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Distortions in Memory for Maps

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Evidence is presented for systematic errors in memory for real and artificial maps, local environments, and visual forms. These errors are attributed to two heuristics that are derived from principles of perceptual organization. Maps of countries or localities are conceived of as figures in backgrounds. Remembering the absolute location of figures is difficult, and is facilitated by remembering locations relative to other figures and/or relative to the natural directions of the figure. In *alignment*, figures are lined up relative to one another, a phenomenon related to perceptual grouping by proximity. In *rotation*, the natural axes induced by a figure converge with frame axes (north–south, east–west, or horizontal, vertical), a phenomenon related to perceptual organization by common fate. Heuristic-induced errors occur in a variety of tasks, and even when subjects are explicitly forewarned. These heuristics may be invoked in forming representations as well as in inference, and function analogously to syntax in locating smaller elements in larger units.

Systematic distortions traditionally have been used in perception, memory, and judgment not as signs of failure of processing, but as consequences of normal processing. This paper will explore a class of distortions that appear in memory for maps, memory for visual forms, and memory for spatial environments, and develop an account for them that derives from principles and phenomena of perception. I begin with the perceptual story, and proceed to empirical findings predicted from it.

In many forms of presentation, maps of countries or specific geographic regions are continuous, sometimes closed contours on backgrounds. These are conditions for evoking a figure–ground effect, one of the strongest and most elementary forms of perceptual organization (Hochberg, 1978). Typically, the figure appears closer than and draws more attention than the background. In the absence of compelling background cues, figures, particularly meaningless ones, are difficult to anchor, and sometimes even appear to float and to spontaneously change position, the autokinetic effect. The autokinetic effect was first reported by astronomers in the 19th century. The illusion of movement was so

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convincing that early observers believed that the stars themselves were moving, until it was realized that different observers reported movement at different times (Howard & Templeton, 1966). Although figures may be difficult to anchor, Rock (1974) and Braine (1978), among others, have argued persuasively that assigning an orientation to a figure is an inseparable, intrinsic part of perceiving it. Braine presented evidence that subjects across cultures and ages agree on the best orientation of simple figures, preferring vertical spatial extension and focal features at the top. Rock showed that vertical symmetry is more salient than horizontal symmetry, and that both are more salient than diagonal symmetry, so axis of symmetry also plays a role in judgments of uprightness. Thus, even a meaningless figure may induce its own coordinates, depending on its shape. The perceptual literature suggests that elongation, symmetry or balance, and focal features would each contribute to formation of a primary axis, with a secondary axis perpendicular to the primary one. There is also evidence to suggest a preference for a primary axis that is vertical.

Of course, the interpretation of a figure depends on its objective orientation within a frame of reference as well as on its natural orientation. Rock (1974) reviewed evidence demonstrating that the same figure is interpreted differently when its orientation is changed. An equilateral rectangle, for instance, is perceived as a square when its sides are parallel to the sides of its frame of reference, but is perceived as a diamond when it is rotated 45°. When a figure is ambiguous, in fact, its orientation with respect to a frame of reference alters its perception, as Attneave (1971), Palmer (1980), and Palmer and Boucher (1981) have shown in research on perceived directionality of triangles. Not only the orientation of the frame of reference, but also the orientation of other figures in the scene affect the perceived orientation of a particular figure.

In all of these investigations, the most effective coordinates have been the canonical Cartesian coordinates. Considerable research in perception and sensation (e.g., Clark, 1973; Howard & Templeton, 1966) has revealed a special status for vertical and horizontal axes. Gravity defines vertical, the horizon defines horizontal. People are vertically extended, vertically symmetric, and move about on the horizontal plane. Visual acuity is superior for arrays displayed vertically or horizontally than for arrays presented at other orientations. The special status of horizontal and vertical is reflected in the language as well, and serves as the basis of many metaphoric extensions of spatial concepts to other domains (Clark, 1973; Clark & Clark, 1977). Mapmakers have traditionally used horizontal and vertical to code the canonical world directions of north–south and east–west. Moreover, we often describe *north* and *south* by using expressions of verticality as in "drive *down* the coast to Monterey." *Left* and *right*, however, are not usually borrowed to indicate east–west direction. While *north* and *south* are anchored to the poles, and *down* is rooted to the ground, neither *left* and *right* nor *east* and *west* are anchored, but are always relative to a point of reference.

In the absence of a strong objective frame of reference, then, there is evidence that a figure, even a meaningless one, induces its own frame of reference in a stereotyped way that depends on its shape. When the natural axes of a figure conflict with those of its frame of reference, according to the principle of perceptual organization *common fate*, the axes of the figure and those of the ground may be drawn toward each other. Suggestive data come from the rod-and-frame task (Asch & Witkin, 1948; Witkin, Lewis, Hertzman, Machover, Meissner, & Wapner, 1954). Here, subjects tended to rotate a rod to a tilted frame even when instructed to align the rod to gravitational upright. The closer the frame to the rod, the greater the rotational force exerted. The convergence of the axes induced by a figure with the axes of the frame is termed *rotation*. Evidence documenting our ability to mentally rotate figures in space has been reported by Cooper and Shepard (1978). When two (or more) figures of a scene are close by, according to the principal of perceptual organization, *proximity*, the figures may be grouped and oriented toward each other (Gogel, 1978). The tendency for two (or more) figures in an array to line up relative to one another is termed *alignment*. Supportive data come from a distance-judgment task developed by Coren and Girgus (1980). Their subjects estimated the distance between pairs of dots. When the pairs were within the same perceptual group, smaller estimates were obtained than when the same distance occurred between perceptual groups.

Where it is difficult to remember the exact positions of figures, either or both of these principles of perceptual organization may be applied as heuristics for anchoring figures in frames or shapes in space. In the case of rotation, the natural axes of a figure and the axes of its frame of reference converge; in the case of alignment, two or more nearby figures group together. Inherent in both heuristics is the property that the location of a particular figure is remembered *in relation to* the natural axes of the figure itself vis à vis the frame of reference or *in relation to* the positions of other figures, or both. Relational heuristics may be effective in part because objective frames of reference may be variable. Maps, for instance, of North America sometimes include South America, and sometimes include Europe, Africa, or Asia; they sometimes appear in a cylindrical projection, where longitude and latitude appear as parallel lines, but size relations are distorted, and sometimes in other projections, where longitude and latitude lines are curved, with less distortion of size. Both alignment and rotation distort visual scenes by imposing more order or regularity than actually exists in the scene, or, put differently, by increasing the predictability between elements of the scene.

These heuristics may be invoked in storage, in the formation of representations of the visual world, as well as in inference, in the utilization of stored information to derive conclusions. They are approximation techniques that facilitate memory for or judgments of location in situations where specific information is difficult to store, as in the exact orientation of geographical regions. In representing the locations of a group of three or four suburbs, for example, we may *align* the cities even though their true locations may instead form a zigzag. The heuristics may also allow inference when information is incomplete, as, for instance, when comparisons are made across regions that have not been stored together. While specialists may directly know the location of the Suez Canal relative to the Panama Canal, others may have to infer it, by comparing their representations of Central and South America to their representations of Africa and the Middle East. Again, these are conditions for inducing alignment, in this case of Africa and South America. Another feature of this example is that the locations of the larger geographic units, Africa and the Americas, may be used to infer the locations of their subunits, the Suez and Panama canals. Stevens and Coupe (1978) have explored this kind of inference, producing systematic distortions in judged spatial relations in both natural and artificial stimuli.

To review, figures, especially those with odd shapes, are difficult to orient and anchor in space. Heuristics may be adopted to facilitate encoding and retrieval of the spatial orientations and locations of figures. Principles of perceptual organization suggest two such heuristics. In rotation, the natural axes induced by a figure and the axes of its frame of reference converge, a phenomenon related to common fate. Vertical and horizontal are natural coordinates for both figure and frame because of their privileged status in sensation, perception, and language. As a consequence of invoking the rotation heuristic, figures that are slightly tilted will be remembered as more vertical or horizontal than they were. In alignment, figures gravitate toward each other, a phenomenon related to perceptual grouping. When this heuristic is invoked, then arrays of figures will be remembered as more lined up, more orderly, than they were. What is remembered, then, is a compromise of the actual stimulus in the direction of greater regularity induced by the heuristics. Naturally, both heuristics may be applied, simultaneously or successively, to the same figure or figures, though for simplicity, they are examined separately. Whether invoked in storage or in retrieval, in constructing representations or in drawing inferences, these spatial heuristics may lead to systematic errors and distortions.

ALIGNMENT

Let us now exemplify this perceptual analysis with some predictions.

Since maps of continents are figures on backgrounds, rotation and alignment should affect the remembered orientation of continents relative to objective axes and relative to one another. Based on the work of Stevens and Coupe (1978), these heuristics should also affect memory for locations of subunits, such as cities, that are contained in continents. If the continent is subjectively moved, then its contents are moved with it. The first two experiments test alignment, first by looking at remembered orientations of cities, and then by looking at remembered orientations of continents. North America and South America, while in relative proximity, are barely overlapping continents (Fig. 1). The alignment heuristic suggests that they should be remembered as more overlapping than in fact they are. Likewise, on the world map, it is compelling to group North America with Europe, and South America with Africa (Fig. 2). Here, alignment would lead to pulling Europe–Africa southward relative to the Americas.

Compass Directions

Method

Alignment was first tested in two tasks using naturally occurring stimuli. In this and in all other experiments reported, Stanford subjects fulfilling a course requirement served as subjects. In general, subjects participated in only one experiment and care was taken to eliminate repeating subjects. Typically, subjects were run in large groups, and participated in other, unrelated experiments before and after those reported here. Since different questions were asked of different groups, the numbers of subjects for each question differ. The first task was *compass directions*. As shown in Fig. 3, subjects were asked to indicate, relative to north, the direction between a pair of cities. Six to ten compass task judgments were presented to subjects in self-paced booklets. Of the pairs, half were fillers (e.g., New Orleans–Stockholm) and half were critical items. The critical pairs were selected so that although one member of the pair was actually north (or east) of the other, the alignment heuristic would mislead people to believe that the opposite relation held between them. For instance, Rome is actually north of Philadelphia, but according to alignment of North America and Europe, Rome should be remembered as south of Philadelphia. Similarly, although New York City is west of Santiago, Chile, alignment of the Americas should lead people to believe that Santiago is west of New York. Thus, members of critical pairs were close on either longitude or latitude. Members of filler pairs were selected to be disparate on both. Fillers were included to camouflage the critical pairs and to prevent a response set of drawing horizontal and vertical lines. Data from fillers were not analyzed primarily because there did not seem to be a fair and reasonable way to treat them qualitatively, given the difficulties of estimating exact angles diverging from longitude and latitude. Order of mention of the cities was counterbalanced across subjects. In this and subsequent studies, data for the critical pairs were scored qualitatively rather than quantitatively. Lines drawn due north or due west (vertical or horizontal) were not counted either for or against the hypothesis even though they are technically evidence for the distortion-by-alignment hypothesis. This is because it seemed likely that when subjects weren't certain or were guessing, they would be more likely to draw horizontal or vertical lines.

Results

Data for the critical pairs are presented in Table 1. For each of the five

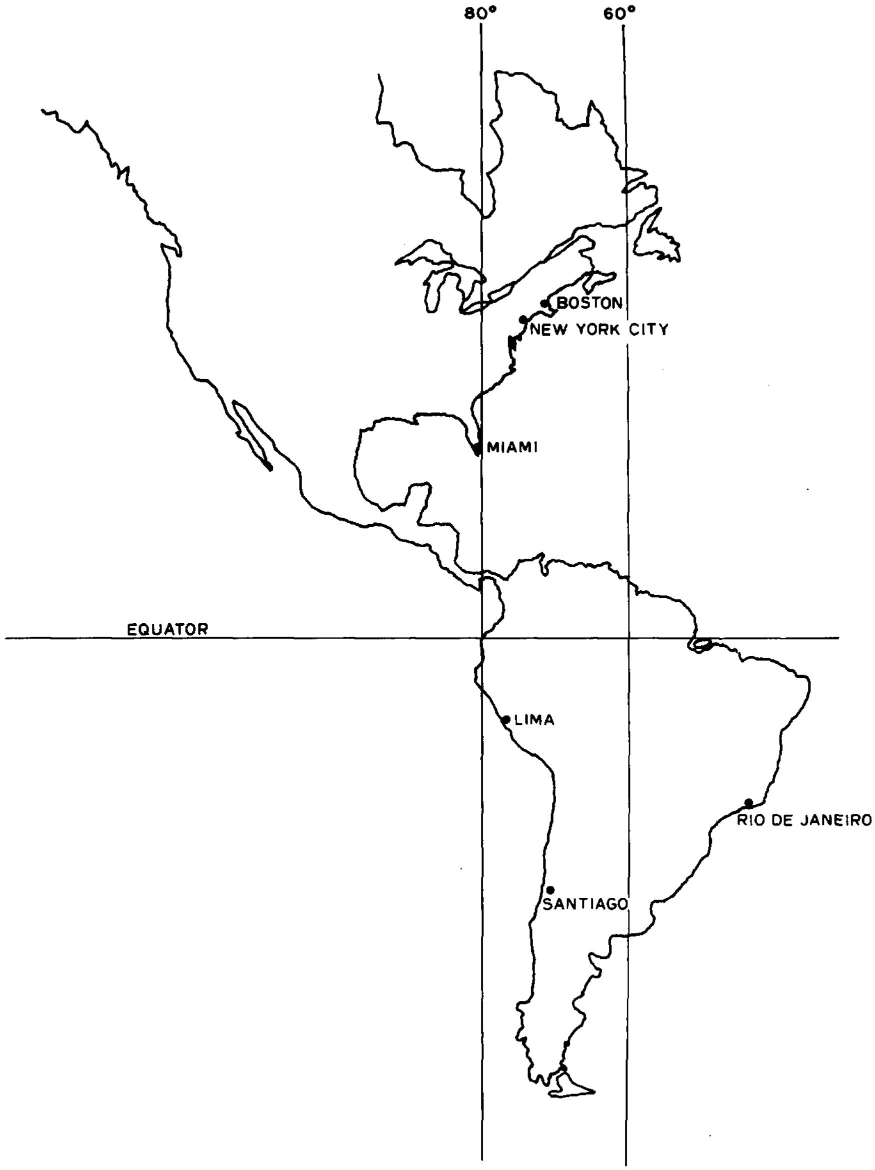

FIG. 1. Map of North and South America with selected cities (cylindrical projection).

comparisons between the Americas and Europe–Africa and each of the three comparisons between North and South America, the number of subjects responding incorrectly and in the direction of alignment significantly exceeded the number of subjects responding correctly or in the direction opposite alignment.

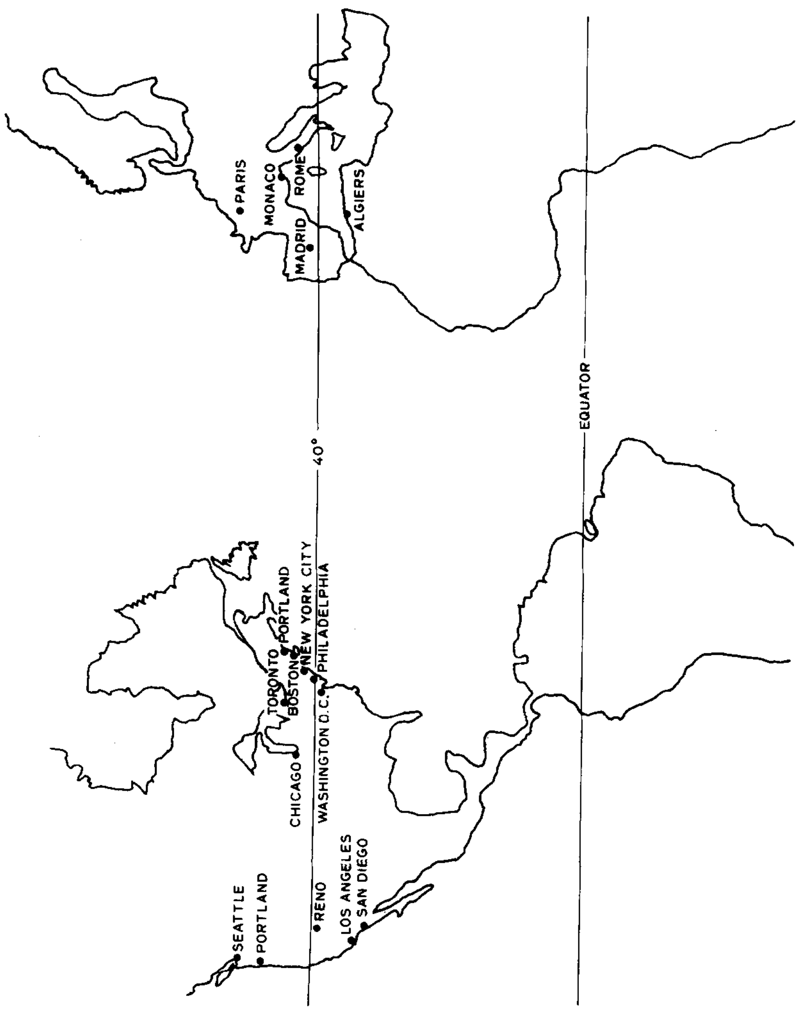

FIG. 2. Map of Europe and the United States with selected cities (cylindrical projection).

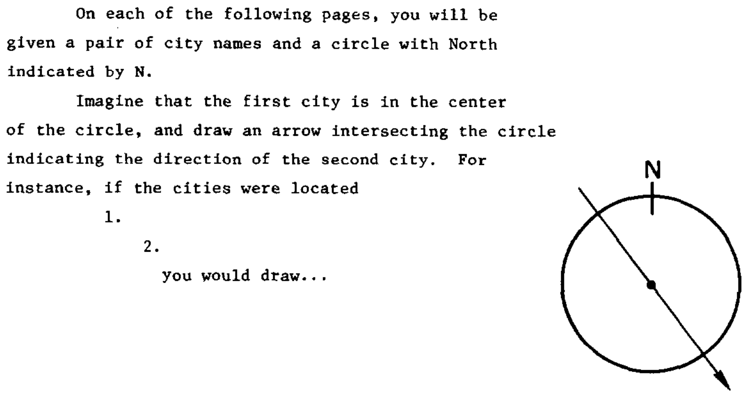

FIG. 3. Sample of compass direction task.

Map Recognition

Method and Results

In another test of alignment, one group of subjects was presented with a comparison between a true map of the Americas (minus Central America) and a map altered so that North and South America were more aligned. They were instructed to select the map that looked more correct to them, and to select one of the two even if they weren't certain. The maps were copied from cylindrical projection maps, like those of Figs. 1 and 2. In a cylindrical projection, longitude lines and latitude lines are straight and parallel, with north–south corresponding to the vertical or up–down axis, and east–west corresponding to the horizontal or right–left axis of the page. The order of correct and aligned maps was counterbalanced. Sixty-five percent (75 out of 115) of the subjects selected the aligned map

TABLE 1
Judged World Direction

	Number of subjects	Alignment error	Neutral (due north or due east)	Correct and overcorrections
East–west pairs				
Philadelphia (S)–Rome	(59)	78	12	10
Los Angeles (S)–Algiers	(169)	59	15	26
Chicago (S)–Monaco	(132)	64	14	22
Washington (S)–Madrid	(134)	47	28	25
Seattle (S)–Paris	(136)	54	26	20
North–south pairs				
New York City (W)–Santiago	(56)	80	2	18
Miami (W)–Lima	(51)	86	6	8
Boston (W)–Rio	(158)	59	5	36

Note. Entries are percentages of subjects indicating designated direction. (S) indicates pair member that is actually south; (W) indicates pair member that is actually west.

of the Americas over the correct map ($z = 3.13, p < .001$). Another group of subjects was presented with a true map of the Americas and Europe–Africa–Asia and a map altered so that the Americas and Europe–Africa were more aligned. Here, 63% (135 out of 215) of the subjects selected the aligned map in preference to the correct map ($z = 3.706, p < .001$).

Thus, support for the alignment hypothesis comes from subjects' systematically erroneous judgments of directions between pairs of well-known cities as well as from subjects' preference for world maps where continents are more aligned than is truly the case. With naturally occurring stimuli, alignment is evident in the vertical (north–south) as well as horizontal (east–west) planes.

ROTATION

When a figure has a natural orientation that does not quite correspond to that of its frame of reference, conditions are ideal for invoking the rotation heuristic, that is, of convergence of the coordinates induced by the figure to the coordinates of frame of reference. As with alignment, rotation was tested twice with naturally occurring stimuli, once with cities and once with continents.

Compass Directions

The area south of San Francisco provides a good candidate for this heuristic (Fig. 4). The San Francisco Bay runs northwest to southeast from the southern border of San Francisco to San Jose, and the coast of California cuts southeast from San Francisco to Monterey, although many residents seem surprised to learn that. Instead, they seem to assume that the San Francisco Bay has its top in San Francisco and its bottom in San Jose, and that top and bottom are due north and due south, respectively. Similarly, the Pacific coastline from San Francisco to Monterey is remembered as running north–south.

Method and Results

The rotation hypothesis was tested using the compass directions task on four critical pairs of well-known Bay Area cities and another four filler pairs. As before, critical pairs were selected so that the city that is truly west would seem to be east under rotation, and fillers were selected at angles to prevent a response set for vertical lines. From Table 2 it is evident that the vast majority of subjects committed rotation errors for key pairs of cities in the Bay Area. Significantly more subjects erred in the predicted directions than responded correctly or erred in the opposite direction for each of the four comparisons.

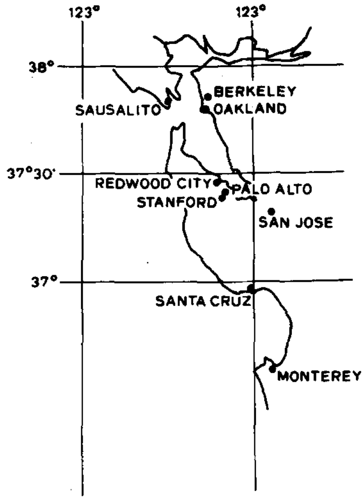

FIG. 4. San Francisco Bay area cities.

Map Placement

The orientation of South America seemed another good candidate for rotation since its natural long axis seems tilted relative to true north–south. Sixty subjects were given cutouts of an outline map of South America with instructions to fix them to a map frame outline where compass directions were clearly indicated and corresponded to the conventional sides of the frame. The map figure was approximately 11.5 × 7 cm and the map frame was about 13 × 10 cm. Map placements were scored by three judges using a template as rotated, corrected, or tilted. Two out of three of the judges agreed in all but one case, and these entered the analysis. Seventy-five percent of the subjects rotated their maps of South America ($z = 3.65, p = .001$)—strong evidence for rotation. Rotation was also evident in data reported by Moar (1979) where maps constructed from subjects' compass directions rotated the United Kingdom to upright, although its "top" (Scotland), tilts quite a bit to the west.

TABLE 2
Judged San Francisco Bay Area Directions

Pair	Number of subjects	Rotation error	Neutral (due east)	Correct and overcorrections
Palo Alto (W)–Monterey	94	62	11	28
Redwood City (W)–Santa Cruz	92	71	10	20
Oakland (W)–San Jose	94	71	9	20
Berkeley (W)–Palo Alto	95	72	5	23

Note. Entries are percentages of subjects indicating designated direction (sums greater than 100% are due to rounding). (W) indicates pair member that is actually west.

ARTIFICIAL MAPS

By now, we suspected that we had exhausted the geographical knowledge of our subjects, and turned to artificial maps to test rotation and alignment.

Method

One map was designed to test alignment, and three maps were designed to test rotation: one triangular island or continent, one elongated island or continent, and one figure modeled on the San Francisco Bay area (Fig. 5). Each map contained four cities labeled by letters. Maps were drawn on separate pieces of standard-sized paper (21.5 × 27.5 cm); map figures varied from 5 × 8 to 7 × 17 cm, approximately. Conforming to convention, north corresponded to the vertical axis of the page, and was clearly indicated on each map. Only one pair of cities was a critical test, and the rest were fillers. As in the naturally occurring pairs, critical pairs were selected so that one member was actually north (or east) of the other, but,

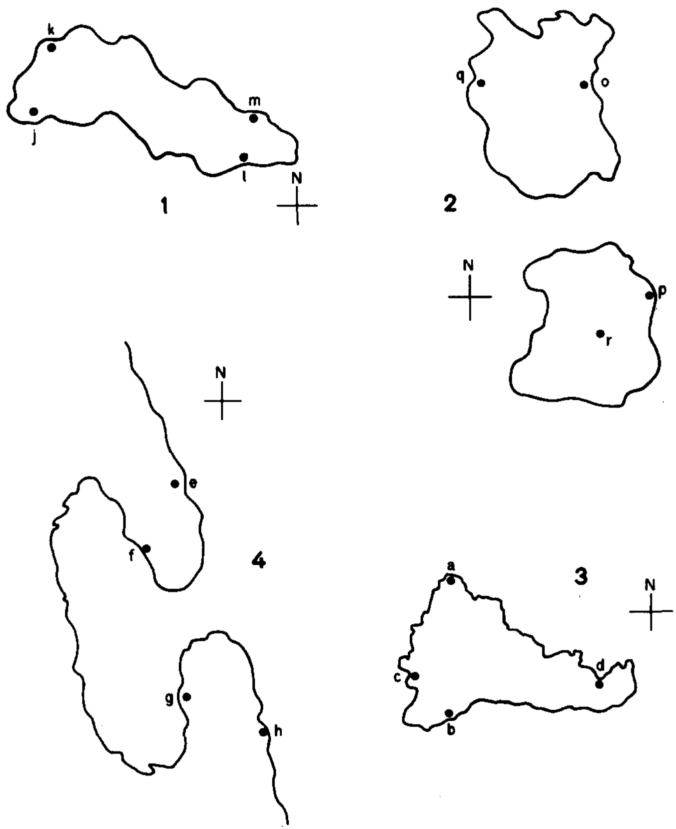

FIG. 5. Four artificial maps. In the alternate forms, maps 1 and 3 were rotated 90° clockwise, and maps 2 and 4 were rotated 90° counterclockwise. The critical pairs for each map were as follows: map 1, j–m; map 2, o–r; map 3, c–d; map 4, e–g.

because of alignment or rotation, would be remembered as south (or west). Each of the 24 subjects saw two of the maps oriented vertically and the other two oriented horizontally. Over subjects, each map appeared equally often in a vertical and a horizontal orientation. Order of maps was randomized. Subjects were run in small groups and were told to study each map carefully in preparation for tests of the information contained in the map. Subjects studied one map at a time for 1 min. Then the subjects completed a small booklet of compass direction questions on all pairs of cities of that map in a random order, and then they drew a free sketch of the map. The same procedure was followed for each map. As before, it was expected that subjects would produce systematic errors in the memory tasks in the direction of greater alignment or rotation.

Results

The fillers on the compass task and the sketches were first used to check each subject's overall memory; all subjects appeared to have learned the approximate shapes of the geographical entities and the approximate locations of all of the cities.

The compass task was scored as follows: Each subject was given a +1 for every correct or overcorrected critical pair, a 0 for a horizontal or vertical line, and a −1 for every aligned or rotated critical pair. Scores could range from +4 to −4. Negative averages would indicate consistent error in the direction of alignment and rotation. The average score was −1.46, which was significantly less than zero ($t = 4.75, p < .001$). While some maps induced more errors than others, there were no overall effects of form, orientation of map form (horizontal or vertical), or type of error (alignment or rotation).

In the sketches, lines were drawn connecting the critical pair of cities. The angle formed by these lines with North was then scored as in the compass task. The average score was −1.08, also significantly less than zero ($t = 3.68, p < .001$). As before, there were no overall effects of form, orientation, or type of error. Sketches, which have more constraints than the compass task, were slightly (.375) but significantly ($t = 1.84$) more accurate than compass directions.

Discussion

Subjects had no difficulty learning the artificial maps and performing the memory task. However, on the critical pairs of cities, they made systematic rotation or alignment errors. Two additional points are of interest. There was no greater tendency to distort map figures that were vertically extended than map figures that were horizontally extended, indicating that indigenous axes may converge with objective ones in figures that have horizontal extension, as well as those with vertical extension and a clear top. Another point of interest emerges from the superior performance on the sketches relative to the compass task. Sketches of entire geographic entities place many constraints on any given pair of places. To locate all four cities on a map, subjects had to take account of the six sets of directions as well as the overall shape of the map and locations of cities vis à vis the shape. In the compass task, the direction between a pair of cities is completely isolated from its context. The greater accuracy for constrained relations corroborates similar findings of Baird, Merrill, and Tannenbaum (1979).

LOCAL DIRECTIONS

Up until now, evidence has been presented for distortions in memory for information contained in maps induced by the alignment and rotation heuristics. Evidence was obtained from highly familiar world maps as well as new, specially constructed maps. Distortions were evident in both recall, that is, compass directions and sketches, and in recognition, that is, preference for aligned maps over true maps.

It seems quite likely that these heuristics are also invoked in remembering local environments that are experienced in everyday navigation rather than learned entirely from maps. Although local environments cannot be looked at in the same way that maps or figures drawn on sheets of paper can be looked at, internal representations of local environments may nevertheless share properties with internal representations of maps. Environments are naturally decomposed into elements, such as buildings, roads, lakes, parks, neighborhoods, hills, and the like. The particular environmental features that are regarded as elements depend on the scope of the environment under consideration. A state might be decomposed into cities, lakes, mountains, and forests, while a town might be decomposed into a commercial district, a residential district, an industrial district, and the like. The elements or parts of environments may have figural properties, and they are likely to be organized, to be interrelated to one another. Both the whole, the general region under focus, and the elements, the parts of the environment, may induce their own coordinates via salient natural internal features. The perceptual conditions that induce distinction of figure, or figures, from background and that induce natural coordinates are also those that encourage use of heuristics for remembering spatial positions. Howard and Templeton (1966, Chap. 12) discuss three types of axes induced by visual figures: (a) axes of symmetry, (b) main-line axes, and (c) landmark axes. Since symmetry is usually not fully realized in environmental stimuli, balance may substitute, so that a natural feature of the environment that bisects a region into two more or less balanced subregions is a likely candidate for an axis. A main-line axis may occur in regions where several major arteries, such as roads, tracks, or rivers, run more or less together in the same direction. They serve to make this direction prominent. Finally, an artery connecting two landmarks may serve as an axis. Thus, even in a spatially extended stimulus with no natural vertical axis, with no natural top, prominent natural axes may be induced by features of the stimulus. These axes may serve as a structure for storing and inferring spatial positions of other features of the stimulus, or of the entire stimulus vis à vis other stimuli. Although the examples have been from real environments, the principles of induction of natural axes apply to other stimuli that are spatially extended and decomposable into elements.

The axes induced by a geographical region may then be adopted as an anchor for rotation. In using rotation, some naturally occurring local elongated feature, such as a road, highway, trail, river, and so forth, is substituted for the objective north–south or east–west coordinates. Less salient geographic features or undifferentiated regions are then described relative to these natural anchors. There is the Left Bank and also the West Bank, uptown and downtown, the East Side and the West Side. Alignment would be expressed in the lining up of roads, buildings, rivers, or other salient features of the environment. For instance, roads that run in more or less the same direction or that intersect with a common road should be remembered as more parallel, that is, aligned, than they are in fact. Similar phenomena would be expected for buildings, train tracks, mountains, trails, borders of lakes, towns, states, and the like.

Rotation and alignment of features of the immediate, experienced environment were tested in two tasks requesting information about the Palo Alto area from Stanford students. Although many of the students may have originally learned the area from maps, after several months in the area, they no longer rely on maps for getting around locally.

Map Sketches

Method

Forty-seven subjects were asked to make sketches of the Palo Alto area, including nine major roads or highways. Of these, five run more or less parallel in a southeast–northwest direction, and the other four form major intersecting routes. Two of the intersections are approximately 90°, but the other two deviate sharply from 90°; one is about 60° and the other, 115°. According to alignment, these two deviant roads should be remembered as closer to 90° than they actually are.

Results

Two of the maps produced contained too many omissions to be of value and were eliminated. Of the remaining forty-five maps, all of the subjects drew the 60° intersection as a 90° intersection although this street is the major entrance to the university ($z = 6.57$, $p < .001$). Thirty-five of the subjects drew the 115° intersection as 90° ($z = 4.17$, $p < .001$), six drew an angle in the correct direction, one drew an angle less than 90°, and three subjects failed to give any information.

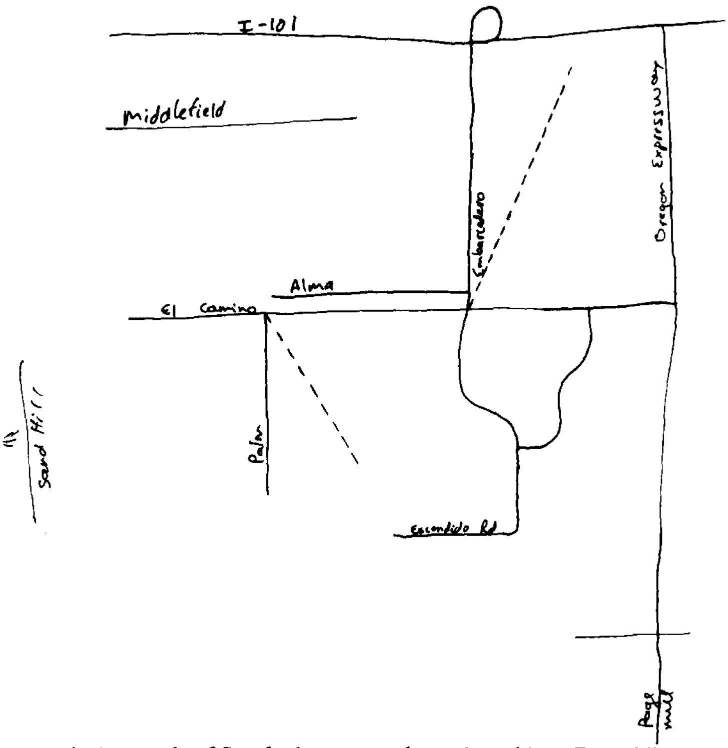

FIG. 6. Typical example of Stanford area map drawn by subject. Dotted lines are correct directions of streets.

The drawings also provided a test of whether Palo Alto area information is retrieved from remembered maps or from the subjects' internal constructions of the area. The orientation of the Bay Area and Peninsula in maps available locally is the canonical orientation, north at the top. Only four of the present subjects drew their maps in the canonical form. There is also a locally available Stanford map that includes most of the major streets in the Palo Alto area, but none of the smaller streets. This map has north toward the lower right-hand corner of the page. Eight of the present subjects drew maps with north to the right. Thirty-one of the forty-five subjects ($\chi^2(3) = 47.89$, $p < .001$) drew maps with north toward the left side of the paper. A typical example is presented in Fig. 6. Note, however, that the major streets are lined up with the sides of the page rather than the canonical directions. The canonical directions would then be diagonal, but are typically left unspecified.

Discussion

Subjects drew local maps distorted in the direction of alignment, as predicted. Familiar streets that in fact are far from parallel were made parallel. Moreover, maps were drawn so that the major streets were drawn parallel to the sides of the page, even though this resulted in making the canonical directions run diagonally. Since subjects did not specify canonical directions, this was apparently not disturbing.

Internal evidence from the map sketches supports the claim that the sketches were drawn from subjective constructions of local environments, rather than from memory of previously learned maps. Only a small minority of subjects drew maps with north near the canonical direction, at the top of the page. Even these maps showed alignment of the major streets to the sides of the page, rather than the canonical directions. The vast majority of subjects drew maps with north to the left, though it is doubtful that they conceptualized the maps in terms of canonical directions at all. These are maps that can be "walked through." The student's present location, Stanford University, is put in the bottom center of the map. If the student, like Alice in Wonderland, were to become very small, she/he could walk through the map exactly as she/he could walk through the streets themselves, turning right on the paper map where she/he would turn right in the world. Rather than being canonical maps, these are egocentric maps, miniature worlds, where the ego is located at bottom center, just where the subject is sitting.

Relative Directions

Method

Another group of 102 subjects received a revised version of the compass directions task. They were asked to draw a line indicating the direction of eight major local streets relative to the direction of the major local thoroughfare, El Camino Real. El Camino is a convenient local anchor; it is an elongated feature that bisects the area into two more or less balanced regions. On each page of a booklet, the direction of El Camino was indicated by a thick line, running horizontally for half the subjects and vertically for the other half. Subjects were asked to draw a line indicating the direction of a variable street relative to El Camino. Four of the streets ran more or less parallel to El Camino, and were fillers. Of the other four streets, two intersected El Camino at almost 90°, and the other two intersected diagonally, at 60 and 115°. These were the same streets used in the previous study, and as before, it was expected that subjects would align them parallel to each other and perpendicular to El Camino Real. At the end of the booklet was a compass task asking subjects to indicate the direction of El Camino Real relative to north. Like the San Francisco Bay, this street runs northwest–southeast. It was expected, however, that subjects would rotate this street to north–south.

Results

Both alignment and rotation were in evidence in the results. The mode and median responses for each of the four streets intersecting El Camino was 90°. Ninety-seven percent of the subjects judged that the 60° intersection was greater than 60°, and eighty percent of the subjects judged that the 115° intersection was less than 115°, both errors in the direction of alignment. Similar findings were reported by Byrne (1979) and Chase and Chi (1980). In the compass task, as well as in the map drawings, diagonal streets were aligned in memory. The mode and median response for the direction of El Camino relative to east–west was 90°, although the correct direction locally is 45–50°. Ninety percent of the subjects judged El Camino's direction to be greater than 50°. Thus, the local axes have converged with the objective ones—good evidence for rotation.

Discussion

A sharp distinction has been maintained between rotation and alignment, at least in theory. Rotation affects a relation between a part and a whole, a figure and its background, whereas alignment affects a relation between one part and another. In practice, there do seem to be cases of distortion where it is not immediately obvious whether they are attributable to alignment or to rotation. For instance, if a major artery, such as a border highway, runs parallel to an axis of the frame of reference, and if other features, such as roads, are distorted in that direction, then it is not clear whether the roads have been aligned with the major artery or whether they have been rotated toward the frame of reference. Although the tendency to report El Camino Real as oriented north–south was presented as an example of rotation, of convergence of El Camino and objective north, it could also have been regarded as alignment of El Camino to the San Francisco Bay, and rotation of the Bay toward north–south. The former interpretation has fewer steps, so is simpler, and in either view, rotation has taken place. Where the orientation of a major feature and the orientation of the frame of reference do not coincide, then there should be no ambiguity in interpreting distortions.

The previous example also illustrates the hierarchical nature of these stimuli. What is a part at one level of analysis can become a whole, a frame of reference, at another level of analysis. The Bay Area serves as a frame of reference for its cities and highways, while the state of California, or the page on which the map is drawn, or the objective longitude and latitude of the region, can serve as a frame of reference for the Bay Area, and so on. Selection of a frame of reference, like selection of parts and selection of orientation, does not seem to be completely arbitrary, but rather determined at least in part by natural size relations and natural geographic regions, as well as by convention, particularly in the case of longitude and latitude.

Now, evidence has been presented for alignment and rotation heuristics in memory for the local environments of daily experience as well as for memory for maps. The next step is to demonstrate these heuristics in memory for visual forms that are not interpreted as maps.

MEMORY FOR SHAPES

The search for systematic distortions in memory for visual forms has had a long and controversial history (see reviews by Allport, 1955; Riley, 1962; Zusne, 1970). Most of the controversy has concerned whether or not errors were in the direction predicted by Gestalt principles, toward good form, symmetry, common fate, and the like. No consensus could be reached regarding the Gestalt hypothesis, and the fact that some distortions could be produced reliably was forgotten in the controversy over their interpretation. The few errors that appeared reliable seemed to result from what was variously termed leveling, normalizing, or assimilation to a schema. For instance, a large gap in a circle is remembered as smaller than it was, and a small gap is remembered as larger. Since a circle is a better form than a circle with a gap, many regarded these findings as contradicting the Gestalt hypothesis. But if viewers have a "schema" of an ideal gap size, then memory for actual stimuli that differ from the schema may be assimilated to the schema.

The majority of experiments in the literature of memory for form were attempts to produce distortions in the shape or form itself, rather than in the position of forms vis à vis the surrounding space or the positions of other forms. The present experiment was an attempt to induce distortions of remembered positions of shapes, by alignment of shapes to each other and by rotation of the figure's induced axes to the axes of the objective frame of reference. In other words, the same distortions were expected for visual forms as were found for maps and environments.

Subjects studied maplike shapes embedded in frames. Immediately afterward, they were given cutouts of the shapes, and empty frames, and asked to attach the shapes to the frames in exactly their previous positions. Two groups of subjects were simply told to study the stimuli for a later test of memory. Another group was told explicitly to pay attention to the position and orientation of the forms in order to avoid making alignment or rotation errors. This group was included to see if warning subjects of typical systematic errors would diminish error. There is also the possibility that subjects, given compensation-for-error instructions, would overcompensate for error. One way of viewing alignment and rotation is as *assimilation* to a more regular, organized, ideal pattern. The compensation instructions were designed to elicit the opposite error, namely, *contrast* toward increased tilt, rather than rotation, and toward increased separation, rather than alignment.

A control group was included to separate memory errors from perception errors. In the perception control, subjects attached the shapes while looking at the stimulus booklets. It was expected that although subjects may make rotation and alignment errors in perception, many more such errors would occur in memory.

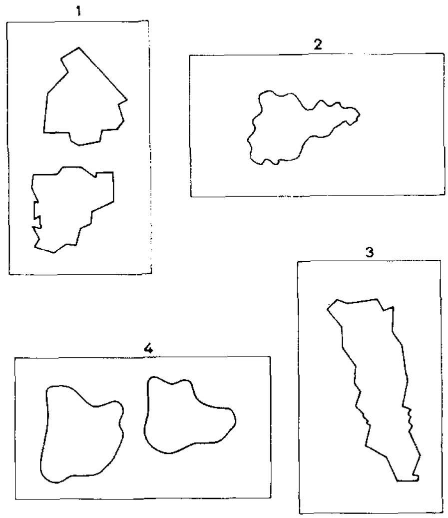

FIG. 7. Four shapes. In the alternative forms, shapes 1, 2, and 4 were rotated 90° clockwise, and shape 3 was rotated 90° counterclockwise.

Method

Stimuli

The four stimuli (see Fig. 7) were similar to the stimuli used in the artificial map study. Two were designed to elicit alignment and two were designed to elicit rotation. Half of each were smooth-edged and half were jagged, to make it more likely that subjects would regard them as shapes and not as maps. Each shape appeared horizontally for about half the subjects and vertically for half the subjects. Each subject saw one jagged horizontal stimulus, one jagged vertical stimulus, one smooth horizontal stimulus, and one smooth vertical stimulus. The forms, which were embedded in frames 6.5 × 12 cm, were drawn on separate sheets of standard sized paper (21.5 × 27.5 cm).

Experimental Conditions

Two memory groups received simple memory instructions. They were told, "On each of the following pages, you will see a picture of a meaningless form. Later, we will test your memory for these forms. . . . You will have 15 seconds to study each picture." In one of these groups ($n = 73$) and in the perception control ($n = 65$), the shapes of Fig. 7 had internal detail to mimic the internal detail ordinarily present in maps. The other simple memory group ($n = 78$) saw the same shapes without internal detail. A third memory group ($n = 60$) was given compensation memory instructions. They were given instructions identical to the simple memory groups after which they were told, "Please pay close attention to the exact *position* and *orientation* of each of the forms. Common errors made in memory for location are to line up forms to the frame or to each other. Try to avoid these errors and remember the *exact locations* of each of the forms." The compensation memory group viewed the shapes without internal detail. Order of stimuli was randomized for each subject.

The forms were presented in booklets, with blank pages separating the forms. Fifteen seconds' study was allowed for each of the four stimuli. Immediately following presentation of the stimuli, subjects opened envelopes containing cutouts of the shapes and stickers for

TABLE 3
Distortions in Memory for Forms

Task:	Perception control	Simple memory		Compensation memory
Stimuli:	Detailed forms	Detailed forms	Empty forms	Empty forms
Positive: more extreme errors	9	8	10	5
Zero: no errors or balanced errors	42	19	9	20
Negative: more alignment and rotation distortions	49	73	81	75
Average score (+4 to −4 possible)	−.62	−1.96	−2.05	−1.97
Number of subjects	64	73	79	60

Note. Entries for the first three rows are percentages of subjects.

fastening them to the frames. Each subject had a response booklet containing two empty vertical and two empty horizontal frames in the same order as his or her stimulus booklet. Subjects were instructed to fasten the shapes "in the exact position" the shapes had in the stimulus booklet. Subjects in the perception control group were told to fasten the shapes to the frames in the response booklet in the exact position as in the stimulus booklet, and they were allowed to use their stimulus booklet in any way to help them.

Results

All responses were scored with templates by three judges as *correct, distorted* (aligned or rotated), or *extreme,* that is, even more misaligned or tilted than the original. For better than 95% of the cases, two out of the three judges agreed, and only these scores entered the analyses. Each subject could receive a score between −4 and +4, as in the study with artificial maps. A negative score was awarded for each aligned or rotated map, a zero was awarded for each correct map, and a positive score was awarded for each extreme (more misaligned or tilted) response. The number of subjects receiving positive, negative, and zero scores by condition is presented in Table 3. The mean scores for the simple memory groups were −1.96 for the detailed shape group ($t = 8.97, p < .001$) and −2.05 for the unfilled shape groups ($t = 10.87, p < .001$). The compensation memory group produced a comparable error rate; the mean score was −1.97 ($t = 9.43$, $p < .001$). Horizontal and vertical stimuli produced approximately equal error rates, and alignment errors occurred slightly more frequently than rotation errors. In Table 4, data from all three memory conditions are combined and broken down by type of response: extreme, or compensatory errors; correct responses; and distortions, or alignment/rotation errors. Most of the extreme scores for single stimuli occurred for stimuli 2 and 3 when they appeared without internal detail

TABLE 4
Frequencies of Memory Errors

	Stimulus pairs (testing alignment)	Stimulus singles (testing rotation)
Extreme errors	44	98
Correct responses	63	66
Alignment or rotation errors	305	245

Note. Data from all three memory conditions combined.

and in the orientations displayed in Fig. 7, irrespective of memory instructions. The perceptual control had a mean score of $-.62$ ($t = 4.76, p < .001$), which is also significant, but only one-third the magnitude of the distortion error occurring in memory. There was a significant difference between scores of the perceptual control group and those of the memory group viewing the same detailed shapes ($t = 5.27, p < .001$). It is possible, then, that some portion of the memory error was perceptual error, but the reverse possibility, that the perceptual error was due to memory error, is also plausible. In fact, even the perceptual control task had a small memory component. In general, subjects glanced at a stimulus page and remembered the orientation long enough to then glance at the empty frame and fasten the shape. Most subjects did not superimpose the empty frames on the stimulus pages. So, the small, systematic distortions in the perceptual condition may very well be errors of memory between looking and responding, given that they were not done simultaneously.

Discussion

Alignment and rotation errors were evident in subjects' memory for relative locations of meaningless forms. Alignment errors occurred slightly more frequently than rotation errors, and both errors occurred equally in vertical and horizontal orientations. Alignment errors have also been found by Taylor (1961) in memory for locations of dots. These distortions cannot be attributed entirely to misperception of the forms, since the error rate in memory was considerably and significantly higher than the error rate in perception. In fact, it seems more likely that the small amounts of alignment and rotation distortion evident in the perception task were due to the small memory component present in that task. Surprisingly, the propensity to commit alignment and rotation errors was not attenuated by careful instructions to avoid such errors. Thus, the data so far support the phenomenon of assimilation, but there has been no support for the phenomenon of contrast (Allport, 1955) even under conditions that might be expected to produce the effect.

GENERAL DISCUSSION

Evidence has been presented for systematic distortions in memory for real world maps, artificial maps, local environments, and visual forms. For all of these diverse stimuli, the distortions have the same character. Where spatial orientations are difficult to remember, heuristics are used to anchor figures to locations, rendering them easier to remember. One way of remembering locations of figures is to organize them relative to one another, a phenomenon related to perceptual grouping. This has been termed *alignment,* and results in remembering locations as more lined up, regular, than in fact they are. For instance, North America is remembered as more aligned with South America, and the United States is remembered as more aligned with Europe, so much so that altered maps are preferred to correct ones. Another way of remembering positions of figures is to organize them relative to the natural coordinates of the figures. Spatially extended stimuli induce their own axes in the normal course of perception (Rock, 1974; Braine, 1978; Howard & Templeton, 1966). These natural coordinates, when they are close to objective coordinates (horizontal–vertical or north–south, east–west), may merge with the objective coordinates, in effect rotating the induced and objective coordinates toward one another. Horizontal and vertical coordinates enjoy a privileged status in perception (Howard & Templeton, 1966) as well as in language (Clark, 1973). This heuristic has been termed *rotation.* For instance, the San Francisco Bay, an elongated, bisecting feature of the local environment, is remembered as running north–south, although it runs northwest–southeast. This in turn distorts memory for the positions of cities that are remembered relative to this natural axis, the Bay. Both heuristics distort visual information by reducing the uncertainty between aspects of the visual display. Rotation, however, affects the "horizontal," or hierarchical, relation between a frame of reference and the elements within it, while alignment affects the "vertical" relations between elements at the same level of analysis.

Alignment and rotation are heuristics, operations performed on stimuli, for anchoring figures, and their contents as well, in space. They were demonstrated in memory for well-known naturally occurring stimuli as well as for new information acquired from artificial stimuli, for information acquired from actual navigation of the environment as well as for information acquired from maps, for visual forms, as well as for geographic entities. They led to undiminished error even when subjects were given elaborate instructions to avoid alignment and rotation errors. The heuristics affected performance in reproduction, recall and recognition memory. They may be adopted in storage, where spatial positions are difficult to encode, as well as in inference, to fill in gaps of knowledge.

That stimuli (figures) are difficult to anchor in space (grounds) has been known for centuries. The positions of stars, very small figures in very large backgrounds, have traditionally been remembered by aligning them relative to one another in meaningful structures, constellations. Another example of a heuristic for anchoring positions in space comes from the work of Stevens and Coupe (1978). They presented evidence that people remember geographic locations hierarchically. Instead of remembering the exact positions of innumerable cities, people remember the positions of larger geographic units, such as states. They then remember which cities belong to which states, and use the locations of the states to remember the locations of the cities. Systematic distortions result. For instance, subjects report that Reno, Nevada, is northeast of San Diego, California, when, in fact, Reno is northwest of San Diego. This occurs presumably because Nevada is generally east of California. Using the general location of a larger unit, a state, to remember the locations of its parts, cities, may be termed a *part–whole* heuristic. Some of the present demonstrations of rotation and alignment depended on a part–whole heuristic as well; for example, when Europe and the United States are aligned, then their elements, cities and countries, are aligned as well. In addition to alignment, rotation, and part–whole heuristics, there are other devices to ease memory for maps and maplike forms. Another example, that affects shape of figures as well as locations, is *straightening*. When edges have many angles and turns, people may eliminate the smaller, less important turns, and remember only the general outline. Milgram's (1976) Parisian informants straightened the Seine in their maps of Paris. The Canadian–United States border also appears to be remembered as straighter than it is. This accounts for the finding of Stevens and Coupe (1978) that people erroneously report that Portland, Maine, is north of Portland, Oregon. Maine borders on Canada, while Oregon does not, so that if the Canadian border were straight, Portland, Maine, would be north of Portland, Oregon, as is believed. Another device for anchoring places to spaces is to make use of distinctive, highly memorable features of figures. For instance, Chicago may be remembered as being at the tip of Lake Michigan, and Gibraltar as being at the entrance to the Mediterranean. Still another device, this one for remembering outlines of figures rather than their locations, is to liken the shape to a familiar figure. Italy can be remembered as a boot, and the USA as a profile of Uncle Sam, with the top of his head in California, his nose in Texas, and his beard, in Florida (Rock, 1974). There are undoubtedly other devices to facilitate memory for spatial positions, to provide a compatible structure on which to anchor locations of figures. Alignment, rotation, and the other devices discussed are similar to a class of simplifying mechanisms that have been variously referred to as leveling, normalizing (Allport, 1955; Chase & Chi, 1980), or assimilation to a schema (Bartlett, 1932; Rumelhart, 1980), where new stimuli are distorted in the direction of some more familiar "ideal." Several theories of picture memory (e.g., Loftus & Bell, 1975) have attempted to distinguish between a visual or perceptual component, specific to visual stimuli, and a semantic, interpretive, or meaningful component, affecting memory for either visual or verbal stimuli. These principles of perceptual organization contribute directly to the perceptual component, although it is not inconceivable that there are analogous effects on the meaningful component of picture memory.

The evidence presented in this paper has been for systematic distortions in remembered location and orientation. Changes in judged orientation and location will typically lead to changes in judged distance, although this was not directly examined here. Still other research has demonstrated systematic distortions of distance relations among elements. Two points within a figure are judged closer than two equally spaced points between two different figures (Coren and Girgus, 1980). Selection of a reference point also affects distance judgments; distances closer to a point of reference are overestimated relative to distances farther from the point of reference (Holyoak & Mah, Note 1). Put differently, discrimination is greater closer to a point of reference. Reference points also yield asymmetries in distance judgments; ordinary places are judged to be closer to a landmark point of reference than vice versa (Sadalla, Burroughs, & Staplin, 1980). Thus, reference points and figural properties also serve to organize spatial knowledge, yielding systematic errors in distance judgments.

The problem of remembering positions of elements of a stimulus as well as the elements themselves is a familiar one in verbal learning, where memory for item and memory for order information are separable (Crowder, 1976). With verbal stimuli, of course, position typically varies on one temporal dimension, whereas position of visual stimuli varies on two or even three spatial dimensions. In the absence of structures, such as words or sentences, that order elements, it is difficult to remember the positions of a string of letters or words. In stories, a causal structure allows sequencing of the separate events; in rituals or ritualized events, a script or temporal structure allows sequencing of the separate events.

Thus, the problem of remembering spatial locations of figures is similar to the problem of remembering order of verbal items; for both, structure promotes memory, but may introduce distortion. Until now, figure and ground have been sharply contrasted. In verbal memory, this distinction breaks down. At some level of analysis, sentences are figures; at other levels, words; at others, phonemes are figures and words are ground. In each case, the ground provides structure for locating the figures. It is possible to analyze visual stimuli in an analogous fashion, at the risk of playing havoc with Gestalt laws. In a canonical scene, the background—sky, horizon, earth—is the ground, and its separate parts or elements are figures. However, a figure, such as a house or tree, can be conceived of as the frame or ground, and its separate parts or elements as figures. Then, knowledge of what the figure is allows location of the parts. If it's a canonical person, the head is at the top, the arms are midway down, and the legs are at the bottom. Similarly, a single part can be regarded as ground, and its elements as figural, so a hand may become a ground for figures, palm, and thumb. The more natural level of analysis for visual stimuli seems to be where a scene is background, with objects as figures, rather than where an object is background, and parts of objects are figures. Objects have better figural properties than object parts or than entire scenes because objects generally have closed contours and are movable as wholes. If there were a picture grammar, it would put constraints on locations of the various objects composing a scene, in much the same way that a grammar places constraints on the sequencing of words in a sentence. In fact, there seem to be very few constraints on placing objects in scenes. Those constraints that gravity or nature impose are more likely to be along the vertical axis—ceilings and sky are up, floors and ground are down—than the horizontal axis. But objects and scenes, like words, sentences, and stories, are meaningful, familiar stimuli. Maps and visual forms, as a class of stimuli, seem to have even fewer constraints to their structure than objects and scenes. The actual relation of figures to their frame of reference and to each other are examples of structural constraints on maps and forms.

Empirical support has been presented for heuristics of alignment and rotation. These are conceived of as organizing operations performed on visual stimuli that may facilitate memory and inference, but that may also produce systematic distortions in the orientation and location of figures on backgrounds. Other perceptual organizing devices that produce distortions of location, shape, and distance were discussed. Since map figures change their shapes and relative locations depending on the projection used to map globe (three-dimensional) locations onto locations on paper (two-dimensional), it may, in fact, be advantageous to store only schematic, relative, partial information rather than exact spatial information. Likewise, three-dimensional objects change apparent shape depending on the location, or frame of reference, of the viewer. Schematic information might allow correct recognition and categorization of the same map, object, or scene under varying projections and points of view.

The perceptual organization devices discussed, for location, for orientation, for distance, have been isolated for the purposes of demonstration. In fact, of course, a distortion of shape may lead to a distortion of location; a distortion of orientation may lead to a distortion of distance. The distinction between figure and ground, then, breaks down in another way; if the figure changes shape or location, the the ground changes also. From the findings discussed, we may characterize spatial knowledge as constructed or inferred, using heuristics and other devices, from bits of partial information at varying levels of generality (Chase & Chi, 1980; Kuipers, 1978; Stevens & Coupe, 1978). If all of the partial, hierarchical, constructed, and inferred information that comprises our spatial knowledge could be put together, it seems unlikely that it could be realized as a two- (or three-) dimensional map. There is no guarantee that our spatial knowledge is internally consistent. Cognitive maps may be impossible figures.

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