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Chapter 9

Topographic Map Reading

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9.0 Introduction: Nature and Context of Problem

Topographic maps are the relatively familiar form of geographic maps in which elevation is represented by contour lines connecting locations of equal elevation. These can be, and are, used as navigational aids for helping to solve quite sophisticated forms of way-finding problems. The present chapter is concerned with how such maps are used for solving localization problems. However, before addressing specifically how topographic maps are used, it is worthwhile to consider such technological aids in the general context of navigation.

Navigation can be considered to be the process by which an organism or machine finds its way through the environment. This obviously involves noting one's current position, planning a route to a desired location, and negotiating that route. At one extreme, navigation tasks involve small-scale spaces in which the entire space can be apprehended immediately and one's current position as well as the desired location can be simultaneously perceived. This is the case, for example, in locomoting around a room or an open field. Even in such instances a certain amount of route planning may be involved. One may have to decide whether to go over or under a barrier, through an aperture (Warren & Whang, 1987), over or under a table, and so on) Such decisions are often made so effortlessly that we tend to forget that they can be problematic. However, their potential difficulty is apparent when the behavior of immature organisms is examined, such as infants deciding how to negotiate a slope (Adolph Gibson, & Eppler, 1990) or deciding what size aperture to go through (Palmer, 1987), or when one observes visually impaired persons using a long cane to detect free paths (Farmer, 1980).

At the other extreme is navigation around large-scale spaces in which all parts of the space are not simultaneously perceivable. The current position or viewpoint of the navigator is presumably perceptually available, but the destination is not, nor are greater or lesser portions of possible routes. In this case the location of the destination needs to be specified in relation to the current position and possible routes determined. For many the problems that arise in everyday life in such situations are all too familiar.

In fact, such difficulties are so common that many cultures have developed aids for facilitating this kind of navigation. Some navigational aids such as optical or electronic beacons make destinations and landmarks more salient or involve sensors for detecting one's own position in the world. However, maps are one of the most useful and common navigational aids in our culture, providing a symbolic representation of spatial information about the environment. Cartographers have elaborated the science of map making for many purposes, but two kinds of maps are particularly useful for navigation. A route map is useful when the environment is structured to provide specific and constrained paths from place to place. In such environments the routes are so important and obvious that route maps often omit much other spatial information. In contrast, the topographic map is useful when the environment is not artificially structured with routes (e.g., roads) connecting locations. The spatial topography of the environment, that is, the elevation above sea level of all points of the environmental surface, is represented by contour lines. Thus, within the limits of map resolution (and map errors), the topographic map presents a two-dimensional depiction of a three-dimensional spatial layout of our environment.

Such topographic maps are widely used for both professional and recreational purposes. Geologists and agronomists among others use topographic maps for navigation in their work, and orienteers and hikers use maps in way-finding recreationally. An important navigational use of topographic maps is to help with problems of localization, that is, determining correspondences between particular locations in the environment and locations on the map. Commonly, the environmental location of interest is the current position or viewpoint of a navigator (i.e., "where am I?" problems). Such localization problems can be characterized in terms of how much a priori information is available about likely current positions. At one end of such an information continuum, *drop-off* problems involve substantial initial uncertainty in current position. (The name comes from the extreme case in which a navigator is literally "dropped off" into a totally unfamiliar environment. This can occur practically in an airplane crash or more generally in losing one's way under certain conditions.) Toward the other end of the continuum are updating problems in which the task is to maintain a sense of the current position with respect to a map as that position changes with locomotion.

Two aspects in the use of topographic maps for solving localization problems make it a particularly interesting cognitive–perceptual problem. First of all, as with other types of maps, there are two perceptual tasks: perception of the environmental scene and perception of the environment via the map. Perception of the scene—the terrain—is prototypical of perception of the natural environment. Perception via the map is what Gibson (1979/1986) termed *mediated* perception—perception of encoded information. Thus, as with pictures, blueprints, text, and so on, one obtains information about something else through an immediate medium of a different kind. In the case of a topographic map, the mode of representation of the environment is particularly interesting in that the X–Y or two-dimensional layout of the map is formally similar to the two-dimensional layout of the environment. In contrast, the elevation information on the map is a symbolic or encoded representation of elevation in the environment. Such a mixture of mode of representation might cause difficulties in map reading. A second intriguing aspect of topographic map reading is the radical difference in perspective between the view of the environment which is typically more or less parallel to the ground from eye level and the view of the map representation of the environment which is typically a bird's eye view with the map more or less perpendicular to the line of sight.

9.1 Background Research

Both psychologists and geographers (especially cartographers) have been active in investigation of map reading. The largest amount of this research is on the use of road and street maps or thematic and political maps. However, when topographic map reading has been investigated, the research has been mostly concerned with problems involving detection of correspondences between information about elevation represented by contour lines and information portrayed in a less encoded way. For example, subjects were asked, using a multiple-choice format, to select the one of several line shapes that best represented the elevation profile of a direction line on a map segment crossing a series of contour lines (Griffin & Lock, 1979). The line shapes varied in degree of curvature, whether they were concave or convex, and in direction of slope (left-to-right or right-to-left). Results indicated that lines of uniform slope were most easily identified, followed by concave lines, and then convex ones.

In the context of the issues of the encoded nature of elevation information and the change of perspective from map to environment, researchers have been concerned with the kinds of information processing that are involved in map reading. Taking a relatively direct approach to this question, Chang, Antes, and Lenzen (1985) analyzed the patterns of eye movements used by map readers examining a series of topographic maps in order to identify the high and low areas. Illustrative of their results was the finding that inexperienced map readers had a more uniform distribution of eye fixations across the map areas than experienced map readers whose fixations tended to be concentrated around the areas of high and low elevation.

A related question has been how navigators are able to determine the correspondence between maps and more iconic representations of the world. Another information processing paradigm, that of reaction time, was employed by Eley (1988) to determine the effects of differences in alignment between map and landform view on map reading. Subjects were asked to indicate whether a particular view of a landform matched what would be seen from a given station point on a map looking in a given direction. Typical mental rotation results were obtained. The greater the required viewing angle of the map deviated from the subject's own orientation to the landform view, the longer the reaction time. A second experiment in this study was directed at the question of difference in perspective of map and environment. The elevation angle of the subject above the landform view was varied, and it was found that a viewpoint 30° above horizontal was more effective than higher or lower elevation angles in terms of speed of processing.

Other research approached information processing less directly. In systematic psychometric research, Sholl and Egeth (1982) examined

individual differences in information processing of map readers. They related performance on a number of map-reading tasks to several more general standard psychometric measures. The map tasks such as landform identification, slope identification, spot elevation, and terrain visualization were factor analyzed yielding two major factors, one being described as spatial visualization and the other as an altitude estimation factor. Surprisingly, standard tests of spatial ability were not highly related to the spatial visualization map-reading factor, whereas verbal-analytic measures were. (The standardized measure of mathematical ability was related to the altitude estimation map-reading factor; yet, finding the altitude of points on a topographic map or finding the highest and lowest elevations on a map would not seem to involve very sophisticated mathematics. The authors suggest that the relationship between mathematical ability and altitude estimation is probably due to arithmetic skills.) In general, the results seem to suggest that our standardized tests do not reflect very well the skills used in a practical task such as topographic map reading.

Overall, the research on topographic map reading is limited in extent, but it is interesting and tantalizing. The results suggest a rather sophisticated skill, but we do not yet understand, either through analysis of individual differences or through analysis of task process, the exact nature of this skill. One reason is simply that there has been relatively little research. Another is that the tasks used are artificial in two respects. They are artificial in the materials used. The samples of the maps themselves are real but are often only tiny segments of real maps. When the experimental tasks involve relating maps to the environment, they typically do not involve the real environment, but employ relatively impoverished sketches. These may, on the one hand, emphasize features that would not be as clear with natural terrain or, on the other hand, omit the incredible richness of natural terrain. The tasks are often artificial in the problems posed. Subjects may be asked only to find high and low spots, to judge the qualitative nature of a landform, and so on, and usually not even to solve a localization problem. (One source for research describing navigation in natural terrain is the *Scientific Journal of Orienteering*, edited by R. Seiler.[1])

The purpose of the remaining part of this chapter is to summarize a program of research on topographic map reading in which an attempt

[1]The *Scientific Journal of Orienteering* can be obtained from the International Orienteering Federation, Secretary General, P.O. Box 76, S-191 21 Sollentuna, Sweden.

was made to use more realistic materials and a more complex and realistic map reading problem than that of much of the previous research. The materials used involve relatively large segments of topographic maps, real environments or photographs of environmental scenes, and localization problems. The prototypic map-reading task examined in this research is the drop-off localization problem, as defined earlier. It was posed to experienced map readers in a real outdoor map reading situation. The data for this prototypic situation consist of the verbal protocols of these map readers as they think aloud working through the problem (as well as the correctness of their solutions). On the basis of these field protocols, additional studies were carried out, some in the laboratory under more controlled conditions, but still using relatively large map segments and photographic scenes. The goal of the research was to identify strategies that experienced map readers use to solve localization problems and the kinds of features in the terrain and on the maps that are important in their solutions.

9.2 Experimental Research

9.2.1 Field Experiment and Protocol Analysis

The approach involved collection and analysis of protocols of experienced map readers attempting to solve drop-off map reading problems in the field. The map readers were recruited from geology and geography departments, orienteering clubs, and other outdoor and wilderness organizations. The range of experience varied from professionals who use topographic maps daily on the job to experienced recreational users. Among the participants was one who hiked the length of the Brooks range in Alaska for recreation and another who consistently places in the top five in national orienteering competitions.

Each participant was driven blindfolded approximately 30 miles and led by foot to a station point on a hill in the generally rolling terrain of central Minnesota. (The majority of protocols were collected from two different sites.) The blindfold was removed, and the participant was given a portion of a topographic map of the area and asked to think aloud while trying to determine the position on the map that corresponded to the location in the terrain. The verbal reports of the participants were recorded, and they were videotaped as well, so as to be able to see what they were looking and pointing at as they engaged in solving this localization problem. The segment of the map they were

Figure 9.1. *Example of topographic map used for drop-off problem at Site A, O'Brien State Park, Minnesota.*

given was an irregular portion of a U. S. Geological Survey map from which all nontopographic information had been deleted. Thus, it contained no information about roads, railroads, fence lines, or distribution of vegetation, and so on. The relatively impoverished map was used to see whether and how the map readers could solve the localization problem with only topographic information. The map did have a distance scale marked on it and elevation values on some of the contour lines. An example of the topographic map for one site is shown in Figure 9.1.

How well did the map readers do? The problem proved to be quite difficult. Initially, the problem was posed to a group of 17 map readers with instructions not to move from the original station except for turning around and moving slightly to see around occluding bushes or brush. Of these, only one person arrived at a correct solution. A second group of 12 map readers was given the task with instructions that permitted free movement while performing the task. Six of these obtained a correct solution. A chi-square test indicates that this difference in performance between the two groups is statistically significant. However, examination of the actual behavior of the participants in the two groups suggests it was not actually the difference in freedom to move that made the difference. Some of the people in the freedom-to-move condition who solved the problem correctly, in fact, only moved after they had arrived at a correct solution; they moved to confirm the solution that they had already arrived at. The analysis of the verbal protocols indicated that those who arrived at a correct solution employed a particular set of strategies that were at least partially missing in those that failed. We now turn to the protocol analysis.

The goal of analysis of the verbal protocols was to identify the kinds of information that map readers used in attacking this localization problem and to characterize the components of the problem-solving process itself, insofar as the method of protocol analysis permitted. To this end the verbal protocols were carefully examined for each subject, and a coding scheme developed that placed each statement into an "information" trace, on the one hand, and a "process" trace, on the other.

Figure 9.2 is an example of an information trace. The horizontal axis indicates the chronological order in terms of the sequence of statements of the map reader. (Each statement is a coherent utterance with a single focus of attention.) The vertical axis specifies the focus of attention, that is, the source of information, whether it is the map or terrain, and three categories of information—features, relations, and attributes. *Features* are the individual topographic objects that are typically identified with a familiar count noun, such as hill, valley, pond, and so on. Each map

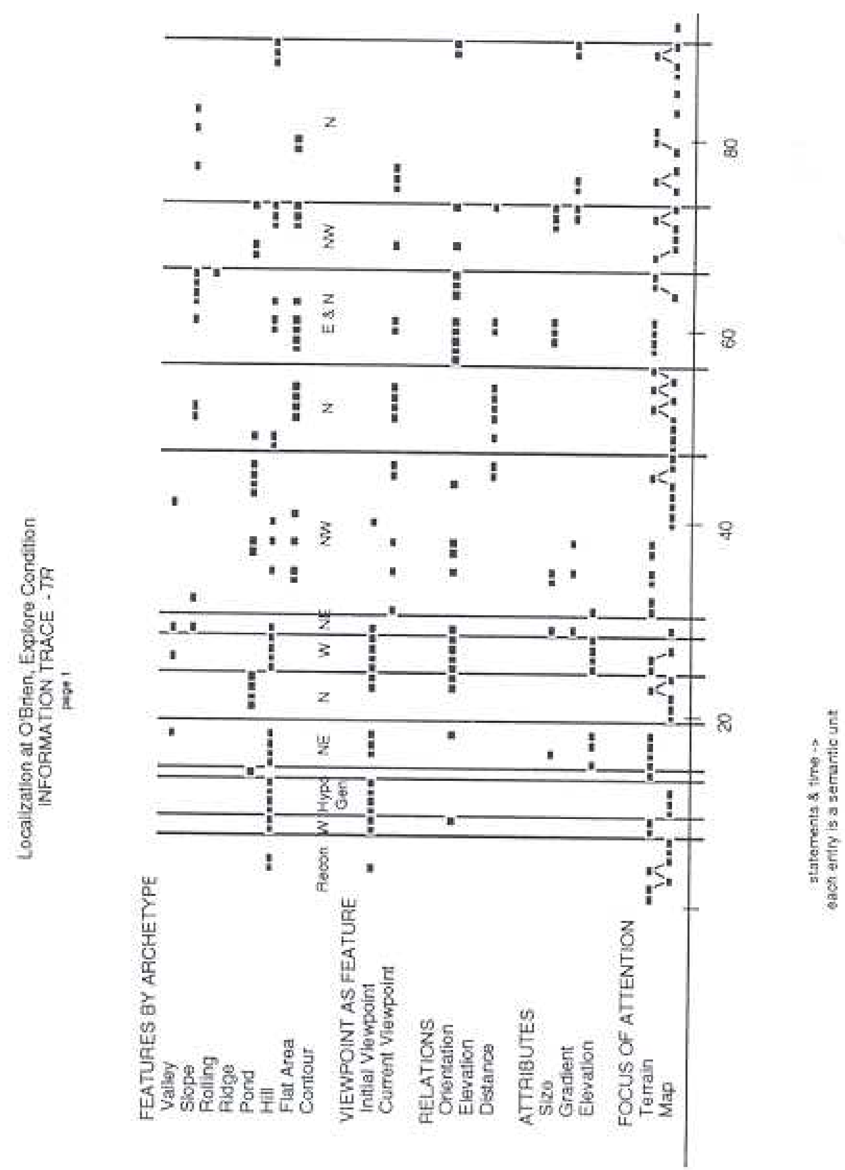

Figure 9.2. *Portion of the "information" trace of a map reader solving the drop-off problem at O'Brien State Park.*

reader's lexicon tended to be small and consistent, although there was diversity between map readers in the specific terms used. The composite lexicon of all the map readers was compressed to form the taxonomy of topographic terms shown in Figure 9.2. *Attributes* are properties that modify individual features. These tend to be bipolar and qualitative and are used to differentiate among similar features, for example, narrow or wide, steep or shallow. Relations are connectives that conjoin two or more features into a single structural unity termed a *configuration*.

Figure 9.3 is an example of a process trace with the horizontal axis again indicating the same chronological order of statements as in the information trace. Hence, the two traces can be coordinated. To make this coordination easier, the vertical axis again contains a focus of attention category. In addition, the vertical axis includes processing categories of metastatement, reconnaissance, matching, other claims, viewpoint hypotheses, and conclusions.

A description of a few of these process categories provides a sense of what they are. *Reconnaissance* involves identification of features, attributes, and relations for subsequent processing. It occurs typically at the beginning of problem solving with broad scanning of terrain or map, but also is found later on in the problem solving process after hypotheses are made and/or tested. An example of reconnaissance focused on the terrain:

> *So, ummm..., standing on a slope here, it's sloping down on pretty much all the way, like 180 degrees sloping down that direction, so. And it looks like there might be a hill behind us, although it's hard to say if it goes down on the other side. But it looks like a pretty high spot in the terrain area, so it's probably one of the higher areas on the map, especially and higher over there. That's about it. (OA 3-5)*[2]

Typical of map reconnaissance would be:

> *"Ahh, looking at the maps, the map, it uh, doesn't show trees so as far as the wooded area and.... It doesn't show like the farms out in that direction, ah. I think the biggest thing is for me to use hopefully would be this long valley if it's a stream of a river system. Umm, looking at*

[2]Coding in parentheses refers to subject and place in protocol from which the quote was taken.

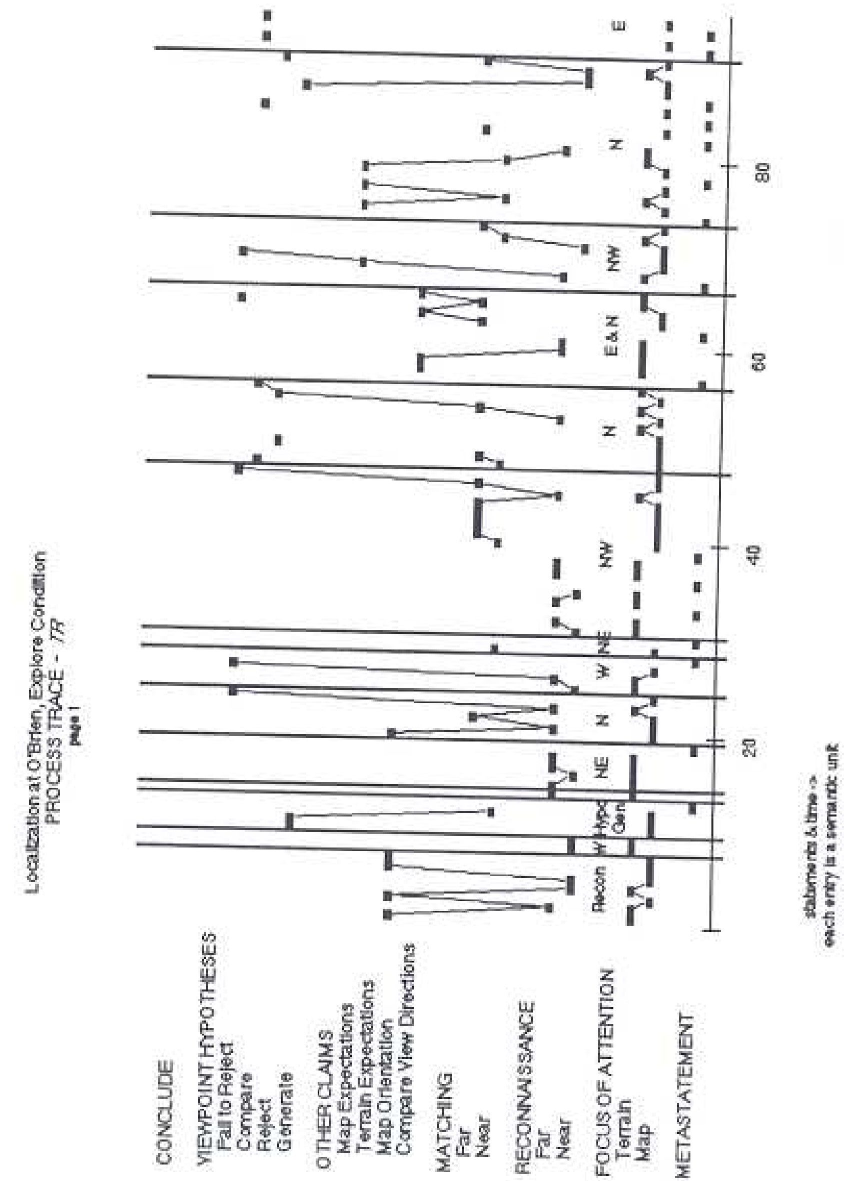

Figure 9.3. *Portion of the "process" trace for the same map reader as in Figure 9.2.*

> *the map there, there appears to be a couple of things that could be a stream valley, umm. This marks a depression with the slash marks.* (DJ 5-9)

Feature matching, the major activity during the localization task, involves matching features in the terrain to features in the map or vice versa. Feature matching does not require the existence of a specific hypothesis about viewing location. Such matching can establish general correspondences between the environmental scene and map, facilitating subsequent generation of specific viewpoint hypotheses. After hypotheses are formed, feature matching plays a key role in their evaluation.

Feature matching is based on a common identification and similar characterization of topographic structures in map and scene. Identification is done in terms of a set of labels and properties, often specific to a particular geographic landform. In the geological area of the present study, the most common features attended to were hills and valleys. Attempting to find correspondences for the mere presence or absence of a hill or valley was not particularly diagnostic of location. Accordingly, map users more commonly attended to the attributes of these features and the relations between them as noted earlier. Consider the following examples:

> *Then down there there's a big valley so I guess that could be this valley going down here, and if that's the case, the high area we're seeing, might be this ridge extending out here, and umm.* (OA 15-16)

> *This area right here, ah, gently sloping while fairly flat on top, so maybe look for some kind of plateau on the map, and, that drops off relatively to my left to the water and to the front. There's a couple of areas on the map that look gently rolling like this area here or over in here, umm, both of them to have a water area off to the left.* (DJ 22-26)

> *Hmmmm, I don't know. There should be a hill on the other side of that, on this wet land right in there. There is a hill I see over there, a grassy hill. Trees behind it. Could be, could be this hill here. It's kind of steep slope, indicated by the closeness of these topo lines right here.* (RB 32-34—-*hypothesis evaluation*)

Viewpoint hypotheses include the generation, comparison, and evaluation of hypotheses about the viewpoint. An hypothesis posits a distinct map location and direction as corresponding to the viewing position. The hypothesis is initially triggered by possible map-scene correspondences between a small number of features or configurations. Evaluation proceeds by examining other scene and map features or configurations using expectations derived from the hypothesis. Often a brief reconnaissance of a local region in the map and/or scene is required to identify additional features and configurations useful in the evaluation process. The strategies involved here have much in common with those used in other diagnostic tasks (e.g., Johnson, Moen, & Thompson, 1988). The following illustrates the generation and rejection of hypotheses:

> *And that other open area that we just barely see, between the, that seems that could be this area here. Umm. But yeah, it looks pretty good. The other side, if that is the case, that we're actually down here now, that, if we were down here, that should be like umm, a ridge going out. I guess there is sort of like a ridge right down there. A little ridge. I don't see it bending to the right though. There's definitely a valley going down there, but yeah. Oh I see. Maybe that valley is this valley. In that case, this makes us up, more... no that doesn't look right either, cause then it should be pretty flat, and it looks sloping more going down there. Hmm, maybe I'm in a completely different location on the map. Hmm, it goes...* (OA 32-40)

> *So what I'm looking at, is that we're kind of on a hump that kind of comes out quite a ways. Maybe I should, seems like we're coming around in direction up a hill like that. So maybe an oblong, more oblong shape hill. Probably something like this down here [referring to map]. Umm, there's more of a ravine on that, but this, this hill here doesn't look like it's big enough. This is the big, seems like the biggest hill in the area, and so to me, that isn't a big enough contour or a big enough hill on this map to signify that's where I'm at.* (JP 50-57)

To *conclude* the problem solving, hypothesis evaluation leads to the tentative rejection or confirmation of hypotheses that have been generated. A final step in the localization process produces the best estimate of actual location and viewing direction. Depending on the search strategy used, this may be based on a comparison of the likelihood of competing hypotheses or may simply be the identification of a single hypothesis that survived a sequential generate-and-test procedure. The subject may be satisfied (success) or unsatisfied (failure) with the final statement. An example of each follows:

> *Let's say these are about 10, 20, this is 30 feet above this line so these actually should be the same height. OK, so I probably wouldn't notice it too much. I think, ah, we're here on this ridge. Umm, let's just look at this one more time here. This is, umm, OK, I think we're here. (RB 96-99)*

> *This one doesn't match because it was too steep. What about this one? Maybe this one. I have to...Let's see. But then, umm, there should be a very sharp or steep valley here, but I don't see that at all, so it's probably not that place. And it's probably not on this....Unless it's down here, umm. Because it's very steep below that, and it's certainly not generally sloping here. So I think the best guess is that we're about here. That's my best guess. It doesn't match completely though. (OA 73-79)*

These excerpts are illustrative of the kinds of protocol statements received and their scoring. On the basis of the analysis we provide the following description of the kinds of information and strategies used in the problem solving of the localization task.

9.2.2 Information and Strategies Identified

The information that was attended to by map readers solving the localization problem was defined basically in terms of the features mentioned in the protocols. In general, these would be different for different geographic areas. In the rolling hills of central Minnesota, the features mentioned most frequently included hills, valleys, flat areas or plateaus, and ridges. However, features such as those seen from a particular viewpoint were not usually distinctive enough to uniquely specify a particular feature on the map. To help reduce this ambiguity, map readers took into account two kinds of constraints on the featural information they attended to. First, the features were qualified by denoting distinctive properties such as relative size, elevation, slope, and so on. These were the attributes coded in the information trace earlier and tended to be specified in bipolar qualitative terms. Features were described as large or small, narrow or wide, steep or shallow. Comparison among features was quite common. One feature was described as larger, broader, or steeper than another. It is noteworthy that metric descriptions in terms of units of distance or degree of slope

were rarely seen, in spite of the fact that metric information was readily available on the map with distance scale and contour lines at standard intervals.

The second constraint on map readers' attention to features was their tendency to focus on assemblies of features, or configurations. Configurations were specified in terms of the features of which they were composed and the relationship among those features. Those relationships again tended to be qualitative and topological rather than metric (e.g., behind, in front of, next to, etc., although sometimes actual elevation was used when looking at the map). Attention to configurations reduced the number of individual items that needed to be considered, and in addition, configurations were more likely to be distinctive than individual features. There were fewer matches to "a hill with a dip and a ridge," than there were to individual hills, valleys, and ridges. The complexity of the configurations was usually relatively small, typically involving two to four individual features.

On the basis of the protocols, especially the information encoded in the processing trace, several strategies used by map readers were identified. These were particularly useful in establishing the correspondences between features in the terrain and on the map necessary for solving the localization problem. First, initial reconnaissance tended to be concentrated on the terrain rather than on the map. Generally, maps include an area much larger than that visible from any particular viewpoint in the terrain. Consequently, the majority of map features will not be relevant to any viewpoint determination, whereas most of the distinctive visual features of terrain will have correspondences on the map. Second, as noted earlier, features were organized into configurations resulting in a reduction of the number of items necessary to attend to and a decrease in ambiguity. Configurations are particularly useful when assembled along the line of sight. Such configurations have a viewpoint-independent property in that they have a linear representation wherever they appear on the map reflecting their linear alignment in the terrain. They also have a viewpoint-dependent property in that once found on the map they constrain the map location of the viewpoint to a line. If several such configurations around a viewpoint are found, they markedly constrain the map location of the viewpoint. Third, considerable attention was devoted to local terrain features around the viewpoint. Although this seems obvious, most approaches to landmark-based robot navigation do not pay special attention to local features of the immediate environment. If a feature or configuration near the viewpoint corresponds to particular features of the map, then the position of the viewpoint on the map is highly constrained. Furthermore, detailed determination of local features is often easier or more accurate than that of more distant features. Fourth, multiple hypotheses were generated and evaluated. A procedural goal is to select quickly a viewpoint hypothesis that can be evaluated against the current view of the terrain. Because terrain features are highly ambiguous, it is difficult to identify landmarks with certainty. Any single viewpoint hypothesis based on a small number of features has a high probability of being incorrect. In complex terrain, it appears necessary to develop a number of different plausible hypotheses for subsequent verification. All successful map readers employed the above four strategies. One or more of the strategies were omitted by those who did not arrive at a correct solution.

Two other strategies also appeared to be quite useful although not uniformly used. A fifth strategy was to compare hypotheses using a disconfirmation procedure. Validation of an hypothesis involves comparing the terrain view with expectations generated from the map based on hypothesized viewpoints. It is most important to note expectations that are not met. If one clear mismatch is found, then the associated hypothesis should be rejected. Because terrain features often look more or less the same, validation based on finding expected features is far less effective than rejecting hypotheses when expected features are not found. Map readers arriving at incorrect solutions often "explained away" incorrect evidence. (The recommendation to look for disconfirming rather than confirming evidence to test alternative hypotheses is a widely accepted component of normative models of inference and decision making [e.g., Platt, 1964; Wason & Johnson-Laird, 1972]. Such a recommendation attempts to counter the pervasive "confirmation bias" found in numerous empirical studies of decision making [Mitroff, 1974; Mynatt, Doherty, & Tweney, 1978; Wason, 1960]. The present work extends the generality of this finding to topographic map reading: Many unsuccessful subjects did not try to eliminate hypotheses. Instead, they tried to "prove" their hypotheses by seeking consistent information. These subjects often concluded by "explaining away" inconsistent evidence as they accepted an incorrect hypothesis. It appears, then, that decision making with the assistance of a topographic map is prone to the same bias and needs to be countered with the same prescription as decision making generally.) Finally, *changing one's viewpoint was important*. Movement to bring obscured features into view or to generate parallax sufficient to gain distance information has clear advantages and is obvious. However, often overlooked is the role of

movement in verifying hypotheses specifically about the viewpoint. Viewpoint hypotheses are used to generate expectations about nearby features that can then be confirmed or disconfirmed by local movement.

9.2.3 Laboratory Simulation of the Localization Problem

The field study enabled the collection of protocols of experienced map readers solving a real drop-off localization problem. However, it was limited both in type of terrain examined and in the control of information available to the map readers during problem solving. A laboratory simulation of the problem provided a first attempt to deal with these issues. The localization problem was posed to map readers through photographs of terrain of different types, whereas the maps of the corresponding areas were masked in varying amounts to manipulate information available. For a subgroup of problem solvers, verbal protocols were collected while performing this task in order to determine just how the specific information affected the solutions.

The field problem, even with map readers able to scan all 360° of the terrain, was quite difficult, as previously mentioned. In order that the laboratory problem could even be possible with only photographs of the terrain, a forced-choice task was developed. Map readers were given map-terrain correspondence problems of two types. In one, the "map" task, they had to select the one of three direction lines (arrows) on the map that specified a view corresponding to a photograph of a scene projected on a large screen. In the other, the "scene" task, they had to select the one of three photographs that corresponded to the view that would be seen from a viewpoint marked on a map looking in the direction of an arrow emanating from that viewpoint. The geography sampled across these problems included more rugged hilly and mountainous terrain in Arizona and New Mexico in addition to the gently rolling hill areas of Minnesota.

For different groups of map readers, circular topographic maps were masked in differing amounts. One group had full or unmasked maps. For a second group, the "inner 1/3" masked condition, an area defined by one-third of the radius of the map directly surrounding the central station point was occluded. For a third group, the "outer 1/3" masked condition, the more distal third of the map's radius was masked leaving a central area corresponding to two-thirds of the radius unmasked. Finally, in the "outer 2/3" masked condition, the area corresponding to the distal two-thirds of the radius was masked leaving only a small central area directly surrounding the station point unmasked. As a consequence, the "inner 1/3" and "outer 1/3" conditions were equivalent in terms of the proportion of the radius masked, whereas the "outer 2/3" masked condition had the smallest amount of visible area (Figure 9.4).

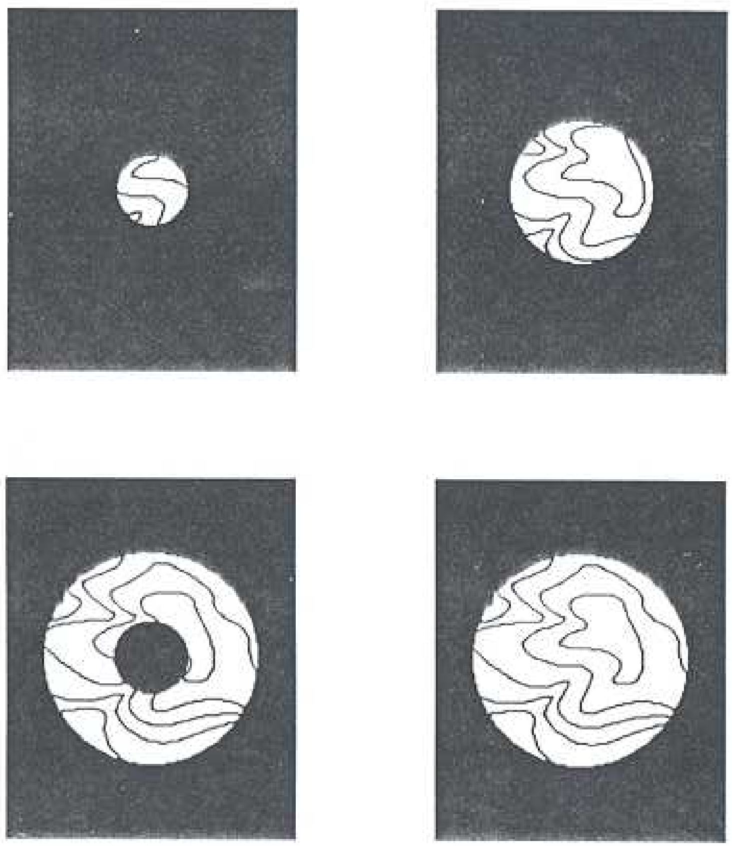

Figure 9.4. *Examples of the different levels of the masked condition used in the laboratory simulation task.*

This masked condition manipulation permits directly addressing the question of the amount of map information needed to solve the task, as well as whether particular areas were favored over others. If the amount of available map area is the only variable affecting performance, the full map condition should produce the best performance, the

performance under the "inner 1/3" masked condition would be the next best, followed by the "outer 1/3" masked condition. Finally, worst performance should occur in the "outer 2/3" masked condition because it has the most map area masked. Deviations from these predictions would point to the areas richest in information, and examination of those areas would suggest the specific features most important for problem solution.

Table 9.1 presents response accuracy on the forced-choice tasks for each location tested as a function of masked condition. On the average, accuracy significantly exceeded chance performance in all masked conditions, although not always at each location. Average performance in the full map and the outer 1/3 masked conditions was equivalent and significantly better than performance in the 1/3 inner and 2/3 outer masked conditions [$t(14) = 2.80$, $p<.01$)], which was also equivalent. This pattern of response accuracy suggests that masking areas of the maps impeded the solution of the correspondence problems, only when the areas were close to subjects' locations on the map or when large areas of the maps were masked.

Masking did not uniformly disrupt performance at each location in this manner, however. As Table 9.1 shows, a variety of patterns of results occurred at different locations. For example, accuracy on the O'Brien A map task, like the pattern of average results, was high in the full map and outer 1/3 conditions, but it was low in the inner 1/3 and outer 2/3 conditions. At the least, this suggests that the outer 1/3 radius area did not contain necessary information to solve the task. Accuracy on the New Mexico map task, however, was very poor in all but the inner 1/3 masked condition, suggesting that map information within the 1/3 radius area was possibly misleading to subjects. On the Afton map and O'Brien B scene tasks, accuracy was high in all conditions except the inner 1/3 masked condition, indicating the importance of information within the 1/3 radius area for success on these tasks. At still other locations, accuracy was either uniformly high across conditions (O'Brien A scene task) or uniformly mediocre (Afton scene task). These results suggest that the entire area of a map representing part of the visible landscape is not typically necessary for the solution of correspondence problems. They also suggest that any particular place on the map (such as near the station point) is not consistently necessary to solve the problems.

Table 9.1

Percent Correct on Forced-Choice Tasks for Each Location by Map Masked Condition

Testing Location and Task Type	Masked Condition[1] Full Map 	Inner 1/3 	Outer 1/3 	Outer 2/3 	Signif. of contrasts among masked conditions
O'Brien A Map Task	81	35	73	40	p<0.05
O'Brien B Map Task	56	60	33	40	
Arizona Map Task	81	47	47	20*	p<0.01
New Mexico Map Task	12	50*	13	7	p<0.01
Afton Map Task	69	18*	80	67	p<0.01
O'Brien A Scene Task	75	82*	67	73	
O'Brien B Scene Task	75	12	73	60	p<0.01
Arizona Scene Task	62	47	73	47	
New Mexico Scene Task	31	65*	47	47	
Afton Scene Task	50	41	53	53	
Mean	59	45	56	45	

*(Notes. Underlined percentages are significantly greater than chance, 33%, at $p < 0.05$. Doubly underlined percentage is significantly less than chance at $p < 0.05$. [1]N = 16 in the full map condition, N = 17 in the Inner 1/3 masked condition, and N = 15 in the Outer 1/3 and 2/3 masked conditions. * Masked conditions used in the protocol study.*

The variation in arbitrary masking by area done here is the crudest kind of manipulation to ascertain the important information. The eventual goal is to predict specifically the features and configurations that are critical for map readers. The results for individual scenes were examined to begin to get at this question. It is not simply the case that any distinguishing feature will be used if it is the only one available. Consider the O'Brien A map task, for example. The results for this

problem fit quite closely the overall pattern of mean results with the performance on the full map condition and on the outer 1/3 condition quite good and performance on the inner 1/3 masked and outer 2/3 masked quite poor (essentially at chance level). In this problem, a distant, large valley on the left could have served as a distinguishing feature in choosing the correct line. This was visible in the inner 1/3 masked condition but not in the outer 1/3 masked condition, but apparently it was not used because performance was so poor. A similar result was obtained in the Afton map task. In the Afton scene, the foreground contained a very distinctive pair of hills that were visible in all the conditions except the inner 1/3 masked. Although the midground was not very informative, there was one very distinctive wide valley far away on the right of the picture that was clearly visible on the map in all the conditions. Although the performance in the two outer masked conditions was as good or better than the full map condition (confirming the importance of the two hills in the foreground), the performance in the inner 1/3 condition was even below chance, suggesting that this far away valley was once again not used.

Assuming that subjects do have a bias toward reliance on foreground features in solving the map tasks, this tendency may lead them into trouble in some situations. The New Mexico map problem is a case in point. Subjects performed best when the inner 1/3 was masked, but when the outer 2/3 was masked, that is, when only the inner 1/3 was visible, the subjects performed at a level significantly below chance. Subjects' comments at the time of testing suggest that they misjudged the foreground slope, perceiving it to be flat or inclining down, even though it actually was slightly rising.

The laboratory simulation task is most valuable for the hints it provides as to the specific information affecting the problem solution. Verification of these hints can be obtained from the verbal protocols collected from the additional map readers given a subset of the original simulation problems.

9.2.4 Protocol Analysis and Laboratory Simulation of Localization

Three map tasks and two scene tasks were selected from the original set of laboratory simulation problems. (The particular tasks and their masked condition are marked with an asterisk in Table 9.1.) Ten additional map readers solved the problems twice, first in a masked condition and then in the unmasked full map condition. As in the field study, subjects were asked to think aloud while solving the problem, this time in the laboratory. The overall results indicate 44% successful solutions in the masked map condition and 64% successful solutions in the corresponding full map condition (see Table 9.1). The performance on the full map condition is significantly above the chance level of 33%, whereas performance under the masked condition does not differ significantly from chance. However, these values approximate the average performance values from original simulation tasks considering the full map, inner 1/3 masked, and outer 2/3 masked conditions from which this subset of problems was taken. Thus, the overall results from these protocol map readers represent a reasonable replication of the original simulation task.

The protocols were scored in the same manner as in the earlier field study. The main scoring category that did not apply in the same way with these laboratory protocols was hypothesis generation. With the laboratory task the hypotheses were in a sense given to the subjects by means of the three choices of map direction or scene. Their task was testing the choices.

We now consider for detailed analysis two of the problems used in this laboratory simulation: the New Mexico map task and the Afton map task. As mentioned earlier and evident from Table 9.1, the New Mexico map task is one in which performance is paradoxically better under the inner 1/3 masked condition than on the full map condition. The results of the present experiment replicate the earlier findings. Six of the 10 new participants chose the correct one of the three map arrows under the masked condition, but only 1 of the 10 under the full map condition. A different pattern was found with the Afton map task: Originally, task performance under the full map condition was better than under the inner 1/3 masked condition. Again the results replicate these additional map readers: 9 of 10 gave the correct answer under the full map condition, while all 10 gave the incorrect answer under the masked condition.

The protocols help account for these patterns. In the inner 1/3 masked condition of the New Mexico map task, the mask covers most of the terrain presented in the slide. This pushed the participants toward a disconfirmation strategy with which they were generally successful. One incorrect direction arrow had a prominent hill in the background that the participants surmised was in the background of the slide. This permitted rejection of that arrow. Then they were able to guess between the other two. For example:

> *1. Umm. The slide is ah, the slide is a fairly flat area, I can't ah.... The map doesn't look particularly flat. Ah, O.K. I guess I could look for, I guess I could look for things in the distance and see if.... It probably isn't (arrow) 2 because if it was in the direction of 2 there's some sort of hill in that direction. And since I'm not seeing a hill in the distance, it probably isn't there, although the trees could be obscuring it. Umm... I guess ah, let's see now. It's hard to say. I'm just going to eliminate 1 for the same reason I guess. Well... 7400 ft. fairly close there, whereas, in that direction (arrow 3) there's also a 7400 ft. point but it's a little further off, so that would be more likely obscured on 3. So 1 is the best guess I can make. (Correct, JS New Mexico, Map-masked condition)*

When they got to the full map condition, they chose the arrow that had the gentlest slope close to the station point. The terrain in the slide appeared to be almost flat, although in fact it was rising, thus accounting for their erroneous responses. Here, as in the field study, errors were caused by incorrectly assessing the terrain of the station point:

> *2. This one looks so flat it's hard to tell anything. I guess if anything those trees are maybe a little bit higher, ah.... It's really hard to tell ah, I guess maybe I can try and eliminate things, umm.... O.K. if I was looking in the direction of (arrow) 1, I would expect to be looking up, right in front of me. Well I don't know how steep a slope that is, but I guess it's a couple of contour lines. Umm, let's see, smaller lines are 20 ft. intervals so that would be up about 40 ft. in the space of 100 yds. It doesn't look like it's going up that much. I'm inclined to think that (arrow) 1 would be going up a little bit more than this one is. Ah, (arrow) number 2 there's generally sort of a... from the left to the right, it's going down. This seems so flat. Doesn't even seem like there's a slight downhill. Number 3 is I guess the flattest looking one. Ah...Hmm... I guess since number 3 looks the flattest looking and this looks so flat, I'm going to guess number 3. Cause there just doesn't seem to be... Number 2, it's too steep a hill going up. I'm sorry, number 1 (rejects arrow 1), and number 2 I'd expect to see a little more of a left to right, left to right downhill, some sort of angle. It seems so flat that I'll say number 3. That's a hard one. (Incorrect JS New Mexico Map-full map condition)*

The Afton Map task was one in which performance under the inner 1/3 masked condition was markedly deficient in comparison with the full map condition as evident in Table 9.1. In fact, the pattern of results for all the masked conditions would suggest that the crucial information for distinguishing among the arrows on the map was close to the station point. From examination of the map and scene, a nearby prominent hill would appear to be the primary critical distinguishing information. Two strategies were identified from the protocols: one in which more attention was paid to the map, and the other in which more attention was spent on the scene. When the center masked map was the focus of attention, the salient feature was a large river valley, and an attempt was made to see how this fit into the scene. Then subjects choose between two plausible direction arrows:

> *3. I am starting by looking at the map and am trying to determine the general shape of the terrain. I believe that this area here represents some high land and this is a river running in a quite deep gorge as indicated by the very close contour lines. This here represents I believe a valley... probably a stream valley which comes up between this high land some other high land on the other side. I am a little surprised looking at the picture because I expected that the land form, for instance, that this describes would appear steeper land than I, appears on the picture. If I was looking in this direction (arrow 3) I think I would be looking downhill and across this...I assume this is a river but maybe I...no I think it must be... and then on to some banks on the other side. If I was looking in this direction (arrow 2), I am looking constantly downhill. And though I don't what is out here, it doesn't appear to be what I am looking there. This (arrow 1) shows that it is slightly downhill and then over perhaps a high point there . Which I think is probably that. I choose direction 1. (Incorrect JD Afton Map task—-masked condition)*

When the scene was the focus of attention in this masked map condition, subjects seized on the salient feature—the hill—and ignored the distance scale and incorrectly selected the direction arrow that showed a hill:

> *4. I guess I'm looking up a hill. From the map I was gonna guess that I was gonna be looking down on pretty much everything. There's looks like two trails going though. I don't have those on the map. I don't, looking for a river but I don't see that in there which should make me eliminate choice 3. Looking to see if there is another hill on here... It appears that number, ah, choice number 1 goes across a low area and then back up a hill to a higher point. And that would be the direction I would choose of the three geographic areas. Number 1. (Incorrect TH Afton Map task—-masked condition)*

In the full map condition of the Afton Map task, all subjects focused on the hill feature and an attribute, orientation of the hill, or the distance of the hill from the station point. This readily yielded the correct answer:

> *5. O.K. This is much easier. O.K. now for number 3 to be correct I want to see a big re-entrant, two big valleys right ahead of me and leading into a lake. I don't see that at all. So, 3 doesn't make any sense at all. Now (arrow) 1. I would see a slight downhill and then a smaller hill in front of me before it drops off into a big valley. There is no indication of a big hill from what I am seeing on the slide to indicate that. So that doesn't make sense. Number 2 does have...ummm... this hill here, this big knoll could easily be that big hill on the map on the slide. And it also looks like you could see some of the things that we're seeing in the background—- the place where the road goes and comes in a lower spot and goes around the hill. That could definitely be around here. And you probably can't see anything off here because it is just too far. So now I would say that it is number 2. (Correct PD Afton Map task—-full map condition)*

The protocols help explain the particular patterns of results obtained for the different problems. In addition, they also illustrate a number of features that frequently occur in the problem solving of subjects in the field as well as in the laboratory simulation. One aspect was a tendency to focus on particular salient features. This occurred with the large river valley in response 3 above and with the hill in response 4 and 5. Even when the focus was on a salient feature, a second aspect of the problem solving involved attempting to find more reliable configurations or combinations of features as what happened with the attributes of the river valley in response 3 and the observation of the low area and hill going to a higher point in response 4. As mentioned before, a common source of error was incorrect registration of the area very close to the viewpoint which occurred in response 2. It was also the case that metric information was often ignored, which led to error as in response 4. However, often ordinal information about the relative heights of features or magnitude of distances was sufficient to decide between hypotheses. Finally, in testing hypotheses, especially in the laboratory simulation, subjects realized that detection of one clear difference between a hypothesized position and what was visible in the terrain was sufficient to rule out a hypothesis. This was exemplified by the disconfirmation strategy in response 1. However, acceptance of an hypothesis usually requires more converging evidence (Smith, Heinrichs, & Pick, 1991), which is one of the results of attending to configurations.

9.3 Conclusion

This chapter described how experienced topographic map readers approach a particularly difficult form of localization task: the drop-off problem. It is possible to describe the performance of these map readers in terms of the information they attend to and the process strategies that they use. The specific features attended to depend on the topography of the particular problems. However, the commonly found ambiguity of features is generally resolved by noting qualitative characteristics or attributes of individual features and attending to relations among multiple features.

It is noteworthy that feature attributes of the topography are generally described with qualitative and ordinal terms instead of metric values. Metric estimations of distance from the viewer to features and distance among features as well as metric judgments of the steepness of hills and valleys is potentially very useful. The maps contain considerable metric information that could increase the precision of map terrain matches. Some relevant psychophysical research, for example, by DeSilva (1985) and Haber (1985), in outdoor environments, suggested that sensitivity to distance across terrain is quite high. Haber, in particular, found that subjects were very accurate in magnitude estimations of distances between markers distributed around an open field, although there was some underestimation of distances along the line of sight (radial distance) relative to distances across the line of sight (lateral distance). However, in almost all psychophysical studies of distance in outdoor terrain, the terrain has been quite homogeneous and flat. In contrast, data have been collected in connection with the present map-reading research involving psychophysical judgments of distance between locations across nonhomogeneous rolling terrain similar to that of the current field study. These judgments turned out to be rather inaccurate and unreliable. There have been almost no psychophysical studies of the steepness of slope in outdoor terrain. Such data collected in connection with the present study have also proved inaccurate and unreliable. Thus, it would appear to be the case that, at least without

special training, people would not ordinarily be sensitive to the metric characteristics of the topographic features they are observing.

Information processes such as reconnaissance, feature matching, and so on. were identified from the protocols of the map readers solving the drop-off problem. Analysis of the use of these processes resulted in descriptions of several process strategies employed by the successful map readers. They include general reconnaissance focusing on the terrain, use of the relations among features to assemble configurations, attention to local terrain features around the viewpoint, and generation of multiple hypotheses about the location of the viewpoint. Testing hypotheses using a disconfirmation strategy is also commonly observed, as is changing one's position in order to gain additional information about the nature of one's own viewpoint.

Of particular interest is the absence in the protocols of any mention of a holistic global visualization strategy. In informal interviews some topographic map readers reported a process of global visualization of the terrain when looking at topographic map. There is practically no evidence for this in any of the protocols collected here. Rather, the processes reported were attention to features and feature or configuration matching. It is possible that the localization task biases the map readers in this direction, and that a task of studying a map for a more general purpose such as getting a feel for the land would lead to the global visualization.

Also of interest is the fact that the protocols provide practically no evidence for any quantitative geometric reasoning, such as triangulation processes, or even qualitative geometric reasoning, such as deciding which side of a line between a pair of features one is on. A conjunction of several such "landmark-pair-boundary" decisions, if appropriately chosen, can tightly constrain one's own position as shown by Levitt, Lawton, Chelberg, Koitzsch, and Dye (1988). It is, of course, possible or even probable that a crude form of triangulation is being carried out semi-automatically and does not appear on the protocols, or that qualitative decisions are being made about landmark-pair-boundaries. Levitt, Lawton, Chelberg, and Nelson (1987) and Sutherland (1992) showed that quantitative triangulation processes, even with only a single pair of landmarks, logically constrains one's position to a circle going through the two landmarks. Thus, if two landmarks are identified in the terrain, map readers should be able to locate themselves on a map at a point that subtends the same angle with the map landmarks as the visual angle subtending the terrain landmarks. There is a partial circle of such points whose circumference goes through the landmarks. This very tight constraint depends on accurate appreciation of the visual angles subtended by landmarks. Preliminary observations suggest that untrained observers have only the crudest sensitivity to the size of visual angles subtended by landmarks.

The material presented in this chapter may be useful in training both the qualitative and quantitative aspects of topographic map reading. On the qualitative side, the types of processes and strategies identified here could be incorporated into training programs. On the quantitative side, procedures could also be developed to improve distance and slope estimation over irregular terrain. Similar, training methods for increasing accuracy of estimation of visual angle should not be difficult to devise and evaluate.

The drop-off localization problem is one of the more difficult uses of topographic maps. A more common use of topographic maps is for updating when one's initial position is more or less precisely known. It will be important to determine what aspects of the processes and strategies identified here will also be useful for the updating problem. The identification and matching of features will almost certainly maintain a central role. Along with terrain reconnaissance, it is very likely that accurate registration of one's own locomotion will be important. This is an aspect of navigation in what was referred to in the introduction as small-scale spaces. Presumably keeping track of one's own movement depends partially on the continuous optical flow stimulation that specifies how far, how fast, and in what direction one is going. This information must be remembered and periodically integrated with map information. Thus, the updating localization problem is a way of relating navigation in large- and small-scale spaces in the context of topographic map reading.

Acknowledgments

The research reported in this chapter was supported by Grant AFOSR-88-0187 from the Air Force Office of Scientific Research and by Grant IRI-8901888, a joint NSF-DARPA Image Understanding initiative, to the University of Minnesota.

The authors are indebted to Bonnie Bennett and Elizabeth Stuck for critical evaluation of an earlier draft of the present chapter and to Karl Rosengren for considerable preliminary observations.

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