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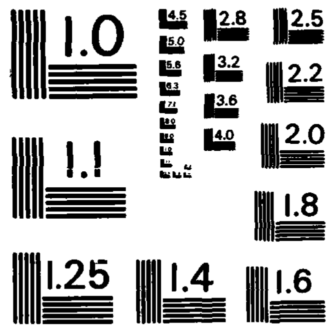

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SPATIAL REPRESENTATIONS OF TAXI DRIVERS

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Carnegie-Mellon University

28 September 1982

Technical Report No. 6

This research was sponsored by the Personnel and Training Research Programs, Psychological Sciences Division, Office of Naval Research, under Contract No. N00014-79-C-0215. Contract Authority Identification Number, NR 157-430.

This report is issued by the Learning Research and Development Center, supported in part by funds from the National Institute of Education (NIE), United States Department of Education.

Unclassified

SECURITY CLASSIFICATION OF THIS PAGE (When Data Entered)

REPORT DOCUMENTATION PAGE		READ INSTRUCTIONS BEFORE COMPLETING FORM
1. REPORT NUMBER UPITT/LRDC/ONR/KBC-6	2. GOVT ACCESSION NO. AD-A121187	3. RECIPIENT'S CATALOG NUMBER
4. TITLE (and Subtitle) SPATIAL REPRESENTATIONS OF TAXI DRIVERS		5. TYPE OF REPORT & PERIOD COVERED Technical Report
		6. PERFORMING ORG. REPORT NUMBER
7. AUTHOR(s) William G. Chase, Carnegie-Mellon University		8. CONTRACT OR GRANT NUMBER(s) N00014-79-C-0215
9. PERFORMING ORGANIZATION NAME AND ADDRESS Learning Research and Development Center University of Pittsburgh Pittsburgh, PA 15260		10. PROGRAM ELEMENT, PROJECT, TASK AREA & WORK UNIT NUMBERS NR 157-430/12-19-80 (458)
11. CONTROLLING OFFICE NAME AND ADDRESS Personnel Training Research Programs Office of Naval Research (Code 458) Arlington, VA 22217		12. REPORT DATE 28 September 1982
		13. NUMBER OF PAGES 31
14. MONITORING AGENCY NAME & ADDRESS(if different from Controlling Office)		15. SECURITY CLASS. (of this report) Unclassified
		15a. DECLASSIFICATION/DOWNGRADING SCHEDULE

16. DISTRIBUTION STATEMENT (of this Report)

Approved for public release; distribution unlimited

17. DISTRIBUTION STATEMENT (of the abstract entered in Block 20, if different from Report)

18. SUPPLEMENTARY NOTES This research was also supported by the Learning Research and Development Center, supported in part by funds from the National Institute of Education (NIE), United States Department of Health, Education, and Welfare. To appear in D.R. Rogers and J.A. Sloboda (Eds.), Acquisition of symbolic skills. New York: Plenum Press, in preparation.

19. KEY WORDS (Continue on reverse side if necessary and identify by block number)

Spatial skill	Taxi drivers
Spatial representation	Expert-novice differences
Cognitive Maps	Navigation in a city
Hierarchical representation	

20. ABSTRACT (Continue on reverse side if necessary and identify by block number)

One of the central questions about cognitive skills is how the necessary knowledge is organized. In the case of spatial skills, there are at least three theoretical viewpoints on the nature of internal representation of large-scale environments. The cognitive mapping approach suggests that this representation is very much like a "map in the head." The more recent geographical approach is still very map-like, but places more emphasis on an abstracted representation based on psychologically salient features and their relationships. The cognitive science approach, on the other hand, recognizes that the representa-

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S/N 0102-LF-014-6601

Unclassified

SECURITY CLASSIFICATION OF THIS PAGE (When Data Entered) tion need not be map-like at all, and emphasizes that the processes which operate on it are an integral part of spatial skill. This study of expert-novice differences among taxi drivers, involving both laboratory tasks and actual driving in the field, has confirmed the validity of the cognitive science approach. Tasks in which a map-like representation would be of value, such as map drawing and placing locations on outline maps, showed no skill differences at all. The representation which did emerge is a hierarchy based upon geographical areas. At the top level are global features (Pittsburgh's three rivers), then general areas (north side, east end), then neighborhoods and, finally, locations within neighborhoods. It may be that this representation is impotant in planning a route, because a general path between the areas of the hierarchy in which the current position and the destination are located can be retrieved first and elaborated as needed. One important component of this elaboration process, which emerged during the study, is the triggering of route knowledge by visual scenes or icons as they are encountered along the way. Both experts and novices tended to notice ways to improve routes in the field as compared to the routes they predicted they would take. In addition, experts were significantly better at recognizing photographs of various street intersections than were novices, particularly for the less well-known areas. Not suprisingly, experts also exhibited superior knowledge of neighborhoods and streets.

ABSTRACT

One of the central questions about cognitive skills is how the necessary knowledge is organized. In the case of spatial skills, there are at least three theoretical viewpoints on the nature of internal representation of large-scale environments. The cognitive mapping approach suggests that this representation is very much like a "map in the head." The more recent geographical approach is still very map-like, but places more emphasis on an abstracted representation based on psychologically salient features and their relationships. The cognitive science approach, on the other hand, recognizes that the representation need not be map-like at all, and emphasizes that the processes which operate on it are an integral part of spatial skill. This study of expert-novice differences among taxi drivers, involving both laboratory tasks and actual driving in the field, has confirmed the validity of the cognitive science approach. Tasks in which a map-like representation would be of value, such as map drawing and placing locations on outline maps, showed no skill differences at all. The representation which did emerge is a hierarchy based upon geographical areas. At the top level are global features (Pittsburgh's three rivers), then general areas (north side, east end), then neighborhoods and, finally, locations within neighborhoods. It may be that this representation is important in planning a route, because a general path between the areas of the hierarchy in which the current position and the destination are located can be retrieved first and elaborated as needed. One important component of this elaboration process, which emerged during the study, is the triggering of route knowledge by visual scenes or icons as they are

encountered along the way. Both experts and novices tended to notice ways to improve routes in the field as compared to the routes they predicted they would take. In addition, experts were significantly better at recognizing photographs of various street intersections than were novices, particularly for the less well-known areas. Not surprisingly, experts also exhibited superior knowledge of neighborhoods and streets.

The issue that guides the present research program concerns the representation of large-scale environments, environments that are too large to be perceived from a single vantage point. In particular, this paper is concerned with the effects of experience on the representation of a large urban environment, and experience is manipulated by the use of expert and novice taxi drivers.

THEORIES OF REPRESENTATION

There are at least three distinct theoretical viewpoints on the nature of the internal representation of large-scale environments: (a) the cognitive mapping approach, (b) the geographical approach, and (c) the cognitive science approach. Each of these is briefly considered in turn.

The Cognitive Mapping Approach

The cognitive mapping, or "map-in-the-head" approach originated with Tolman's (1948) seminal paper in which he discredited the idea that animals (and people) learn to navigate around their environment solely by means of stimulus-response associations between cues in the environment and motor responses. For example, he conclusively demonstrated that rats can navigate a maze by means of an external cue or landmark because, when given a chance, they will head directly toward the goal box rather than follow the route they learned through the maze. Tolman concluded that rats (and people) navigate by means of a "cognitive map" of their environment, a 2-dimensional internal representation with topological and perhaps even geometric properties of external maps.

Another influential map-in-the-head theory is that of Piaget (Piaget and Inhelder, 1956), who suggests that as children's cognitive processes develop, there are also fundamental changes in the nature of their spatial representations. Before children enter Concrete Operations, at around 5 or 6 years of age, their spatial knowledge is organized primarily as routes. Thus, they can navigate only over known paths and are generally incapable of taking shortcuts or navigating off of known routes. Near the beginning of the Concrete Operations Stage, however, children acquire topological properties of their environment and thus are able to navigate with respect to landmarks as well as routes.

The Russian psychologist Shemakin (1962) has made a similar distinction in the development of children's spatial representations from route knowledge to survey knowledge. Shemakin suggested that the most notable shift in children's spatial knowledge occurs when they are able to leave known routes, know the bearings of landmarks, and in general navigate toward known locations without having travelled that route before.

Finally, according to Piaget, there is an additional improvement in spatial representation toward the end of the Concrete Operations Stage at around 11 or 12 years of age, when children acquire adult-like Euclidean representations, in which metric properties of the environment are also included as part of the representation. Thus, in addition to routes, landmarks, and topological properties, fairly accurate metric properties of distances and bearings are also included in the representation and more importantly, the child now has the adult-like ability to navigate with respect to some abstract frame of reference, such as the cardinal directions.

Finally, some people have suggested that adults, when they learn a new environment, proceed through these same Piagetian Stages in their representations (Appleyard, 1969).

The Geographical Approach

Lynch (1960), in his classic book The Image of the City, has proposed a slightly different version of a map-in-the-head theory. Lynch conducted extensive interviews and field studies in an attempt to determine those parts of the city that are most imaginable and memorable and otherwise salient in peoples' minds. His idea was to generate a map of the city with these psychologically salient parts as the basic elements -- a kind of mental geography, if you will. Lynch's impressive analysis of the relative imageability of the cities of Boston, Jersey City and Los Angeles has had a tremendous impact on geographers, urbanologists, and city planners, and it has served as a model for the psychological analysis of the city.

Lynch's theory is based on five abstract elements: paths, nodes, edges, landmarks, and regions. Paths, landmarks and regions are self-explanatory. An edge is a boundary between regions, either real, such as a river or railroad, or imaginal, such as a street. A node is a focal point, such as a city square or railroad station, where some important activity takes place. According to Lynch, the psychological representation of the city is an abstracted 2-dimensional representation comprised of these five types of basic elements. Note how Lynch's theory differs from the earlier theories in that abstract elements are stressed. This geographic approach has been criticized on the grounds that it assumes too much of a geographic 2-dimensional representation (Chase and Chi, 1981; Downs and Stea, 1973).

The Cognitive Science Approach

The cognitive science approach differs from the earlier theories mainly in that it does not assume a map metaphor, and it places an emphasis on process and representation together as integral components. Another characteristic of the cognitive science approach is its emphasis on hierarchical representations. A side issue that is often associated with the cognitive science approach is the analog versus propositional debate, but for the purpose of the present discussion, we will remain neutral on that point.

The best cognitive science theory of large-scale environment is Kuipers' (1978) TOUR model. In this model, the environment is represented as a propositional network of relationships, and the basic elements of the network are very Lynch-like. Routes, for example, are propositional structures that contain a series of locations along a path, the path's bearing, and other information that tells how to get from one place to the next along the route. Regions are built up out of collection of routes, regions can be nested hierarchically within larger regions, and so on.

Inferencing rules are also included so that if a path is incomplete, some simple inferences can be made in order to figure out how to get to a destination.

The learning mechanism is very simple. A you-are-here pointer is moved about through the representation, corresponding to movement within the environment, and new locations and routes are simply added to the existing propositional network as they are encountered in the environment. In this way, a mental model of the environment is constructed as a person moves through the environment making associations, and this knowledge is stored as a large propositional network of routes, landmarks, regions and the like.

On several grounds, the TOUR model is an incomplete theory. The contents of working memory are stored as a list of features associated with the you-are-here pointer, and there is no provision for perspective-taking and imagining a schematic map in the mind's eye. The inferencing rules are still not powerful enough to solve a simple geometric problem that people do all the time, namely, given the direction from A to B and the direction from A to C, people can complete the triangle and figure out the direction from B to C.

In an earlier review article Chase and Chi (1981) drew a distinction between inference rules and automatic procedures. In contrast to the above kind of geometric inferences, automatic procedures are those that operate when travelling well-known routes. At choice points along a well-known route, perceptual features from the environment automatically retrieve the appropriate choice of route from the long-term memory knowledge base. This type of perceptual or "Iconic" knowledge seems to be rapidly and automatically retrieved without interfering with ongoing cognitive processing. The present paper will stress the acquisition of this type of knowledge with expertise.

THE PAILHOUS STUDY

The best study of taxi drivers was conducted over ten years ago by Pailhous (1969) on expert and novice taxi drivers of Paris. In his theorizing, Pailhous was greatly influenced by Piaget. Pailhous proposed that taxi drivers represent the streets of Paris as a 2-tiered hierarchy: a base and a secondary system. The base network consists of the major arteries of Paris, the frequently used thoroughfares selected to minimize travel distance between regions. Pailhous operationally defined the base network as those streets that were highlighted on the Paris map, about 10% of the total number of streets. The secondary street system was defined as the other 90% of the streets. The base network evolved, according to Piaget, in order to cover the city with a grid network of major streets and minimize the amount of travel in the secondary network.

Pailhous found that both experts (average 10 years experience) and novices (less than 8 months experience) used the base network. When drivers had to choose between a long and a short base route, the experts almost always selected the short base route whereas the novices often selected the longer base route. When Pailhous presented drivers with a detour problem, he found that over half the experts used the secondary network to get around the barrier in an optimum way, whereas almost all the novices selected a longer base network route to get around the barrier.

Pailhous suggested that the basic strategy of taxi drivers is to maximize the amount of travel on the secondary network. Thus, drivers attempt to get to the base networks as quickly as possible and stay on the base network as long as possible. Experts, however, modify this basic strategy in order to utilize the secondary network to shorten the route by staying longer on the secondary network than the novice and leaving the base network sooner than the novice. Pailhous further speculated that drivers have an accurate, metric representation of the base network and an approximate topological representation of the secondary network. Further, drivers use a "bird's-eye" image of the base network for navigating but they have a ground-view image of the secondary network and they navigate with respect to landmarks in the secondary network.

ANALYSIS OF PITTSBURGH TAXI DRIVERS

In the present study, a wide variety of tasks was run on Pittsburgh taxi drivers. The basic sample consisted of 5 experts with 10 or more years of experience (average = 18.2 years), 5 novice drivers with less than one year of experience (average = .7 years), and 5 intermediate drivers with 1 to 10 years of experience (average = 5.7 years), although in some cases more than 5 subjects per group were run. Also a control group was included that consisted of 9 non-taxi drivers with several years driving experience (average = 6.5 years).

Each driver was given several hours of extensive laboratory testing, followed by a 2 or 3 hour field test. The laboratory tests included questionnaires; map drawing; naming of streets; landmarks and neighborhoods; distance estimation; picture recognition; and a variety of route generation tasks. The field test included 19 route generation problems: 10 routes that were also given in the laboratory and 9 new problems.

The results of this extensive study will be reported in detail elsewhere. In the present paper, the major findings are summarized and discussed in terms of their implication for the nature of the underlying representation. The results are presented in three sections: (a) cognitive mapping tasks, (b) defining the base network, and (c) route-finding tasks.

Cognitive Mapping Tasks

In none of these cognitive mapping tasks were there any skill differences. Of particular interest in these tasks, outside of the fact that no skill differences emerged, is evidence for the structural and hierarchical nature of the representation. Included among the cognitive mapping tasks were: (a) drawing a map of the important parts of Pittsburgh, (b) drawing a map of several selected quadrilateral street intersections, (c) naming as many neighborhoods as possible, (d) placing 20 of the most well-known neighborhoods on an outline map of Pittsburgh, and (e) making distance estimates between various locations.

Drawing a map of Pittsburgh. In this task, subjects were asked to draw a map of the important parts of Pittsburgh, and their map drawing was video taped. As is the case with many reproduction tasks, the output is structured. Adjacent neighborhoods, for example, tend to be drawn together and the chunk structures (related streets, groups of neighborhoods, etc.) are separated by pauses. Although none of these results are quantified here, these structures are obvious from an inspection of the protocols.

Another interesting analysis of the protocols concerns what is drawn first. Over two thirds of the subjects (18 of 26) started their drawings with the river system. Other types of first items included streets (3/26) and neighborhoods (3/26). It is suggested that people start their drawings with some more global features -- in this case the river system of Pittsburgh -- that can serve as a reference in order to place the more local features (neighborhoods).

Drawing streets. Four sets of quadrilateral street groups were selected because of their shapes. None of them was a standard rectangular shape and few of the streets met a right angles. For each shape, the subject was told the four streets and asked to draw a map of the four streets as accurately as he could. The idea was to see if experts with many years of driving experience would draw the shapes correctly.

The drawings were rated by two raters on a 5-point scale: (1) completely wrong, (2) containing topological errors, such as the incorrect placement of streets, (3) topologically correct, such that all the streets were in their correct relative locations, (4) topologically correct with additional metric information, such as a proper angle of intersection or elongated shape, and (5) topologically correct and metric features correct, i.e., the correct shape. There was virtually perfect agreement between the two raters.

Table 1 shows the frequency of each rating as a function of skill level. There are no skill differences, and only about 5% of the maps received a 5 rating. The mode was 3, and the next highest frequency was a 2, which means that a majority of the time, drivers simply drew the streets in a square shape, getting the relative location of streets correct (3) or else making an error (2).

Insert Table 1 about here

If taxi drivers have access to a bird's-eye metric view of the city, they certainly can not draw it.

Recalling neighborhoods. Subjects were asked to write down as many neighborhoods of Pittsburgh as they could remember, and their writing was video taped and pauses between neighborhoods were recorded. In general, subjects tended to recall neighborhoods together that lie in the same larger geographic area (North Side, South Side, East End), and that are usually adjacent to each other on the map. The average pause time between neighborhoods was about 10 seconds for pairs of neighborhoods within the same region and about 18 seconds for pairs of neighborhoods that lie in different regions ($p < .001$). Thus, it appears that they are retrieved from memory in chunks that contain local clusters of neighborhoods.

Placing neighborhoods on a map. Subjects were asked to place the 20 most well-known neighborhoods on an outline map of Pittsburgh. Figure 1 shows the average placement of each neighborhood for the 15 taxi drivers together (solid lines) and the 9 control subjects together (dashed lines). The tail of the arrow is where the center of the neighborhood is located and the head of the arrow is the average placement.

Insert Fig. 1 about here

The striking feature of these data is the pronounced distortion of placements toward the river junction, which is the most prominent landmark in the area. It is not clear from these data whether the reference point is the river junction or the Downtown area. Nevertheless, these data are a very clear instance of a general phenomenon: memory for location tends to be distorted toward a reference point (Nelson and Chaiklin, 1980). These data are interpreted as evidence of hierarchical organization: Neighborhoods are stored in memory with respect to a prominent global feature (three rivers) or perhaps the central Downtown neighborhood.

<u>Distance estimations</u>. Subjects were given pairs of well-known locations in the Pittsburgh area and asked to judge the direct distance ("as the crow flies") between them. Distances varied between .75 and 1.69 miles, and the locations were either within a neighborhood or in different neighborhoods. Further, locations between neighborhoods were separated either by a physical barrier, such as a river or railroad track, or no barrier.

Insert Fig. 2 about here

The data are shown in Fig. 2 for each skill level and each type of distance judgment. There were no skill differences, as everyone tended to overestimate distances. Distances were overestimated only about 20% for locations within the same neighborhood. However, distances were greatly overestimated for locations separated by a neighborhood boundary. Further, neighborhoods separated by a physical barrier were overestimated slightly more. This result is another instance of a generaly phenomenon: Distance estimates across hierarchical boundaries are greatly over-estimated (Stevens, 1976).

To summarize the results so far, it appears that drivers have a hierarchical organization of locations within neighborhoods, and neighborhoods within larger geographic regions. The larger regions are associated with global features of the environment (the 3 rivers). Experts do not have a map in the head that they use to navigate, or at least, any map imagery that they may have is not the basis of their skill. In fact, in agreement with Pailhous (1969), our experts claim that they hardly ever use maps.

Defining the Base Network

In this part of the study, an attempt was made to generate a subject-defined base network. Each subject was asked to "List all the main streets that you know of in Pittsburgh." Each subject was also asked to name as many streets as he could think of in various selected neighborhoods of Pittsburgh, including the Downtown area, the neighborhood in which the cab company is based, the driver's own home neighborhood, and four lesser-known neighborhoods.

The first difficulty was in defining a base network. If the base network is defined as those streets named by more than 25% of the drivers as major streets, then there was only about a 40% overlap between this subject-defined network and Pailhous (1969) definition, which is the set of highlighted streets on the standard Rand-McNally map of Pittsburgh. Second, this response-defined set constitutes only about 2% of the total street system of Pittsburgh, far less than the 10% defined by Pailhous for Paris streets. Nevertheless, for the rest of the study, the base network is defined as this response-defined measure: streets named by more than 25% of the drivers.

The first question of interest is whether experts can name more streets than the novices. Table 2 shows that in general there is a relationship between skill level and number of streets named within neighborhoods. The relationship is weakest for the Downtown area, which is presumably familiar to all drivers and the relationship is strongest for the four unfamiliar neighborhoods. Although the absolute number of streets recalled is less for the four unfamiliar neighborhoods, the rank order (Experts, Intermediates, Novices, Controls) and the statistical reliability ($p < .001$) is strongest for these neighborhoods.

Insert Tables 2 and 3 about here

A similar result was obtained when we asked drivers to name, or otherwise indicate that they recognized pictures of intersections. Table 3 shows the percentage of pictures recognized as a function of skill level for three types of intersections and the Parkway, which is the major interstate highway system serving the Pittsburgh area. There are two things of interest here. First, skill differences tend to show up on the secondary intersections rather than the base intersections. As with the naming of streets, expertise tends to show up on the less well-known streets. Second, virtually everyone recognized pictures of the Parkway although hardly anyone named it when asked to name the major street system. When asked about this discrepancy, most people said that the Parkway never occurred to them when they were generating the major streets. This is the only good evidence in this study that supports Pailhous' contention that street systems are hierarchically organized.

Generating Routes

It is in the ability to generate routes that expertise really emerges. Taxi drivers were given 21 route-finding problems in the laboratory, followed several weeks later by a field study in which 19 problems were given, 10 repeat problems from the laboratory and 9 new problems. Drivers were given an origin and a destination in the laboratory and they were asked to describe the shortest route from the origin to the destination, disregarding traffic, and further, if there was a longer but faster route, to describe it. If, in the judgment of the experimenter, it was possible to follow the driver's instructions, even though some of the actual streets weren't named, the route was scored correctly.

All the origins and destinations were on the response-defined base network, but the routes were of several different types. Eight problems involved a fairly straightforward route on the base network and four problems involved two alternative base network routes, a long and a short. Four more problems were best solved by generating a route through the secondary network. There were several other types of problems that will not be discussed in this short paper.

The basic data of interest are summarized in Tables 4 and 5. Table 4 contains the data from the eight problems with a base network solution and the four problems with a long and a short base network solution. Table 5 contains the data from the four problems with a solution involving the secondary network. The routes of Table 4 were divided into several categories: (1) improved route using the secondary network, (2) shortest base route, (3) longer base route, and (4) lacked knowledge, either because the origin and/or destination were unknown, streets were missing, or the route was disconnected. The routes of Table 5 were divided into two categories: (1) a short route through the secondary network, or (2) a long route on the base network.

Insert Tables 4 and 5 about here

Comparing the experts and novices on the base network (Table 4), it appears that the expert is more likely to use the short base route or generate an <u>improved</u> route through the secondary network, whereas the novice is likely to either take a longer route or else not have sufficient knowledge to generate a solution. Skill effects are much more prominent, however, in problems with a solution through the secondary network (Table 5). Experts were able to generate a short route through the secondary network 85% of the time, whereas novices generated a longer route on the base network 70% of the time. As with the naming and recognition of streets described in the previous section, expertise manifests itself particularly on the lesser travelled streets.

Finally, the data from the field study are summarized in Table 6, which shows the percentage of routes from the laboratory study that were the same, improved or longer in the field. The results from the field study can be summarized as follows. As in the laboratory study, experts were better than novices. Experts were more likely than novices to take the routes in the field that they said they would in the laboratory. Regardless of skill level, a substantial proportion (25%) of routes were <u>improved</u> in the field.

Insert Table 6 about here

This last result seems particularly important because it suggests that there is an additional source of knowledge in the field that is sometimes not available in the laboratory. The phenomenon seems fairly straightforward. It was often noticed that as drivers set off on routes that were apparently the same as the one generated in the laboratory, they would notice a shorter route along the way that had not occurred to them in the laboratory. This additional source of knowledge can be characterized as perceptual or iconic knowledge that triggers known routes associated with these visual cues. It is suggested that this perceptual information, embedded in the knowledge base or automatic procedures, is an important component underlying navigational skill of taxi drivers.

CONCLUSIONS

Not surprisingly, expertise in taxi driving tended to emerge when drivers were asked to find routes, particularly routes through the lesser-known streets. The expert's ability to name and recognize more of these lesser-known streets than the novice is additional evidence that expertise involves a larger knowledge base acquired through years of practice. The concept of a 2-tiered hierarchy of base and secondary street systems did not receive much support in the present study. Also, there was no support in the present study for Pailhous' (1969) contention that experts, as well as novices, use the base network. Rather, it seems that the expert uses the secondary network whenever he can. There are two alternative theoretical interpretations, either of which is compatible with the present data: either (1) there is no hierarchical division of the street system (with the exception of the Parkway in Pittsburgh) and streets vary on a continuum of familiarity, or (2) the preferred street system, or base network, expands with expertise.

The absence of any skill effects in the various cognitive mapping tasks lends little support to the idea that taxi drivers navigate by means of a map in the head. The results do, however, suggest that the large-scale representation of locations is hierarchically organized such that locations are nested within neighborhoods, neighborhoods are nested within large regions and larger regions are located with respect to more global features. The importance of neighborhoods in the present study contrasts with the apparent disregard of neighborhoods of the Paris taxi drivers studied by Pailhous (1969).

Finally, it is suggested that the hierarchical organization of neighborhoods is important in terms of economy of storage, and that this hierarchy serves as a integral part of planning a route. Hierarchical storage means that one need only store relative locations of places within a neighborhood. To retrieve the relative locations across a hierarchical boundary, one need only retrieve the relative location of the two neighborhoods and the relative location of each place with respect to its own neighborhood. To get from a location in one neighborhood to another location in a different neighborhood, it is suggested that the driver first finds a route that connects the two neighborhoods, and then the rest of the route is either subsequently generated or it is filled in as the driver goes along. It is this "filling-in" process that involves automatic procedures. The driver can continue following a global plan until cues from the environment are encountered that trigger specific routes at choice points along a route. Some such process as this, it is suggested, underlies skill differences, as the number of these automatic procedures increases with experience.

Acknowledgments

I wish to thank Richard Eastman for his invaluable assistance at every stage of the research, and I thank Michelene Chi for her conceptual help in all phases of the research. Alex Rudnicky very generously provided translation of the Pailhous article. Financial support from the Office of Naval Research is gratefully acknowledged.

Figure Captions

1. Average placement of the 20 most well-known neighborhoods of Pittsburgh by 15 taxi drivers (solid lines) and 9 control subjects (dashed lines). The head of the arrow is the average placement and the tail of the arrow is the center of the neighborhood. Subjects made their placements on an outline map containing the 3 rivers and the city limits.

2. Average error (miles) for Experts, Intermediates, Novices and Controls for three types of distances estimates: Within neighborhoods, between neighborhoods, and between neighborhoods separated by a physical barrier.

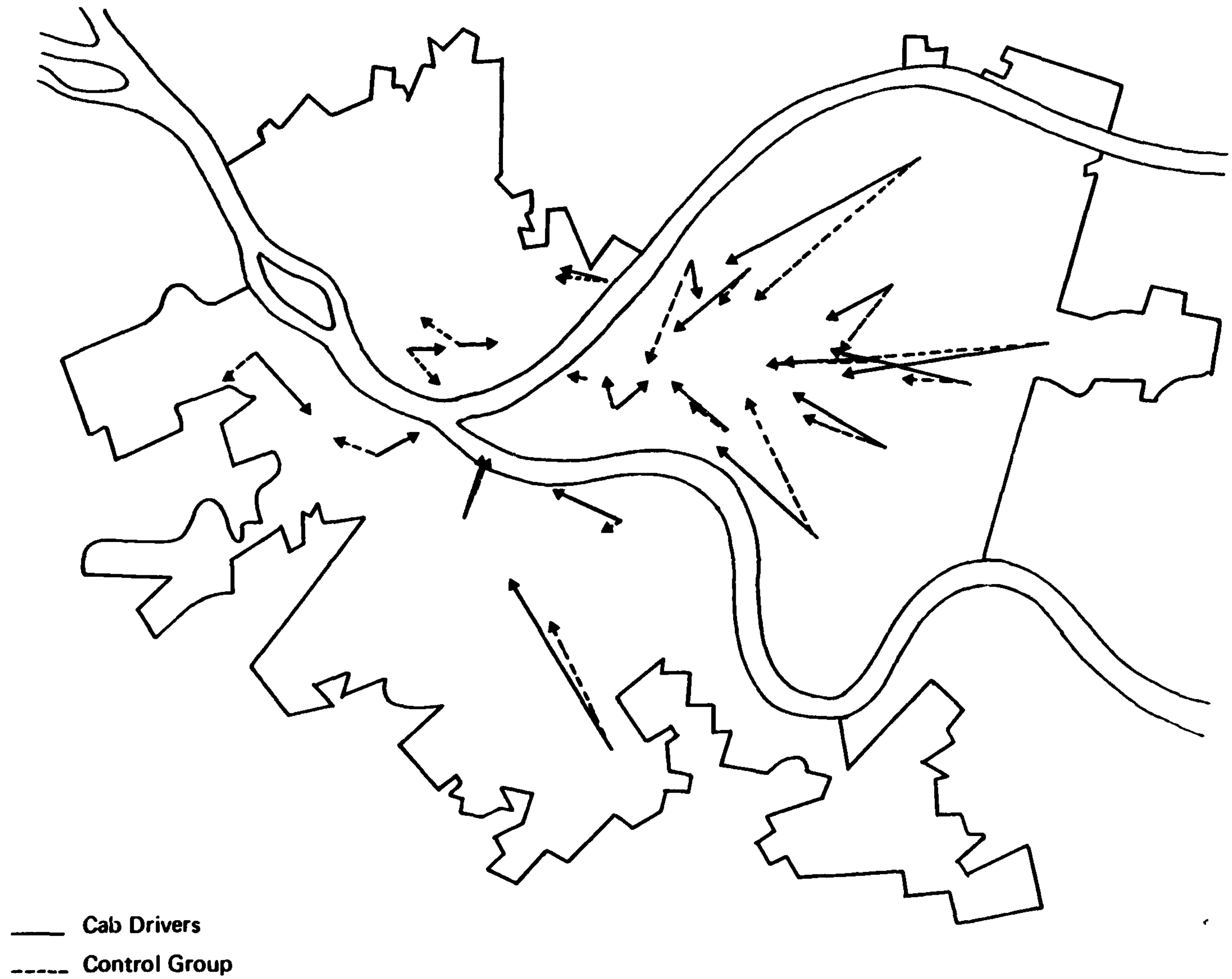

Figure 1

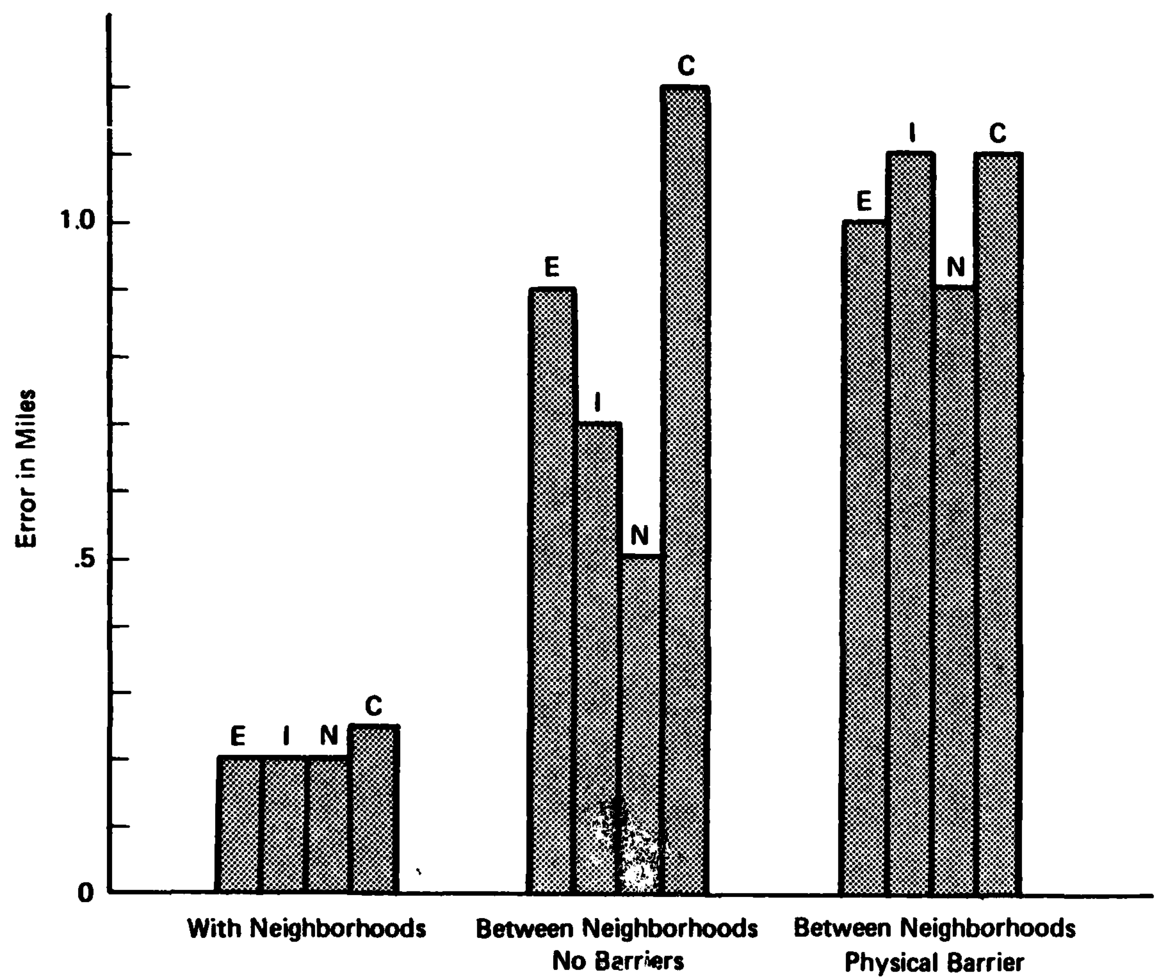
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Figure 2

Quadrilateral Street Groups

	Ratings				
	1	2	3	4	5
Experts (5)	1	5	9	4	1
Intermediates (5)	3	4	7	4	2
Novices (5)	0	9	3	6	2
Cab Drivers (15)	4	18	19	14	5
Controls (9)	2	13	15	6	0

Table 1

TABLE 2

Average Number of Streets Named for

Various Neighborhoods

	Downtown	Oakland*	Best Known	Four Unfamiliar Neighborhoods
Experts	27	49	50	16
Intermediates	30	37	32	9
Novices	20	21	15	4
Controls	17	19	19	1

*Location of Cab Company

TABLE 3

Percentage of Pictures Recognized for

Various Types of Street Intersections

	Base x Base	Base x Secondary	Secondary x Secondary	Parkway
Experts	75	67	20	92
Intermediates	92	62	10	96
Novices	81	55	3	81
Controls	59	32	1	96

TABLE 4

Frequency of Various Route Solution as a Function of Skill Level

	Improved Using Secondary	Short Base	Long Base	Lacked Knowledge
Experts	9	34	16	1
Intermediates	5	37	16	2
Novices	2	31	18	9

Base to Base
Utilizing Secondary

	Short Using Secondary	Long Using Base
Expert	17	3
Intermediate	9	11
Novice	6	14

Table 5

Comparison of Routes
Generated in the Lab
and
Travelled in the Field

	Percent		
	Same	Improved	Longer
Experts	74	26	0
Intermediates	64	23	14
Novices	55	23	21

Table 6

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