it is easier to portray a two-dimensional space on a piece of paper than a three-dimensional space. But, in addition to the constraints of the medium, there are cognitive reasons for portraying maps as two-dimensional overviews. First, it seems that people readily conceive of three-dimensional environments as two-dimensional overviews, in itself a remarkable cognitive achievement. This is attested by the invention of two-dimensional overview maps by diverse and dispersed cultures as well as their spontaneous invention by children. Next, three-dimensional diagrams are difficult to construct and difficult to comprehend (e. g., Cooper, 1984; Gobert, 1999). Architects and other designers, for example, prefer to first construct two-dimensional plans or overviews and two-dimensional elevations before integrating them into three-dimensional sketches or models (Arnheim, 1977). As Arnheim points out, the considerations important for plans differ from those important for elevations. Like maps, plans display the spatial relations among large structures, providing information useful for navigating among them. Plans, then, are a presentation useful for evaluating function. Elevations provide information about what the structures look like, important for recognition of them. Elevations are a presentation useful for evaluating aesthetics. In addition to these reasons, for many purposes, three-dimensional information about environments is simply not needed, and may even interfere; the spatial relations among the large features is sufficient information.

2.2. Maps Omit Information

The next thing to notice about maps is that they omit information. One of the reasons for this has to do with the very nature of mapping. Borges' invented fable of an Empire where the Art of Cartography was perfected so that a map of the Empire the size of the Empire could be created was just that, a fable, an absurdity (Borges, 1998). The very usefulness of a map comes from its reduction of space. Reductions in size require reductions in information to be useful. An aerial photograph does not make a good map. Maps omit information because much of the information in space is not only not relevant, but also gets in the way of finding the essential information. Maps are typically designed for a communicative purpose; that purpose determines what information should be kept and what information can be eliminated. Consider, for examples, two kinds of maps created by seafaring cultures (Southworth & Southworth, 1982). Coastal Eskimos carried carved wood outlines of the coastline with them in their canoes to guide them in their travels. The Marshall Islanders in the Pacific, who navigate among islands too distant to be seen for much of their voyages, constructed maps out of bamboo sticks and shells. The shells indicated islands and the sticks ocean currents, identifiable from the flotsam and jetsam that accumulates along them. For more familiar examples, consider the information useful for a map to guide drivers in the city or, alternatively, a map to guide hikers in the mountains. Details of types of roads and intersections are important to the former, whereas topographical details are important to the latter.

2.3. Maps Regularize

Yet another characteristic of maps in practice is that they simplify and regularize information. A classic example is the London subway map, which has served as a model for subway maps all over the world. The London subway system, like many subway systems, is quite complex, with many different lines and intersections. The information important to travelers includes the general direction of the lines, the stops, and the intersections with other lines. The specific directions, path curvatures, and distances are not usually critical. So the lines on the London subway map are presented as straight lines, oriented vertically, horizontally, or diagonally, ignoring the finer distinctions of local curves and orientations. This simplification, however, facilitates computing the desired information, the general directions and the connections, and the distortions produced by the regularization do not cause sufficient errors to create problems.

2.4. Maps Use Inconsistent Scale and Perspective

Road maps illustrate another common feature of maps. They use inconsistent scale. Indeed, roads, rivers, railroads, and other important environmental information portrayed in maps would simply not be visible if scale were consistently adopted. In addition, many maps violate consistent perspective. Consider, for example, a popular kind of tourist map. These present an overview of the city streets superimposed with frontal views of frequently visited landmarks, such as churches and public buildings. Presenting both perspectives in a single map is a boon to tourists. It allows them to navigate the streets in order to find the landmarks, and then to recognize the landmarks when they see them. Maps with mixed perspectives are by no means a modern invention. For example, maps portraying overviews of paths and roads and frontal views of structures and living things are clearly visible in petroglyphs dating back more than 3000 years in northern Italy (Thrower, 1996).

2.5. Maps Exaggerate, Fantasize, and Carry Messages, Aesthetic, Political, Spiritual, and Humorous

In 1916, King Njoya presented the British with a map of his kingdom, Banum, in northwestern Cameroon. To impress the Europeans with his modernity, he put 60 surveyors to work for two months to construct the map. While fairly accurate, the map exaggerates the size of the capital, and locates it, incorrectly, smack in the center of the kingdom (Bassett, 1998). Maps influenced by the political, mythical, historical, or fantastic are common all over the world. In medieval Europe, T-O maps were popular. They were called that because they looked like T's embedded in O's, the circular background for the world. East, the direction of the (presumed) beginning of the world, Adam and Eve, the rising sun, was at the top (hence the word "oriented" from *oriens* or east). The top bar of the T was formed by the Nile on the south or the left and the Dan on the north or the right. The Mediterranean formed the vertical bar. Such maps portrayed religious beliefs and reflected elegant geometry and symmetry more than actual geography. They also added decorative depictions, of Adam and Eve in the Holy Land, of the four winds, and more. Maps mixing geography, beliefs, and history are not unique to Europeans. T-O maps appeared in Asia (e. g., Tibbetts, 1992), Similar maps appeared in preColumbian Mesoamerica, for example, a map showing the imagined or real migrations of the ancestors superimposed on a geographic map (Mundy, 1998). Maps of the heavenly spheres appeared in both Europe and Asia (Karamustafan, 1992).

Humorous maps enliven newspapers, books, and journals. Perhaps best known are the "New Yorker's View of the World" maps of Steinberg that graced the covers of the New Yorker as well as many dormitory rooms. Such maps take a local perspective so that close distances loom larger than far distances. They also include landmarks likely to be of interest to the New Yorker and omit those of less interest. A more recent example from the New Yorker was a map of New York City as the palm of a hand, with Broadway as the lifeline and the boroughs as fingers. These are but a few of many, many examples of maps that are designed to convey far more than geography, and that sacrifice geographic accuracy for other messages.

Put briefly, maps, those produced by professionals as well as amateurs, are schematic (for a related view, see Freksa, Moratz, and Barkowsky, this volume). Schematic maps are created for a specific goal or goals, usually communicative, and they distill and highlight the information relevant to those purposes. They eliminate extraneous information to remove clutter, making the essential information easier to extract. They simplify and even exaggerate this information. People's minds also schematize spatial and other information. In fact, many of the ways that minds schematize correspond to the way that maps schematize. Internal representations of environments omit and regularize information, they mix perspectives, reduce dimensionality, and exaggerate. This can lead to internal "representations" that are impossible to realize even as a three-dimensional world (e. g., Tversky, 1981; in press, a). Matching external schematizations to internal ones may also facilitate processing information from maps. Of course, the match between internal schematizations of environments and external schematizations of maps is no accident; both are products of human minds. Moreover, these same processes, omission, use of inconsistent information, regularization, exaggeration, politicization, beautification, and more, appear in other depictions and external representations.

3 Characterizing Graphics

When people talk or think about abstract concepts, they often do so in terms of spatial concepts (e. g., Clark, 1973; Lakoff and Johnson, 1980). There is good reason for this. Spatial competence appears early in life and is essential for survival (e. g. Tversky, in press, a). Bootstrapping abstract thought onto spatial thought should allow transfer of spatial agility to abstract agility. Graphic visualizations of abstract concepts and processes such as those in economics, biology, chemistry, physics, mathematics, and more should pay similar benefits. An examination of graphics produced by children and adults throughout history and across cultures reveals some general characteristics of the way they use space and the elements in it to convey meaning (Tversky, 1995; in press, b).

3.1. Spatial Relations

Graphics, such as maps, consist of elements and the spatial relations among them (for a broader view of this analysis, see Tversky, in press, b). Whereas maps use space to represent space, graphics can use space to represent other concepts, such as time, quantity, and preference. Underlying the use of space is a simple metaphor, distance in depictive space reflects distance in real space, or, in the case of abstract graphics, distance on some other dimension or feature. The spatial mapping from the represented world to the visualization can convey information at different levels, categorical, ordinal, interval, or ratio. Even written alphabetic languages use graphic devices in addition to symbolic ones to convey meaning. At the categorical level, only groupings are meaningful; elements in one group share a feature or features not shared by elements in other groupings. Organizing names of students by classes, clubs, or dormitories are examples of categorical groupings. Separating the lists spatially is a rudimentary use of space to indicate groupings. There was a time when words were not separated in writing; the current practice of putting spaces between words is also a rudimentary use of space to indicate groupings. Parentheses, boxes, and frames are visual devices that accentuate spatial separation in conveying categorical information. In the case of ordinal mappings, the order of the groups is meaningful. A rudimentary way to indicate order is spatial (or temporal) order of a list: ordering children by age or ordering a shopping list by the route through the supermarket. The spatial order of the list reflects some other order. Indentation as in paragraphs or outlines is another simple way of indicating order. Networks and trees convey order by augmenting the spatial devices with visual ones. For interval mappings, the distance between the groupings as well as the order is meaningful, representing the distance on some other dimension. X-Y graphs are familiar examples of using space to express interval relations. Graphs are also common for ratio mappings where the zero point is meaningful so ratios are meaningful. For the prototypical map, the sort produced by government agencies, mapping is ratio. For the typical map, the sort produced for special purposes like driving or tourism, the mapping from actual space to depictive space may be, as we have seen, complex and even inconsistent.

Direction of Spatial Mappings. Although direction in space is objectively neutral, cognitively, it is not neutral, even for young children. Children from cultures where language is written left to right as well as children from cultures where language is written right to left were asked to place stickers on a square sheet of paper to represent items that could be ordered by time, quantity or preference (Tversky, Kugelmass, and Winter, 1991). On one trial, they were asked to represent the time they get up in the morning, the time they go to school, and the time they go to bed. On another trial, they were asked to represent a TV show they loved, one they didn't like at all, and one they sort of liked. Some of the youngest children did not put all the items on a line; that is, their representations were categorical, not interval. Most of the children's mappings preserved ordinal information, but only children around 11 years of age preserved interval information. As for direction, children from all language cultures mapped increases in quantity or preference from left to right, from right to left. and from down to up. The one direction they avoided for mapping increases was from up to down. The only mappings to follow the order of writing were the temporal ones.

The bias to map up to more or better or stronger is not restricted to children. A survey of common visualizations in college text books, such as those portraying evolution and geological eras, revealed that time is usually conveyed vertically, with the present time, the pinnacle of evolution, at the top (Tversky, 1995). Words like "pinnacle" indicate that these biases are present in language as well. We say someone's at the "head" or "top" of the class or below the mean. For gestures as well, up is generally good or strong or powerful or successful, and down the opposite. Thus vertical mappings seem loaded, with the good/more/powerful pole at the top and the bad/less/weak pole at the bottom. In contrast, as the politicial consensus attests, the horizontal left/right axis is more neutral.

3.2. Elements

Graphics portraying information that is not spatial, but rather abstract, use elements in space as well as space to convey that information. Think, for example, of an evolutionary tree. It uses nodes and lines and perhaps icons to convey the development of species. Or consider a diagram of the workings of a machine or system, such as a car or a power plant. Like the evolutionary tree, it uses lines, nodes, and icons to convey the system parts and their causal relations. Icons can depict literally or figuratively. More literal icons are widespread in simple contemporary graphics, such as road and airport signs, where a curve in a sign indicates a curve in the road and a place setting indicates a restaurant stop. They also occur throughout history in petroglyphs, cave paintings, and ideographic scripts. Ideographic scripts as well as contemporary icons make use of "figures of depiction" as well. In ideographic scripts, ideographs for animals, for example, often included only part of the animal, the head or horns, and ideographs for rulers often portrayed an association to the role, such as a staff or crown. Icons common in graphical user interfaces do likewise; scissors can be used to cut unwanted text and a trash can to dispose of unwanted files.

Expressing Meanings Using Space. Space, then, as well as visuospatial devices, can be used to convey abstract concepts in cognitively natural ways. Starting from abstract concepts and examining the devices used to convey them emphasizes the point. Similarity can be represented by similar appearance, such as font or color, and difference by different appearances. Groupings, based of course on similarity, can be represented by proximity in space, and emphasized by devices that suggest enclosures, such as circles, boxes, frames, and parentheses. Connections between groups are readily conveyed by devices that indicate paths, especially lines, connected or broken. Orderings may be conveyed in a variety of ways including order in space and order on visual dimensions such as brightness or size. A popular device to indicate direction is an arrow. Arrows may be cognitively compelling for two reasons. Arrows as weapons fly in the direction of the arrowhead. Water and other substances flow downward in rivulets that converge, forming arrows in the direction of the flow. The concept of extent can be readily represented by spatial extent, length or area, and the concept of proportion can be readily represented by spatial proportion, as in pie charts.

4 In Sum

Depictions reflect conceptions of reality, not reality. This holds for depictions of things in the world as well as things in the mind. Maps, drawings, graphs, and diagrams are forms of communication. As such, they are inherently social devices used in social interactions. As in most social interactions, veridicality may not be the primary concern. Rather the primary concern may be affecting the cognitions, emotions, and ultimately, the actions of those for whom the communication is intended and designed.

References

Arnheim, R. (1977). The dynamics of architectural form. University of California Press: Berkeley.

Bassett, T. J. (1998). Indigenous mapmaking in intertropical Africa. In Woodward, D. and Lewis, G. M. (Editors). History of cartography. Vol. 2 Book 3: Cartography in the traditional Africa, America, Arctic, Australian, and Pacific societies. Pp. 24-48. Chicago: Chicago Press.

Beniger, J. R. & Robyn, D. L. (1978). Quantitative graphics in statistics. The American Statistician, 32, 1-11.

Borges, J. L. (1998). On the exactitude of science. Collected Fictions. P. 325. Translated by Andrew Hurley. New York: Penguin.

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

Cooper, L. A. (1989). Mental models of the structure of visual objects. In B. Shepp & S. Ballesteros (Eds.), Object perception: Structure and process. (pp. 91-119). Hillsdale, N. J.: Erlbaum.

Freksa, C., Moratz, R. and Barkowsky, T. (2000). Schematic maps for robot navigation. In C. Freksa, W. Brauer, C. Habel, & K.F. Wender (Eds.), *Spatial Cognition II – Integrating abstract theories, empirical studies, formal models, and practical applications.* Berlin: Springer.

Gobert, J. D. (1999). Expertise in the comprehension of architectural plans. In J. Gero and B. Tversky (Editors), Visual andspatial reasoning in design. Pp. 185-205. Sydney, Australia: Key Centre of Design Computing and Cognition.

Karamustafan, A. T. (1992). Cosmographical diagrams. Celestial mapping. In Harley, J. B. and Woodward, D. (Editors) The history of cartography. Vol. 2. Book One Cartography in the traditional Islamic and South Asian Societies. Pp. 71-89. Chicago: University of Chicago Press.

Lakoff, G. & Johnson, M. (1980). Metaphors we live by. Chicago: University of Chicago Press.

Mundy, B. E. (1998). Mesoamerican cartography. In Woodward, D. and Lewis, G. M. (Editors). History of cartography. Vol. 2 Book 3: Cartography in the traditional Africa, America, Arctic, Australian, and Pacific societies. Pp. 183-256. Chicago: University of Chicago Press.

Southworth, M. and Southworth, S. (1982). Maps: A visual survey and design guide. Boston: Little, Brown and Company.

Thrower, N. J. W. (1996). Maps and civilization: Cartography in culture and society. Chicago: University of Chicago Press.

Tufte, E. R. (1990) Envisioning Information. Cheshire: Graphics Press.

Tversky, B. (1995). Cognitive origins of graphic conventions. In F. T. Marchese (Editor). Understanding images. Pp. 29-53. New York: Springer-Verlag.

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

Tversky, B. (In press, a). Levels and structure of cognitive mapping. In R. Kitchin and S. M. Freundschuh (Editors). Cognitive mapping: Past, present and future. London: Routledge.

Tversky, B. (In press, b). Spatial schemas in depictions. In M. Gattis (Editor), Spatial schemas and abstract thought. Cambridge: MIT Press.

Tversky, B., Kugelmass, S. and Winter, A. (1991) Cross-cultural and developmental trends in graphic productions. Cognitive Psychology, 23, 515-557.