Navigation in Electronic Environments

Stephen C. Hirtle
School of Information Sciences
University of Pittsburgh
Pittsburgh, PA 15260 USA

Abstract

The ability to locate information in a complex information space requires specialized tools to support searching and browsing behavior. Inherent in browsing is the ability to navigate through informational items, while retaining a sense of orientation. A tripartite theory of spatial information is presented based on cognitive studies of navigation in physical spaces. The analysis presented leads to additional insights for information designers. In particular, it is shown how the inclusion of structural components, such as neighborhoods and landmarks, can improve the navigability of electronic spaces.

Keywords: Hypertext, World Wide Web, Navigation

1 Introduction

As information becomes increasingly available in electronic form, the need to navigate through an information space in an efficient manner becomes increasingly important. Examples of electronic environments include the World Wide Web, on-line help systems, information retrieval and information visualization systems, among others. Navigation in these electronic environments is a particularly difficult problem given the multiplicity of navigational strategies, the varied goals of users, and the combinatoric problems associated with unrestricted topologies of networks [10]. In this paper, the role of navigation in searching, locating, and finding information in electronic environments is reviewed.

Navigation itself is a multi-faceted process [5, 10]. The goal of navigation can be specified in simple terms (e.g., getting from one place to another without getting lost), economic terms (e.g., modifying the cost structure of access to objects in the environment), aesthetic terms (e.g,, safe and graceful movement through an environment), or computational terms (e.g., providing a mechanism for route verification and correction, in the case of errors). The process of navigation could be viewed as series of small steps or choices, which provide for the opportunity of new discoveries. While orientation is often not included in models of electronic navigation, Wittenburg, [24] has recently suggested a vector based model akin to that used by the Polynesian navigators sailing between islands. Finally, navigation often includes a social component [1] which entails information exchange between individuals or cooperative problem solving.

One approach to the problem of electronic navigation, which we have found to be beneficial, is to compare navigation in the physical world with navigation in electronic worlds, with a focus on the underlying cognitive structures and the implicit metaphors that are adopted by the navigators of the space [11]. Kim and Hirtle [11] have argued that some of the difficulty in traversing virtual spaces, such as the World Wide Web, is due to the lack of identifiable neighborhoods and notable landmarks. Appropriate formal analyses can also lead to the development of intelligent views of a space, such as modified fisheye views and other "you-are-here" pointers for electronic worlds. In the next two sections, we review principles from the cognitive side of the coin, then in section 4 suggest methods for incorporating these principles into the design of navigational tools.

2 A View from the Real World

Research on cognitive mapping has examined the ability of individuals to acquire and use spatial information. The acquisition of spatial knowledge has been shown to be based on the use of organizing principles, such as the use of hierarchies, reference points, rotational and alignment heuristics and other related principles. These organizing principles, in turn, result in what Barbara Tversky [23] has coined a "cognitive collage" of multimedia, partial information. Inherent within this collage is the ability to extract slices of information sources, such as visual cues, route information or linguistic labels. The collage necessarily operates at multiple levels, allowing one, for example, to discuss and plan a route, using highway systems or one's back alley with equal ease. In our own lab, we have shown that the need to structure space is so strong that subjects will impose hierarchies on an otherwise homogeneous distribution, which results in biases judgment of distance and orientation [15].

2.1 A Theory of Spatial Information

Given this background, a theory of spatial information must then include at least three levels: (1) a theory of the cognitive representation of space; (2) a theory of the use of spatial metaphors in the interface between user and computer; and (3) a theory of the storage of spatial data. The claim is made here and elsewhere (e.g., [16]), that spatial information will be useful to the extent that it is mirrors the internal representation (level 1) and that implied metaphor of the interface must match the adopted metaphor of the user (level 2).

The success of implementing or using spatial concepts will depend in part on the user's ability to understand or comprehend spatial knowledge. Therefore, the first step is consider how spatial information is processed and stored by individuals, not by the spatial information system. Likewise, users of information system typically adopt a physical metaphor for understanding and interpreting the command systems [13, 18]. Appropriate metaphors can lead to improved system usability, whereas inappropriate metaphors can lead to decrement in performance and user errors. The need for the formalization of metaphors for spatial reasoning, as proposed by Kuhn and Frank [12], is necessary for second level of the a spatial information theory.

3 Hypertext Navigation

As an example of how the three levels described above interact with another and the resulting empirical investigations that are necessary to build a complete a theory of spatial information, we consider the role of spatial cognition for the exploration of hyperspace. Several authors have noted that in many systems there is a problem of getting lost (see [11] for a review). This "lost-in-hyperspace" phenomenon occurs for several reasons. First, real space has real constraints, whereas hyperspace does not. Nodes might join in a strict linear order, a tree, a network, a cycle or any number of other topologies. Some topologies are indicative of a book, others of a museum, and others of an unorganized wilderness. You-are-here maps are either absent or uninformative when present.

The World Wide Web (WWW) provides a particularly interesting virtual environment, given the immense size, inherent complexity, and dynamic nature of the Web. The ability to find information in the WWW is dependent on a variety of inter-related factors, including the navigability of the space, the transparency of the information, and the expertise of the user. Tools must support both browsing and searching activities and these should be complementary. Fixed classification schemes were developed for storage, rather than browsing, and should be not be viewed as the solution to the complex problem of finding useful information.

3.1 Graph theoretic approach

Navigability of the graph has been formalized by Furnas [3] among others. Furnas defines an Efficiently View Traversable (EVT) graph to a graph in which the number of outgoing links is smal compared with the size of the graph and distance between pairs of nodes is small compared to the size of the structure. By example, he shows that modification of linear graph into a tree or into a fish-eye view will result in a increase in the traversability of the graph. Here a fish-eye view is taken to mean links from a site to other major headings within nearby neighborhoods are available from a site. Strogatz and Watts [22] have also shown that adding only a few shortcuts dramatically decreases the distances in a network, but that providing additional shortcuts will not improve the efficiency of traversal further.

Furnas [3] argues that traversability is not enough to make it navigable as the navigability depends on the ability to follow a cues. In particular, a space is view navigable (VN) if every node has good residue at every other node and the amount of out-link information is small. Residue is reflected in the semantic content of link labels. Thus, a dictionary has good residue, since in moving from one entry to another, it is unambiguous whether to scan forwards or backwards in the entries. Together, these two ideas, EVT and VN are needed for what Furnas [3] calls Effective View Navigability (EVN). That is, a space must have an efficient structure and appropriate labels to lead a user to find the information that is needed.

3.2 Cognitive map approach

A second approach to the problem of electronic navigation is to turn to the heuristics that people use to navigate physical space. There are different types of spatial knowledge, such as route and survey knowledge. In simple spaces, individuals begin to acquire survey knowledge upon the first exposure to the space, whereas in complex spaces, such as hospitals, survey knowledge is rarely acquired even after years of experience.

Furthermore, aspects of the representation can be generalized to the characteristics of the physical space. For example, architects and urban planners have learned that undifferentiated spaces are harder to learn than rich environments. Even an idea as simple as using different colors on different levels of a parking garage will increase the likelihood of recalling where your car was parked upon return. Thus, aids in helping the user structure space and differentiate neighborhoods should lead to fewer errors and greater satisfaction with hypertext systems [11].

A second solution is to consider the second level of analysis and examine the metaphor that users adopt in hyperspace [6, 11]. Here the focus is on the relationship between the virtual space and the users' understanding of the virtual space. A critical observation is that the virtual space need not have a physical correlate to be easily traversed, and the inclusion of a physical correlate does not guarantee avoiding disorientation. For example, understanding the mapping of a video game that assigns the top row to the bottom row, and the left edge to the right edge is easily understood and visualized, even if it is physically impossible in real-space. Likewise, as people may find themselves lost in a museum of interconnected rooms, the corresponding hyperworld would be equally disorienting [2], even though such a space obviously exists in the real world. Instead, disorientation is often the result of either adopting the incorrect metaphor or the lack of an appropriate metaphor.

On-line aids, such as history trees, maps, and fish-eye views, can assist the user both in developing an appropriate metaphor and locating one's self in the virtual space. Pointers with some degree of redundancy will tend to more useful. However, the exact methods which prove to be of the most use in a given situation will depend on the structure of the virtual space and the preferences of the user. Rarely do most information systems build on both of these factors.

In our own lab, we have most recently begun to explore these hypotheses in hypertext navigation, by examining the role of imposing structural cues in the virtual space. Such studies highlight the benefits and problems in generalizing about navigational behaviors between real space and virtual space.

4 Cognitive principles for electronic environments

To test whether the ability to navigate in space in dependent upon cognitive structures, we have to examine in depth two structural characteristics of the environment: landmarks and regions. Since the writings of Lynch [14], landmarks and regions have been identified as critical components for organizing space. The problem of how to transfer these concepts to electronic worlds is the focus of the two studies.

4.1 Landmarks

The ability to navigate in an environment is dependent upon one's ability to form a spatial representation of that environment, and landmarks play a key role in the creation of such a cognitive map. A landmark is an object or location external to the observer which serves to define the location of other objects (or locations). Heth et al. [7] describe two ways landmarks are fundamental to navigation. First, landmarks are the memorable cues which are selected along a path, particularly in learning and recalling turning points along the path. Second, landmarks enable one to encode spatial relations between objects and paths, enabling the development of a cognitive map of a region. This distinction can also be described as landmark-goal relationships, where landmarks are cues along a path to a goal, and landmark-landmark relationships, which provide a global understanding of the environment [20]. Sorrows and Hirtle [21] argued that landmarks are important for navigation in both real and electronic environments.

Navigation can be considered in both open terrain and networked environments, and these environments may be either physical or electronic spaces. The term 'networked environment' refers to an area where movement is restricted to particular paths, such as cars driving on developed roads or a person following links in a hypertext environment. Open terrain environments are not restricted to movement along predefined paths, for example orienteering, open terrain robot navigation, or visualization interfaces for document spaces. In each of these environments, the purpose of navigation could be any of a variety of tasks or goals, such as directed at arriving a known goal, searching for a possible but uncertain goal, or meandering/browsing in the environment. This leads to the question of what tasks and in what environments landmarks are either beneficial or necessary and what types of landmarks work best in different environments.

In the World Wide Web, Mukherjea and Hara [17] define a landmark as a node which is important to the user because it helps to provide an understanding of both the organization and the content of that part of the information space. Glenn and Chignell [4] describe landmarks as part of a symbol system which is both visual and cognitive, and in which the visual and cognitive functions are intricately tied. Although these and other definitions of landmarks in the WWW seem compatible, a key problem exists in how to determine specifically what nodes are landmark nodes. Algorithms have been proposed which use the connectivity of a node, the frequency of use of a node, and the depth of the node in the local WWW directory structure. Sorrows and Hirtle [21] have extended the typologies of landmarks to include three distinct categories: visual, structural and semantic. The categories are shown to apply to both real and virtual environments.

4.2 Neighborhoods

In many ways, neighborhoods form the dual of landmarks. Whereas landmarks represent a important beacons and/or decision points, regions suggest common constraints, such as, navigation tools, home pages, and indices in the case of electronic worlds.

In our lab, we have begun to explore the nature of electronic neighborhoods. Hirtle, Sorrows and Cai [9] contrasted navigation through a hypertext space, with and without implicit neighborhoods defined, to show that the inclusion of neighborhoods increased the navigability of the space. In this study, neighborhoods were induce by coloring the background of a set of pages to be consistent with the content and structure of the pages in an academic department. For example, faculty pages might be blue and course information might be yellow. Search times were compared with sets of pages where the background was either monotone or colored randomly. Consistent with a theory of spatial information, the spaces where neighborhoods were indicated by color were easier to search.

5 Summary

The ability to locate information in a complex information space requires specialized tools to support searching and browsing behavior. Inherent in browsing is the ability to navigate through informational items, while retaining a sense of orientation. Furthermore, the electronic navigation can be improved through the induction of neighborhoods and the inclusion of landmarks within electronic spaces. Additional research is needed to examine the interaction of electronic structural components with navigational tools.

6 Acknowledgments

The author thanks Molly Sorrows, Misook Heo, Guoray Cai, and the other members of the Spatial Information Research Group (SIRG) at the University of Pittsburgh for their assistance in cultivating the ideas presented in this paper. The ideas also benefited from discussions through the Varenius Project of the National Center for Geographic Information and Analysis and the associated financial support of NSF.

7 References

[1] Dieberger, A. A city metaphor to support navigation in complex information systems. In Hirtle, S. C., & Frank, A. U. (Eds). *Spatial Information Theory : A Theoretical Basis for GIS.* Springer-Verlag, 1997.

[2] Foss, C. L. Detecting users lost: Empirical studies on browsing hypertext, Technical Report No. 972, INRIA, Sophia-Antipolis, 1989.

[3] Furnas, G. W. Effective View Navigation, In *Human Factors in Computing Systems CHI '97 Conference Proceedings*, ACM, 1997.

[4] Glenn, B. T. & Chignell, M. H. Hypermedia: Design for browsing. In H. R. Hartson & D. Hix (Eds.) *Advances in Human-Computer Interaction*, Vol. 3. Norwood, NJ: Ablex Publishing Corp. 1992.

[5] Golledge, R. G. *Wayfinding behavior : Cognitive mapping and other spatial processes.* Baltimore: Johns Hopkins Press, 1999.

[6] Gray, S. Using protocol analyses and drawings to study mental model construction during hypertext navigation. *International Journal of Human-Computer Interaction*, Vol. 2, pp. 359-377, 1990.

[7] Heth, C. D., Cornell, E. H. and Alberts, D. M. Differential use of landmarks by 8-and 12-year-old children during route reversal navigation. *Journal of Environmental Psychology*, Vol. 17, pp. 199-213, 1997.

[8] Hirtle, S. C. & Sorrows, M. E. Designing a multimodal navigational tool for locating buildings on a college campus. *Journal of Environmental Psychology*, Vol. 18, pp. 265-276, 1998.

[9] Hirtle, S. C., Sorrows, M. E., & Cai, G. Clusters on the World Wide Web: Creating Neighborhoods of Make-Believe. In the *Proceedings of Hypertext'98.* Pittsburgh, PA, 1998.

[10] Jul, S., Furnas, G. W. Navigation in Electronic Worlds. *SIGCHI Bulletin*, Vol. 29 (4), pp. 44-49, 1997.

[11] Kim, H., & Hirtle, S. C. Spatial metaphors and disorientation in hypertext browsing. *Behaviour & Information Technology*, Vol. 14, pp. 239- 250, 1995.

[12] Kuhn, W., & Frank, A. U. A formalization of metaphors and image-schemas in user interfaces. In D. M. Mark & A. U. Frank (Eds.), *Cognitive and Linguistic Aspects of*

Geographic Space, (pp. 419-434). Dordrecht: Kluwer, . 1991.

[13] Kuhn, W. Metaphors create theories for users. In A. U. Frank, & I. Campari (Eds.) *Spatial Information Theory: A theoretical basis for GIS*. (pp. 336-376). Berlin: Springer-Verlag, 1993.

[14] Lynch, K. *The Image of the City*. Cambridge, MA: MIT Press, 1960.

[15] McNamara, T. P., Hardy, J. K., & Hirtle, S. C. Subjective hierarchies in spatial memory. *Journal of Experimental Psychology: Learning, Memory and Cognition*, Vol. 15, pp. 211-227, 1989.

[16] Medyckyj-Scott, D. J., & Blades, M. Spatial information systems. *Geoforum*, Vol. 2, pp. 215-226, 1992.

[17] Mukherjea, S. & Hara, Y. Focus+context views of world-wide web nodes. *Hypertext '97: The Eighth ACM Conference on Hypertext* (Southampton, UK). New York, NY: ACM Press, 1997.

[18] Norman, D. A. *Design of everyday things*. New York: Doubleday, 1988.

[19] Passini, R. Wayfinding design: Logic, application and some thoughts on universality. *Design Studies*, Vol. 17, pp. 319-331, 1996.

[20] PastergueRuiz, I., Beugnon, G., & Lachaud, J.P. Can the ant Cataglyphis cursor(Hymenoptera: Formicidae) encode global landmark-landmark relationships in addition to isolated landmark-goal relationships? *Journal of Insect Behavior* Vol. 8(1), pp. 115-132, 1995.

[21] Sorrows, M. E. & Hirtle, S. C. The nature of landmarks for real and electronic spaces. Freksa, C., & Mark, D. M. (eds.) (1999). *Spatial information theory: Cognitive and computational foundations of geographic information science.* (Lecture Notes in Computer Science 1661). Berlin: Springer. 1999.

[22] Watts, D. J. and S. H. Strogatz. Collective dynamics of 'small-world' networks. *Nature*, Vol. 393, pp. 440-442, 1998.

[23] Tversky, B. Cognitive maps, cognitive collages, and spatial mental models. In A. U. Frank and I. Campari (Eds.), *Spatial information theory: Theoretical basis for GIS*, Springer-Verlag, Heidelberg-Berlin, 1993.

[24] Wittenburg, K., Ali-Ahmad, W., LaLiberte, D., & Lanning, T. Polynesian navigation: Locomotion and previewing aspects In *Human Factors in Computing Systems CHI '98 Conference Proceedings*, ACM, 1998.