J. S. Gero, B. Tversky and T. Purcell (eds), 2001, *Visual and Spatial Reasoning in Design, II*
Key Centre of Design Computing and Cognition, University of Sydney, Australia, pp.

# SPACE AS A BASIS FOR REASONING

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**Abstract.** We use space as a basis for reasoning whenever we use a spatial representation of a nonspatial concept to make decisions or inferences. From a psychological perspective, our tendency to create and reason fluidly from spatial models is somewhat surprising, because using a spatial model to reason involves creating correspondences between two semantically unrelated concepts: space, and something that isn't space, whether that be time, performance, or the desirability of a new job. Our proficiency in using space as a basis for reasoning relies our abilities to detect similarities in the structures of very different concepts. In this paper I discuss two types of similarities between space and nonspatial concepts and describe how those similarities influence reasoning from spatial representations.

## 1. Using Space to Reason

We use space as a basis for reasoning whenever we create a spatial representation of a nonspatial concept and use that representation to make decisions or inferences (Gattis, 2001a; Gattis and Holyoak, 1996). We use calendars to decide what day would be best to schedule an out-of-town seminar, graphs to decide whether an experimental manipulation is having the hoped-for effect, and lists of pros and cons to decide whether to stay or go. Likewise, we sometimes create spatial models that don't exist on paper. When adults are asked to reason about the relative value of different people, such as "Mantle is better than Mays. Mays is better than Moskowitz. Is Mantle better than Moskowitz?", they report creating a spatial ordering of the names (De Soto, London, and Handel, 1965; Gattis and Dupeyrat, 2000). Our gestures also reveal mental models based on space: when people discuss the relative merits of two options in a relationship or a career, their gestures create two contrasting spaces on each side of the body, and once those spaces are established, a particular location consistently represents a particular option for both participants in the conversation (Gattis and Frosch, 2000).

From a psychological perspective, our tendency to create and reason fluidly from spatial models is somewhat surprising. Using a spatial model to reason involves creating correspondences between two very different and semantically unrelated concepts: space, and something that isn't inherently spatial, whether that be time, performance, or the desirability of a new job. Studies of analogical reasoning have long demonstrated that people have difficulty using one concept to reason about another concept, especially when the two concepts are semantically unrelated. In a series of studies, Mary Gick and Keith Holyoak (1980; 1983) told adults a story about a general whose army converges on a fortress from many directions to attack the fortress while avoiding land mines. When those adults were then given a problem about a doctor trying to destroy a tumor, for which a similar convergence of forces would solve the problem optimally, only about 20 percent spontaneously produced the convergence solution.

In this paper I would like to argue that our proficiency in using space as a basis for reasoning is attributable to our analogical reasoning abilities, and more generally our abilities to detect similarities in the structures of very different concepts. The dim portrait of our analogical reasoning abilities just presented may seem an odd starting point for claiming that space is a base, or source analogy, in reasoning. There are several reasons to be encouraged, however. When two problems are semantically similar, or when people are given a hint to use one problem to solve another, the tendency to reason analogically improves dramatically. Similarly, experts are more likely to use analogies, and when it comes to space, we are all thoroughly experienced. Perhaps most importantly, however, successful analogies rely on detecting the structural similarities between problems (Holyoak and Thagard, 1995; Markman and Gentner, 1993), and the ways in which we think and talk about space in everyday life emphasise the structural aspects of space.

## 2. Polarity as a Basis for Reasoning

One aspect of the way we think and talk about space is polarity. When we walk down the street, we walk forward, not backward, and we see what is in front of us, not what is behind us. The construction of our bodies, such as our eyes and our feet, bias us toward a particular end of the horizontal space in which we move. Not surprisingly then, people are also quicker at remembering objects in front of them than objects behind them (Bryant, Tversky and Franklin, 1992). Our representation of horizontal space is asymmetrical: front is more important, or positively weighted in comparison to back. The way that we think and talk about vertical space is similar. Our most important sensory receptors are at the tops of our bodies, not the bottom, and we see objects falling from above to below more often than in the opposite direction (Clark, 1973). Up is more important and more positive than down.

Polarity is not limited to spatial dimensions, however, we also organise other perceptual dimensions asymmetrically. In the 1950's and 60's, psychophysicists interested in crossmodal magnitude judgements of stimulus dimensions such as loudness, brightness, hardness, and roughness made an interesting discovery. Not only were people able match the magnitudes of stimuli that were seen with entirely different stimuli that were heard or felt, but the way in which they matched the stimuli indicated that for most perceptual dimensions, one aspect of the dimension, such as hardness, is the primary attribute, and one aspect of the dimension, such as softness is the inverse (Stevens, 1975). In other words, as with horizontal and vertical space, many dimensions have a particular direction of increase: like up, loud, rough, and hard are more important and positively weighted.

Polarity is not simply a characteristic of perception, however, it is a characteristic of language as well. Dimensional adjectives like fast and slow have an asymmetric structure, as illustrated by the observation that "How fast is your car?" is an acceptable question, but "How slow is your car?" is a joke or insult. Similarly, asking a friend "How loud was the music?" does not necessarily imply your friend now has hearing damage, but "How quiet was the music?" conveys that he most certainly does not.

For some time the polar structure of perception was assumed to be a fixed property of our sensory systems, and the polar structure of language was assumed to be a unidirectional influence of perception on language. More recently, however, we have learned that perceptual and linguistic polarity interact. Linda Smith and Maria Sera (1992) asked children between the ages of 2 and 5 to match toy mice that varied in either size, in achromatic hue, or in the loudness of a sound emitted from the mice. Older children matched a bigger mouse with a louder mouse, but did not distinguish between whether big matches dark or light. Younger children, in contrast, matched a big mouse with a dark mouse but did not distinguish between whether big matches loud or quiet. Smith and Sera explained these results by proposing that early in development, the dimensions of size and achromatic hue are perceptually polar, but the dimension of loudness is not. Loudness is linguistically polar, however, whereas achromatic hue is not: neither dark nor light describes the dimension of hue, and each term refers more or less to its own end of the dimension. Thus linguistic structure appears to influence perceptual structure, as well as the other way around.

The perceptual and linguistic polarity of dimensions is relevant to reasoning with spatial models because spatial dimensions are asymmetrically organised, such as the height, length, and the steepness of lines, and concepts such as time, quantity, value and performance are organised asymmetrically as well. I have recently been investigating whether perceptual and linguistic polarity influence the way in which we reason with graphs. I am particularly interested in how children reason with graphs because children's performances early in development may tell us something about the structure of spatial reasoning. Children between the ages of 3 and 6 and adults were shown a simple drawing of two slanted lines with one common point but different angles, much like function lines in a Cartesian graph. Half of the children saw lines slanting upward and half of the children saw lines slanting downward. We knew from pilot testing that the most salient difference between these particular lines in each drawing was their slope. As can be seen in Figure 1, in the upward-slanting lines, the top line has greater slope, and in the downward-slanting lines, the lower line has greater slope.

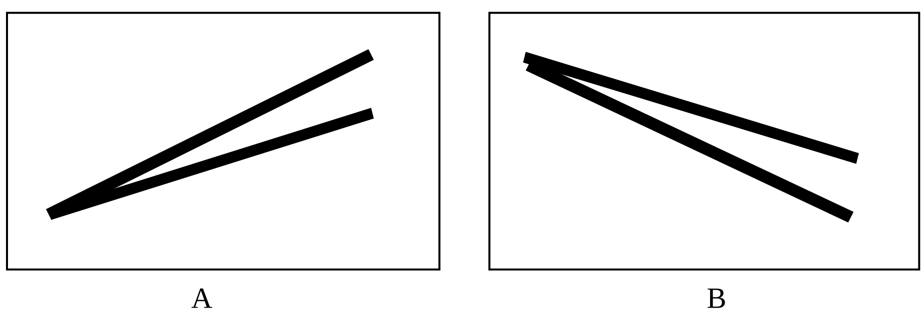


*Figure 1.* Diagrams used to investigate whether perceptual and linguistic polarity influence the way in which we reason with graphs. Children and adults were shown either the diagram on the left or the diagram on the right and asked to make an interpretive judgement about which of two animals varying along some dimension was represented by that line.

We asked the children to make an interpretive judgement about the what the lines might represent. For instance, in one condition the experimenter said, "I want to tell you a story about these two lines. Imagine that there are two bears. They are very good friends and play together. They also have a lot in common, but there is one way in which they are different: One is big and one is small. These two lines stand for the two bears. Look at this line. Does this line stand for the bear who is big or the bear who is small?" Each child was asked to make three judgements, "Does this line stand for the bear who is big or the bear who is small?", "Does this line stand for the dog who is loud or the dog who is quiet?", and "Does this line stand for the rabbit who is dark or the rabbit who is light?" I chose these three comparisons because I wanted to know whether children's performance on this very abstract task would show a similar interaction between perceptual and linguistic polarity to that observed in Smith and Sera's studies.

When adults are asked to make the same interpretive judgements, their answers are consistent with the linguistic polarity of big/small, loud/quiet, and light/dark. As mentioned earlier, big is positive with respect to small, and loud is positive with respect to quiet, but neither light nor dark is positive with respect to the other. Adults report that the top line in Figure 1A and the bottom line in 1B represent the big bear and the loud dog, while the bottom line in 1A and the top line in 1B represent the small bear and the quiet dog. In constrast, adults make inconsistent assignments for the light and dark rabbits – sometimes they say that the line with greater slope represents the dark rabbit, and sometimes the opposite. The assignments that adults make suggest that in the absence of meaningful information telling us how to interpret a spatial model, we sometimes use perceptual and linguistic polarity to assign a meaning, and those assignments are consistent across individuals and a variety of linguistic terms, as long as the linguistic terms provide a polar structure. The positive end of a perceptual dimension, such as slope, can be matched with the positive end of a nonspatial dimension, such as loudness, to lead to consistent interpretations of spatial representations despite the lack of any deeper structural cues or more meaningful guidance.

Older children made similar judgements to those made by adults: big and loud were consistently paired with greater slope, and small and quiet were consistently paired with less slope, whereas judgements about dark and light were random. The judgements made by younger children were less consistent, with big, loud, and dark sometimes being paired with greater slope, but not in all conditions of the experiment. The ability to detect and use polarity in interpreting spatial representations thus seems to emerge early and to become increasingly organised with age and experience. We are now investigating whether that development depends on language learning or other forms of experience.

## 3. Relational Structure as a Basis for Reasoning

We also perceive and talk about the relational structure of space. We are very good at remembering the order and layout of objects, an ability that is exploited by academics who keep piles of papers on their desks, and nonetheless seem to locate the requested paper immediately. We conceive of our environment as containing objects which may be described in terms of a single spatial relation (for instance, right to left) or multiple spatial relations (right to left and top to bottom, diagonally, and so on). We are also adept at using the relational structure of space to talk about the relational structure of nonspatial concepts. In the context of a two-dimensional representation such as a graph, calendar or diagram, we may talk about individual elements (such as "I have an appointment on Thursday at 9.") and how those elements are related across a single dimension of space (such as "I have appointments at 9 every day next week."). We can also identify relationships between two dimensions (such as "Temperature is decreasing as altitude increases.", or "In this sample temperature is decreasing faster than in that sample."). When we do so, we rely on a mapping between spatial and conceptual dimensions (Gattis and Holyoak, 1996).

A second area I have investigated about how children reason with graphs is their ability to use relational structure to map concepts to space (Gattis, 2001b). In some of these experiments, children around the age of 6 were given diagrams similar to graphs and asked to make interpretive judgements similar to those described in the previous section. I chose children of this age because I wanted the children be old enough to reason about fairly complex relations, such as how two dimensions can be integrated, and young enough that they would have very limited exposure to and instruction in the rules of graphing.

Children were familiarised with graphs in a three-step procedure. In the first step, they were shown a drawing resembling a horizontally- stretched L (see Figure 2), and were taught to map values such as time and quantity to the horizontal and vertical lines. On the vertical line, children either mapped increases upward or downward. In the second step, children were taught how the values from each line could be integrated to form a new line that represented both values in a "meeting point" (see Figure 3). In the third step, children were shown a similar frame with two data lines, and were asked to make a judgement about the relations between those lines. The judgement that children were asked to make was either about a value on a single dimension, such as quantity, or a value that integrated both dimensions, such as rate.

If children are sensitive to similarities of relational structure even before they receive graphing instruction, they ought to distinguish between a judgement about a single dimension and a judgement about the integration between dimensions by choosing a spatial cue that corresponds in relational complexity. So judgements about quantity would correspond to differences in the height of the lines, for instance, while judgements about rate would correspond to differences in the slope of the lines. In contrast to the impoverished knowledge of children in the polarity experiments, in these experiments children were given a brief instruction that was intended to heighten their awareness of the way in which correspondences could be established between a spatial representation and a nonspatial problem, and of the relational structure of each. Nonetheless we did not give them any instruction about how a relation between two dimensions might be represented, such as that one of the rules of graphing is that slope represents the rate of change between the x and y variables. Whereas in the polarity studies we expected that children's judgements were driven by the differences in slope, and the question asked was simply which adjectives were paired with greater and lesser slope, in these experiments we expected that children's judgements would sometimes correspond to the height of the line, and sometimes to the slope of the line, depending on the relational structure of the concept being probed.

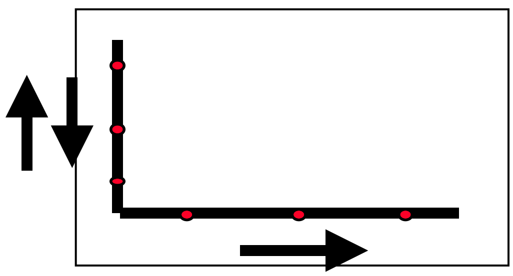

*Figure 2.* Diagrams used to investigate whether young children are sensitive to relational structure when reasoning with graphs. In the first step, children were shown an L-shaped frame and taught to map values such as time and quantity to the horizontal and vertical lines The arrows represent the direction of increases. On the vertical line, children either mapped increases upward or downward.

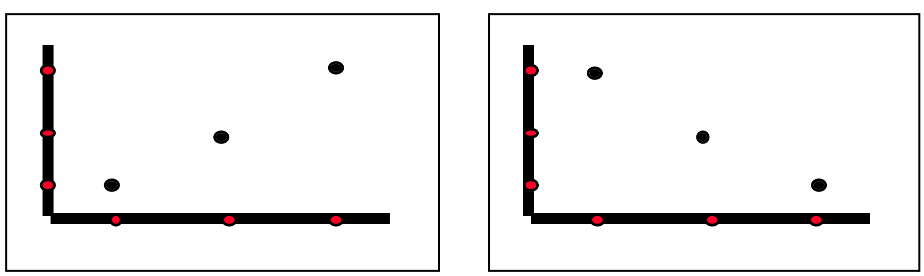

*Figure 3.* In the second step, children were taught how the values from each line could be integrated to form a new line.

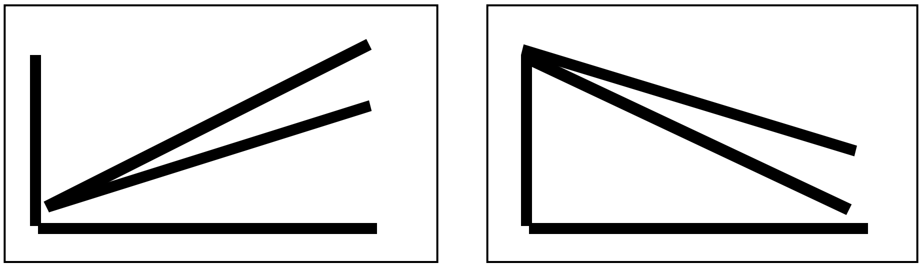

*Figure 4.* In the third step, children were shown the same frame with two data lines. Children who had mapped increases along the vertical from bottom to top saw upward-sloping lines and children who had mapped increases along the vertical from top to bottom saw downward-sloping lines.

When children were taught to map time and quantity to the horizontal and vertical lines, and then asked to make a judgement about quantity, their judgements corresponded to the height of the line, regardless of whether they had mapped time or quantity to the vertical line, and regardless of whether they had mapped increases upward or downward. Thus children seemed to use a simple rule to make quantity judgements: “more is up.” In contrast, when other children who were also taught to map time and quantity to the horizontal and vertical lines in the same procedure were asked to make a judgement about rate rather than quantity, their judgements corresponded to the slope, rather than the height, of the line. Like adults in previous studies (Gattis and Holyoak, 1996), 6-year-olds appear to use a different but equally simple rule to make rate judgements: “steeper is faster.” What is significant about this tendency is that it suggests that before having formal instruction in graphing, children are sensitive to similarities in the relational structures of spatial representations and nonspatial concepts, and can use those similarities to create an analogy that allows them to reason in surprising ways, despite their incomplete understanding of how graphs are made.

## 4. Conclusions

We use space as a basis for reasoning about a nearly unlimited variety of nonspatial concepts. This seemingly complex and effortful task is facilitated by the ways in which we think and talk about space. Our spatial language and spatial representations emphasise the structural aspects of space, such as polarity and relational structure, and these structural aspects of space help us to create reliable correpondences between space and other concepts.

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