Navigation in Electronic Worlds
Workshop Report

Susanne Jul
Computer Science and Engineering
University of Michigan
1101 Beal Av.
Ann Arbor MI 48109-2110 USA
+1 313-763-9074
sjul@umich.edu

George W. Furnas
School of Information
3080 West Hall
University of Michigan
Ann Arbor MI 48109-1092 USA
+1 313-763-0076
furnas@umich.edu

http://www-personal.umich.edu/~sjul/nav97

ABSTRACT
This report summarizes a workshop at CHI'97 that focused on issues in navigation in electronic information environments. In addition to trying to clarify definitions of navigation and related concepts, the workshop explored aspects of the psychology of navigation, navigation as a task and properties of worlds (and their content) that affect in how and whether people can find their way around. The workshop also began to explore interactions between tasks, the navigator, the world that is navigated and the content of that world. The workshop drew participants from a broad variety of backgrounds allowing discussion from psychological, theoretical and design perspectives.

KEYWORDS
Navigation, Information Structure, Residue, Scent.

PARTICIPANTS
Keith Andrews, *Graz University of Technology, Austria;* Mark Apperley, *University of Waikato, New Zealand;* Adrijana Car, *Technical University Vienna, Austria;* Stuart K. Card, *Xerox PARC, USA;* Mary Czerwinski, *Microsoft Corp., USA;* Nils Dahlbäck, *Linköping University, Sweden;* Rudy Darken, *Naval Postgraduate School, USA;* Andreas Dieberger, *Emory University, USA;* George Furnas (Organizer), *University of Michigan, USA;* Stephen Hirtle, *University of Pittsburgh, USA;* Susanne Jul (Organizer), *University of Michigan, USA;* Laura Leventhal, *Bowling Green State University, USA;* Jock D. Mackinlay, *Xerox PARC, USA;* Laurence Nigay, *Laboratoire CLIPS_IMAG, France;* Stephen Payne, *University of Cardiff, UK;* Peter Pirolli, *Xerox PARC, USA;* George G. Robertson, *Microsoft Research, USA;* Bob Spence, *Imperial College, UK;* Alistair Sutcliffe, *City University, UK;* Michelle A. Vincow, *University of Illinois, USA.*

INTRODUCTION
Whether in the physical world, the World Wide Web, or Virtual Reality, people need to determine what is in their environment and find their way around. Unfortunately navigation—the process whereby people determine where they are, where everything else is, and how to get to particular objects or places—is often not a simple task: people get lost and their searches frustrated. Electronic worlds provide both special challenges and opportunities in navigation. As electronic worlds become vast, distributed, and more integrated with daily activities, improved support for navigation is increasingly needed. Fortunately, good interface and information design may provide such support and offer new ways of navigating.

Some of the problems of helping people find information in an electronic world are being addressed by search engines. These are not, however, a complete solution, as any users confronted with thousands of only semi-relevant query return items can attest. Not only are such return sets unwieldy, but often queries posed out of the (cyber-)blue suffer because the user has no knowledge ahead of time of what is available (a strength of browsing and navigation), cannot limit their search in a guided supported way (e.g., by sequential navigation towards an area of interest), etc. The increasingly apparent need for interfaces to go beyond the query is manifest in the emergence of a second generation of navigational interfaces to the World Wide Web such as Yahoo! This is simultaneously a return to and improvement upon the Web's original navigational model of interaction, temporarily abandoned in favor of a pure search model. The two models are complementary and need to be understood better—along with the relationship between them—not just in the World Wide Web, but in electronic worlds in general.

This workshop addressed the navigational model of interaction and sought to understand navigation as a user activity, and information and electronic worlds as contexts for that activity. The first objective of the workshop was to establish a dialogue between individuals who are currently separated by discipline and domain, but whose work shares a focus on human navigation. The second objective was to produce a common understanding of navigation, and the issues it raises in electronic worlds, with that understanding to be shared with the greater community of researchers and practitioners. The third and final objective was to draw from this understanding implications for designing better navigational aids and more easily navigable worlds. The focus of this workshop was primarily on theory, the fundamental understanding of navigation and design for navigation, rather than on practice.

This report summarizes the discussions of the workshop. It inherits certain strengths and weaknesses resulting from the broadly varying perspectives of the individuals who came together. The participants all had considerable depth of knowledge in various aspects of navigation, and we often experienced a paradoxically enjoyable frustration in trying to bring coherence to the terminology and conceptual frameworks so we could gain from the richness each brought to the table. The experience was very stimulating, but clearly only a beginning. We offer this report in that same work-in-progress spirit.

ORGANIZATION

Twenty individuals were selected from an outstanding pool of fifty-nine applicants for the two-day event. Selection decisions were based on position papers submitted in response to an open call for participation. Participants were chosen with a goal of ensuring representation from industry and academe, research and practice, theory and design, and understanding of psychology, information science, and computer science. All participants were requested to prepare for the workshop by reading all position papers of other participants and by preparing mini-posters about themselves. The mini-posters, which were displayed on the walls, contained a one-sentence definition of navigation, an enumeration of the participant's three favorite navigational aids and a description of two of the most important research issues in navigation. Additionally, some participants were asked to prepare materials for group discussion. After an introductory session led by the organizers, sessions alternated between group discussions led by participants (who had prepared materials in advance) and ad hoc breakout sessions.

DISCUSSION HIGHLIGHTS

Early discussions focused on definitional questions and on gaining a fundamental understanding of navigation and navigational concepts. Later discussions then moved on to factors that affect navigation including properties of information and information spaces. Concluding discussions concerned implications for design and needs for further research. Notably, affective and aesthetic factors came out in almost all discussions, but were never an explicit session topic.

The Blind_2 Leading the Blind_1

The workshop started with an exercise aimed at giving participants a shared, first-hand experience with navigation. Participants were sent out, in pairs, to wander the conference hotel with one member of the pair blindfolded. For five minutes the sighted partner tried to disorient the blindfolded partner. Then each pair, having wandered to various random places in the hotel, opened a sealed envelope with new instructions. They were to change the blindfold to the other partner, and the formerly sighted (now unexpectedly blindfolded) partner was to direct the formerly blindfolded (now sighted) partner back to the starting place. Note that at this point neither partner would have found it easy to find the way back alone: the well-oriented person was now blindfolded, and the sighted person was disoriented. They had to reflect on, communicate about, and work with their respective partial knowledge and fragmented experience. To mirror the real world fact that navigation is rarely the only task one must do at any given time, over the course of the navigational exercise, partners had, as a distractor task, to learn a series of personal facts about each other.

Not surprisingly, the factor cited as being the most helpful was prior familiarity of the space. Other comments revealed the role of serendipity—brushing against a plant—and the use of multiple modalities—seeing, later hearing, a fountain, or remembering a change from a hard to a carpeted surface. The importance of stability of the space was emphasized by the disruptions caused by stairs and elevators, particularly when it was necessary to equate these two kinds of movement in vertical distance traveled, and by random changes, such as a door being closed that before had been open. Many of the reactions were emotional in nature, relating to feelings of discomfort, safety, stimulation, etc. These brought out the importance of a recovery or fall-back strategy—take off the blindfold—and reliance on safety provisions in the environment—walls and the partner. The potential high cognitive overhead for the navigation task was clear in that everyone periodically had to stop the secondary task of getting to know each other in order to concentrate on navigation. We finished the exercise by discussing briefly how each of these observations might generalize to navigation more generally.

In Pursuit of Definitions

One of our early efforts was to clarify what we meant by "navigation." We used the twenty definitions prepared in advance by the participants as a starting point for discussion. It was immediately clear that navigation is many things to many people, for instance:

> *Navigation is ... about finding your way confidently and successfully to your goal while discovering fresh delights along the way.*
>
> Mark Apperley

> *Navigation is the cognitive process of acquiring knowledge about a space, strategies for moving through space, and changing one's metaknowledge about a space.*
>
> Laura Leventhal

> *Navigation = Wayfinding + Locomotion*
> *"Knowing where to go" + "Getting there"*
>
> Rudy Darken

> *Navigation is getting lost.*
>
> Jock Mackinlay

Basic aspects of navigation

After some discussion of the individual definitions, there were four basic aspects upon which everyone could readily agree. While they do not constitute a definition, they will likely be essential to one:

Locomotion

Something moves—either the navigator or an object that is the focus of the navigator's attention. This assumes a concept of *location*, in particular, a *here* and a *there* (or not-here). The movement is *directed*, i.e., deliberate decisions are made in choosing among locations. The movement is *purposeful* in that it is undertaken in service of meaningful goal.

Decision-making

In being a directed and purposeful activity, decisions must be made continually regarding strategies for reaching the goal and determining whether the goal has been reached. These decisions sometimes follow a plan and sometimes respond to the environment. They depend on both declarative and procedural knowledge and frequently require coordination of knowledge in different forms (orientation).

Process

Navigation is an incremental real-time process that integrates these two components (locomotion and decision-making).

Context

Each navigation process takes place in a particular information environment (set of locations) and is inextricably tied to that environment.

Several other important common themes were noted. The navigator's subjective experience was thought to play an important role in navigation: many participants' individual definitions used words with significant affective content such as "safe," "graceful," "confident," and "fresh delights." As noted above, Mackinlay pointed out that errors are unavoidable in the navigation process, so it was generally agreed that recovery strategies are essential. Attention management is also a critical issue since navigation usually competes with other cognitive processes. Finally it was noted that the process is potentially collaborative and social.

The navigation task distinguished

As a continuation of the definitional discussion, Furnas presented some distinctions among concepts closely related to navigation. First he distinguished between two tasks, *searching* and *browsing*, and two tactics, *querying* and *navigation*, for accomplishing those tasks. These two distinctions are fairly independent as shown in Figure 1 and are characterized as

Searching

The task of looking for a known target.

Browsing

The task of looking to see what is available in the world.

Querying

Submitting a description of the object being sought (for instance, using keywords) to a search engine which will return relevant content or information.

Navigation

Moving oneself sequentially around an environment, deciding at each step where to go next based on the task and the parts of the environment seen so far.

		Tactics	
		Query	Navigate
Tasks	Search		
	Browse		

Figure 1 Task/tactics distinction

Note that, for example, one can search by either query or navigation, and that, while typical browsing activity uses a navigational approach, one could "browse" a database by giving it off-hand, exploratory queries.

Furnas then presented a taxonomy of navigational subtasks developed by Jul and Furnas:

Locomotion

Mechanics of moving a single step.

Steering

Mechanics of controlling each step of locomotion.

Traversal

Stringing together sequences of steering steps to move larger distances in a world.

Route following

A traversal involving accurately following a deliberate path, e.g., from some given starting place to some final place.

Route finding

Finding a good path, e.g., from a starting place to destination, with desired properties for the path and destination.

Map building

Constructing a representation—mental or physical—with spatial structure to aid multiple route following and finding tasks.

An additional subtask, *orientation*, plays an important role in each of these tasks. It involves aligning one representation of the world with another or with the world itself: e.g., using a compass to line a map up with the world, connecting some place in one's mental representation with the current location in the world. *Error recovery* was again invoked as another fundamental cross-cutting task.

Psychology of Navigation

Hirtle presented an overview, prepared with Dahlbäck, on the psychology of navigation in the real. In the real world people use landmark, route and survey [8]. Landmarks are conceptually and perceptually distinct locations. Route knowledge is understanding of the environment described in terms of paths between locations and relative to locations along those paths. Survey knowledge describes the relationships among locations, e.g., in the form of maps. All forms of knowledge may be acquired either through navigating the world or by studying maps although there are differences in the processes and, in the short term, in the properties of the knowledge acquired [9]. Survey knowledge can be impossible to obtain in complex environments. Landmarks and regions play an important role in helping people to structure the world

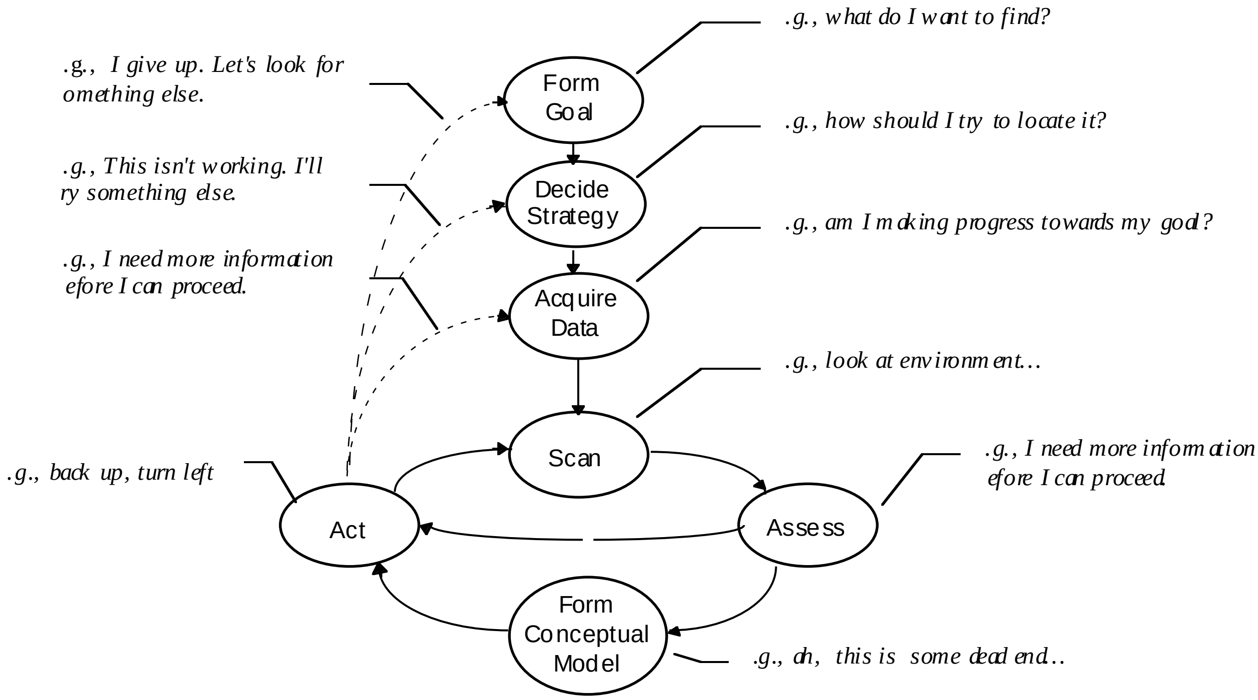

Figure 2 A General Framework for the Navigation Process

conceptually [1, 4]. Navigational planning occurs at multiple levels—conceptual, path and motor (affirming the task taxonomy of Jul and Furnas). Of course, individuals vary in what form of knowledge they favor and in expertise in different levels of planning. Hirtle cited work illustrating navigation as a multi-level activity [10] and work describing navigational knowledge as a "cognitive collage" [11] of information in different formats, points of view, etc.

Framework for the Navigation Process

Darken, Nigay, Robertson, Spence and Vincow elucidated a general framework for action proposed by Spence and considered how it might be elaborated for navigational activity. The general framework is shown in Figure 2. A navigation task begins with the navigator deciding what the object of the task is to be. Are we looking for a specific item? A group of items? Information about the contents of the space? Next, a strategy or plan must be devised to accomplish this task. Do we use a search engine? Follow semantic categories (e.g. Yahoo!)? Use road signs? Information may be needed to guide the execution of the navigation task. This might come from a map, asking directions, or other external source. Finally, the actual execution of the task begins. The navigator scans the environment for relevant information to the task. An assessment is then made as to whether or not this is what was expected and, possibly, whether adequate progress is being made towards completion of the task. All the while, information about the environment is being collected in a conceptual model (e.g., a cognitive map). Based on the results of the assessment, an action is taken. This could be an actual movement such as following a hyperlink or turning left at the next intersection. It could also be a cognitive movement such as giving up on the task and starting a new one, giving up on the strategy and reformulating a new one, or deciding to seek external information again (e.g., consult a map).

Situated vs. Plan-based Navigation

Czerwinski et al. examined the differences between situated and plan-based navigation. They characterized situated navigation as employing situation-specific knowledge, landmarks, and incomplete information. It is a reactive strategy that is employed when the goal looks achievable and/or close. They characterized plan-based navigation as employing survey knowledge and generating, in advance, a complete plan for achieving goal. It is used for general navigation to the goal. They noted that error recovery, in each case, often involves switching to the other strategy. For example, after getting lost following signs, you may stop and consult a map. Individual differences impact which strategy is favored, e.g., the navigator's expertise, domain knowledge, spatial abilities. The group identified several design approaches for supporting either navigational strategy, including highlighting salient landmarks, providing aid in constructing an overview of the world, using distinctive multimodal cues, providing information and feedback of proximity to target, constraining search possibilities and/or the view.

Designing for Navigation

Dahlbäck, Darken, Nigay, Payne, Sutcliffe and Vincow worked to develop a characterization of issues in designing for navigation. This was based, in part, on a discussion prepared by Darken and Leventhal on Models of Navigation. They identified four types of issues, as

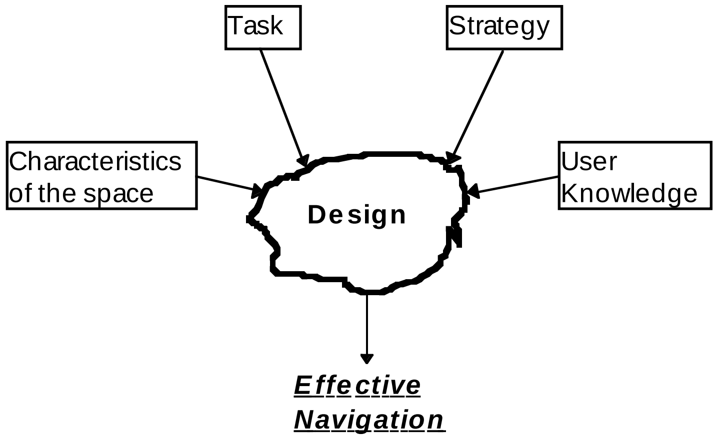

Figure 3 Designing for Navigation

illustrated in Figure 3: characteristics of the space (world to be navigated), task, strategy and user knowledge. These are approached differently by different groups: Designers need a framework of the issues, while researchers need a framework of past and future research on the issues. Characteristics of the space include its topology (whether it is continuous or discrete, if continuous—its dimensionality, if discrete its type—tree, directed acyclic graph, general graph, etc.), what movement is possible and how movement is constrained, what frames of reference are available and the density and discriminability of cues (see also *Cues Leading to Relevant Info* later in this report). Tasks include search and learning. Search issues include number and existence of targets, the goodness of fit of specifications of entities, and what they called "connotative" (properties) versus "denotative" (names) descriptions of entities in the world. Learning issues can be divided into naive search, perceptual learning, and conceptual learning. Strategies can be based on topological considerations or on information retrieval techniques. Issues of user knowledge include knowledge of domain, device, world as well as understanding of task and strategies, and encompass syntactic and semantic knowledge.

Levels of Structure/Semantics

Apperley, Car, Jul, Leventhal and Spence discussed different types of structure that need to be considered in navigational design. They identified three levels of structure, as illustrated in Figure 4: the inherent structure of the information, the imposed structure and the user's cognitive map. For example, in the World Wide Web there is an inherent physical structure of files and network topology. Links provide an imposed structure that may or may not be made evident by a browser. Finally, each user has a cognitive map of the information that may relate it to specific tasks or topics. The group noted that there may be multiple imposed structures to a body of information. These may be constrained by the inherent structure and, in addition, may be imposed by the designer of the presentation, by properties of the world in which it is placed, or by a browsing tool. The user's cognitive map is based on the user's previous knowledge, experience and their views of the imposed structure. The group pointed out that it is most commonly an imposed structure that is navigated.

Moderated vs. Non-Moderated Information Spaces

In a presentation related to levels of structure, Apperley et al. pointed out that navigation is strongly influenced by the extent to which the information space has been moderated, that is, the extent to which its structure has been coordinated or controlled. In a moderated information space—typically an "in-house" world or a controlled web—inherent structure can be dictated and metadata made available generally. The space is fully "known" in advance so the moderator can provide a definitive map of it. Navigational aids can be tailored for and integrated with the information. In a non-moderated world—such as the World Wide Web—structure tends to be anarchic and metadata must be derived. The space is not fully known, so navigators must construct their own maps and depend on serendipitous discovery. Navigational aids tend to be observed, subtle, subliminal and are often retrospective in nature.

Cues Leading to Relevant Info

Andrews, Furnas, Hirtle, Mackinlay and Pirolli worked to develop the concepts of *navigational residue* or *scent* discussed by Furnas [2, 3] and Pirolli [6]. While the concepts are equivalent, the differing metaphors used to describe them highlight different perspectives. Other names suggested were "trace," "hints," and "cues." The basic insight is that, in order to navigate through a world with minimal prior knowledge of its layout, each local view must present information (e.g., signs, labels, views of distant landmarks, etc.) that will help the navigator make their next navigational decision. This information directs the navigator towards distant objects, and so can be thought of as residue or scent of such objects.

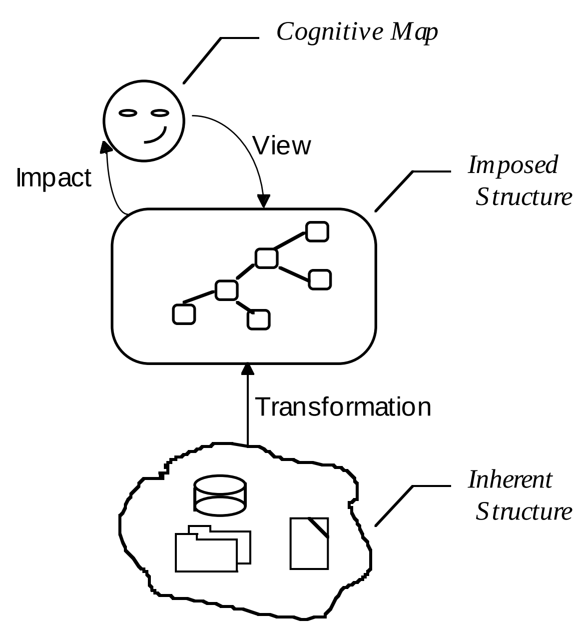

Figure 4 Levels of structure

Navigation requires that you can always find such traces of your arbitrary remote target near your current location, and that those traces must not be misleading—they must draw you off in the right direction. Furthermore, a single navigational clue must generally lead to groups of objects—there is no room for individual labels to everything. This means that the clustering structure and the labeling (residue or scent) must be carefully designed together if navigation is to be possible. Note that decisions to arrange or group distant objects can be made on the basis of their content or on the basis of the relationships between them (e.g., the link structure [7]). Residue information may be static or dynamic. Static residue may be embedded in the content of information objects whereas dynamic may be tailored for the particular circumstance of the current view.

The *CARE* properties—Complementarity, Assignment, Redundancy and Equivalence—developed by Nigay [5] may be used to describe relationships between cues. For example two cues can be used in a complementary way for conveying information about near and distant objects.

The group identified a variety of issues that need to be considered including the possible need for different cues for nearby and faraway information, and meaningful ways of aggregation in information structures (hierarchy, hypercube, lists, graphs, etc.).

RESEARCH ISSUES

From the many research questions brought forth in the course of the workshop, participants identified a set of issues that seem to be of particular interest at this time:

Characterizing the Navigation Process

How can we characterize the navigation process that users go through in both its detail and variety?

Integrated Taxonomy

What are different kinds of information spaces/structure and different kinds of navigation related tasks? What are the consequences for navigational processes and strategies?

Navigational Aids Survey

What navigational aids have been used or proposed? How and why do they work? What navigational processes and strategies do they support? (A long but preliminary list was compiled at the workshop and may eventually appear.)

Design Process of Navigational Worlds

What are the design and solution spaces for navigational design. What are the characteristics of successful visualization and navigational techniques? Are there special design methods that are particularly useful for navigational design?

Scalability

How can navigation succeed as electronic worlds get ever larger?

Residue/Scent

How can nearby clues of remote information be managed so that it is both usable and useful.

Mapping Between Structure and Semantics

What are the relations between semantic structures and visualization structures? What structures are appropriate to which tasks? What is the nature of the interaction between the inherent structure, imposed structure and the user's cognitive model? How does the extent to which the inherent structure has been moderated affect the imposed structure?

Social Navigation

Often people can help each other find things, leading to the general question of what social process act as navigational aids? How can these be supported?

CONCLUSIONS

The discussion was broad and far-ranging reflecting the breadth of the topic and the diversity of the participants. While no definitive solutions were reached, much of the problem space was laid out. It seems clear that navigation is a situated task that frequently and rapidly alternates between discovery and plan-based problem-solving. As such, it is important to understand each of the components of the task—the navigator, the world that is navigated and the content of that world, but equally important to understand the synergies between them. Affective and aesthetic factors, initially under-appreciated by many participants, proved their significance by continually resurfacing in discussions.

If the size of the applicant pool was any indication, the workshop represents a growing interest in various aspects of navigation, particularly as it applies to electronic worlds. The many discussions among researchers with various backgrounds left us with an appreciation for the richness of navigation, and hopefully will encourage a deeper understanding of its various phenomena and how they can be related to design in the coming years.

ACKNOWLEDGMENTS

We would like to thank all the participants in the workshops for their efforts before and during the meeting, for their contributed notes, and their feedback on drafts. We would also like to thank the ACM for its support of this CHI activity.

REFERENCES

1. Couclelis, H., Golledge, R. G., Gale, N., Tobler, W. (1987). Exploring the Anchorpoint Hypothesis of Spatial Cognition. *Journal of Environmental Psychology*, 7, 99-122.
2. Furnas, G. W. (1995). Effectively View-Navigable Structures. Paper presented at the 1995 Human Computer Interaction Consortium Workshop (HCIC95), Snow Mountain Ranch, Colorado, Feb. 17, 1995. Manuscript available at `http://http2.si.umich.edu/~furnas/POSTSCRIPTS/EVN.HCIC95.workshop.paper.ps`
3. Furnas, G. W. (1997). Effective View-Navigation. *Human Factors in Computing Systems CHI '97 Conference Proceedings*, New York, NY: ACM Press, 367-374.

4. Hirtle, S. C., Jonides, J. (1985). Evidence of Hierarchies in Cognitive Maps. Memory & Cognition, 13(3), 208-271.

5. Nigay, L., Coutaz, J. (1995). A Generic Platform for Addressing the Multimodal Challenge. *Human Factors in Computing Systems CHI '95 Conference Proceedings*, vol. 1, New York, NY: ACM Press, 98-105.

6. Pirolli, P. (1997). Computational Models of Information Scent-Following in a Very Large Browsable Text Collection. *Human Factors in Computing Systems CHI '97 Conference Proceedings*, New York, NY: ACM Press, 3-10.

7. Pirolli, P., Pitkow, J., Rao, R. (1996). Silk from a Sow's Ear: Extracting Usable Structures from the Web. *Human Factors in Computing Systems CHI 96 Conference Proceedings*, New York, NY: ACM Press, 118-125.

8. Siegel, A. W., White, S. H. (1975). The Development of Spatial Representations of Large-Scale Environments. In Reese, H. W. (Ed.). *Advances in Child Development and Behavior, Vol. 10*. New York: Academic Press.

9. Thorndyke, P. W., Hayes-Roth, B. (1982). Differences in Spatial Knowledge Acquired from Maps and Navigation. *Cognitive Psychology*, (Oct.) vol. 14(4), 560-589.

10. Timpf, S., Volta, G. S., Pollock, D. W., Egenhofer, M. J. (1992). A Conceptual Model of Wayfinding Using Multiple Levels of Abstraction. In Frank, A. U., Campari, I., Formentnini U. (Eds.) *GIS — from Space to Theory: Theories and Methods of Spatio-Temporal Reasoning*. Lecture Notes in Computer Science. Berlin Heidelberg: Springer-Verlag. 348-367.

11. Tversky, B. (1993). Cognitive Maps, Cognitive Collages, and Spatial Mental Models. In *Proceedings of European Conference, COSIT '93: Spatial Information Theory - A Theoretical Basis for GIS*. Marciana Marina, Elba Island, Italy. Lecture Notes in Computer Science. Springer-Verlag. 14-24.