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DISTORTIONS IN MEMORY FOR VISUAL DISPLAYS

Barbara Tversky
Stanford University
Stanford, California

ABSTRACT

Systematic errors in perception and memory present a challenge to theories of perception and memory and to applied psychologists interested in overcoming them as well. The present paper reviews a number of systematic errors in memory for maps and graphs, and accounts for them by an analysis of the perceptual processing presumed to occur in comprehension of maps and graphs.

Visual stimuli, like verbal stimuli, are organized in comprehension and memory. For visual stimuli, the organization is a consequence of perceptual processing, which is bottom-up or data-driven in its earlier stages, but top-down and affected by conceptual knowledge later on. Segregation of figure from ground is an early process, and figure recognition later; for both, symmetry is a rapidly detected and ecologically valid cue. Once isolated, figures are organized relative to one another and relative to a frame of reference. Both perceptual (e.g., salience) and conceptual factors (e.g., significance) seem likely to affect selection of a reference frame.

Consistent with the analysis, subjects perceived and remembered curves in graphs and rivers in maps as more symmetric than they actually were. Symmetry, useful for detecting and recognizing figures, distorts map and graph figures alike. Top-down processes also seem to operate in that calling attention to the symmetry vs. asymmetry of a slightly asymmetric curve yielded memory errors in the direction of the description. Conceptual frame of reference effects were demonstrated in memory for lines embedded in graphs. In earlier work, the orientation of map figures was distorted in memory toward horizontal or vertical. In recent work, graph lines, but not map lines, were remembered as closer to an imaginary 45° line than they had been. Reference frames are determined by both perceptual and conceptual factors, leading to selection of the canonical axes as a reference frame in maps, but selection of the imaginary 45° line as a reference frame in graphs.

DISTORTIONS

With the best of intentions, scientists, newspaper editors, and textbook authors select graphic displays to present their ideas more clearly and more vividly to their readers. Nevertheless, some of the effects are not only unintended, but unwanted. For example, in figure 1, presumably the striping on the bars was selected to differentiate the bars, not to instantiate the herringbone illusion, where straight lines are perceived as tilted (this example comes from Schultz, 1961 through Kruskal, 1982). In figure 2 (from the business section of the August 2, 1987, *New York Times*), the graphic artist wanted to contrast two related sets of numbers, the debt and the debt service ratio, year by year. I don't think that the graphic artist intended to create a figure with such a strong tendency to reverse that it makes it difficult to focus on any one section of the graph. Figure 3 takes us from the realm of perceptual illusions to experiments in judgment by Cleveland, Diaconis, and McGill (1982). These statisticians asked knowledgeable subjects to estimate correlations from scatter plots and found that higher estimates were given when the point cloud was smaller (or the frame larger). Figure 4, popularized by Tufte (1983) and reprinted by Wainer (1980), is taken from the *Washington Post* of October 25, 1978. Here, the graphic artist probably thought it would be clever to represent the metaphor of the diminishing dollar quite literally. However, only the *length* of the dollar represents the decline of purchasing power, not the *area*, yet it is the area that is picked up by the human observer. So, although the Carter dollar purchases a bit less than half of the Eisenhower dollar, the Carter dollar looks less than a quarter of the area of the Eisenhower dollar.

The next example of distorted perception brings me to research in my laboratory. Let me first tell you about a number of different phenomena we have studied, and then I will try to account for them in an analysis of perceptual organization, where both perceptual and conceptual factors are operative. First, I will discuss examples of perceptual factors. Jennifer Freyd and I (1984) asked subjects to look at figures like that at the top of figure 5, and then decide whether it was more similar to a slightly more symmetric figure or to an equally different, but slightly less symmetric, figure. When we selected nearly symmetric figures like that one, subjects nearly always chose the more symmetric alternative as the more similar. What's more, when subjects were asked to select which of the bottom figures was identical to the top figure, subjects were faster to select the identical figure when the alternative figure was *less* symmetric than the original (as in fig. 5) than when it was *more* symmetric than the original. These effects obtained for nearly symmetric figures, but not less symmetric ones. That was rather complicated, but these experiments, and others like them (see Riley, 1962, and Freyd and Tversky, 1984, for reviews) suggest that there is a symmetry bias in perception. Not only do viewers rapidly detect symmetry, but they also perceive nearly symmetric figures as more symmetric than they are. That is, small deviations from symmetry are overlooked. Human faces, for example, are rarely perfectly symmetric, though we think of them as such. The outer men in figure 6 (taken from Neville, 1977, p. 335), for example, are actually the same man at the same time. The two outer pictures were constructed by taking the right and left halves of the actual face in the center, and reproducing them in mirror image. It is only by seeing how different the two constructed symmetric faces are that we become aware of the asymmetry of the original face.

Diane Schiano and I (1987 manuscript, "Distortions memory for graphs and maps") looked for and found distortions toward symmetry in memory for maps and graphs. We presented maps or graphs like those in figure 7 to different groups of subjects. Sometimes, the subjects were asked to sketch the curves of the graphs or the rivers of the maps, and other times, they were asked questions about the content of the maps or graphs. This was done to induce a natural comprehension attitude toward the figures, and to prevent subjects from simply memorizing line shapes. We then asked judges who knew nothing about the hypotheses to rate whether the drawn curves and rivers were more or less symmetric than the original ones. The remembered curves, whether in maps or graphs, were judged more symmetric than the originals. These errors in the direction of symmetry, however, apparently occur in perception, not in memory. We asked another group of subjects to copy the curves, and the copied curves were also judged to be more symmetric than the originals, and to the same degree. The first effect to be accounted for, then, is a tendency to perceive nearly symmetric figures as more symmetric than they actually are.

For the next two effects, I turn to maps. In figure 8 are two maps of the world; which one is correct? If you are like the subjects I have run, most of you will pick the bottom one; that is, the incorrect one. Let me give you another chance. In figure 9 are two maps of the Americas; my apologies to Central America, which was excised not because of the political situation, but for visual reasons. Again, which map is the correct one? And again, I will predict that most of you will prefer the left, incorrect, one. Why do the incorrect maps look better? Basically, because the incorrect ones are more *aligned*. In the incorrect map of the world, the U.S. and Europe and South America and Africa are more aligned than they are in true map. And in the incorrect map of the Americas, North and South America are more aligned. I found memory errors in the direction of greater alignment for these maps, for directions between major cities on them, for artificial maps, and for visual blobs (Tversky, 1981). Others have found similar results (e.g., Byrne, 1979).

The second prevalent error I have found in maps I termed *rotation*. I asked a group of subjects to place a cut-out of South America in a frame where the canonical directions, north-south and east-west, corresponded, as usual, to the vertical and horizontal sides of the frame (fig. 10). Although the actual orientation is on the right, most of the subjects uprighted South America to the angle of the left-hand figure, or even more so. Not only South America is perceived as tilted. Those of you who live in the Bay Area, or who arrived from the San Francisco airport may think that you drove southwest to Monterey. Most of my local respondents made mistakes like that; for example, thinking that Berkeley is east of Stanford and Santa Cruz is west of Palo Alto. Not so, as this true map of the area shows (fig. 11). Just as for alignment, I have found memory errors of rotation toward the axes for real map figures, for directions between cities on them, for roads, for artificial maps, and for visual blobs (Tversky, 1981). Unlike the symmetry distortion, the distortions produced by alignment and rotation are stronger in memory than in perception; that is, small tendencies toward alignment and rotation appeared in a copy task, but much greater errors appeared in a memory task.

Until now, we have demonstrated that there is a bias toward symmetry in both maps and graphs that appears in perception and is preserved in memory. I have also demonstrated, primarily in maps, biases toward alignment with other figures and rotation to a vertical/horizontal frame of reference that appear slightly in perception and stronger in memory. Now is the time to start to account for these systematic errors by an analysis of perceptual organization, or more specifically, by the effects of perceptual factors in perceptual organization (fig. 12). One of the earliest forms of spatial organization is distinguishing figures from grounds. Because figures are more likely to have symmetry, closure, and other, similar properties than backgrounds, these are valuable cues to figureness (e.g., Hochberg, 1978; Koffka, 1935; Kohler, 1929; Wertheimer, 1958). Symmetry, or near-symmetry, is rapidly and easily detected (e.g., Barlow and Reeves, 1979; Chipman and Mendelson, 1979; Carmody, Nodine, and Locher, 1977; Corballis, 1976). Thus, because of its usefulness in figure discrimination, symmetry seems to be rapidly detected and small deviations from symmetry are overlooked so that nearly symmetric figures are coded and remembered as more symmetric than they really are. Now for anchoring figures in space. In an empty field, figures appear to float, a phenomenon well-known to star-gazers, called the autokinetic effect. In order to perceive and remember the locations of figures, it is useful to anchor them to other figures and/or to a frame of reference. In fact, given that perceivers and the world are rarely static, this seems to be the only way to organize the elements of a scene. Although valuable in locating and orienting figures, anchors pull figures closer to them in memory, yielding systematic errors. Map bodies and graph curves are figures on backgrounds; they are often nearly symmetric, they appear sometimes with other figures, and typically appear in a reference frame. Thus, the analysis of distortion in terms of perceptual organization applies to maps and graphs, and accounts for the errors of symmetry, alignment, and rotation.

This, briefly, is the perceptual analysis. Now, I'd like to present two cases where, we believe, conceptual factors enter into the perceptual analysis of maps and graphs and yield further distortions. This work was also done with Diane Schiano. The first effect brings us back to symmetry. The graph curves we asked subjects to study were slightly, but noticeably, less than symmetric. Given that people perceive such curves as more symmetric than they really are, we wondered if we could weaken or strengthen that belief or perception by an accompanying description of the curve, and consequently alter people's memory of the curve. Again, we presented a variety of graphs for subjects to remember, and tested memory either by asking subjects to draw the graphs or to describe some aspect of the relation depicted by the graph. This time the graphs also included descriptions of the functions. For the nearly-symmetric curve of interest, half the subjects received a description emphasizing its symmetry, that is, "Notice that the curve rises smoothly and falls smoothly." The other subjects received a description emphasizing its asymmetry, that is, "Notice that the curve rises sharply and falls slowly." The curves drawn from memory were given to judges who were unaware of the experimental conditions. The results were just as expected: when attention was directed to the symmetry of the curves, remembered curves were drawn more symmetric than when attention was drawn to the asymmetry of the curve. This result is reminiscent of one of the truly classic experiments in psychology, that of Carmichael, Hogan and Walter (1932).

The second conceptual factor is more subtle, and addresses the issue of what determines the frame of reference. In the absence of any conceptual or meaningful factors, there are often perceptual factors that provide a frame of reference. The typically horizontal and vertical lines of the actual frame of a picture are one example (e.g., Howard and Templeton, 1971). For an environment, the natural vertical plane, up-down, and the two natural horizontal planes, left-right and front-back, form a reference frame; when this is reduced from two to three dimensions, the front-back dimension drops out (e.g., Clark, 1973), usually leaving the horizontal and vertical axes of the picture frame as a reference frame. For maps, there is an additional conceptual factor that is typically perfectly correlated with the perceptually salient axes, namely the canonical directions, north-south and east-west. Thus far, the evidence for alignment has come either from maps and environments, where both perceptual and conceptual factors suggest the horizontal and vertical as a reference frame, or from visual blobs, where perceptual factors suggest the horizontal and vertical.

Schiano and I wondered if simple straight-line functions at various angles in x-y coordinates would be anchored to those coordinates, and thus distorted toward them. Of course, the x-y coordinates form a natural reference frame for graph functions, but unlike streets, graphed functions are rarely perfectly horizontal or vertical. Moreover, there is another reference frame for graphed lines, the (in this case) implicit 45° line. This is the identity line, where x=y, and as such it provides a very important reference point for graphed lines. Above it are steep rises, and below it are shallow ones. The experiments we ran were very similar to the previous graph experiments: there were critical stimuli and distractors, and the memory task was designed to elicit comprehension of content, not just remembering the line. The exact same stimuli were presented as maps to another group of subjects. Subjects were told that the angled lines were paths or short-cuts; they weren't very convincing maps, as can be seen in figure 13. In contrast to the prior work on maps showing alignment to the closest axis, horizontal or vertical, the graph lines were remembered as closer to the imaginary 45° line than they actually were. The map lines showed no systematic distortion, and differed considerably and significantly from the graph lines. We ran this study again, this time using dotted graph lines rather than filled ones. Again, graph lines were remembered as closer to the forty-five degree line, and map lines showed no systematic distortion. This is evidence, we believe, for conceptual factors that influence selection of frame of reference and thereby affect the perceptual analysis, representation, and memory of visual displays.

I have presented a perceptual analysis of figure detection and organization. Both these processes can lead to systematic distortions, which were demonstrated in perception and memory of maps and graphs. Conceptual factors were also shown to affect the perceptual analysis and encoding of visual scenes, and to also yield errors of memory, the description of symmetry in one case, and the selection of a frame of reference in the other. The bottom line is "What you see ISN'T what you get."

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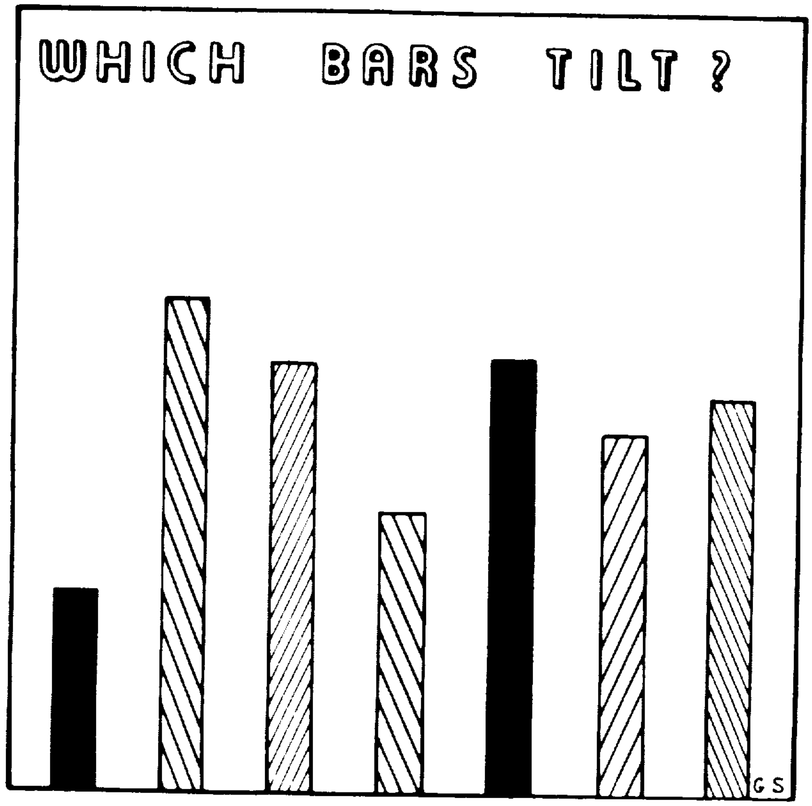

Figure 1.– Hypothetical graph taken from Schultz, G. M. (1961). Beware of diagonal lines in bar graphs. Prof. Geogr., 13, 28-29 (reprinted by Kruskal (1982)).

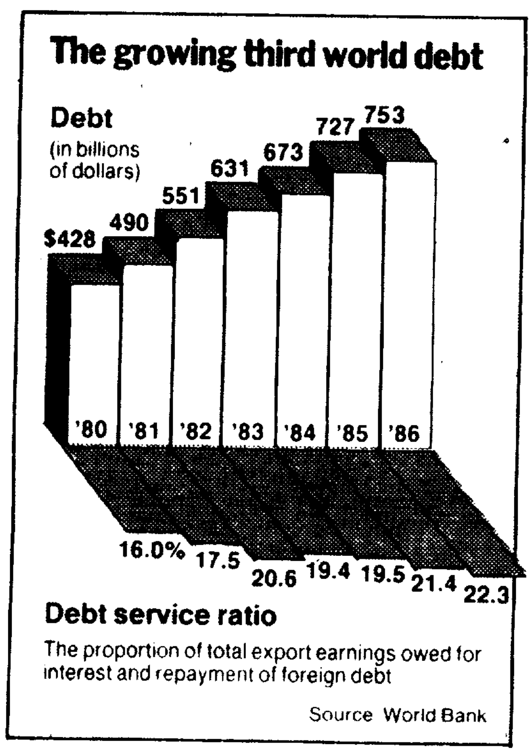

Figure 2.– Graph taken from The New York Times, August 2, 1987. (Copyright © 1987 by The New York Times Company. Reprinted by permission.)

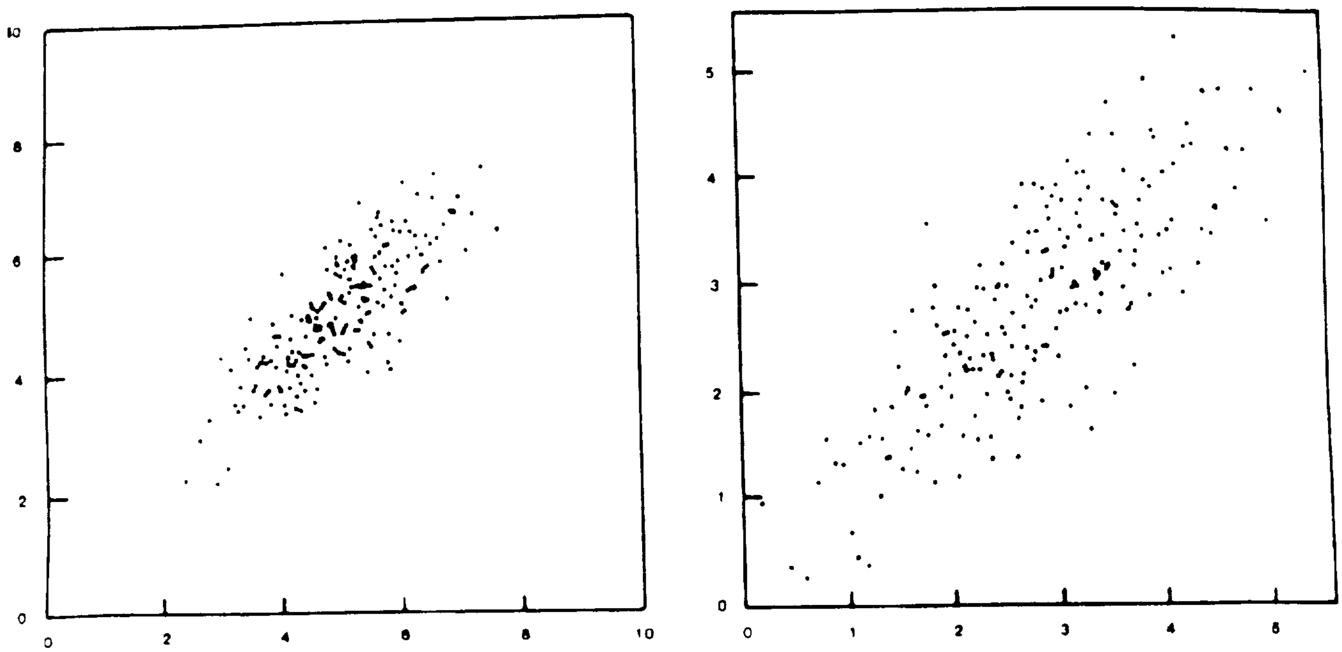

Figure 3.– Stimuli used by Cleveland, Diaconis, and McGill (1982). Although the correlations in the two scatterplots are the same, the right-hand one in the smaller frame is judged to be higher.

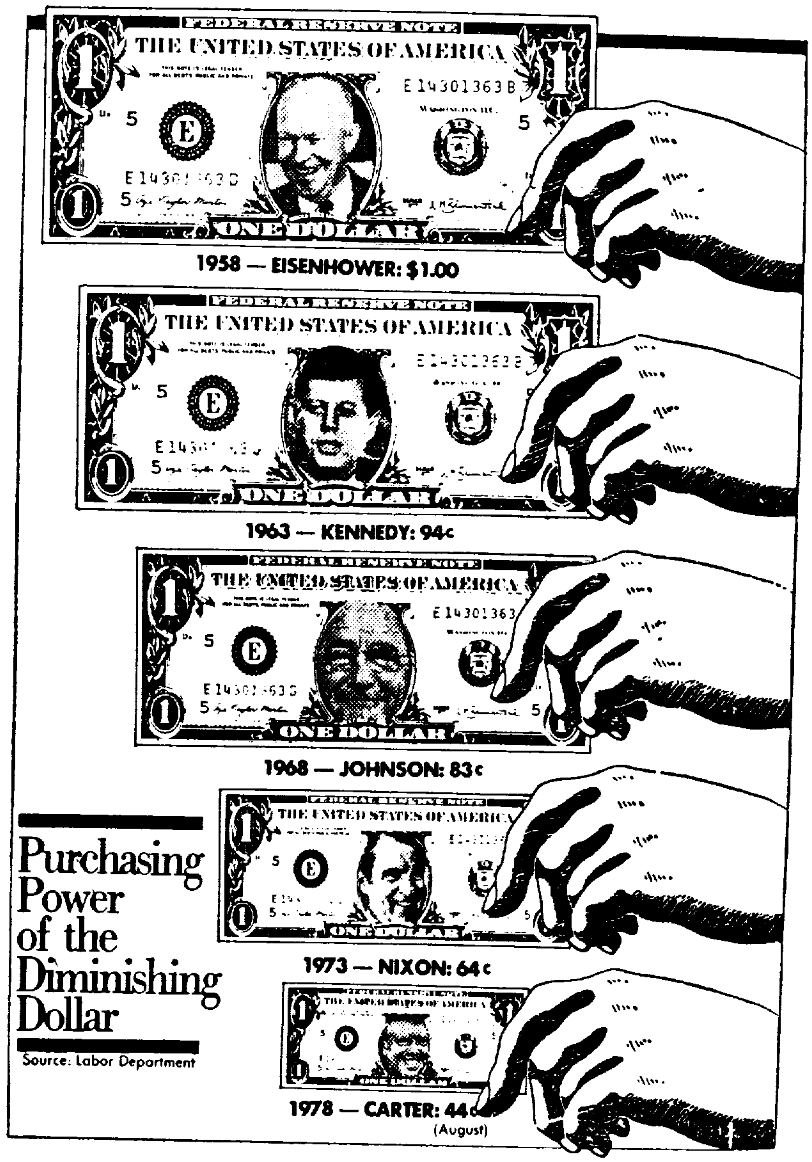

Figure 4.– Graph taken from The Washington Post, October 25, 1978 (reprinted by Tufte (1983) and Wainer (1980)).

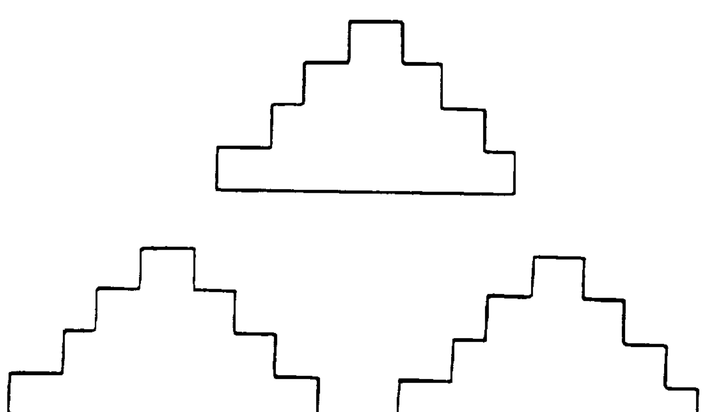

Figure 5.– Figures used by Freyd and Tversky (1984).

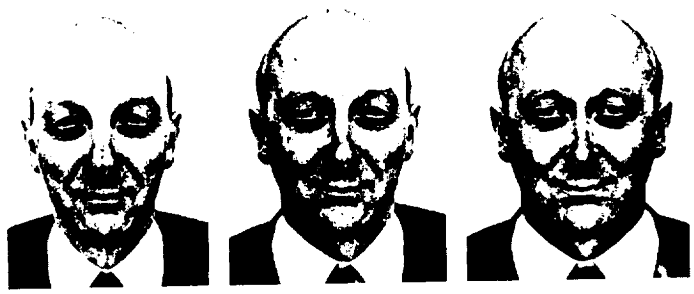

Figure 6.– Face taken from Neville (1977). The left and right faces were constructed by taking the left and right halves of the original photograph and reproducing them in mirror image, producing faces that are symmetric, unlike the original.

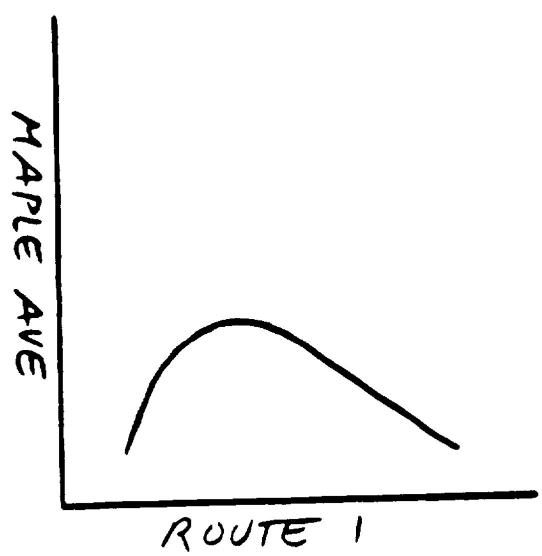

Figure 7.– Map curve used by Tversky and Schiano (1987 manuscript).

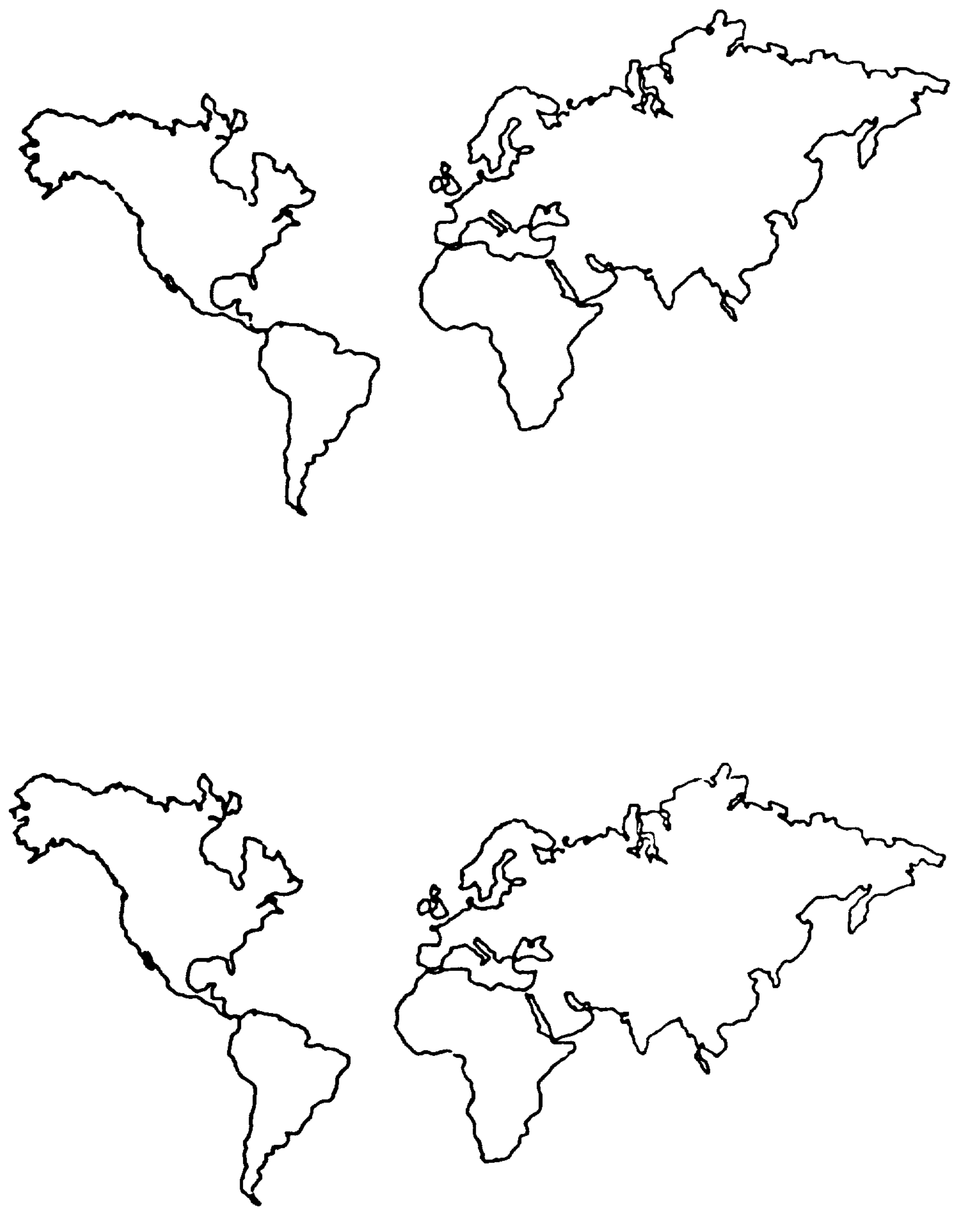

Figure 8.– World map stimuli used by Tversky (1981). Subjects incorrectly prefer the lower map, in which the U. S. and Europe, and South America and Africa are more aligned.

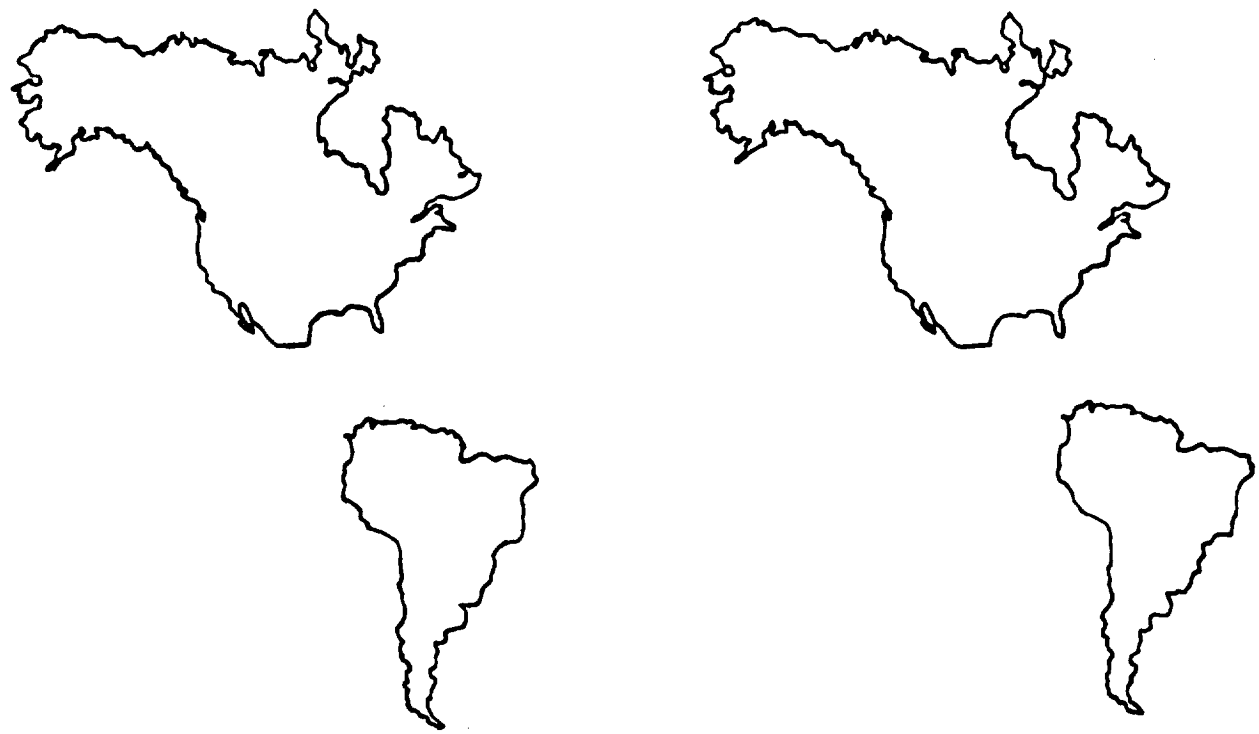

Figure 9.– Map of the Americas used by Tversky (1981). Subjects prefer the incorrect left one.

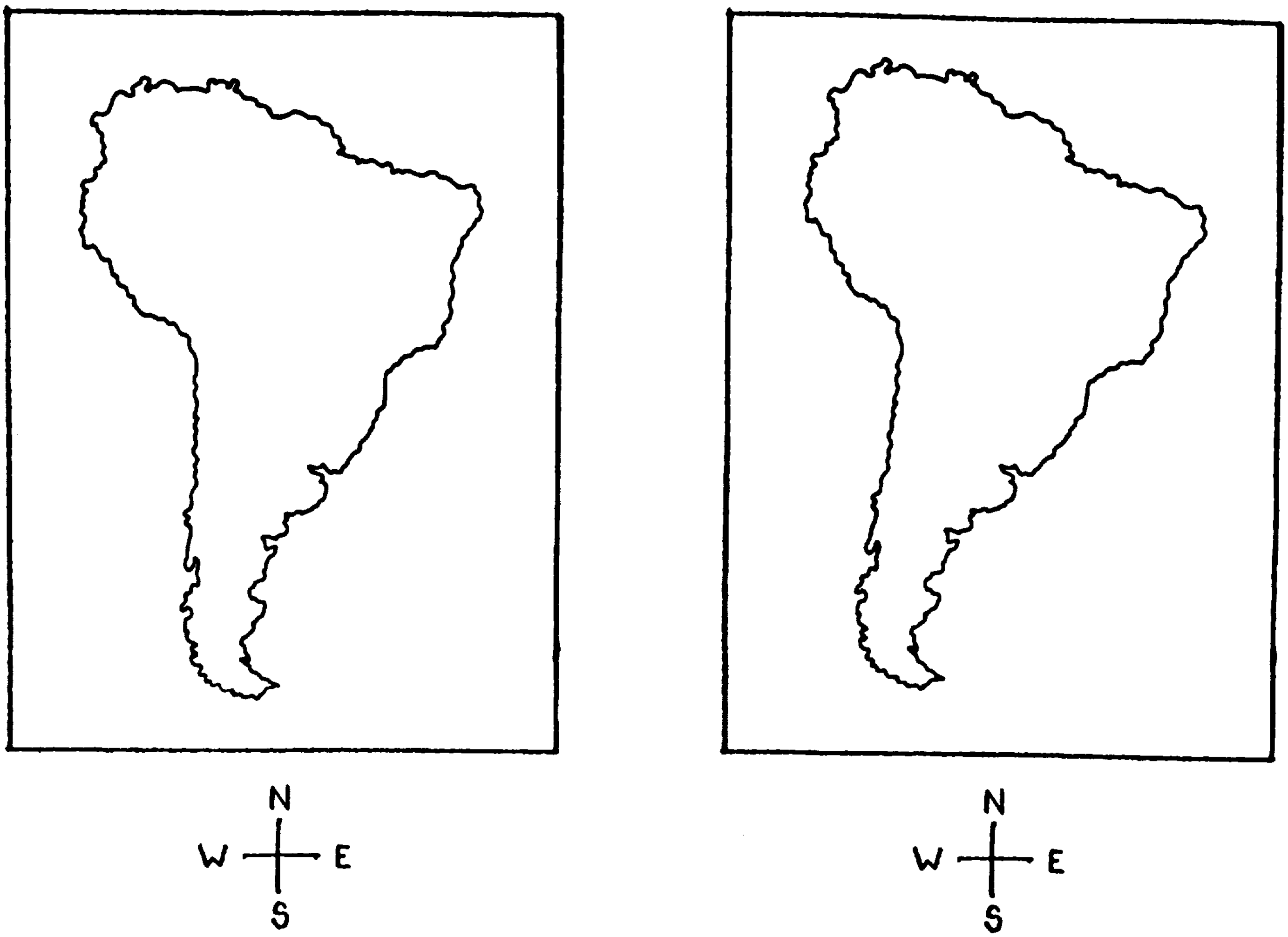

Figure 10.– The correct orientation of South America is on the right, but subjects typically upright it, as in the example on the left (from Tversky, 1981).

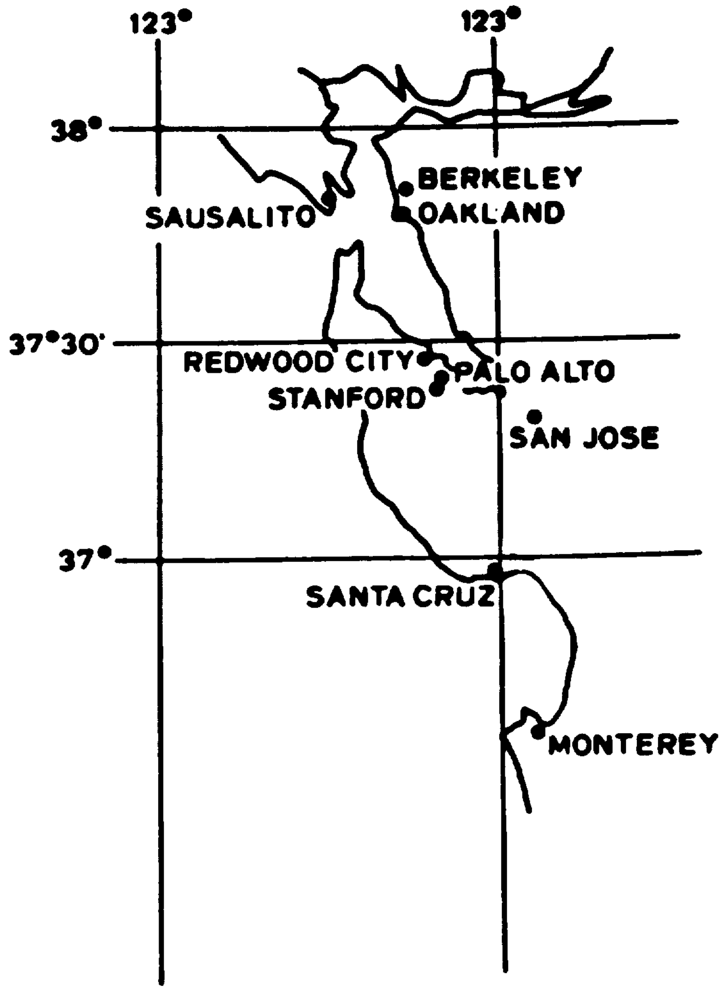

Figure 11.– The correct map of the San Francisco Bay area. Subjects erroneously report that Berkeley is east of Stanford and Palo Alto is east of Monterey (from Tversky, 1981).

Process	Perceptual Cue	Perceptually-induced Error	Conceptually-induced Error
Figure segregation/ identification	Symmetry	toward symmetry	description enhances or reduces effect
Figure location/ orientation	Other figure	toward other figure	
	Frame of reference	toward frame of reference	graphic medium (e.g., maps vs. graphs) determines frame of reference (e.g., vertical/horizonal axes vs. 45° line)

Figure 12.– Summary of perceptual analysis and resultant errors.

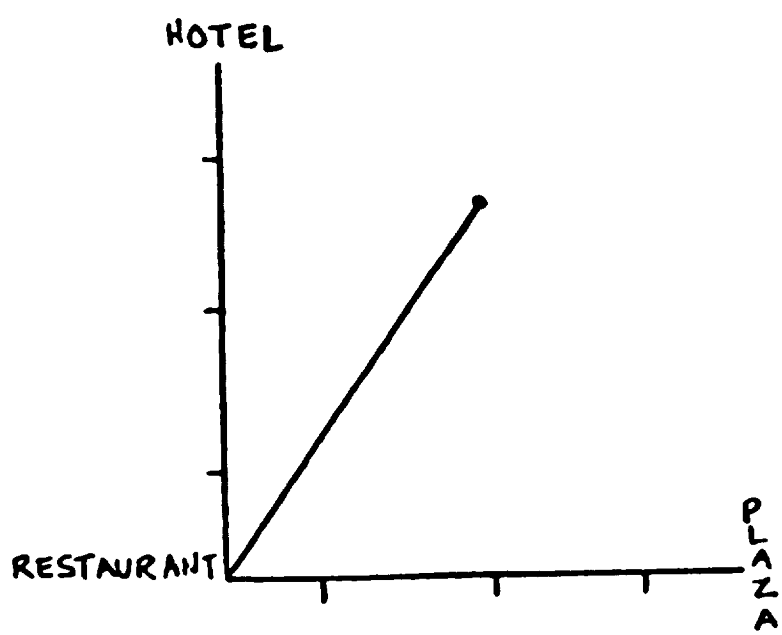

Figure 13.– Straight-line maps and graphs used by Tversky and Schiano (1987 manuscript).