GPS and Road Map Navigation: The Case for a Spatial Framework for Semantic Information

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ABSTRACT

Urban environments require cognitive abilities focused on both spatial overview and detailed understanding of uses and places. These abilities are distinct but overlap and reinforce each other. Our work quantitatively and qualitatively measures the effects on a user's overall understanding of the environment after navigating with either a GPS or a road map in a previously unknown neighborhood. Experimental recall of spatial and semantic information indicates that using a road map enables subjects to demonstrate a significantly better spatial understanding, identify semantic elements more often using common terms, place semantic elements in spatial locations with greater accuracy and recall semantic elements in tighter clusters than when using a GPS. We conclude that a spatial understanding is a necessary framework for organizing semantic information that is useful for inferred tasks.

Categories and Subject Descriptors

H.5.2 [Information Systems] – Information interfaces and presentation (e.g. HCI) – Users Interfaces – Evaluation and Methodology.

Keywords

Navigation, Semantic information, Spatial information.

1. INTRODUCTION

Computer interfaces often must present different kinds of complex information in meaningful ways; that is, in ways that fit the inherent structure of a setting. Urban visualization is a particularly difficult setting involving enormous quantities of heterogeneous spatial and semantic information. Any city is described by hundreds of maps with overlapping scope and detail, as well as by dense lists of building uses, names, zip codes, political jurisdictions, road intersections, zoning types, flood plain information, etc. Current interfaces suffer from a lack of integration of these spatial and semantic forms of knowledge. There has been some recent work in the computer-human interaction community focusing on GPS interfaces. Driving simulators have been used for some studies, but they can artificially simplify real world settings [3,20]. On the other hand,

real world studies have been largely anecdotal [9,14,16]. This paper reports the findings of a real world experiment combined with quantitative measures of subject recall.

The goal of this article is to examine how spatial and semantic information about an urban environment are acquired, coded, stored, recalled, and decoded, while also defining how these processes are inter-related. To better understand these cognitive processes, we use the concepts of cognitive maps and semantic networks that provide parallel information about the environment. We then test the ability to form a spatial understanding and how this can influence the ability to organize semantic information.

Specifically, we utilize two common forms of navigation (GPS and road map) as instruments to explore a neighborhood. Through this study, we examine if the use of a GPS diminishes one's spatial awareness of an urban environment, and if so, in what manner and to what extent the understanding is affected.

Urban legibility is an important contemporary issue for the discipline of urban design. Historically, the physical form of the urban environment represented not just a collection of buildings, but also a concrete cosmology of the world, implying a stable meaning to the overall structure of the city. For instance, one could count on the center of a city as the physical setting for the city hall or the cathedral. Today urban designers are confronted by urban environments with overlapping systems of movement and information that have made the reading of geometry insufficient for an understanding of the city. The ongoing discourse about the role of the physical setting amid the proliferation of mobility and information underlies our approach to this work.

Furthermore, we propose to study the legibility of the urban environment based upon two forms of knowledge, spatial and semantic. There is considerable evidence from cognitive neuroscience that people process sensory information along two distinct, parallel pathways: a "where" pathway, concerned with spatial and functional information about the environment, and a "what" pathway, focusing on object recognition and semantic knowledge [1,8,15,26]. In the case of a person attempting to navigate an urban environment, we propose that the stream of "where" information forms a cognitive map of their surroundings while the "what" pathway collects semantic information in a network structure. Therefore, our investigation is based on the premise that spatial understanding can be studied though cognitive maps and semantic understanding can be studied though semantic networks.

Cognitive maps are simultaneous and pattern-based mental representations of a place. Sketch mapping is one method used to externalize cognitive maps that is often represented in literature
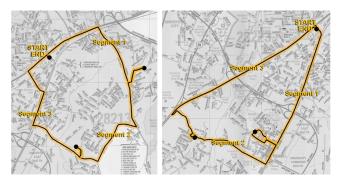
Figure 1. Routes each participant traveled through the urban environment. Route A (left). Route B (right).

from users in either familiar or new situations [2,3,18]. They are distinguished from precise geographic maps as being less scientifically absolute (and therefore more subjective), and as a means to simplify the idiosyncratic graphic features more or less in accordance with the tenets of perceptual psychology to reduce cognitive load.

A semantic network is linear, sequential and verbal. It is represented in literature by elements that are related categorically and hierarchically [11,12,19]. Categories of semantic information can be preset and communal, but can also arise from individual or group understandings of the environment. Just like the development of a cognitive map, one's categories of semantic information serve to reduce complexity and cognitive load.

The devices used in this study, a GPS and a road map, present both spatial and semantic information to users. A road map has lines, colors, and patterns, but also names of roads, areas and landmarks. A GPS delivers step-by-step direction to a destination as well as a graphic representation of the space of the urban environment. While it is apparent each method uses different techniques to convey an urban understanding, both require processing by the user, and the nature and difficulty of that processing is the focus of this study.

Our work quantitatively and qualitatively measures the effects on a user's overall understanding of the environment after navigating with either a GPS or a road map in a previously unknown neighborhood. Later revealed to be a half truth, we began by hypothesizing that a road map is more effective in assisting the formation of the spatial information, whereas a GPS is more useful for understanding the semantic aspects of the environment.

To investigate our hypothesis, we designed a within-subject experiment involving 18 participants who drove routes in the university area of Charlotte, NC. Each participant was randomly given two preselected routes and was instructed to use either a GPS or a road map for each route (Figure 1). Upon completion of each navigation session, participants were asked to complete a series of recall questions. Based on the results of our study, we conclude that a road map is indeed superior to a GPS in assisting in the formation of a spatial cognitive map. However, in gaining semantic information of an environment we find a GPS and a road map to be equally effective, but in different ways: a GPS tends to provide a diverse understanding of semantic elements whereas road maps provide a more structured and focused understanding.

2. RELATED WORK

Relevant literature to our work covers many research fields. Therefore, we parse this discussion into three areas: cognitive mapping and spatial understanding, semantic information and navigation studies.

2.1 Cognitive Mapping and Spatial Understanding

The term cognitive map was first used by psychologist Edward Tolman in *Cognitive Maps in Rats and Men* [23]. He describes a maze previously mastered by rats that is blocked at a critical point and replaced by a series of radically arranged alternatives. His finding is that the rats greatly prefer the route that demonstrates an understanding of the spatial overview of the maze. Partly a reaction against strict behaviorism, his work leads directly to the development of cognitive psychology.

Kevin Lynch's book *Image of the City* develops the idea of a mental map from the viewpoint of urban theory [18]. Based on empirical studies of sketch maps by residents of Boston, Jersey City, and Los Angeles, Lynch develops a set of categories, including paths, edges, nodes, districts and landmarks, that are used in understanding and wayfinding through these urban environments. Lynch's work has been seminal not just within urban studies, but also in a wide variety of fields as an example of an underlying cognitive process.

Chown discusses error tolerance and generalization in cognitive maps. He contends that human cognitive maps are not precise, complete, nor necessarily accurate [6]. These inherent inaccuracies of internal mental representations are hard to understand primarily due to the importance of navigation as an everyday activity. Regardless, information stored in cognitive maps is usually sufficient for human needs. Chown's work realizes the difficulties that lie in quantitative analysis of cognitive maps but makes light of research in need of further investigation.

Studies show that when elements are located relative to one another they are remembered as more aligned relative to a reference frame than they actually are. For example, a majority of subjects preferred maps in which North America and Europe appear in greater east-west alignment. Findings suggested people distort mental representations of the environment based on the north-south east-west axes of the world as a process of simplification to reduce the cognitive workload [21, 25].

Cognitive mapping and how humans understand the environment spatially are well-studied topics that provide this analysis with a rich background of the ways humans recall, store, and code information in relation to the geographic environment. Tolman's introduction of spatial overviews, claims significance in this investigation by explaining our participants' ability to recall the environment in a spatial snapshot. We relate to Lynch's work not only by how humans perceive the environment through simplified cognitive elements, but also how these elements have some resemblance to those recalled by our participants. Spatial distortions and inaccuracies are also noted to explain the discrepancies humans have in judging spatial locations. We find this to provide reasoning for how our participants were unable to recall elements in their correct geographic locations.

2.2 Semantic Information

A few investigations have studied the environment in not only a spatial manner, but also using semantic information [11,12,19]. Semantic information, in this discussion, refers to a specific type of knowledge representation where objects or elements (in our case, in the environment) have some implied relationship with one another. This type of knowledge representation develops when the brain organizes information. For many, this involves associating elements as clusters or hierarchical structures.

One experiment that shows evidence of semantic clustering is that of Hirtle and Mascolo [12]. By using a sorting task based on names of selected landmarks, they found participants commonly grouped landmarks in a government cluster (court house, town hall, police station, post office, bank) and a recreation cluster (playground, pool, golf course, dock, beach).

Similarly, Hirtle and Jonides [11] found that people cluster landmarks based on nonspatial attributes. Subjects in the study completed a memorization task on city landmarks in Ann Arbor. By noting the order in which landmarks were recalled, the authors developed a hierarchical tree for each subject. In each case, they found that subjects showed clustering bias, rating within-cluster pairs as closer together than equally distant between-cluster pairs.

Work conducted by Mohan and Kashyap [19] exposes the semantic information in a hierarchical schema they refer to as the relational model. This model is able to show semantic information as one-to-many relationships (resulting in tree structures) as well as many-to-many relationships (resulting in lattice and network structures). Through a process of sub-classing, they classify objects such as country, state, county, and city into a hierarchy.

Although an urban environment contains an abundance of semantic information, these studies prove humans carry a form of structured knowledge when relating urban elements to one another. We find these works beneficial for their methods of extracting knowledge organizations (semantic hierarchies and semantic categories) from cognitive processes.

2.3 Navigation Studies

Burnett and Lee conducted a navigation study to analyze a person's ability to build cognitive maps [3]. Using a driving simulator, they studied a person's memory when using a paper map or voice-automated direction guidance. As one method of analysis, they used scene recognition, where participants placed scenes from the route in sequential order. Second, they used a categorization scheme proposed by Appleyard [2] to evaluate sketch maps based on their complexity. Their findings indicated those who use voice-automated guidance have worse memory of the area than those who use a traditional printed map. While this may prove there are differences in recall using various navigational methods, there is some subjectivity in this categorization process. In addition, this study does not utilize a real life navigation environment. One can assume that irregularities in the natural geographic environment contribute to our cognitive map development and are important to our real life perception of space.

Recent work at the University of Tokyo [13] investigated the effectiveness of a GPS device in comparison to a paper map or direct experience when walking urban routes. Among many things, their study showed GPS users travel more slowly, make larger direction errors, and draw poorer topological sketch maps than those who used a map or direct experience. As a result, they conclude that a GPS is ineffective for navigation as compared to other methods. While some of these findings are similar to ours, we note a significant difference in our performance measures; perhaps a result of navigation on foot versus in-car.

Studies often use comparative navigation tasks as a way to understand cognitive processes performed during wayfinding. Furthermore, experts can apply quantitative measures to the recall of elements to define map building abilities and user efficiency.

3. USER EXPERIMENT

This experiment focuses on mental representations of the environment, specifically spatial and semantic information acquired during car navigation. While recent studies focus on usability of navigational aids [9,13,14,16], our study aims to uncover differences in the information a person stores using two common instruments: a conventional road map and a GPS.

3.1 Participants

Twenty college students (10 men and 10 women) participated in the experiment. Participants' ages ranged from 18 to 45. To ensure the results were consistent, it was important that the participants had no prior knowledge of the environment during navigation. Therefore, two of twenty participants said they were familiar with the routes and were eliminated from the experiment.

3.2 Study Areas and Routes

Each participant was observed while navigating two routes, one with a road map and one with a GPS. Route A and Route B (Figure 1) were similar in geographic surroundings, each approximately six miles in entire length, and had the same number of turns. Both routes consisted of three segments that the driver navigated one after another. Once the drivers finished the first segment, they started the second segment from the ending point of the first segment. The third segment lead the driver back to the starting point of the first segment. Participants were informed of the route to follow by a highlighted area on the road map or by a pre-programmed destination in the GPS. The order of which navigation method to use and which route to navigate were determined at random.

3.3 Environmental Factors

To control for environmental variables, traffic flow and weather conditions were taken into consideration. Participants were asked to navigate during low traffic periods of the day, reducing the possibility of heavy traffic conditions. To ensure that the participant had clear visibility, weather conditions were monitored to eliminate the possibility of precipitation.

3.4 GPS Navigation

All participants used the same GPS (Garmin Nuvi 760) mounted in the test vehicle. The system provided the user with a three-dimensional first-person view that dynamically updated as the user moved through space. In addition, the GPS provided voice automated directions to assist the user when navigating. Participants were given no time to review the route before navigation, although they were given time to ask questions about how the device performed. All three destinations for each of the two routes were pre-programmed in the GPS.

3.5 Road Map Navigation

Each participant was given a traditional road map at the beginning of each navigation session (three maps per route, one per segment). Each map showed a highlighted route for participants to follow, clearly marked with the starting point and the final destination. Participants were given time to review their relative position and the location of the destination before navigation.

3.6 Procedure

Each participant was first asked to complete a pre-experiment questionnaire and the Santa Barbara Sense of Direction Scale [10] to provide data about their prior experience of navigating a vehicle using various methods (road map, GPS device, written directions). The participant was then reviewed by the investigator to have met all inclusionary criteria (valid drivers license, no prior route knowledge) for the study.

After completion of the pre-experiment questionnaire, the participant was asked to navigate one of the two routes (all three segments). The participant was guided to the starting point and informed of which method (GPS or road map) to use and when to begin. During navigation, the investigator recorded field observations (length of time to navigate, number of turn mistakes made). Upon arriving at the final destination, the participant was guided by the investigator to a controlled room and asked to answer a post-experiment questionnaire (section 3.7) based on recall questions pertaining to the route. Participants were not given a time limit to complete the questions; on average it took each participant 35 minutes. After the participant completed the questions, they were asked to complete the other route using the other navigational aid. Upon arrival at the final destination they were again guided to the study room and asked the same series of questions in the post-experiment questionnaire.

3.7 Post Experiment Questionnaire

The post-experiment questionnaire consisted of a series of recall exercises including a sketch map, element recall and grouping, written direction recall, and scene recognition. Each participant was informed they could use as much time as needed to complete the questions. The sequence of the questionnaire was designed such that participants were not likely to form a bias from one question to the next. We discuss the questions in specific areas: spatial information, semantic information, spatial and semantic information combined, and scene recognition.

3.7.1 Spatial Information

We first asked participants to draw a sketch map of the trip they navigated, including all elements they were able to remember (Figure 2). Once this was complete, they were given another set of questions relating to their map. With the initial sketch map drawn by the participant in hand, they were asked to specify locations where they remembered taking a turn, the length of each segment, and how much time it took to complete each segment. The next investigation was that of written directions. We asked participants to write down the route they just navigated as though they were giving someone a set of step-by-step directions.

3.7.2 Semantic Information

This section covers element recall and element groupings similar to methods performed by Hirtle and Mascolo [12]. Participants were first asked to list as many things as they could remember from the trip on index cards (one card per item remembered).

They were also informed that this exercise could cover a broad range of items (small or large). Following this element recall, participants were asked to group the elements (index cards) by how they believed the elements could be related to each other.

3.7.3 Spatial and Semantic Information Combined

Using the aforementioned index cards, we again asked participants to group the elements (index cards) but this time by where they thought the elements were located spatially. In addition, participants were asked to place each element listed on the index cards onto the sketch map they produced using a numbering method (Figure 5a).

3.7.4 Scene Recognition

Similar to methods proposed by Burnett and Lee [3], participants were shown a total of nine photographs taken along the route (two photographs were not actually along the route and served as dummy scenes). Of the nine photographs, they were asked how many of the scenes they recognized. Then participants were asked to place the scenes they recognized in the sequential order in which they were viewed when driving.
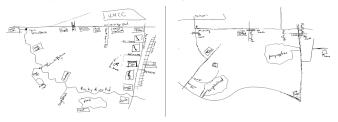

Figure 2. Sketch map comparison across the two methods drawn by the same subject. Left is drawn after road map navigation and the right is drawn after GPS navigation.

4. RESULTS

The results of this experiment were evaluated on two major dimensions: accuracy in spatial recall and qualities of semantic recall. Our spatial analysis was primarily based on the sketch maps produced by participants, while our analysis of semantic memory was based largely on the index cards participants generated to describe objects and impressions they remembered from the route. Unless otherwise indicated, all statistical tests employed a two-tailed paired-response t-test to measure within-subject differences. Tests with a p value less than .05 were considered to be statistically significant.

Of the 18 participants, nine were female and nine were male. Ages ranged from 18 to 45, with an average age of 23.44. The number of years participants had lived in the city where the experiment took place ranged from zero to 33, with an average residence length of 4.31 years. Participants' mean score on the Santa Barbara Sense of Direction scale was 3.45, which is below the scale's reported mean of 4.7 [10].

There were no significant differences in any of the following measures based on gender. There were also no significant correlations between these measures and age or length of residence. The Santa Barbara Sense of Direction Scale did not positively correlate with any of our accuracy measures, although it showed a significant negative correlation with a participant's ability to correctly place index cards (semantic elements).
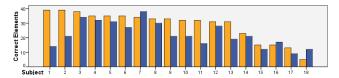
Figure 3. The difference in sketch map accuracy between the two conditions, showing the number of correct map elements (turns, road segments, and road names) for each participant. Only three cases show a participant produced a more correct sketch map in the GPS condition (orange, road map) (blue, GPS).

Table 1. Participant's sketch map accuracy measured by the number of correct, incorrect, and missing turns, road segments, road names, and the number of landmarks. The values were summed for overall measures of complexity (total elements), accuracy (correct elements), and errors (incorrect and missing elements). Based on a two-tailed paired-response t-test, participants made more complex and accurate sketch maps using a road map, and had fewer missing elements.

Dependant variable	Road map		GPS			Sig. (2-tailed)
	Mean	S.D.	Mean	S.D.	t	
Total Elements	38.22	9.87	31.67	9.15	2.94	0.002**
Correct Elements	28.78	10.09	22.39	8.44	3.37	0.004**
Incorrect Elements	2.72	5.20	4.67	5.85	-1.1	0.288
Missing Elements	9.67	9.88	16.17	8.49	-3.64	0.002**

** *p* < .01

Table 2. Written narrative of route recall. There are no significant differences between the two groups, although in the road map condition a trend toward more correct road names and fewer missing turns approaches significance.

Dependant variable	Road map		GPS			Sig. (2-tailed)
	Mean	S.D.	Mean	S.D.	t	
Correct road names	5.29	2.91	3.41	2.60	2.08	0.054
Number of missing turns	4.41	3.73	7.24	2.91	-1.83	0.086

4.1 Spatial Accuracy

In general, the use of road maps was consistently found to be associated with superior spatial recall. As we hypothesized, the sketch maps produced in the road map condition were significantly more correct and thorough than those produced in the GPS condition. We calculated the accuracy of sketch maps by counting the number of turns, road segments, and road names that correctly corresponded to the actual route, as well as those that were incorrect or missing. These values were then summed to produce an overall number of correct, incorrect, and missing elements on each sketch map. Comparing these accuracy measures between the two conditions showed a strong advantage for the road maps (Figure 3). For instance, sketch maps produced in the road map condition contained more correct, more total and fewer missing turns, roads segments and road names (Table 1). There was no significant difference in the number of incorrect elements between the two conditions. These findings strongly suggest that, although GPS navigation tends to be faster and less prone to errors, there is a distinct advantage to road map usage in enhancing spatial memory of an urban environment.

In reproducing a set of written directions, users in the road map condition tended to remember more road names correctly and had fewer missing turns, although both of these effects were shy of significance (Table 2). This suggests that the advantages of the road map do not apply nearly as strongly when users recall route information sequentially rather than spatially.

4.2 Semantic Recall

We measured semantic recall by analyzing the index cards participants produced that described objects and impressions along the route. While neither method was clearly superior in this respect, the differences between the two suggest that GPS navigation leads to a broader but less clearly organized semantic memory, while the use of a road map leads to a more structured and focused semantic memory.

Between the two methods, there was no clear difference in the number of index cards produced. There was also no difference in the number of categories participants placed the cards in when asked to group them semantically or spatially.

There was, however, a significant difference in the type of information recalled. In order to study the amount of unique detail in participants' semantic recall, we tallied the number of times each index card observation was repeated by any participant in either route and marked those observations that appeared ten or more times as being highly common. This list included three frequently noted landmarks (the bookstore that served as the starting and ending point, the university, and the railroad tracks crossed on both routes) and five common generic observations (pedestrians, gas stations, churches, stoplights, and apartment complexes). By removing these observations, we were able to calculate the percentage of index cards that reflected relatively more unique observations (Figure 4). This percentage was found to be significantly higher in the GPS condition than in the road map condition (Table 3) suggesting a greater breadth of semantic recall in GPS navigation.

4.3 Semantic and Spatial Recall Combined

We focused on two measures of how participants combined semantic and spatial information: the groupings of index cards by location, and the placement of index cards on the sketch map. As mentioned, there was no difference in the number of categories participants produced when asked to group their index cards by location. However, there were differences in how participants placed index cards on the sketch map they had drawn. By analyzing the accuracy of the index card placement we noticed participants in the road map case placed objects correctly significantly more often (Table 3), indicating a better sense of the location of semantic elements in the road map condition.

There were also broader differences in the way that participants placed the index cards on their sketch maps. We analyzed these trends in placement by marking the positions of all cards placed on the sketch maps, normalizing the maps to a constant size of 3200 by 2400 pixels, and clustering the index cards by location using an adaptive k-means clustering algorithm with a distance threshold of 500 pixels (Figure 5). This provided a quantitative overview of whether participants placed index cards evenly across the map, or concentrated them in a smaller number of locations.
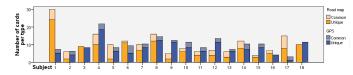
Figure 4. The total height of the bar shows the total number of index cards generated. The lighter-colored area of each bar shows the number of cards containing the most common observations. This proportion tends to be much higher in the road map condition (orange).

Table 3. Semantic recall: analysis of index cards noting objects and impressions. While there was no difference in the number of index cards produced, index cards in the road map condition were significantly more likely to contain one of the eight most common observations. The percentage of cards that contained a more unique observation was significantly higher in the GPS condition, suggesting a greater variety of semantic memory. Alternatively, placement of index cards on sketch map on the road map condition were more likely to accurately recall the position of these observations.

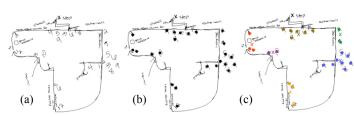| Dependant variable	Road map		GPS			Sig. (2-tailed)
	Mean	S.D.	Mean	S.D.	t	
Number of index cards	10.50	6.10	9.56	4.06	0.57	0.578
Common index cards	3.28	2.29	1.83	1.10	2.78	0.013*
Unique index card %	65.99%	21.45%	78.51%	16.53%	-2.25	0.038*
Total placed cards	9.89	6.55	8.17	4.56	1.06	0.303
Correct placement %	93.77%	11.87%	84.61%	17.22%	2.15	0.047*

*$p < .05$

(a)　　　　(b)　　　　(c)

Figure 5. The process of clustering index cards on sketch maps for analysis of placement. This sketch map shows a participant using GPS navigation on Route A. Participants were asked to place the elements (listed on their index cards) onto the sketch map they drew. The cards were labeled with numbers by the observer (a). Each map scaled to 3200 by 2400 pixels for a more standardized comparison. Each index card was recorded as a point (b). Adaptive k-means clustering to place each point into a cluster on its position, using a threshold of 500 pixels (c). Points of the same color were clustered together, and X marks the centroid of each cluster.

Table 4. Differences in the placement of index cards on the sketch map by clustering the points by distance. Participants in the road map case tend to have slightly more clusters than in the GPS condition, although this effect does not reach significance. However, clusters of index cards in the GPS case tend to be much sparser, as indicated by the greater average distance between individual cards and the center of the cluster

to which they belong. This suggests that index cards in the GPS case are placed in a less organized fashion than the more structured (and correct) placement in the road map condition.

Dependant variable	Road map		GPS			Sig. (2-tailed)
	Mean	S.D.	Mean	S.D.	t	
Number of clusters	4.94	1.39	4.00	1.33	-1.77	0.094
Points per cluster	2.39	0.79	2.78	1.18	1.29	0.216
Avg. distance to cluster center	182.78	38.50	227.94	62.36	-3.175	0.006**

** $p < .01$

Table 5. Unlike Burnett and Lee's [3] virtual environment, the table shows no difference between GPS and road map navigation in scene recall. Failing to replicate this finding suggests the effect may not extend to a real-world urban environment.

Dependant variable	Road map		GPS			Sig. (2-tailed)
	Mean	S.D.	Mean	S.D.	t	
Correct scenes	6.00	1.06	5.82	0.95	0.72	0.484
Correctly ordered scenes	3.76	1.55	3.82	1.71	-0.10	0.918

There was a slight trend towards participants producing more clusters of index cards in the road map condition, although this difference did not reach significance (Table 4). However, index cards in the GPS condition had a significantly higher average distance from the cluster's center, suggesting more spread-out placement (Figure 6).

Taken together, these findings suggest a scattershot memory for the spatial locations of semantic observations after using a GPS for navigation. Road map users seem to hold a more robust connection between semantic and spatial information, while the scattered placement of index cards in the GPS case suggests less structured recall.

4.4 Scene Recognition

Unlike Burnett and Lee [3], we found no significant difference between the two conditions in terms of recognized scene images or scene ordering (Table 5). However in the road map condition there was a significant negative correlation between the number of correct elements in the sketch map and the number of correctly recognized scenes (R(16) = -0.48, p = 0.04). No such relationship existed in the GPS condition. A possible explanation for this finding is that participants who successfully fit route information to a top-down spatial structure may have been less adept at adopting a first-person view when recalling the route.

While our test of scene recognition reflects the study performed by Burnett and Lee, our results indicate a noteworthy difference between their study using a simulated driving test and our study using the real world environment. Although there are many more factors to control in a navigation experiment in the real world than in a simulator, we argue that results from a real world experiment are particularly significant due to the complexity of the environment. Specifically, the images in the scene recognition portion of Burnett and Lee's study show a virtual environment that is flat with few buildings and trees. It is therefore not

surprising that it is easier for their participants to recognize images and scenes in this simplified environment. In our experiment, the participants are driving through an urban environment that is lively and complex, and therefore more difficult for the participants to remember accurately.

Our results overall show a clear advantage for road maps over GPS for recalling purely spatial information after a navigation task although, the recollection of semantic knowledge shows a less straightforward pattern between the two methods. While neither method has a clear advantage in semantic recall, there is evidence that road maps encourage recollection that is more accurately linked to spatial positions, while a GPS is associated with a broader range of semantic observations.
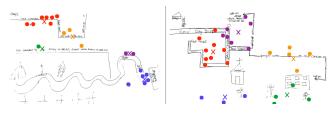

Figure 6. The same participant produced very different index card layouts in the road map and the GPS conditions. In the GPS case, index cards are scattered across the sketch map, while they are tightly clustered in the road map condition.

5. DISCUSSION

Our quantitative analysis provides a basis for understanding the relationships between spatial and semantic understandings of an urban environment. Our findings reflect similar studies in cognitive and neuroscience literature in that we have clearly found a dissociation between semantic and spatial recall in the context of understanding and recalling an urban environment, analogous to the distinction between "what" and "where" knowledge in neuroscience.

The focus of our study is not on the performance of GPS and road map users during navigation tasks, but rather on the structuring of semantic and spatial information. While the concept is not new, there has been limited evidence on how the two pathways relate to one another in understanding urban environments. In our study, we focus on using two methods to directly combine spatial and semantic information by asking the participants to group semantic elements (index cards) spatially, and then place the semantic elements onto a spatial representation (sketch map).

We believe that a wider understanding of the urban environment is more adaptive and useful than focusing only on one narrow task; we are less concerned with route than with survey knowledge [7,17,22], or to put it more precisely, we are concerned with the way in which survey knowledge emerges from navigating routes.

GPS and road maps each present users with both spatial and semantic information, but there are significant differences in the manner in which users process this information. Specifically, our study confirms that:

1. using a road map allows users to demonstrate a significantly better spatial understanding than using a GPS,
2. using a road map allows users to identify semantic elements significantly more often using common terms compared to using a GPS,

3. using a road map allows users to be significantly better at correctly placing semantic elements in spatial locations than using a GPS, and
4. using a road map causes users to concentrate semantic elements in tighter clusters than using a GPS.

The first finding shows that road map users have a better spatial understanding of the study area, as measured by an evaluation of the sketch maps, for both correct and incorrect elements. Despite the fact that users are presented with spatial information in both a road map and a GPS, this finding implies that using a road map tends to allow for the formation of a more accurate cognitive map.

The next three findings all relate to semantic information. We find that road map users, who have a more fully formed cognitive map, tend to use a common set of semantic terms, place them more accurately and tend to more tightly cluster them in location. Taken together, these findings suggest that the spatial cognitive map may form a framework that structures the naming, arrangement and accuracy of semantic elements.

We surmise that semantic elements tend to be difficult to organize relative to an understanding of urban environment, or indeed in any geographic scale. This is confirmed by studies of inaccuracies caused by semantic classification of spatial information. In a classic example, our semantic classification of north/south position on Europe and the United States leads us to assume incorrect locations [21,25].

Lastly, it is relevant to note that as a driving aid, a GPS is superior to a road map. In this study, participants make more mistakes and wrong turns using a road map than a GPS. Interestingly, when using a map, the more mistakes a participant makes, the more accurate his sketch map is. Presumably this is due to the fact that more cognitive effort is put into understanding the correct routes.

The results from our study suggest that a better cognitive map (spatial understanding) gives a more solid foundation on which to place semantic elements. A failure to develop a spatial understanding might inhibit the ability to gain an overview that can structure semantic information. GPS devices may have the unintentional effect of making a route more accurate while at the same time making broader understanding more difficult.

6. FUTURE WORK

Our goal is to work toward the integration of spatial and semantic information in urban environments as an example of combining heterogeneous information in interface design that matches the cognitive abilities of users.

First, we are observing the way in which cognitive maps are formed by studying groups of people who have recently become familiar with new cities. We are analyzing the sketch maps drawn by these participants to understand the principals by which the maps are drawn. Using the vectors from the maps, we plan to develop an algorithm that can automatically generate a (simplified) cognitive map from any complex geographic map. Although some work has been done with route simplification, the techniques for an overall spatial understanding are undeveloped.

Second, we are seeking to extend and modify techniques developed by Chang et al. [4,5], which currently simplifies complex urban models by using principals of urban legibility to create hierarchical clusters of buildings. The current algorithm uses only spatial concepts, but we are studying methods to add

semantic information about the urban model that will influence the order in which clusters of building are formed. This will allow a clustering of buildings based on a semantic category of interest, for example restaurants. The form of the urban model will then reflect the semantic information of the environment.

7. CONCLUSION

Technology is constantly changing the ways through which we understand and interact with our environments. In this article, we present an experiment comparing the use of a GPS and a road map to measure spatial and semantic recall of participants in order to investigate their understanding of an urban environment.

GPS devices have proven to be very capable of providing accurate route information to the user. However, we conclude that using a road map leads to a better spatial understanding, and that this spatial understanding correlates with a semantic understanding that is more accurate and focused for the placement of elements.

Our original hypothesis that a road map is more effective at the spatial information and a GPS is more effective at organizing semantic information was overly simplistic and missed the interaction of semantic and spatial understanding. Based on our study, we now see that these forms of cognition can compliment each other, and that spatial cognition constitutes a framework for a semantic understanding.

The emergence of GPS devices may lead to better route information, but at the same time lead to degradation in the overview understanding recorded by cognitive maps. There is a need for interfaces to include spatial overviews that allow for inferences about survey information, and that combine semantic and spatial information in an intuitive manner.

8. REFERENCES

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