Heads Up: Using Cognitive Mapping to Develop a Baseline Description for Urban Visualization

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Abstract— **Kevin Lynch's work on urban legibility has taken on new importance as the delivery of information about cities has shifted largely to mobile computing devices. This study extends his work with the aim of quantifying the number and type of elements that constitute a competent cognitive map of a city. We conducted a user study of 109 student sketch maps of Chicago that test the frequency and nature of the elements identified by Lynch (path, edge, district, node and landmark), their interrelationship and the effect of gender, prior experience and scale. We find that (1) participants identify two distinct urban scales, one at the neighborhood level and the other citywide, (2) competent cognitive maps involve relatively small numbers of elements: 15 (+/-7), (3) the selection of elements for the sketch map may include any of the elements identified by Lynch, but the frequency of landmarks and districts is negatively correlated, (4) participants recall significantly more districts and nodes at the citywide level, and (5) in addition to Lynch's identification of physical landmarks, participants also identify landmarks by function; such functional landmarks are more frequent at the neighborhood level.**

Keywords-legibility; cognitive mapping; urban visualization.

I. INTRODUCTION

The image of the city, a phrase coined by Kevin Lynch in 1960, has been widely used by urban planners and geographers as a means of conceptualizing the way users perceive and organize spatial information. The five categories postulated by Lynch (path, edge, node, district and landmark) have been the basis of subsequent research. Despite this literature, there are two salient research questions that remain unanswered:

- First is the epistemological question: are all the items in this set of categories at the same level of specificity; are they commensurable? Are there significant differences between the kinds of information that each category is describing?
- Second is the methodological question: is there a way to quantify the sufficiency of the elements and to test their relative frequency? In other words, are all these elements recognized by users as equally valid and are there significant relationships between their frequency of use?

The results of our empirical study will assist in the design of urban visualizations at all scales. We do so by uncovering those specific elements of the environment that may be regarded as most useful and recognizable. Specifically, our work is centered upon generating a baseline description of the urban environment from humans' cognitive maps.

Literature from urbanism, cognitive science and geography is a starting point for understanding environmental cognition. The seminal figure is Kevin Lynch who examines perceptions of urban environments in order to better understand how humans make sense of their surroundings. We adopt Lynch's concept of legibility defined as "visibility in a heightened sense, where objects are not only able to be seen, but are presented sharply and intensely to the senses" [1]. Lynch discovered that the mental maps which people use to help them find their way through cities are composed of five essential elements: paths, edges, districts, nodes and landmarks. Much like Lynch, we assert that legibility is crucial to the urban setting and involves visual and mental processes.

The central concept of such work is the idea of a spatial mental model [2], referred to by Lynch as mental map [1], or more generally understood as a cognitive map which proposes that the brain can acquire, code, store, recall and decode information about the relative locations and attributes of various phenomena in a spatial context. The development of a cognitive map often operates using schematization; some elements are emphasized and others are deemphasized to reduce cognitive workload. Cognitive maps of the environment cannot preserve metric information about the environment, but do preserve topological relations coherently. For instance, during wayfinding tasks it is common that a user's topological knowledge is more pertinent than knowledge of one's exact distance to an object and the precise dimensioning betweens objects. Therefore, one is more likely to be concerned with the type of elements recognized and remembered rather than the elements precise distance from one's own position in space. For this reason, we find hand-drawn sketch maps, a method commonly used by Lynch [1] and Appleyard [3,4], most useful as a means to capture schematized and topological knowledge about the environment.

In order to generate a baseline description of a cognitive map, we conducted a user study of architectural students after a field trip to the city of Chicago, distant from their home university. We asked each student to draw a sketch map of Chicago using an open question protocol. The resulting sketch maps were coded to identify spatial characteristics of the city using paths, edges, districts, nodes and landmarks.

Our subsequent analysis was aimed at quantifying spatial elements in the sketch maps. How many of Lynch's elements did participants on average feel were necessary to use in order to give a clear depiction of the city? Just as important, we wanted to determine if the use of one type of element substitutes for another. If you identify a lot of landmarks, do you in general use fewer paths? Does previous knowledge of a city affect your use of elements? Does gender?

Our objectives in this study are:

- By means of a user study, extract a simple but complete set of spatial elements that are essential to constructing cognitive maps;
- Establish the base level of each element for a competent description of a cognitive map;
- Measure and study the relative interdependence of each element in describing an urban environment;
- Discover differences, if any, in the number of elements for users based on gender, previous experience and map scale.

The result of this study is an understanding of the number, type and interdependence of elements that form a cognitively adequate description of an urban setting that can serve as a guide in urban visualization design.

II. Related Work

A. *Urban Visualization*

In recent years, several innovative mapping applications have used cognitive mapping, although without any quantitative understanding about the elements that constitute such a mental map.

LineDrive [5] is a navigation interface that incorporates principles of map distortion with the rendering of routes, adjusting lengths and angles to more closely approximate the kind of simplifications that mimic users experience. This approach focuses almost entirely on segment elements of routes, and demonstrates a subtle and effective adjustment to individual users. The shortcoming of this approach is the lack of contextual information, leading to problems with users becoming confused after a single wrong turn.

Copernicus [6] attempts to correct flaws within the LineDrive system by adding spatial context to the interface. Generally, this involves adding paths and neighborhoods (cities and towns) to the established routes from LineDrive. This represents an advance in terms of legibility, but leaves unsolved the issue of how much information to display and which types of elements should be used.

Researchers at Carnegie Mellon on the MOVE [7] system have developed mapping software that uses some of the principles from LineDrive in a two dimensional interactive network that adjusts as the user moves through the city. This corrects some of the original problems, but does not address directly the issues of cognitive mapping.

Some interfaces have attempted to incorporate landmarks into maps [8], focusing on selection processes for identifying landmarks and geo-referencing them on tourist maps. This represents an advance in the sort of data related to landmarks, but it does not address their relationship to the user.

There has also been some effort related to GPS navigation systems in cars, notably at SIGCHI 2008. These studies evaluate user behavior while in a car [9], performance of a driving simulator to study accuracy rates of proposed systems [10], and quick search versus categorical semantic search techniques [11]. But again, none of this research establishes guidelines for display visualizations.

Therefore, we identify a need to rely on the research of urban planners, cognitive scientists and geographers who examine the question of urban legibility. More specifically, we are interested in research that identifies a base set of spatial elements that are recognizable in any city. While each of the following fields of research focus on cognitive maps of the city in unique ways, we want to address the most relevant work in relation to our focus on element recognition, setting aside issues of spatial proximity judgments and element recognition sequencing.

B. *Cognitive Science*

To begin our overview of cognitive science related work, we should be clear about our use of the terms cognitive map and sketch map. By cognitive map, we mean the internal mental image that enables people to code, store and decode spatial information. By sketch map, we mean an external representation of a cognitive map that is solicited by the need to communicate in daily life (and by researchers).

The term cognitive map was first used by psychologist Edward Tolman in "Cognitive Maps in Rats and Men" [12]. He describes a maze previously mastered by rats that is blocked at a critical point and replaced by a series of radially arranged alternatives. His finding is that the rats greatly preferred the route that demonstrated an understanding of the spatial overview of the maze. Partly a reaction against strict behaviorism, his work led to the development of cognitive psychology.

A closer examination of cognitive maps later carried out by Ronald Briggs explains what factors cause their development [13]. He identified three complementary ways in which cognitive maps are created about a city: through an individual's sensory modalities, from symbolic representations such as maps, and from ideas about the environment that are inferred from experiences in other similar spatial locations. Much like Lynch's notions of legibility, Briggs also asserts that an individual's sensory modalities, including visual, auditory, olfactory and kinesthetic, play a significant role in cognitive map development. We find this insight useful in recognizing that cognitive map development is highly complex and involves more than just visual qualities. This work also explains the subjectivity and variability in such work.

C. *Urban Design and Planning*

As previously mentioned, the work of Lynch is a starting point for our study [1]. In addition to his claim that the city's image is represented in memory through five common elements, Lynch also develops three principle parts necessary for an environmental image: identity, structure and meaning. We recognize or identify objects, we notice a recognizable pattern, and we draw emotional value in relation to them. These principle components involved in constructing an image of a city are fundamental to our work and occur at the beginning of cognitive map development.

As an extension of Lynch's work on image construction, urban designer and environmental behaviorist Amos Rapport highlights the importance of meaning in the built environment by recognizing three levels of meaning [14]. Denotative meaning coincides with object recognition; a lower level meaning that manifests in identifying intended uses of a setting. A middle-level meaning, also called connotative meaning, refers to the emotional values associated with the object and is centered upon evaluative judgments such as how much you like the appearance of an area. Last, abstract meaning refers less to an object than to broader values. For instance, when looking at a place through "cosmologies, cultural schemata, worldviews, philosophical systems and the sacred," one experiences abstract meanings. Rapport's levels of meaning solidify the notion that legibility of the environment can be highly complex yet can be clearly organized based on specified personal values. Most importantly, people apply different types of meaning with different levels of significance to the same elements of the environment.

Donald Appleyard, a collaborator with Lynch, also worked in the field of environmental cognition and planning. While most of Appleyard's work focused on a view of the city from a navigational standpoint, his work in Ciudad Guayana [3] addresses the image of the environment as a tool to plan for a better community. He was interested in how residents structured their city and asked them to draw maps of their local area. Using these maps, he developed a categorization of various types of sketch maps (sequential, spatial, fragmented, scattered, chain, mosaic, branch and loop, and patterned). This method defines how residents conceptualize and structurally organize their city and shows that a recognizable path system is the main structural organizer for residents. Appleyard's study proves influential to our work in stressing methods of abstracting schematized information (i.e. topographical elements) from sketch maps.

D. Geography

The approach of geographers is not distant from the aforementioned theorists. As Peter Gould explains geographers who reach across traditional disciplinary boundaries to other social and behavioral sciences, find the truly satisfying explanation they seek to come from emphasizing the human as much as the geography [15]. For the following scholars, cognitive mapping proves a way to understand the spatial aspects of human behavior.

Geographer Reginald Golledge [16] focuses on the development of cognitive maps starting with specific landmarks to larger general areas. First, a person acquires declarative knowledge of discrete places, things and events. Next, they develop an understanding of a node and path sequencing of the environment. This provides the subject with a connective structure of transit paths and concentrated locations. Last, a completely integrated spatial representation is developed including characteristics of distance, direction, orientation, proximity, clustering and hierarchical ordering.

Similar to Golledge's work, findings from a study using participant sketch maps drawn over a period of ten months shows that landmarks and relative locations are among the first components that are learned, followed by paths, and then building from the framework of paths the initial relative locations become more precise [17]. As a three-step process, this serves as an incremental approach for which to understand the relationships and integration of elements in the environment.

Hintzman and others [18] reconfirm a sequential development of a cognitive map based on studies of orientation and target domains. They argue that instead of recalling the environment as a holistic cognitive map participants first recall the origin and target in memory, activate the shortest route between them and then span the route for a correct response.

III. USER EXPERIMENT

A. Procedure

We conducted a user study of 109 architectural students after a four-day field trip to the city of Chicago. Within two weeks of returning from the trip, participants gathered in a study room equipped with a desk, a questionnaire and a writing utensil. To start, participants were given a brief overview of the study for the first time, but were not told about specific elements later used for analysis. Participants were then instructed to complete all questions in a thorough manner and to take as much time as needed.

B. Experiment Questionnaire

The experiment questionnaire primarily consisted of a recall exercise that included drawing a sketch map of the city. Other questions included background information about the participant such as gender, age and familiarity with the city.

The sketch mapping statement was phrased, "Now that you have traveled to Chicago, think about the environment you experienced. Imagine that you have a friend who has never been there before. Draw them a map to help them to understand and navigate Chicago." We intentionally left the statement open ended to allow the participant to draw freely in order to capture the most influential elements in each person's mental map.

C. Participants

Sixty-one males and 48 females participated in the study. Participants' ages ranged from 19 to 38 years old with an average age of 21. Based on questionnaire responses, 26 of the 109 participants said they had visited Chicago prior to the trip. Therefore, to ensure the results of the study were consistent, we analyzed the 26 sketch maps by testing for the equality of group means (student's t-tests) and found no statistically significant difference in any measure of element recognition in comparison to the participants who never visited Chicago prior to the study (Table I).

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D. Data Analysis Procedures

Upon completion of the user study, we created a set of instructions for coding the maps based on Lynch's five elements. The instructions included definitions for each of the elements based on Lynch's description and a comparable example in a city other than Chicago.

In order to validate the clarity of the instructions, ten coders (4 professors, 6 students) were given the coding instructions and a random sampling of 30 maps. The coders performed content analysis by counting the number of each kind of element on the maps: paths, edges, districts, nodes, landmarks for their physical presence and landmarks based on their functional significance.

Researchers then studied the results of the ten coders and analyzed the consistency of coders' findings. Discrepancies with high significance were identified and consequently, researchers modified the coder's instructions to clarify the related areas. Researchers also determined that 13 of the 30 maps had a higher occurrence of discrepancies than the other 12 maps. These 13 maps, along with the revised instructions, were returned to the 10 coders for recoding.

The second round of coding with the revised instructions decreased the discrepancies between coder results. Next, two members of the research team coded all 109 maps per the revised set of instructions. The researchers compiled their results and determined a final set of element counts for the set of maps. The researchers also recorded the area in square miles for each map based on the elements noted as farthest from the city center using an online map digitizer tool.

IV. RESULTS

Our analysis showed gender and prior experience visiting Chicago did not have a relationship to the total number or type of elements drawn on the maps (Table I). However, we discovered significant results concerning sketch map scale, average number of elements, element interdependency and types of landmarks identified.

TABLE I. AVERAGE NUMBER OF ELEMENTS

	Gender		Prior Experience	
(total maps)	M (61)	F (48)	Yes (26)	None (83)
All Elements	15.97	14.04	14.27	15.39
Paths	5.38	4.81	4.65	5.28
Edges	1.44	1.29	1.38	1.37
Districts	1.84	1.71	1.65	1.82
Nodes	1.77	1.58	1.5	1.75
Landmarks	5.54	4.65	5.08	5.17

A. Map Scales

Participants drew their sketch maps at a variety of scales ranging from 0.12 to 170 square miles, but the distribution was not even. After arranging the sketch maps in ascending order based on area, we analyzed the percent change between subjects' maps and noticed over a 100% change in area from 8 to 19 square miles, and as a result, we developed two catgories of maps: neighborhood level and citywide level (Fig. 1).

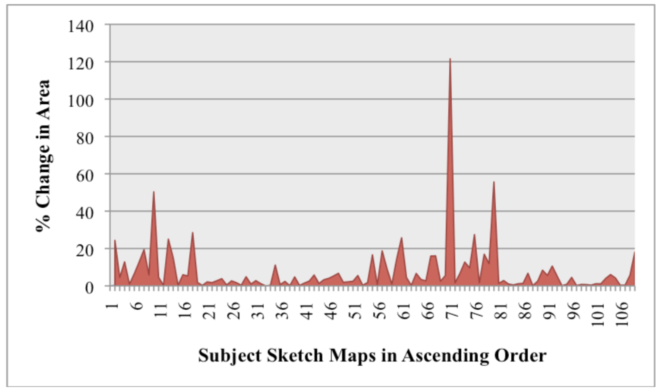


Figure 1. Percent change in area from subject to subject using 109 sketch maps arranged in ascending order. Given the over 100% percent change between subject 70 and 71, we divided the subject's maps into two groups: neighborhood level (70 total) and citywide (39 total).

A total of 70 neighborhood level sketch maps had an arithmetic mean of 2.02 square miles, with a standard deviation of 2.02. The 39 total citywide sketch maps had an arithmetic mean of 85.4 square miles and a standard deviation of 39.6. The standard deviations serve as indicators as to how closely the data cling to the sample mean. A small standard deviation indicates a set of data distributed tightly around the mean, whereas a large standard deviation indicates a wider range of areas across the sample maps.

We were surprised by the emergence of two distinct scales; nothing in the protocol suggested any bias toward the scale of the maps. We believe that this represents an inherent inclination on the part of the subject toward viewing the city as either a small comprehensible unit or a large extension in space.

B. Average Number of Elements

One of our central questions was how many elements would generally be understood as necessary for a competent sketch map of a large urban environment. Our evidence in Table II and III points to a relatively limited number of total elements: all sketch maps combined revealed an average of 15.12 (+/- 7.48); neighborhood level maps 14.2 (+/- 7.83); and citywide level maps 16.77 (+/- 6.58). We believe that the number of total elements is related to two factors: the need to provide clear representation and the limits of cognitive recall.

The amount and clarity of spatial information that can be presented is probably of particular concern to our subject group (design students), but it is likely also an issue to any user. We believe that this number of elements can be understood as each user's best guess of what would be legible to a third party.

The limits of cognitive recall also tend to simplify sketch maps. Cognitive maps always have less detailed information than geospatially constructed representations; they represent information that can be quickly recalled. While this limits the amount of information, it is good guide to the limits of efficient recall.

TABLE II. AVERAGE NUMBER OF ELEMENTS FOR ALL SKETCH MAPS

	All Sketch Maps (109 maps total)
All Elements	15.12 (+/- 7.48)
Paths	5.13 (+/- 4.20)
Edges	1.38 (+/- 0.65)
Districts	1.78 (+/- 1.48)
Nodes	1.69 (+/-1.13)
Landmarks	5.15 (+/- 3.98)

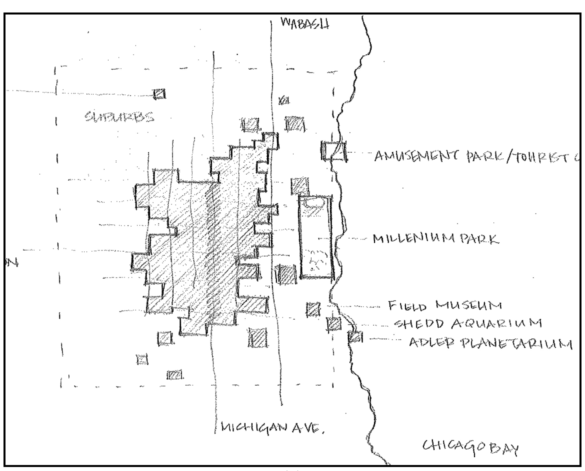
TABLE III. AVERAGE NUMBER OF ELEMENTS FOR NEIGHBORHOOD AND CITYWIDE SKETCH MAPS

	Neighborhood Level (70 maps total)	Citywide Level (39 maps total)
All Elements	14.2 (+/- 7.83)	16.77 (+/- 6.58)
Paths	5.17 (+/- 4.48)	5.05 (+/- 3.71)
Edges	1.3 (+/-0.67)	1.51 (+/- 0.6)
Districts	1.34 (+/- 1.27)	2.56 (+/- 1.52)
Nodes	1.41 (+/- 1.08)	2.17 (+/- 1.05)
Landmarks	4.97 (+/- 4.34)	5.46 (+/- 3.24)

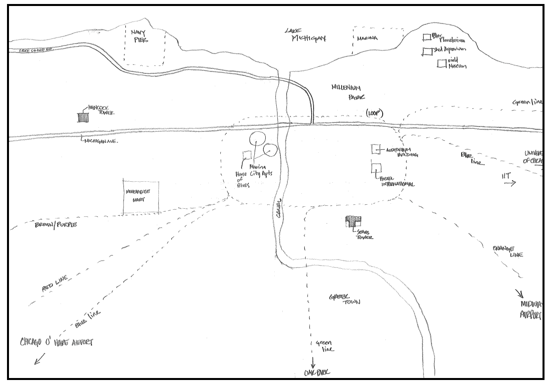
C. *Element Interrelationship*

We were interested in how the use of the Lynch's five elements would be managed by the subjects. We began the study with the hypothesis that some of the elements might be less important, or that one element category might quantitatively dominate the others. To our surprise, we found that all of the five elements were used in the sketch maps (although occasionally, a subject omitted an element type), and that Lynch's description seemed to fit the untutored sketch maps produced by the participants.

Second, using all 109 sketch maps, we found a significant inverse correlation between landmarks and districts. Subjects appeared to describe the city either in terms of landmarks or districts, but not generally as both. We are aware this finding may only be true for our subject population or for the city of Chicago, but it is suggestive that either landmarks or districts are sufficient to develop a cognitive map and that they both may be referencing similar spatial attributes. This would suggest that interface designers might use either one element or the other, but not need to duplicate them (Fig. 2a and 2b)



(a)



(b)

Figure 2. Two participant sketch maps showing the inverse relationship between districts (a) and landmarks (b).

Third, our qantitative analysis reveals a 91% increase in the amount of districts and 53.9% increase in the amount of nodes drawn in the citywide level maps when compared to the neighborhood level maps (Table IV). Districts are areas of a city, from several blocks to a large area, which share some kind of identifying characteristic and nodes are spots within a city which can be entered and at which different activities occur in multiple structures (e.g. parks, squares, shopping/entertainment centers, etc.). Based on these explanations, our finding suggests both districts and nodes serve as instruments for participants to reduce their cognitive workload when recalling the complexity of a citywide image.

TABLE IV. PERCENT CHANGE IN ELEMENTS

	Neighborhood	Citywide	% Change
All Elements	14.2	16.77	18.1%
Paths	5.17	5.05	2.3%
Edges	1.3	1.51	16.2%
Districts	1.34	2.56	**91%**
Nodes	1.41	2.17	**53.9%**
Landmarks	4.97	5.46	9.9%

D. *Semantic and Physical Landmarks*

We began the study with a hypothesis that the nature of landmarks has changed since Lynch's study. We have previously written about the emergence of a dispersed form of urbanism that relies less on architectural form and more on the flow of people and information [19, 20, 21].

Recalling that Lynch's definition of landmarks is based solely on formal attributes (e.g. a tower), we were specifically interested to see if subjects would identify landmarks based on their form or on their function. Our subject group would be if anything prejudiced as architecture students towards form; however, we found that overall 22% of landmarks are identified functionally (Table V).

Additionally, we found that the percentage of functionally defined landmarks was significantly higher for neighborhood level maps (27%) than for citywide (15%) (Table VI). We speculate that the finer grain of the neighborhood level maps explains the higher use of functional landmarks, but even at the citywide level, Lynch's definition of landmarks based on form neglects semantic landmarks which appear with significant frequency. We believe the amount of functionally significant landmarks identified in the maps confirms our original hypothesis about the changing nature of urbanism, even within a more traditional city such as Chicago.

TABLE V. RECALL OF PHYSICAL VERSUS FUNCTIONAL LANDMARKS

	Physical Presence	Functional Significance
Landmarks	77%	22%
Average	4 (+/- 3.06)	1.15 (+/- 1.9)

TABLE VI. PHYSICAL VERSUS FUNCTIONAL LANDMARKS

	Neighborhood Level		Citywide Level	
	Functional	Physical	Functional	Physical
Landmarks	27%	73%	15%	85%
Average	1.34	3.63	0.8	4.67

V. CONCLUSION AND DESIGN GUIDELINES

The use of cognitive maps in urban visualization impacts at least two types of interfaces. The most obvious impact is on what we might call "heads up" applications. These applications are for devices that must convey a maximum amount of information as quickly as possible. Mobile devices of all types, including but not limited to GPS devices, must not distract drivers or users from their immediate task. Cognitive maps can provide interface designers with a quantitative understanding of the most important elements and their relationship, helping to set limits on the numbers and type of elements.

By contrast, urban mapping and visualization may seem unlikely candidates because of the immense amount of data (layer upon layer of information about roads, buildings, flood zones and businesses) and the heterogeneity of the information. But here too, cognitive maps provide us with insights about the layering of information. Given a complex set of data, an interface designer will need to sift through this wealth of information to foreground the most important and provide a hierarchy of primary, secondary and tertiary information within a densely packed interface. Cognitive maps, because of the variety of elements, also provide one method to combine spatial and semantic information. Thus, for complex systems, cognitive maps provide us with guidance for "drilling down" into complex information.

Design guidelines for mapping interfaces:

- The number of elements used in interactive maps should be limited to approximately 15. Top level maps should guide user interaction.
- Landmarks and districts are redundant and a choice should be made to use one or the other.
- Maps are likely to be understood at the citywide level or the neighborhood level; good design will incorporate both scales into the interface.
- Designers should consider including both physical and functional landmarks in their maps.

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