Some Ways that Graphics Communicate

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Some Ways that Graphics Communicate

A century and a half ago, a young Ojibwa woman sent the letter in Figure 1 to someone she was interested in (Mallery, 1972). The letter portrays a schematic map with a message superimposed. The map is to her home, marked by her totem, and is addressed to the man she wishes to visit her, marked by his totem. The message is her arm beckoning him to her home. Graphics such as these appear dispersed across space and time. They not only serve as messages, but also as geographic, historical, and economic records, as poetry, stories, and myths, and as proclamations, announcements, and orders. Everywhere, graphics preceded written language. Even today, graphics are in common use as they are more readily understood by speakers of disparate languages than are written languages. This chapter presents an analysis of graphics produced by children and adults across time and across space. The primary interest is in the semantics of graphics, in particular, how they use space and the elements in it to communicate in cognitively natural ways. This is in contrast to words, which communicate primarily symbolically. The visuospatial nature of graphics, then, gives them both advantages and disadvantages relative to language. Graphics can use space and the elements in it to convey concrete concepts directly and abstract concepts metaphorically. However, many abstract concepts do not have natural analogs. Such concepts, for example, nonexistence or counterfactual, may be better expressed in language.

Kinds of Graphics

Consider the varieties of graphics humankind has produced. The prototypic graphic, of course, is a depiction of something in the world, or something imaginary that is similar to something in the world, a picture. Although such depictions bear enough resemblance to things in the world to be recognizable, they are not necessarily attempts to reflect the world as accurately as possible. On the contrary, many early depictions routinely violate spatial and temporal principles presumably in order to portray more than a particular view of a scene or object. Depictions, ancient and modern, from many cultures display inconsistent, often multiple, perspectives. Mixing or violating perspectives allows a communicator to convey more information than could be conveyed from a single consistent perspective. Thus multiple perspectives can relate more of the meaning or essence than a single consistent perspective, a device used to great effect by modern artists, notably Cezanne and Picasso. Similarly, many depictions mix time, portraying in the same painting or vase or relief scenes from different time periods, often ordered by importance rather than by time (Small, 1999). In addition, depictions may exaggerate or distort certain features and omit others. The intent seems to be to convey conceptions of things rather than momentary perceptions of them.

Another common and ubiquitous graphic is a map. Like depictions of things that are real or resemble the real, maps, too, are not always designed to be spatially accurate. As for depictions, these violations of accuracy of appearance from a single viewpoint are presumably in the service of what their creators wished to convey. A device common in both ancient and modern maps is to present an overview of a street plan along with frontal views of important landmarks. This clever mixing of perspectives provides the traveler with routes to follow as well as allowing the traveler to recognize the landmarks encountered en route. In addition to mixing perspectives, maps also often tell stories, especially the histories, real or mythic or both, of the cultures that created them. Migrations, genealogies, and battles are superimposed on an overview of the geography of the territory (see Harley & Woodward, 1987, for examples from diverse cultures). Even contemporary maps created with the benefits of aerial photography and hi-tech GPS violate strict accuracy. If they didn't violate size scale constraints, for example, roads wouldn't be visible on maps.

Diagrams, yet another common form of graphic, are not meant to reflect physical reality completely and veridically. Rather they are meant to be schematized renditions of actual or abstract systems, from the structure of a chair or a house to the organization chart of a company or institution. As such, they are meant to reflect conceptual reality. They portray an analysis of the parts of a system and their interrelationships, structural, causal, or power.

Depictions, maps, and diagrams of actual systems are ancient and universal or nearly universal forms of graphics. Graphics of abstract systems and of data, in sharp contrast, are a modern (18th c.), Western invention (e. g., Beniger & Robyn, 1978; Tufte, 1983). Graphs appeared first and were first used to display a single variable against time, for example, balance of trade. In fact, despite the development of many creative visualizations, X-Y line graphs are perhaps still the most common form of data display (Cleveland & McGill, 1985; Zacks, Levy, Tversky, & Schiano, in press).

No matter what their form or purpose, all graphics consist of elements arranged in space. Both the characteristics of the elements and their spatial arrangement are used to communicate. Cross-cultural studies as well as analyses of historical documents show communality in the way that elements and space are used in communication, suggesting that some graphic devices are cognitively natural. We will first examine elements, then spatial relations.

Graphic Elements

The oldest and easiest form of element is simply a depiction of the thing to be communicated. For example, the Ojibwa love letter depicted the tent of the young woman, the surrounding landscape, her totem, and that of her friend. But so many ideas we wish to express cannot be directly depicted. Then we resort to figures of depiction (e. g., Tversky, 1995), such as metonymy, where a part represents a whole, or synecdoche, where a symbol represents the whole, such as the crosses indicated a graveyard in the love letter. These devices were common in early ideographic writing, (see, for examples, Figure 2). The head or horns of an animal represent the animal in several languages, and the symbol of office, a scepter, represents the ruler. Of course, these same sorts of figures of depiction are rampant in computer applications, where scissors are used to cut parts of documents and trash cans to eliminate unwanted files.

Importantly, graphics make use of elements other than depictions or icons that bear resemblances to or figuratively represent the things they signify. Some seemingly abstract graphic elements, such as lines, curves, crosses, blobs, boxes, and arrows, appear in many different kinds of graphics and seem to be readily and meaningfully interpreted within their contexts. Four case studies will illustrate the use of graphic elements to convey other ideas. The first is a study of children's inventions of arithmetic notation which provides a suggestive comparison to the historical development of arithmetic notation. The next three projects come from our laboratory. They will elucidate the cognitively natural ways graphic elements are produced and interpreted. Each of our projects is based on a different kind of graphic, one on maps, one on diagrams, and one graphs.

Children invent arithmetic

The notation system for arithmetic familiar to any grade schooler on the planet actually took hundreds of years to develop (e. g., Hughes, 1986; Ifrah, 1999). Curious about the difficulties of inventing such a system, Hug investigated children's inventions. His informants were preschool and early school-age children. He gave them pencil and paper, then showed them various displays. The children's task was to "put something down on paper that represented" whatever was displayed. First, he displayed various quantities of bricks. The younger children, but even many of those already in school and learning the number system, put down forms of tallies. That is, they put one mark for each brick. The more rudimentary systems used by the younger children were iconic; that is, the marks represented objects, in many cases, bricks, but in other cases, other objects. The more refined systems used a simple line for each brick. The oldest children, with the benefit of schooling, put down a numeral corresponding to the actual number of bricks.

Inventing a way to represent the cardinal number of objects was not difficult for the children, and their solutions converged. A harder task and one yielding more diversity of graphics was to represent *no* bricks on the table. Some children left the page blank, some put a slash line, some made up a symbol, others, again the older, schooled children, put down a zero. Also difficult were representations of addition and subtraction. As for zero, there was little uniformity, though hands removing bricks were used by a number of children. At least one child used walking soldier-like icons to suggest that the bricks are walking away.

Intriguingly, what was easy and uniform for the children was early and uniform across cultures, and what was difficult and varied for the children was late to develop in cultures. Tallies appear widely across cultures whereas numeral systems were developed later and more rarely; in fact, they were more often borrowed than invented. Zero appeared only in the 7^{th} century, and symbols for addition and subtraction appeared even later, in the 15^{th} century (Hughes, 1986). These parallels between historical and individual inventions over time suggest that ontogeny recapitulates phylogeny (Hughes, 1986).

Line, curves, crosses, and blobs: Conveying routes

Lines appearing in one-to-one correspondence to the number of things, then, have been invented by children and by many cultures to represent number of things. Lines have been used to represent other concepts as well, for example, segments of roads. A number of years ago, we stopped passers-by near a student dormitory and asked them if they knew how to get to a popular fast food place off campus (Tversky and Lee, 1998, 1999). If they said they did, we asked them either to sketch a map or to write down directions to the restaurant. Table 1 contains two of the route directions and Figure 3 contains two of the maps given by informants. Note that route maps differ from regional maps in that they only include the information needed to get from the start to the destination, meaning that much detail, even of the roads followed and structures encountered, is omitted.

Following an analysis developed by Michel Denis (1997), we coded both depictions and descriptions into their elements. Significantly, although depictions are concrete and potentially analog whereas descriptions are symbolic and discrete, there were a number of striking parallels between depictions and descriptions that served as route directions. Lines, curves, crosses, and blobs, for example, were all used to designate portions of paths or routes from start to end points. Corresponding to each in the descriptions was a small set of verbal instructions. The lines in the maps corresponded to the expressions, “go down” or “go straight” in the descriptions. The curves in the maps corresponded to the expression “follow around” in the descriptions. The crosses signifying intersections corresponded to “make a” or “take a,” or “turn.” Lines, curves, and crosses are simple diagrammatic components of routes that have apt correspondences between forms of lines and forms of motion along paths. Blobs were schematized bounded regions, and for the most part, served to represent buildings or other environmental structures which, in overviews, appear as regions of varying shapes.

Each of these graphic devices schematizes the visual information, much as subway maps do, rather than presenting it more accurately metrically. Roads and paths, for example, take many more forms than just straight or curved line segments. Yet this is all the information the depictions encoded, thus apparently all the information that is needed to adequately communicate the route. Likewise, for directions, "go down" or "follow around" are sufficient for most cases. The same sort of schematization occurred for depictions and descriptions of turns. Although the actual intersections varied considerably, most were schematized in the drawings to approximately 90 degrees. Those cases where the depicted intersections differed from 90 degrees did not necessarily correspond to the deviations from 90 degrees found on the ground. Similarly, the language of the descriptions did not distinguish the degree of turn. Finally, blobs, usually circles or ellipses, were used to represent landmarks, typically buildings, irrespective of the shapes or appearances of the actual landmarks. Depicting a solid figure was apparently sufficient, just as the names for landmarks in the descriptions denoted solid figures usually without specifying appearance in greater detail.

The pragmatics of communication, linguistic or pictorial, demand that where more information is needed to distinguish one path or landmark from another, both descriptions and depictions would be expected to provide it. The parallels between descriptions and depictions of routes, both for the segmentation into elements and for the semantics of the elements, give encouragement to the possibility of automatic translation between sketch maps and route directions. Indeed, participants given parallel tool kits, either descriptive or depictive, were able to use the tool kits to construct comprehensible directions (Tversky & Lee, 1999). Of course, the routes participants selected to describe or depict were known to them; otherwise, they could not have produced coherent maps or directions. Schematic maps like these, using straight and curved lines, crosses, and blobs, are found in cultures all over the world (e. g., Harley & Woodward, 1987). Those maps, like these, portray actual space more or less schematically.

Bar and lines: Conveying data

An example of natural uses of graphic elements in an abstract domain comes from studies of productions and interpretations of bars and lines for portraying data (Zacks & Tversky, 1999). As noted earlier, lines are one-dimensional features that can form paths, thereby serving to connect one place to another. Lines can also serve to signify paths between abstract rather than concrete entities, such as different values on the same dimension. Bars on the other hand, are two-dimensional containers. They naturally serve to include some things within, separating those things from things in other containers. Lines connecting A and B seem to say that A and B are similar in sharing a dimension in common, but differ in having different values on that dimension. Bars, by contrast, seem to say that things that are contained in one bar share a feature or set of features that differ from the feature or features shared by things contained in another bar.

Does the underlying notion of connectors and separators affect how lines and bars are interpreted or used? In one study, students were presented with one of the graphs shown in Figure 4. Both bars and lines display imaginary data for height over a discrete variable, sex, or a continuous variable, age. The students were asked to write a brief description of the information portrayed in the graph. The interpretations were scored as trends or discrete comparisons by judges blind to condition. Trend descriptions included: “height increases from women to men,” “height goes up with age,” and even, “as people get more male, they get taller.” Discrete comparison descriptions included: “men are taller than women,” “older kids are taller than younger.” Because lines connect and bars separate, we expected more trend descriptions for lines and more discrete comparisons for bars. This is exactly what happened. In fact, the effect of graphic display was stronger (accounting for more variance) than the effect of the underlying variable, discrete for men vs. women or continuous for age.

Mirror-image results were obtained when we asked participants to construct data depictions from descriptions. We gave participants descriptions of discrete comparisons, "height for males (12 year olds) is greater than height for females (10 year olds)," or descriptions of trends, "height increases from females (10 year olds) to males (12 year olds)." Participants tended to produce bar graphs for discrete descriptions and line graphs for continuous ones, again overriding the underlying nature of the dependent variable.

The ways in which lines and containers are interpreted and used to communicate abstract information, then, is cognitively compelling. Lines connect and bars separate. These perceptual units carry conceptual meaning, affecting how depictions are interpreted and how descriptions are visualized.

Arrows: Conveying order

Arrows are another perceptual unit that appears in depictions, both concrete and abstract. In route maps, they are used to indicate direction of movement. In fact, about half the participants in the study of Tversky and Lee (1998) used them for that purpose. In diagrams of systems, arrows appear to indicate direction of power, or control, or causality. As for maps of environments, diagrams of systems by themselves are structural, and neutral with respect to direction. Are arrows a cognitively natural perceptual unit comparable to lines, curves, and bars? A case can be made that they are. One place that arrow-like figures appear in nature is in river junctions, or on a smaller scale, in water runoff. In both cases, the arrow-like form created from the juncture indicates the direction of flow of the water. Another place arrows commonly occur is as tools created by humans. Here, too, the arrowhead point indicates the direction of movement, in this case, of the projectile. The transition from movement in space to movement in time to movement in causality seems to be a natural one, certainly one reflected widely in the ways people talk.

To ascertain whether arrows serve to indicate causal direction in diagrams, in ongoing research, Julie Heiser and Barbara Tversky presented students with one of three diagrams, of a bicycle pump, a car brake, or a pulley system. Arrows were added to half the diagrams. Students were simply asked to interpret the diagrams. When there was no arrow, students' descriptions were more structural. For example, for the pulley system without arrows, one student wrote: "A three pulley system with a load/weight." In contrast, when arrows were present, the descriptions were more causal or functional. For example, for the bicycle pump with arrows, one student wrote: "Pushing down on the handle pushes the piston down on the inlet valve which compresses the air in the pump causing it to rush through the hose." Interestingly, most of the time, the structure was implicit in the functional descriptions. This suggests that it may be easier to infer structure from function than function from structure, a possibility we are now testing. We are also investigating the mirror-image situation, asking students to produce diagrams from either structural or functional descriptions. The expectation is that arrows are more likely to be included in the diagrams produced from functional than from structural descriptions.

Underlying conceptual structure: Depictive and descriptive units

These three studies point to powerful correspondences between depictions and descriptions of the same conceptual material. The correspondences in turn suggest that depictions and descriptions are similarly schematized because both are driven by the same conceptual analysis of the domain. For example, in order to construct an external representation of instructions to get from A to B, the route is first schematized to an ordered list of actions around landmarks and route segments. Either a depiction or a description can then be constructed from the schematization. For route directions, then, the correspondence between depictions and descriptions is at the level of words or phrases and the structured linking of them.

For graphs, the correspondence between depictions and descriptions is at a level more general than the level of words. For interpreting or producing bars and lines, the common underlying conception is of the relationship between the variables, as a trend or discrete comparison. For diagrams, the correspondence between depictions and descriptions is yet more general, at the level of conceiving of the entire system as a structural one or a causal one.

Despite these variations in the generality of the correspondences between depictions and descriptions, in all cases, perceptual units—lines, curves, containers, arrows—map onto conceptual structures. The underlying meaning suggests a natural way of interpreting graphics as well as a natural way of constructing graphics from an interpretation.

Graphic Space

Like the graphic elements themselves, the space between graphic elements has also been used to convey meaning in cognitively compelling ways. An example so obvious that it typically goes unnoticed is the space between words. There was a time when language was written as strings of letters without breaks between words. Grouping the letters that belong to one word separately from those that belong to another by a spatial device, an empty space between the letters, makes it easier to distinguish the words. Written language has other examples of spatial devices that convey meaning naturally. For example, ideas are separated by paragraphs, which are signaled by indentation and/or skipping a line, and outlines make successive use of indentation to signal subordination.

Space can be used meaningfully at several levels, depending on the degree of spatial information that is intended to be conveyed. The weakest level is the nominal, or categorical, level, where things are merely separated into groups by a common feature or features, like the letters that belong to different words (see Stevens, 1946, for a discussion of scale types). Stronger constraints come when order is indicated spatially, as in indentation for paragraphing or successive indentation in outlines. Order can be indicated in other ways. A straightforward way is to order things in a list the way they are ordered on some other variable: children by age, scientific discoveries by dates, countries by GNP, groceries by route through the store. Partial orders are commonly represented by hierarchical trees, where one direction, usually horizontal, is meaningful, and the other is not. Still more information is represented when space is used intervally. In many X-Y graphs, not only is the order of elements in space meaningful, but also the distances between the elements. Interval representations allow inferences such as the lag time between scientific discoveries and commercial applications is getting shorter and shorter. Finally, when a zero point located in space is meaningful, then ratios of spatial distances between elements are also meaningful. Ratio representations allow inferences such as the distance between Chicago and San Francisco is more than twice the distance between Chicago and New York. With the notable exception of pie charts, which are appropriate for ratio relations but not for interval ones, uses of space to represent interval and ratio relations are often the same, differing in the interpretation.

Let us now turn to some examples of graphic inventions that use space in these ways. The examples come primarily from cross-cultural studies on children of varying ages. The historical inventions that will be discussed echo those of the children.

Children invent writing

In a series of studies, Lilianna Tolchinsky Landsman and Iris Levin asked pre-literate children from several different cultures, all with alphabetic scripts, to take dictation (Tolchinsky Landsman & Levin, 1985; 1987). Of course, there was no expectation that they would write real words. Rather, the goal was to characterize the graphic symbol systems the children would invent. Naturally, their inventions were not pure, as the children had been exposed to writing even if they did not know how to decipher the code or even what the code was. Early on, children wrote down one mark for each word, much like the ideographic scripts that preceded the alphabet in which each character corresponded to a word. Older children often used several characters for each word, much like the scripts they would eventually learn. The words children invented often resembled the concepts they were representing. For example, larger concepts got larger words, and when a choice of colors was given, the choice corresponded to the color of the thing represented. In some cases, written words were longer for concepts that took longer to say, again indicating that the children were absorbing something of the nature of the alphabetic scripts they would acquire. In all cases, spaces separated words. Children began writing from the top of the page and always placed words on a line. These features characterize all written languages as well, although sometimes the lines are horizontal, sometimes vertical, sometimes beginning at the left, sometimes at the right, but always from the top.

The devices that children inventing writing produce, then, strongly resemble the devices invented across cultures for the same purposes. Of course, children's exposure to the writing systems of the surrounding culture may have biased at least some of their inventions, but nevertheless, the ubiquity of the inventions suggests that they are cognitively compelling.

Children invent graphs

How do children use space to convey abstract concepts? We investigated this by providing children with square pieces of paper and stickers, and asking them to arrange the stickers in space to represent a number of relative concepts: time, quantity, and preference (Tversky, Kugelmass, and Winter, 1991). Children were first acquainted with the task by representing spatial relations, specifically, the arrangement of small dolls on a line. Then, to elicit representations of time, the experimenter sat next to the child and asked the child to think about the times of day when the child ate breakfast, lunch, and dinner. The experimenter then put a sticker down in the middle of a blank, square piece of paper to represent the time for eating breakfast, and asked the child to put down a sticker showing the time for eating lunch and another sticker for the time for eating dinner. Other time questions followed. One question about quantity asked the child to think about the amount of candy in a handful, the amount of candy in a bag full, and the amount of candy collected at Halloween. A preference question asked the child to think about a food the child loved, a food the child didn't like, and a food somewhere in between. The participants included Hebrew-speaking Israelis, Arabic-speaking Israelis, and Americans. These cultures are of interest partly because of the directions of their writing systems. English is written from left to right, whereas Hebrew and Arabic are written right to left. The right to left tendencies are much stronger in Arabic than in Hebrew for several reasons. Arabic script is connected and each character is formed from right to left, whereas Hebrew has no script and most letters are formed from left to right. In Hebrew, the arithmetic system follows the Western left to right order, but in Arabic, arithmetic is taught from right to left until the middle school years when the Western conventions are adopted. Participants ranged in age from preschool to college.

One question of interest was how much information from the conceptual relations the children preserved in the spatial mappings. Would this vary with age or culture? In fact, the amount of information preserved in the mappings increased with age, but did not vary across culture. Some of the youngest children only preserved nominal or categorical relations in their mappings. That is, they regarded time for breakfast, lunch, or dinner or preference for TV shows as different but not as on an ordered continuum. These children placed their stickers haphazardly on the page. Such children were unusual. Most of even the youngest children ordered the stickers on a line, mappings that preserved ordinal information. Some of the relations children were asked to map had clearly unequal distances between the items, for example, time to wake up, time to go to school, and time to go to bed. Despite the clear differences, only the older children's mappings preserved interval information. To test the limits of this, a new group of children were given special procedures designed to call attention to the different intervals and to elicit interval mappings. For the most part, these failed. By 12 years, however, children began to map interval spontaneously.

Another question asked of the data concerned the directionality of the increases. Would they vary with language or with concept? In fact, directionality varied both with language and with concept. For preference and quantity, increases were mapped approximately equally across cultures from right to left, from left to right, and from bottom to top. The only direction to indicate increases that was avoided was top to bottom. These practices reflect what seem to be biases about horizontal and vertical space. Horizontal space is neutral, the right and left halves of the body are relatively symmetric, especially in comparison to the top and bottom or front and back halves, which are clearly different. What's on the right and what's on the left in the space around the body is for the most part arbitrary, an accident of one's current point of view. What's up and what's down in the world, by contrast, is no accident. What's up defies gravity, exhibits strength. People grow stronger as they grow taller. Larger piles, of goods or money, are higher. So “up” is associated with more, better, stronger. This apparently natural association between space and meaning is reflected in language and gesture as well. We say someone’s at the top of the world or the top of the heap and we give a thumbs up or a high five.

Spatial displays of temporal relations, however, were different. All groups mapped temporal order from down to up. They also used the horizontal axis, but the specific direction depended on the direction of writing in the language. Many English-speakers plotted increases in time from left to right whereas Arabic speakers tended to plot temporal increases from right to left. As noted, in Hebrew writing is less lateralized than in Arabic; similarly, the graphic mappings of Hebrew speakers were also more evenly distributed from right to left and from left to right. Some of the Arabic speakers, and only the Arabic speakers, mapped later times to lower. This, of course, corresponds to the way calendars and date books are organized, the beginning, the earliest time at the top.

Spatial relations then, can be used spontaneously to convey abstract, non-spatial relations by children and adults in different cultures. Space is readily used to convey categorical and ordinal relations; it may also be used to convey interval relations. There is some consistency in the spatial direction used to convey increases. First, increases are nearly always conveyed vertically or horizontally, not diagonally or circularly. The particular horizontal direction is neutral, except for the case of temporal increases, in which case, horizontal direction tends to follow writing order. As for the vertical axis, increases in quantity and preference (but notably not in time) overwhelmingly correspond to upwards direction, in correspondence with language and gesture, where up indicates more, better, and stronger. Moreover, these correspondences seem grounded in the world, where, in general, more things make higher piles and stronger things are taller.

Depicting Abstractions

Graphics have been produced by different cultures throughout history for different ends. They portray reality and myth; they record history and present proclamations; they convey models of things and of systems. To convey these various meanings, they use characteristics of elements as well as the spatial relations among elements. Many of these depictive devices have been invented and reinvented across cultures and ages for similar meanings. As such, they are readily interpreted, even if novel. Thus, they appear to have a degree of cognitive naturalness. Elements may resemble the elements to be mapped, or they may represent them figuratively. As the preceding studies have shown, a small group of geometric forms may be used to convey abstract meanings directly. For example, in sketch maps, straight-line segments indicate straight roads, curved line segments indicate curved roads, crosses indicate intersections, and blobs suggest environmental structures. Note that these depictive units, like language, are schematic or categorical; none normally captures exact metric relations. In graphs, lines link and bars separate, so that line graphs are interpreted and produced for trends whereas bar graphs are interpreted and produced for discrete relations. In diagrams, arrows indicate temporal sequence from which causal sequence is readily. The presence of arrows in diagrams encourages causal over and above structural interpretation.

Spatial relations among elements are also readily produced and interpreted using the basic underlying metaphor that proximity in space reflects proximity in an abstract dimension. Graphic space may preserve abstract spaces at several levels of information. At the nominal or categorical level, items are separated into groups that share a common feature or features, but there is no relationship implied between groups. At the ordinal level, items have differing values on the same underlying feature, yet the distance between them is not intended to be meaningful. Distance between items is meaningful at the interval level (and ratios of distances at the ratio level, where zero is meaningful).

General abstract meanings may also be expressed in depictions. Equivalence, for example, can be expressed by grouping items that are equivalent and spatially separating them from items that are not. Equivalence can also be indicated pictorially, by various frames, such as boxes, bars, and () and by similar appearance, as in fonts, sizes, colors. Connections between items can be depicted by lines of various sorts. Order among items may be indicated both spatially and pictorially as in indentation of paragraphs or in outlines as well as the order in which a set of items is listed, for example, children in order of age, groceries in order of a path through the supermarket. Pictorially, orders, especially partial orders, can be represented as trees. Similarly, degrees of relationship, such as similarity, salience, or strength, can be suggested spatially by degree of proximity, or pictorially by degree of appearance, color or size for examples. Proportion can be indicated by spatial proportion. Direction is conveniently conveyed by arrows, whether the direction is spatial, temporal, causal, or other.

Change can be easily expressed by actual change, as in animation, though animations can present both perceptual and cognitive difficulties (see Morrison, Tversky, and Betrancourt, 2000). Other effective ways to indicate change are by artfully selected successive stills, as in comics (McCloud, 1994) or instructional materials (Zacks and Tversky, in preparation) or flowcharts with arrows.

In sum.

Words are certainly the prototypic medium of communication. They can be concrete or abstract, succinct or expansive. They can be audible or viewable, and they are portable. But words bear only symbolic relations to the concepts they represent. Therein lies their limits and their power, the power of abstraction. By contrast, depictions use elements and the spatial relations among them to convey concrete and abstract meanings quite directly. Using space and the elements in it to convey meaning also capitalizes on the impressive capacity people have to process and store spatial and visual information. Therein lies the powers of depictions. They can grab and keep attention by being attractive or humorous or frightening. They can demonstrate knowledge directly rather than indirectly, as in maps and models. They can promote inferences based on spatial and visual reasoning. They can serve as external representations of thought, alleviating mental processing load. As external representations, they are open to a community of users who can inspect, reinspect, and revise them. There is more to depictions than meets the eye.

References

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

Cleveland, W. S., & McGill, R. (1985). Graphical perception and graphical methods for analyzing scientific data. Science, 229, 828-833.

Denis, M. (1997). The description of routes: A cognitive approach to the production of spatial discourse. Cahiers de Psychologie Cognitive, 16, 409-458.

Gelb, I. (1963). A study of writing. Second edition. Chicago: University of Chicago Press.

Harley, J. B., & Woodward, D. (Eds.). (1987). History of cartography, Vol. 1. Cartography in prehistoric, ancient and medieval Europe and the Mediterranean. Chicago: University of Chicago Press.

Hughes, M. (1986). Children and number: Difficulties in learning mathematics. Oxford: Blackwell.

Ifrah, G. (1999). The universal history of numbers: From prehistory to the invention of the computer. NY: Wiley.

Mallery, G. (1972). Picture writing of the American Indians. (Originally published by Government Printing Office, 1893). NY: Dover.

McCloud, S. (1994). Understanding comics. N.Y.: HarperCollins.

Morrison, J. B., Tversky, B., & Betrancourt, M. (2000). Animation: Does it facilitate learning? AAAI Spring Symposium on Smart Graphics. Menlo Park, CA: AAAI Press.

Small, J. P. (1999). Time in space: Narrative in classical art. Art Bulletin, 81, 562-575

Stevens, S. S. (1946). On the theory of scales of measurement. Science, 103, 677-680.

Tolchinsky Landsmann, L., & Levin, I. (1987). Writing in four- to six-year-olds: Representation of semantic and phonetic similarities and differences. Journal of Child Language, 14, 127-144.

Tolchinsky Landsmann, L., & Levin, I. (1985). Writing in preschoolers: An age-related analysis. Applied Psycholinguistics, 6, 319-339.

Tufte, E. R. (1983). The Visual Display of Quantitative Information. Cheshire, CT: Graphics Press.

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

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

Tversky, B., & Lee, P. U. (1998). How space structures language. In C. Freksa, C. Habel, & K. F. Wender (Eds.), Spatial cognition: An interdisciplinary approach to representation and processing of spatial knowledge (pp. 157-175). Berlin: Springer-Verlag.

Tversky, B., & Lee, P. U. (1999). Pictorial and verbal tools for conveying routes. In C., Freksa, & D. M., Mark, (Eds.), Spatial information theory: Cognitive and computational foundations of geographic information science (pp. 51-64). Berlin: Springer.

Zacks, J., & Tversky, B. (1999). Bars and lines: A study of graphic communication. Memory and Cognition, 27, 1073-1079.

Zacks, J., & Tversky, B. (In preparation). Event segmentation in instruction.

Zacks, J., Levy, E., Tversky, B., & Schiano, D. (In press). Graphs in use. In M., Anderson, B., Meyer, & P., Olivier (Eds.), Diagrammatic reasoning and representation. Berlin: Springer.

Figure Captions

Figure 1. Letter from Ojibwa woman. From *Picture Writing of the American Indians* (Vol. 1, p. 363), by G. Mallery, 1972, (Originally published by Government Printing Office, 1893). NY: Dover. Copyright 1972 by Dover Publications Inc. Reprinted with permission.

Figure 2. Pictorial signs in the Sumerian, Egyptian, Hittite, and Chinese languages. From *Study of Writing* (p. 98) by I. J. Gelb, 1963, Chicago: The University of Chicago Press. Copyright 1963 by The University of Chicago Press. Reprinted with permission.

Figure 3. Maps drawn by informants. From “How space structures language” by B. Tversky and P. Lee, 1998, *Spatial cognition: An interdisciplinary approach to representation and processing of spatial knowledge*, p. 168. Copyright 1998 by Springer-Verlag. Reprinted with permission.

Figure 4. Bar and line graphs used by Zacks and Tversky (1999). From “Bars and lines: A study of graphic communication,” by J. Zacks, and B. Tversky, 1999, *Memory and Cognition*, p. 1074. Copyright 1999 by the Psychonomic Society, Inc. Reprinted with permission of the author.

Table 1

DW 9
From Roble parking lot
R onto Santa Theresa
L onto Lagunita (the first stop sign)
L onto Mayfield
L onto Campus drive East
R onto Bowdoin
L onto Stanford Ave.
R onto El Camino
go down few miles. it's on the right.

BD 10

Go down street toward main campus (where most of the buildings are as opposed to where the fields are) make a right on the first real street (not an entrance to a dorm or anything else). Then make a left on the 2nd street you come to. There should be some buildings on your right (Flo Mo) and a parking lot on your left. The street will make a sharp right. Stay on it. that puts you on Mayfield road. The first intersection after the turn will be at Campus drive. Turn left and stay on campus drive until you come to Galvez Street. Turn Right. go down until you get to El Camino. Turn right (south) and Taco Bell is a few miles down on the right.

BD 3

Go out St. Theresa
turn Rt.
Follow Campus Dr. way around to Galvez
turn left on Galvez.
turn right on El camino.
Go till you see Taco Bell on your Right

Examples of Route Directions[1]

[1]From "How space structures language" by B. Tversky and P. Lee, 1998, *Spatial cognition: An interdisciplinary approach to representation and processing of spatial knowledge*, p. 167. Copyright 1998 by Springer-Verlag. Reprinted with permission.

Figure 3

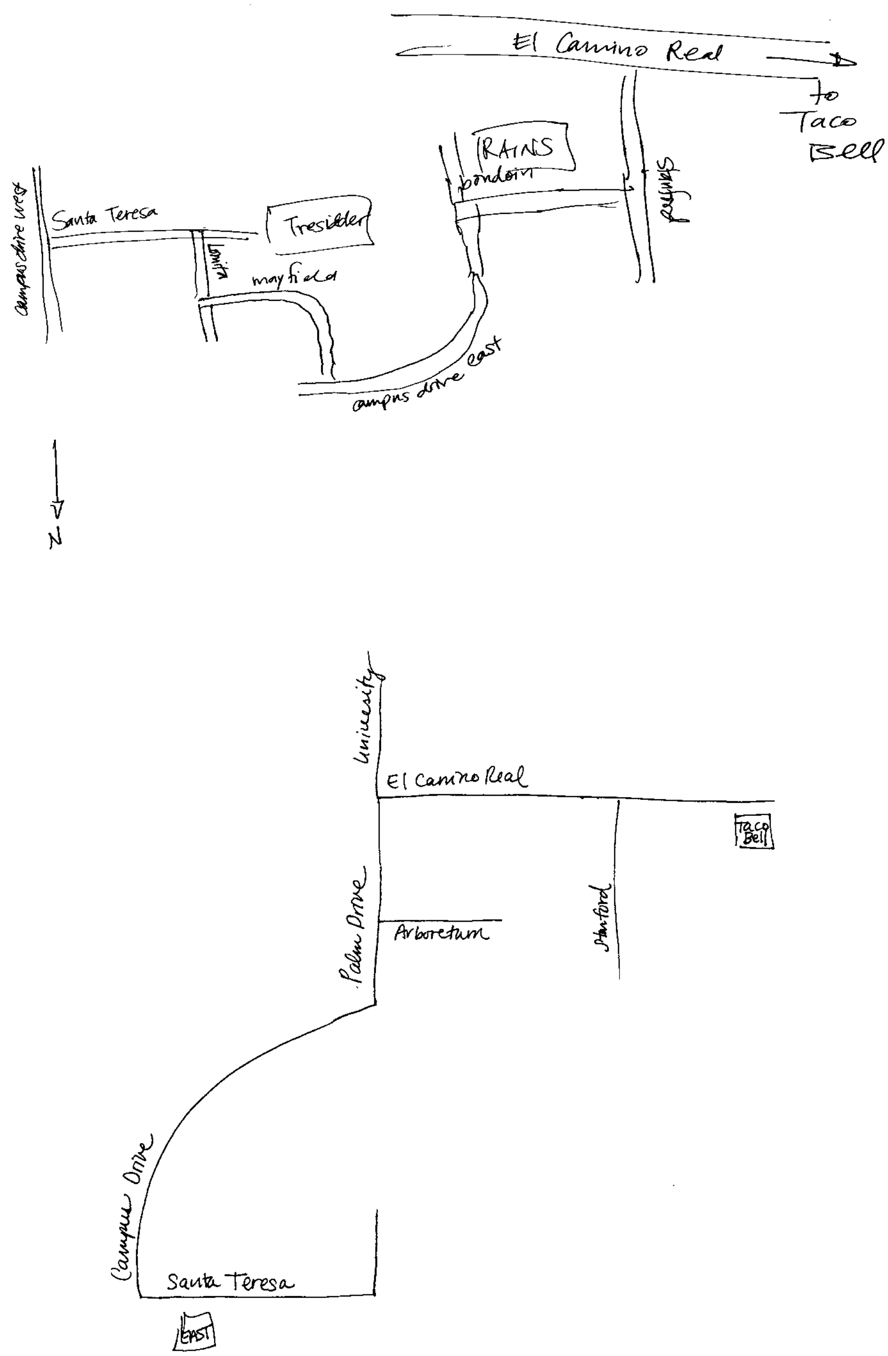
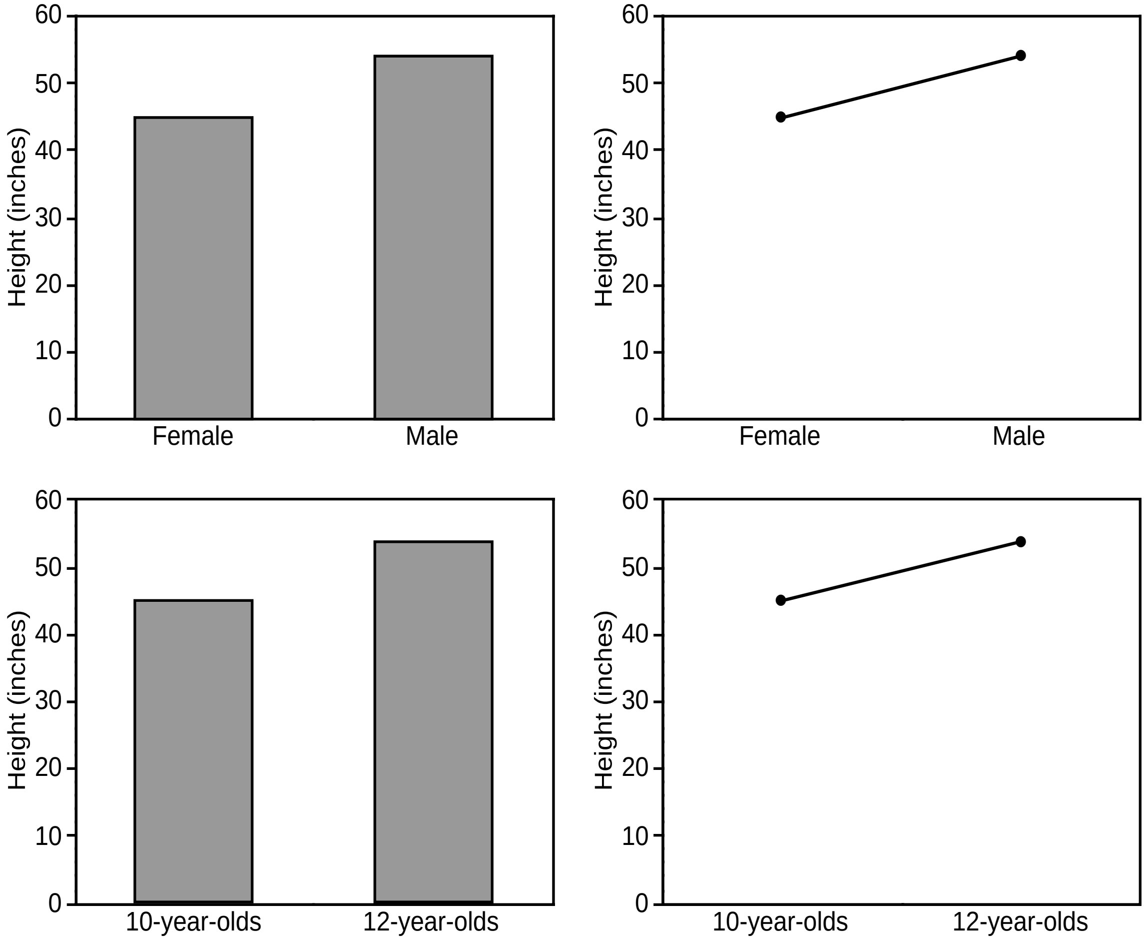

El Camino Real
to Taco Bell
RAINS
bowdoin
Stanford
Santa Teresa
Tresidder
campus drive west
Lomita
mayfield
campus drive east
N
University
El Camino Real
Taco Bell
Palm Drive
Arboretum
Stanford
Campus Drive
Santa Teresa
EAST

Figure 4


Height (inches)
60
50
40
30
20
10
0
Female
Male
10-year-olds
12-year-olds