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Distortions in Judged Spatial Relations

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In three experiments, we explore distortions in subjects' judgments of relative geographical relations. People make large systematic errors in judging the geographical relations between two locations that are in different geographical or political units. There is a strong tendency to distort the judged relation to conform with the relation of the superordinate political unit. To account for this result, we present a model in which spatial information is stored hierarchically. Spatial relations between any two locations are stored explicitly only if those locations are within the same superordinate unit. Spatial relations not stored are inferred by combining the relations from between and within superordinate units.

Madrid (Spain) is farther north than Washington (DC).
Seattle (USA) is farther north than Montreal (Canada).

The above two statements are correct, yet they contradict the opinions of most people. Many people make large errors in judging relative geographical relations when the two locations are in different geographical or political units. The anomaly is more than a pleasant curiosity; it reveals the presence of internal structure in the representation of geographical information. Some relationships are inferred, rather than examined directly.

In any information processing system, there is a trade-off between memory and computation. If information is stored explicitly, little or no computation is required but memory space is increased. If information is inferred, storage requirements are reduced but extra computation is required. Moreover, if information is not stored explicitly, there is a chance

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of making errors in the inferences. Thus, by storing the information that all birds can fly, one can avoid storing the fact explicitly with the representation of every bird in memory. But this savings in storage can produce errors; some birds cannot fly. Similar errors occur in judgments of geographical locations. By storing the information that the Pacific Coast of the Americas is west of the Atlantic Coast, one can save the necessity of storing relative east–west locations for a huge set of location pairs. The price is occasional errors: The Pacific entrance of the Panama Canal actually is east of the Atlantic entrance (it is south-southeast).

In this paper we report three experiments which examine the errors resulting from inferential processes in spatial judgements. Experiment 1 examines judgments about real world locations which are in different political or geographical units. Experiments 2A, 2B, and 3 examine judgments about locations on simple maps learned in the laboratory. In the discussion, we suggest a model of the representation and inference process to account for the results of these experiments.

EXPERIMENT 1

The first experiment was designed to assess to what extent distortions like the anecdotes of the introduction really do exist. We examined subjects' knowledge about the direction between geographical locations in North and Central America. We chose pairs of locations so that their geographical direction was different from the general direction of their superordinate political or geographical units. Subjects were asked to estimate the direction between the pairs. For example, the state of Nevada is east of the state of California, but the direction from the city of San Diego (California) to the city of Reno (Nevada) is north-northwest.

Method

Materials. Five location pairs (listed in Fig. 1) chosen according to the above criteria and 15 filler pairs were presented to subjects in a questionnaire. The filler items were constructed using southwestern US cities and states. Each pair was presented on a separate page. One member of each pair was labelled with the word "from," the other with the word "to." A circle, 5.08 cm in diameter, with a vertical line, 0.32 cm in length, intersecting the top of the circle on its vertical bisector was printed next to each pair of locations. The vertical line was labelled "N." The pages of the questionnaire were randomized for each subject with the restriction that at least one filler question occurred between any two test questions.

Subjects. The subjects were 10 undergraduate students at the University of California, San Diego who volunteered in response to a campus advertisement. They were paid $2.00 an hour.

Procedure. Subjects were instructed to indicate the direction from the location labelled "from" to the location labelled "to" by drawing a line from the center of the circle, intersecting the edge in the estimated direction. They were told to do this by imagining that the location labelled "from" was at the center of the circle and then drawing a line in the straight-line direction toward the second location. They were told that "N" meant north.

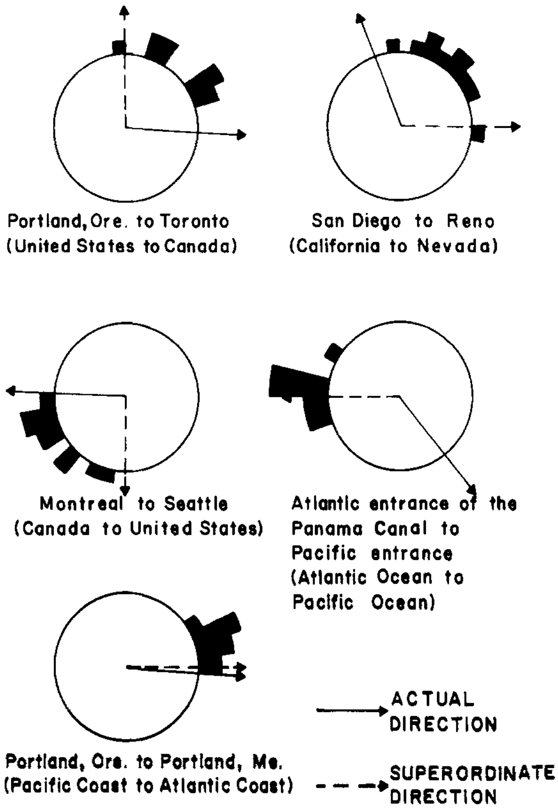

FIG. 1. Response distributions for Experiment 1. Judged locations are listed under each polar-coordinate histogram. The superordinates are indicated in parentheses. For all graphs, north is vertical.

Using fictitious cities, the experimenter gave two examples on a blackboard. The questionnaire was administered in a group in conjunction with other experiments in which the subjects were participating.

Results

Each response was measured to the nearest five degrees. For each pair of locations, shown in Fig. 1, the responses are plotted on a polar coordinate histogram. The actual directions, determined from a Miller cylindrical projection, are indicated by solid arrows and the directions between the superordinate units of the locations are indicated by dotted arrows. All of the averaged responses and all but two of the 50 individual responses are distorted in the direction of the superordinate units. Examination of the results show no other systematic tendencies. The results confirm the anecdotal evidence. There is a strong tendency to distort direction relations toward the direction of the superordinate relationships. Furthermore, the result does not seem to rely on unfamiliarity with the locations being judged. The experiment was done in San Diego, yet subjects were as poor at judging the San Diego–Reno direction as they were for those less familiar to them.

EXPERIMENT 2A

If the interpretation we have proposed is correct, then we should find that geographical judgements are inferred when the items being judged are in different units. To demonstrate this, we need simply devise stimuli that cause the subjects to form and use internal units. The stimuli turn out to be very simple; we need only three cities and two superordinate regions.

Method

Subjects. The subjects were 10 University of California, San Diego undergraduates different from those in the previous experiment who volunteered in response to a campus advertisement. They were paid $2.00 an hour.

Materials. Prototypical stimuli are shown in Fig. 2. On each of these maps there are two key cities, labelled "x" and "y," and a filler city, labelled "z." There are two sets of stimuli, one in which we tested subjects' memory for the relative direction of the key cities along the vertical dimension and the other in which we tested their memory for relative direction along the horizontal dimension. The key city configurations differ in these two conditions only by a rotation of 90 degrees. For both of these tested dimensions there are three types of superordinate information. In the *homogenous* condition, the cities are shown as part of a single homogenous unit without county information. In the *congruent* condition, the superordinate county direction is the same as the city direction along the dimension tested. Thus, for the congruent horizontal stimulus in Fig. 2, city x is in Alpha County, city y is in Beta County, city x is west of city y, and Alpha County is west of Beta County. In the *incongruent* condition, the superordinate county direction is opposite from the city direction along the dimension tested. Thus, for the incongruent horizontal stimulus in Fig. 2, city x is in Beta County, city y is in Alpha County, city x is west of city y, but Beta County is east of Alpha County.

Each of the conditions in Fig. 2 was tested twice by including the configurations illustrated and six additional stimuli formed by rotating each of the originals 180 degrees. In the final stimulus set, each city was labelled with a letter of the alphabet, immediately below it in the horizontal condition, or immediately to its right in the vertical condition. The labels were chosen randomly for each stimulus. Counties were always labelled with a Greek letter, spelled out, plus the word "county." A small compass rose that displayed the four major geographical dimensions was shown in the lower right corner of each map.

Each map was 21.6 × 21.6 cm square. The two key cities were always separated by 1.27 cm along the dimension tested and 12.7 cm along the other. In both the congruent and incongruent conditions, the cities were .64 cm from the border.

A set of questions was constructed for each map. Each set included a key question which asked the direction of the key cities along the test dimension. For the stimuli in Fig. 2 in the horizontal condition, this question is "Is x east or west of y?" Within a condition, east and west or north and south were tested equally often. There were four filler questions dealing with direction and county location of cities for each map in the congruent and incongruent conditions. For the homogenous condition, there was a single filler question. The questions were randomized within each set.

Procedure. Subjects were told that we were interested in how much they could remember about simple maps. They were told that while each map was in front of them they were to try to memorize it because they would be asked questions about it.

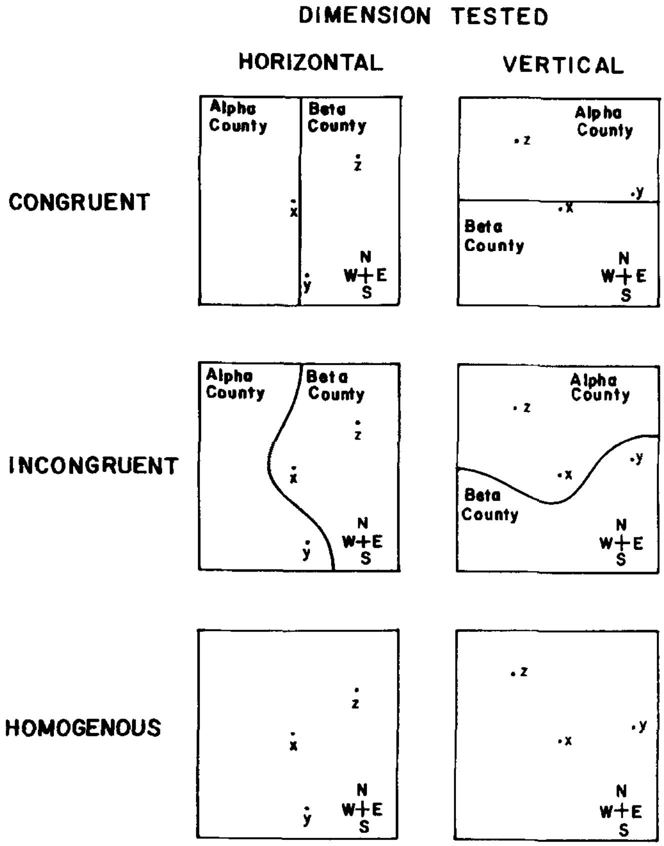

FIG. 2. Prototypical stimuli for Experiment 2A.

Subjects were run individually, seated at a table across from the experimenter. For each trial the experimenter said "ready" then placed the stimulus map on the table in front of the subject. After 20 sec the experimenter removed the map and placed a sheet containing the questions in front of the subject. The subject answered the questions on a separate sheet, taking as much time as necessary. When done, the answer sheet and questions were removed and the next trial began. No feedback was given. The maps were presented in random order, subject to the restriction that no two of the same type of county organization appeared in succession. The entire session lasted about 20 min.

Results

The results support the view that subjects encoded the maps in terms of superordinate units; subjects made about three times as many errors in judging the relative directions in the incongruent condition than in the other two. The percentage of errors for each condition is shown in Table 1.

These data were analyzed using an analysis of variance. The only significant effect was that due to superordinate information [$F(2,18) = 6.08$, $p < .01$]. Dimension tested was not a significant factor [$F(1,9) < 1$] nor

TABLE 1

ERROR PROPORTIONS FOR EXPERIMENT 2A

	Dimension tested		
	Horizontal	Vertical	Mean
Congruent	.10	.25	.18
Incongruent	.40	.50	.45
Homogenous	.15	.15	.15
Mean	.22	.30	

was its interaction with superordinate information [$F(2,18) < 1$]. Newman–Keuls tests show that as predicted, the incongruent condition is significantly different from both the congruent condition [$Q(3,18) = 4.44$, $p < .05$] and the homogeneous condition, [$Q(2,18) = 4.07$, $p < .01$].

One possible explanation of these results is that they are due to a perceptual illusion. We asked six different subjects (not part of any other experiments) to answer the incongruent questions while the stimuli were present in front of them; the subjects were perfect.

Experiment 2A provides additional support for the idea that maps are represented in terms of superordinate units in memory. Even for these simple stimuli, there is a substantial effect of superordinate structure on the memory for subordinate spatial relations.

EXPERIMENT 2B

There are some potential objections to Experiment 2A. The incongruent condition had two counties, whereas the homogenous condition did not. This difference in information might invalidate that comparison. In addition, the incongruent county lines ran at a slight diagonal, so subjects might have used them to align geographical dimensions, accounting for their errors. Experiment 2B remedies these objections. In addition we examined subjects' confidence in their responses.

Method

Subjects. The subjects were 12 University of California, San Diego undergraduates different from those in the previous experiments. They were recruited with a campus advertisement and were paid $2.00 an hour.

Materials. The stimuli were similar to those used in Experiment 2A with minor exceptions. The county lines for the incongruent condition were adjusted so that they were precisely vertical except for the curved part separating the key cities. The homogenous condition was modified by adding a county line identical in shape to that used for the incongruent condition but placed so that it did not pass between the key cities. An extra city was added to each configuration (making a total of four cities) so that there was always at least one city in each county in all conditions. Cities and counties were labelled in an identical manner to Experiment 2A except that we used animal names instead of Greek letters for the counties. The number and types of stimuli, dimensions of the map, key city separation, and key city relationship to the county borders were identical to Experiment 2A. Questions were identical in form to those used in the incongruent and congruent conditions of Experiment 2A.

The stimulus maps were arranged in booklets, one for each subject. The stimuli in each booklet were arranged in a different random order with the constraints that order of each stimulus in relation to the others of its organization type was balanced across subjects, and stimuli representing the same type of organization were separated by at least one other map. Eight filler maps were included which did not resemble any of the stimulus maps and contained no incongruent conditions.

Procedure. Subjects were given instructions similar to those of the previous experiment. A 5-point confidence rating scale was explained to them (1 corresponding to "just guessing" and 5 to "absolutely positive"). The confidence scale was also written on a blackboard in clear view of each subject.

Subjects were run in groups seated at a large table with the stimuli and questions presented in booklets. For each trial, the experimenter said "ready," paused and then said "begin." Subjects immediately turned to the next map in their booklet. At the end of 20 sec, the experimenter said "stop" and the subjects immediately turned to the questions, taking as long as necessary to answer them. The complete session lasted about 30 min.

Results

Errors. The results confirm Experiment 2A. Subjects again made more errors in the incongruent condition than in the other two (Table 2). The only significant effect in these data from an analysis of variance is that due to superordinate structure [$F(2,22) = 11.07, p < .01$]. Neither the effect of dimension [$F(1,11) < 1$], nor its interaction with organization [$F(2,22) = 1.72, p < .20$] were significant. Newman–Keuls tests show that as predicted, the incongruent condition is significantly different from both the congruent condition [$Q(3,16) = 6.43$, $p < .01$] and the homogenous condition [$Q(2,16) = 3.54$, $p < .05$]. A Newman–Keuls test also suggests that the congruent condition is different from the homogenous condition [$Q(2,16) = 2.89, p < .10$]. However, this difference should be interpreted with caution since it did not appear in Experiment 2A. It could be explained by assuming that subjects encode the spatial relationships of the superordinates prior to or more accurately than the spatial relationships of the subordinates.

The overall pattern of results replicates and supports the conclusions drawn from Experiment 2A.

Confidence ratings. The confidence ratings show no difference across organization condition (Table 2). Superordinate structure had no reliable effect [$F(2,22) = 1.91, p > .10$]. However, a specific contrast (Congruent vs Incongruent and Homogenous) suggests there may be a difference [$F(1,16) = 5.23$, $p < .05$], so this should be interpreted with caution. There was a reliable effect due to dimensions [$F(1,11) = 6.80, p < .05$]. Subjects were more confident when questions dealt with the vertical dimension. The interaction between superordinate and dimension was not significant [$F(2,22) = 2.36, p > .10$].

TABLE 2

ERROR PROPORTIONS AND CONFIDENCE RATINGS FOR EXPERIMENT 2B

	Dimension tested					
	Horizontal		Vertical		Mean	
	Errors	Conf.	Errors	Conf.	Errors	Conf.
Congruent	.04	4.2	.04	4.7	.04	4.4
Incongruent	.50	3.4	.42	4.3	.46	3.8
Homogenous	.13	3.5	.33	4.0	.23	3.8
Mean	.22	3.7	.26	4.3		

The fact that the confidence ratings were generally high suggests that responses in the incongruent condition were not the result of guessing or confusion. Rather, subjects were quite confident of their responses. This would be expected if subjects integrate the information they have stored in a normal manner to arrive at their responses. Subjects think these tasks are easy; they do not realize they are making errors in the incongruent condition.

EXPERIMENT 3

Gibson (1929) has demonstrated that under certain conditions lines are remembered as straighter than they actually are. Suppose that subjects remember the city locations in relation to the border and then remember the lines as straighter than they were. This could possibly account for the results of the previous experiments. In this experiment, we examine memory for direction when all boundaries are straight.

Method

Subjects. The subjects were 14 undergraduates from the University of California, San Diego different from those in the previous experiments. They participated as part of a course requirement.

Materials. Prototypical stimuli for each of the major conditions are shown in Fig. 3. There are two different superordinate directions: one in which the counties are east-west of each other (the EW condition) and the other in which they are north-south of each other (the NS condition). The second factor is the amount the relative direction of the key cities (labelled x and y) differs from the superordinate direction. There are three levels of deviation: 15 degrees, 45 degrees, and 75 degrees. Examples of each of these for both superordinate directions are illustrated in Fig. 3. Each map contained two filler cities added with the constraint that a single city was in each of the four quadrants of each map. As a control for spatial asymmetries, we used the same physical configurations of cities in the 15 degree EW and 75 degree NS conditions, in the 75 degree EW and the 15 degree NS conditions, and in both of the 45 degree conditions.

Note that in Fig. 3, the relative directions of the key cities in the EW condition all deviate

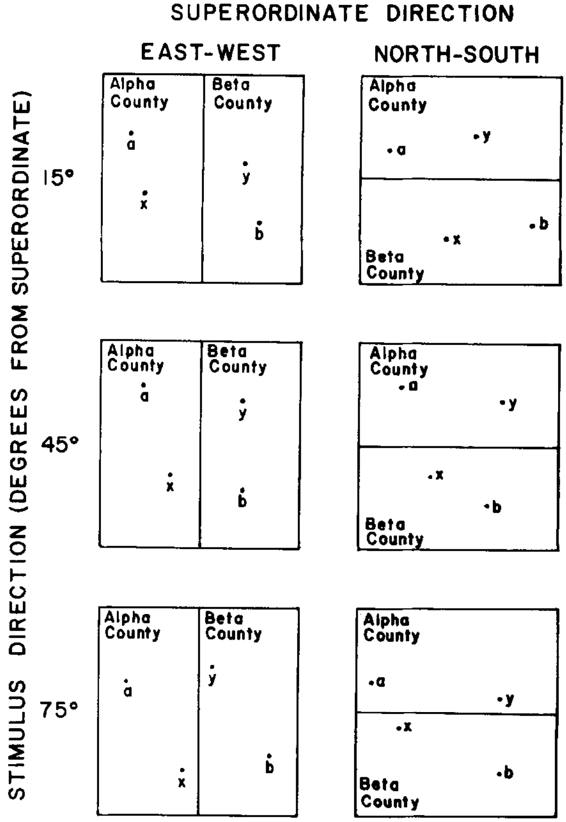

FIG. 3. Prototypical stimuli for Experiment 3.

from the superordinate direction in a counterclockwise direction but in the NS condition, they all deviate in a clockwise direction. To control for any possible biases this might introduce we also included six additional stimuli so that each level of deviation was also represented as a clockwise deviation for the EW condition and as a counterclockwise deviation for the NS condition. Pairs of configurations corresponding to those of Fig. 3 were also physically identical.

In order to present all 12 stimuli to each subject without repeating the same physical configuration of cities we constructed a second set of stimuli by reflecting all 12 originals about the horizontal axis. Two different sets of stimuli were constructed from the total set of 24 so that within each set, all three deviations were represented in both clockwise and counterclockwise directions for both superordinate conditions. Identical physical configurations were not repeated in either set.

Cities and counties were labelled in a manner similar to that of Experiments 2A and 2B, except that county names were taken from the names of small midwestern US towns.

A set of questions was constructed for each of the stimulus maps. These asked what county each city was in and the directions between three different pairs of cities, one of which was always the key pair. A 2.5 cm circle with a dot in the center was printed beside each direction question. A booklet of questions, with one page for each stimulus was prepared for each subject. The questions were randomly ordered on each page. The order in which the two key cities were presented for the direction estimate was balanced across subjects.

Procedure. Subjects were given general instructions similar to those of Experiments 2A and 2B.

Subjects were told to answer the direction questions by drawing a line from the center of the adjacent circle, intersecting its edge in the estimated direction. The experimenter gave two examples on the blackboard using fictitious cities.

The subjects were run in two groups of seven. Each of the groups received one of the stimulus sets presented in a random order. The stimulus maps were projected on a screen in the front of the room. The projected size of each map was about 1 m by 1 m and key cities were always about .5 m apart. Subjects were from 1.5 m to 3 m from the screen.

For each trial, the experimenter said "ready," checked to ensure that all subjects were watching the screen, and then displayed the stimulus. The stimulus remained on for 20 sec and was then removed. The subjects immediately turned to the next page in their response booklets and answered the questions. When they finished, they turned their booklets face down and the next trial began. No feedback was given. The entire session lasted about 30 min.

Results

Errors. The responses are distorted toward the superordinate county direction and the amount of distortion increases as the deviation of the stimulus direction from the superordinate increases.

We scored the data using two different procedures. In the first, responses were scored as 0–179 degrees of deviation from the original stimulus. Deviations were counted as positive if they were on the vertical side of the original stimulus direction and negative if they were on the horizontal side.

The second scoring procedure was motivated by pilot data. Even with well learned maps, some responses occur which are about 180 degrees different from the correct direction. About 3% of the responses in the present experiment fall in this category. This is an interesting phenomenon but it obscures the present analysis. Therefore, in the second procedure, we scored the responses as undirected lines deviating by 0–89 degrees from the original stimulus direction. Deviations on the vertical side of the original stimulus were counted as positive, those on the horizontal side as negative.

The data from the second analysis are shown in Fig. 4. The horizontal axis indicates stimulus deviation from the superordinate; the vertical axis indicates response deviation from the original stimulus. Perfect performance would result in all points falling on the horizontal axis. Performance which used only superordinate information would result in all points falling along the diagonals. The graph illustrates that subject's responses are a compromise between the actual direction and the direction of the superordinate counties.

An analysis of variance shows that there is a significant effect due to superordinate direction [$F(1,13) = 23.16$, $p < .001$], that amount of stimulus deviation has no reliable main effect [$F(2,26) = 1.82$, $p > .10$], and that there is a significant interaction of superordinate direction with stimulus deviation [$F(2,26) = 10.29$, $p < .001$]. An analysis based on the

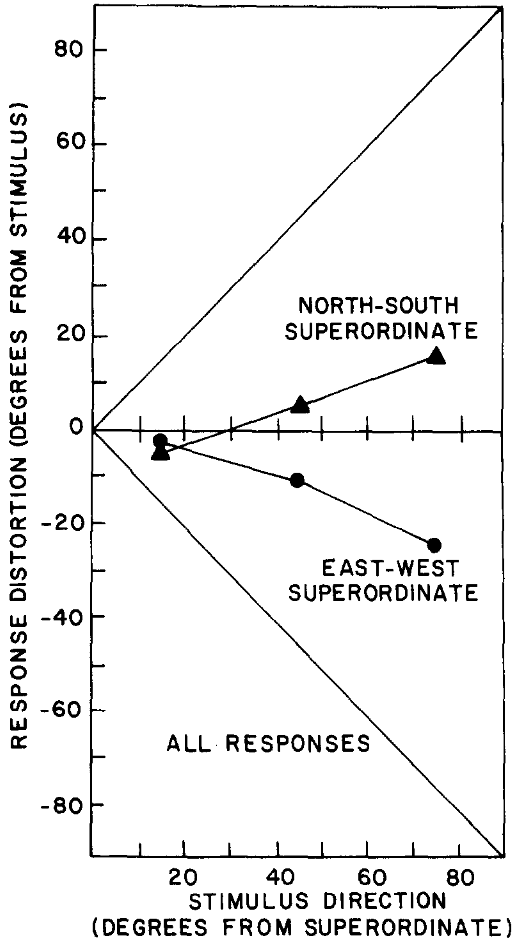

FIG. 4. Mean response distortions for Experiment 3. Distortions is measured as degrees of deviation from the original stimulus. Positive distortions indicate those more vertical than the original; negative distortions are those more horizontal.

first scoring procedure shows the same pattern. Superordinate direction is significant [$F(1,13) = 17.88, p < .001$], stimulus deviation is not significant [$F(2,26) = 1.98$, $p > .10$], and the interaction between these two factors is significant [$F(2,26) = 5.44, p < .025$].

It is possible that these results are due to guessing strategies. Most of the time the subjects may know the direction but when they do not, they might guess based on their knowledge of the general county direction. We examined this possibility by conditionalizing the responses on the basis of confidence level. Figure 5 shows only the high confidence responses (confidence levels 4 and 5) scored using the second procedure. This represents 29% of the data; only one response is affected by differences in the scoring

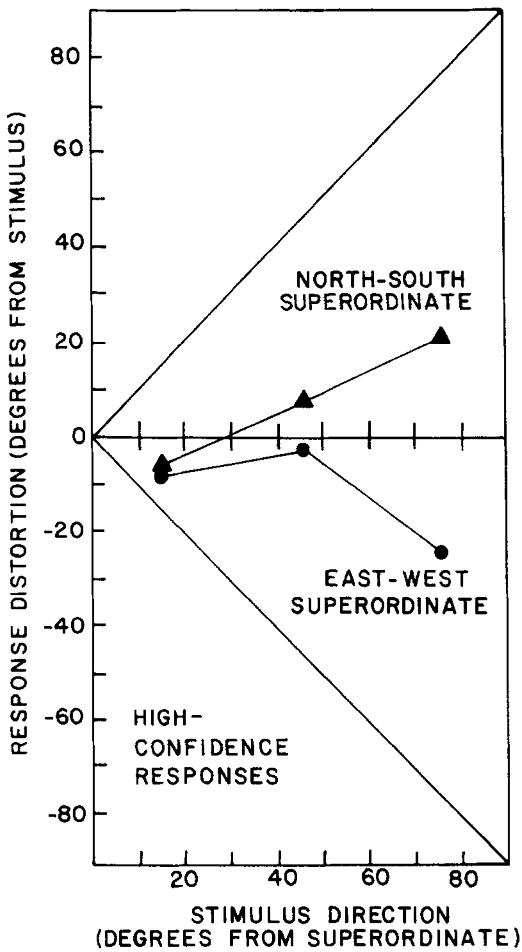

FIG. 5. Mean response distortions for high confidence responses of Experiment 3. Positive distortions are more vertical than the original, negative distortions are more horizontal.

procedures. It is apparent that the high confidence responses follow the same pattern as the remainder. Thus, the observed responses are probably not due to guessing strategies.

It is unlikely that errors in this experiment are due to a perceptual illusion. Induction effects on perceived orientation show a maximal effect of about 10 degrees for lines which deviate from a major spatial axis by about 45 degrees. Angles near the vertical or horizontal tend to be perceived as distorted toward the nearest major axis (Bouma & Andriessen, 1970). In this experiment, maximal distortion was observed for angles nearest a major spatial axis and then the distortion was away from the major spatial axis.

Confidence ratings. The mean confidence ratings for all six conditions are shown in Table 3. All values are approximately 3, halfway between "just guessing" and "absolutely positive" on the scale. An analysis of variance shows no significant effects. The ratings are generally lower than those of Experiment 2B, but the direction estimate required in this experiment is much more precise than the simple categorical responses of Experiment 2B. The confidence ratings show that subjects were not aware when they were distorting the original information.

DISCUSSION

Superordinate structure systematically distorts how spatial relationships are remembered. The judged direction between geographical locations that are in different units reflects both the actual relationships and the relationships of the superordinate units. This result holds for real world locations (Experiment 1) and for simple maps learned in the laboratory (Experiments 2A, 2B, and 3). Furthermore, as the deviation between the actual direction and the superordinate direction increases, the amount of response distortion also increases.

We believe these results reflect the storage-computation trade-off. We propose that spatial information is stored hierarchically as in Fig. 6. This figure shows a formal representation for spatial information about six regions: the states Ohio and Colorado, and the cities Cincinnati, Columbus, Denver, and Pueblo. The notation is that of semantic networks (see Norman, Rumelhart, & the LNR Research Group, 1975). Concepts, representing regions, are represented by nodes (and thus appear as angular brackets). Relations, representing spatial relationships among regions, are represented by spatial predicates (and thus appear as ellipses). The nodes they relate are indicated by arrows labelled "from" and "to." The special relation which holds between a region and its subregions is indicated by an arrow labelled "Part-of." In order to deal with the storage-computation tradeoff, we assume that two principles of storage and inference govern the representation of spatial information in terms of these structures:

TABLE 3

MEAN CONFIDENCE RATINGS FOR EXPERIMENT 3

Superordinate direction	Stimulus deviation from superordinate direction			
	15°	45°	75°	Mean
North-south	3.06	2.96	3.30	3.11
East-west	3.03	3.22	3.18	3.14
Mean	3.05	3.09	3.24	

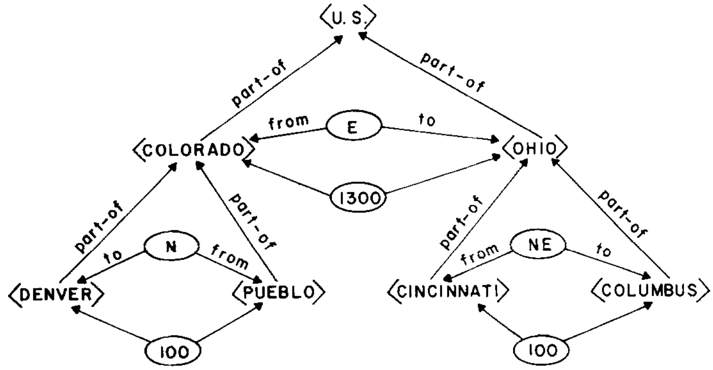

FIG. 6. A hierarchical representation of spatial information about locations within the US.

(1) Generally information about spatial relationships between regions is stored only for regions encoded as part of the same superordinate unit.
(2) Relations between two regions not stored explicitly must be inferred. The inference process combines the relations between superordinates with the relations of the subregions within their respective superordinates.

Thus, Fig. 6 represents the information that the US is an immediate superordinate of both Ohio and Colorado, that Colorado is an immediate superordinate of Denver and Pueblo, and that Ohio is an immediate superordinate of Cincinnati and Columbus. Because three pairs have common superordinates, they have spatial information stored about their relationships to each other. We have represented direction and distance relations which hold between each respective pair of regions. Note that none of the 12 possible additional pairs has a common immediate superordinate, so no spatial information is explicitly stored about their relationships. This means that in order to infer the relationship between Columbus and Denver, three sources of information must be combined: the superordinate relations holding between Colorado and Ohio; the relation of Columbus to the rest of Ohio (only partially represented in the figure); and the relation of Denver to the rest of Colorado (again only partially represented). Generally the reconstructed information will be accurate enough for most purposes. Only under special circumstances, such as those selected for our experiments do serious distortions occur.

The important properties of this representation are its hierarchical structure and corresponding inference process. The experiments we report say little about the types of spatial relations that hold between units. In addition to representing all pairwise relations within a given unit, there are several other possibilities. Each region could be organized around a few distinguished points such as key landmarks or geometrical features like the center of a region (Palmer, 1975). Direction and distance relations would connect each unit to one or more of these landmarks or features. Each region could be encoded as a set of subregions determined by perceptual grouping of elements or in terms of geometrical divisions such as top half, bottom left quadrant, etc. This scheme simply requires additional levels in the basic hierarchy. Finally, each region could be encoded in terms of a coarse grid or polar coordinate system which allowed a small number of categories for each coordinate. The present experiments do seem to rule out schemes which use relatively precise information. For example, the precise polar coordinate representation proposed by Kosslyn and Schwartz (1977) seems to predict that people would not make errors of the type we report.

Given a hierarchical representation, there are at least two ways that the inference process might operate. The first weights higher level information more heavily than lower level information. If relations representing direction and distance are encoded about the relationships of units, then information at higher levels typically will be based on more instances than that at lower levels. Thus, it would be reasonable for the reconstructive processes to weight the higher level information more heavily.

A second possible inference procedure can be considered to be a levels of processing analysis (Craik & Lockhart, 1972). If the representations of regions are structured hierarchically in terms of geometrical units like "top-half," "top-left-quadrant," "top-left-quadrant-of-the-top-left-quadrant," then spatial information can be stored and inferred to an arbitrary level of precision, given enough time and effort. Distortions arise because the level of processing necessary for precise encoding or inference is typically not performed. Thus, people might encode a northern city near the western border of a county as simply being in the northwest quadrant or encode detailed information but not bother to apply inference procedures below the level of "northwest quadrant," thereby erring when asked the direction between the city and a city in a different unit.

The distortions presented in this paper are difficult to account for in terms of representations based on imagery metaphors (e.g., Kosslyn, 1973, 1975; Kosslyn & Pomerantz, 1977; Paivio, 1975). Simple imagery models fail to deal with the multilevelled structuring necessary to account for our results. The hybrid analog/propositional model proposed by Kosslyn & Schwartz (1977) can in principle account for our data. To do this requires that the propositional component include hierarchical structuring and that the inference processes construct the analog image from the hierarchically structured information. However, the image itself would play no substantive role in this explanation and it is difficult to see any role that it could play.

Organizational units need not always be based on politically defined regions. The organization of spatial information must depend on the ultimate use of the stored information. Thus, airline pilots are likely to use both routes and political units to organize locations, creating errors that are quite different from those we report. We have induced subjects to use political units, but it is likely that different task demands would induce different organizations. Similarly, there are probably other inference mechanisms that people use. For example, if people are specifically asked to recall shape information, then the types of errors we observed might be minimized. Regardless of the units used, or of the existence of other inference strategies, the principles of hierarchical representation and reconstruction are of critical importance in the way that people encode spatial information. Higher order organizational structure cannot be ignored. This structure causes systematic errors in judgments about spatial relationships.

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