**Title**: Indoor Navigation Aids for Visually Impaired People: Developing Cognitive and Computational Foundations

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**Abstract**

Full participation in modern society requires *mobility*. It is so simple that most people take it for granted, but finding one's way across campus to a class, locating one's doctor's office in a large medical center, or just walking down the street to meet a friend can be difficult or impossible for people with visual impairment. Existing aids such as the white cane and guide dog are of great help, particularly in avoiding obstacles along one's way. However, they do not solve other key problems faced by visually impaired people especially for indoor navigation aids, including route planning, learning spatial layouts, and discovering landmarks or other points of interest. Thus, there is an opportunity to develop new technological navigation aids for visually impaired people.

This proposal pursues that opportunity. The overarching goal is to develop new scientific knowledge and embody it in a prototype computational navigation aid, tailored specifically for indoor navigation. Achieving this goal requires applying knowledge from a variety of specialties, solving challenging problems in each, and integrating the results; these specialties include cognitive science and computer science. Theories of spatial cognition are necessary to identify information processing subtasks (e.g., obstacle avoidance, wayfinding, and localization), environmental cues and information resources required to complete these tasks, and the cognitive demands associated with particular presentations of information. Research in human-computer interaction (HCI) is required to systematically map the space of multimodal navigation interfaces and produce particular interfaces tailored to specific users, tasks, and use situations. Closely allied research in spatial databases is required to represent spatial knowledge, query for upcoming or nearby landmarks, and compute efficient and easy-to-follow routes. Collaboration across these areas is needed to solve many of these problems, e.g., learning the structure of a new space, and to produce a working prototype navigation aid.
PROJECT DESCRIPTION

Imagine you are blind or severely visually impaired. You have an appointment with an orthopedic specialist in a large, unfamiliar medical complex. The taxi drops you off at the main entrance. Using your white cane or guide dog, you find your way into the lobby. You know that the doctor is in room 715, but you can’t read the printed signs and you don’t know the building layout. You are not even sure where the elevators are, and whether there are steps, furniture or other obstacles in the lobby. Although you are independent and determined to find your own way, despite the risk of getting lost or bumping into things, you wonder wistfully why modern technology can’t yet provide you with equipment to help guide you to your destination.

This scenario shows the needs for navigation aids for visually impaired people and the difficulties faced by people with visual impairment for mobility. Independent travel through urban environments, including complex indoor spaces such as schools and office buildings, is an important prerequisite for full participation in modern society. The four million Americans with visual impairment (including those who are blind and those with low vision) are threatened with reduced mobility, limiting their opportunities for education, employment, commerce, and social interaction. Existing navigation aids, such as the white cane and the guide dog, provide important help, specifically to avoid obstacles. New technological aids that incorporate GPS guidance (Figure 1) provide additional help for outdoor navigation. However, there is a significant unmet need for navigation aids for indoor spaces.

Figure 1. Outdoor Navigation Aids (GPS, Braille notetaker, and guide dog). A GPS receiver on the shoulder strap is connected to a portable Braille notetaker. Software on the notetaker identifies current position and nearby points of interest, and helps with route planning.

The long-term goal of the proposed research is to build the cognitive science and computer science foundations required for effective technological assistance for visually impaired people. We will embody and test our ideas in a prototype navigation aid. Achieving this goal will require us to address many challenging research questions, such as the following. What are the critical cognitively demanding tasks for indoor navigation? What information is essential to help people do these tasks? How can it be presented in ways that impose minimal extra cognitive burdens and do not interfere with environmental cues? How can necessary information be sensed from the
environment and represented efficiently, thus enabling the computation of critical navigation assistance functions such as route planning and obstacle avoidance?

To achieve our goal and address these questions, we will pursue three specific research activities. First, we will apply theory from spatial cognition to guide the design of experiments to identify key user tasks, the information resources required to complete these tasks, and the cognitive demands inherent in these tasks. Second, we will develop a framework for producing multimodal presentations of navigation information; the framework will catalog the variety of ways – speech, non-speech audio, haptics, and visual – that information can be presented and include an algorithm for generating coherent multimodal presentations that satisfy user preferences, minimize cognitive demand, and avoid interferences with environmental cues. Third, we will extend spatial database models and develop algorithms to represent critical information about indoor spaces, create navigable maps, efficiently process user-centered queries, and compute routes that are efficient in both distance traveled and cognitive demand required to follow them.

We will embody our research results in prototype navigation aids to test our ideas. The ultimate goal is to create a navigation aid using an instrumented white cane and a personal digital assistant (PDA). In this proposal, we will develop an initial prototype using laptops, not PDAs, due to the availability of superior computing hardware and software on laptops. The laptops have been already acquired before and been available for the prototype development. Mobile computing devices, e.g., PDAs and laptops, will take advantage of available context (e.g., service to acquire maps for a new building) by exploiting mobile computing standards, e.g., open location services and ubiquitous service discovery protocols, to facilitate interoperability of navigation aids across different buildings and possibly across indoor and outdoor spaces.

A team able to take on these challenges requires broad expertise, in the topics of visual impairment, cognitive science, human-computer interaction, and spatial databases. We have that team. Gordon Legge is an internationally recognized scholar in cognitive science and low vision research. Being visually impaired, he brings both professional and personal insights to the topic of this proposal. Loren Terveen is an internationally recognized leader in the area of human-computer interaction (HCI). Shashi Shekhar is an internationally known scholar in the area of spatial databases and was elected an IEEE Fellow for contributions to spatial database storage methods, data mining, and geographic information systems.

One of the co-PIs, Dr. Legge also participates in a multi-institutional consortium for the development of wayfinding technology for visually impaired people. Through the consortium, he is actively collaborating with the Sendero Group LLC, a leading company in applications of outdoor GPS technology for use by visually impaired people. We plan to connect with the Sendero Group LLC to extend accessible navigation aids using GPS to indoor space in this proposal. The PI and co-PIs have significant experience in collaborative interdisciplinary research projects and have been working for several years. We recently teamed up and submitted a proposal to the National Science Foundation (NSF) Universal Access Program to support the fundamental research on this topic, which also got a support letter from the DTC. The proposal was well received by the NSF and got a “Highly Competitive” summary rating (based on 1 Excellent and 4 Very Good reviews). However, this proposal was not funded due to the lack of track record of the collaboration between cognitive science and computer science. DTC seed money will go a long way to establish this track record to develop a prototype for the proposed indoor navigation aids for visually impaired people, which will also help us prepare for other external funding opportunities in the near future, e.g., resubmitting the revised proposal containing the preliminary results from this proposal to the NSF Universal Access Program.
BUDGET AND BUDGET JUSTIFICATIONS

A graduate RA will be identified who has the expertise in human-computer interactions and spatial databases, and also interest in the cognitive and/or user-interface aspects necessary for human performance testing. The budget for the graduate RA will be $25,671 (9 months, 50%). The detailed budget information is available as follows:

- Salary: $18.90/hr (assumes a 3% increase) * 780 hrs = $14,472
- Tuition: $11.10/hr worked (est. in phase II budget instructions) * 780 hrs = $8,658
- Health benefits: 12% (est. in phase II budget instructions) * salary ($14,472) = $1,737
- Network and Computer Service fees @ $1.30/hr * 780 hrs = $804

Totally, 50% RA w/tuition benefits (9 months): $25,671

The graduate RA will dedicate time to the following three research tasks and develop the prototype for the proposed indoor navigation aids for visually impaired people.

T1. Identifying User Tasks and Information Needs
We must begin by understanding the major tasks that visually impaired people face when navigating in indoor environments. We also need to identify key information necessary to perform these tasks, learn user technology preferences, and uncover other user requirements. The literature and our previous research suggest two high-level navigation tasks: exploration and routing. We will observe and probe subjects engaged in everyday navigation activities to see how well these two task descriptions apply and refine them as necessary. Previous work and theory suggest that certain information is useful for these navigation tasks. For example, the Maplet theory states that local geometrical information, e.g., configuration of the current intersection, is sufficient to learn a layout through free exploration.

We will use methods that (a) are appropriate for naturalistic contexts (instead of laboratory settings), and (b) allow us to test design ideas very early in the process. In particular, we expect to use a version of a contextual interview, modified and augmented as necessary to take into account that the “work context” is a relatively brief walk through a building. This research activity will identify key navigation tasks faced by visually impaired users, important information used to complete these tasks, user technology requirements and information delivery preferences. Dr. Legge and Dr. Terveen will work closely with the RA on this task.

T2. Measuring Cognitive Demands of Specific Tasks for Navigation Technologies
Although input from verbal messages can support the development of cognitive maps, the process appears to be less automatic and probably more cognitively demanding than normal visual input. We plan to develop a dual-task method for measuring cognitive demand during wayfinding. In a typical dual-task procedure, subjects perform a Primary task and a Secondary task concurrently. In one variant of this procedure, the demands on cognitive function (working memory, attention, etc) of the primary task are assessed by measuring decreased performance on the Secondary task while inducing the subject to maintain constant, high performance on the Primary task.

The major outcome of this study will be a method for assessing the cognitive demands associated with wayfinding and measurements of the cognitive demands of specific navigational technologies. Dr. Legge will work closely with the RA on this task.
**T3. Developing Representation, Algorithms, and Interfaces for Navigation Aids**

Task **T1** will tell us what types of navigation information users need, and reveal user preferences for information presentation. Task **T2** will produce knowledge about the cognitive demands imposed by various presentation modes and specific options. We will augment our results with analyses of prior empirical and theoretical work to produce a 'catalog' of possible and preferred ways to present particular types of information; we call these *mappings*. For example, *distance-to-destination* might be expressed by the loudness of an audio tone, a spoken utterance, or the amount of vibration in a vibro-tactile alarm. For each of these options, we will note user preferences and cognitive demands.

We need a way to represent the mappings, and then compute coherent multimodal presentations. First, we will create a formal language and spatial database support for representing mappings. Next, we will develop a synthesis component. Once the formal representations and algorithms are specified, a working implementation must be created to drive the prototype navigation aid. We will explore different possibilities. These might range from a real-time generator that continuously applies its full set of synthesis rules to another that 'compiles' many parameters to produce user and task-specific implementations. Dr. Shekhar and Dr. Terveen will work closely with the RA on this task.
Biographical Sketch for Shashi Shekhar

Shashi Shekhar is currently a Professor of Computer Science at the University of Minnesota, Minneapolis, MN, USA. He was recently elected an IEEE fellow for contributions to spatial database storage methods, data mining, and geographic information systems. He has co-authored a textbook on Spatial Databases (Prentice Hall, 2003, ISBN 0-13-017480-7) and has published over 150 research papers in peer-reviewed journals, books, and conferences, and workshops. He is a co-Editor-in-Chief of Geo-Informatica: An International Journal on Advances in Computer Sc. for GIS and a member of the NAS/NRC Mapping Science Committee. He served on the Board of Directors of University Consortium of UCGIS (2003-2004), the editorial boards of IEEE Transactions on Knowledge and Data Eng. as well as the IEEE-CS Computer Science & Eng. Practice Board. He also served as a program co-chair of the ACM Intl. Workshop on Advances in Geographic Information Systems, 1996. Shekhar's research accomplishments include databases for managing spatial graphs (e.g. road maps), parallelization of GIS, routing algorithms for Advanced Traveler Information Systems, and archival of traffic measurements. His group has developed, CCAM, one of the most efficient clustering and indexing methods for large road maps as well as algorithms for path evaluation as well as for computing shortest paths. More details are available on http://www.cs.umn.edu/~shekhar.

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Professional Preparation
1990  Ph.D., Computer Science University of California, Berkley
1989  M.S., Business Administration University of California, Berkeley
1987  M.S., Computer Science University of California, Berkley
1985  B.S., Computer Science Indian Inst. of Tech., Kanpur, India
Appointments
2001- Professor, University of Minnesota, Minneapolis, Minnesota
1995-2000 Assoc. Professor, University of Minnesota, Minneapolis, Minnesota
1989-1995 Asst. Professor, Univ. of Minnesota, Minneapolis, Minnesota
Research Interests
Data and knowledge engineering, spatial database management, spatial data mining, and geographic information systems.
Five Related Publications
Five Other Publications


Synergetic Activities
- Active participation in broadening the participation of groups underrepresented in science via supervising over two dozen undergraduate (UG) students from historically black colleges in Army High Performance Computing Research Center annual summer workshops (1997-present), NSF Research Experience for UGs (1999) and UG Research Opportunity Program (UROP).

Collaborators and Other Affiliations
- In past 48 months I have collaborated with Prof. V. Kumar, Prof. J. Srivastava, Prof. P. Schrater, Prof. T. Burke, Prof. M. Bauer, Prof. M. Donath, Prof. A. Tripathi, Prof. G. Karypis, Prof. J. Riedl, Prof. J. Konstan, and Prof. L. Terveen (all Univ. of Minnesota);
- My thesis advisors were Prof. C. V. Ramamoorthy and Prof. L. A. Zadeh (all University of California, Berkeley).
- I supervised the Ph.D. thesis of Prof. T. A. Yang (U. Connecticut), Prof. B. Hamidzadeh (Boeing Research), Prof. Duen Ren Liu (Taiwan), Dr. Mark Coyle (Siebel), Dr. Siva Ravada (Manager, Oracle Spatial Data Group), Dr. Ms. Xuan Liu (IBM TJ Watson Research Center), Dr. C. T. Lu (Northern Virginia Center, Virginia Tech), Dr. Ms. Weili Wu (UT Dallas) and Dr. Ms. Huang Yan (U North Texas).
- I supervised post-doctoral work of Dr. S. Chawla (University of Sydney), Prof. B. Y. Hwang (Korea), Prof. H. Diwakar (Pune U., India), Dr. F. Polat (Bilkent U., Turkey), Prof. I. Singh (India).
Gordon Legge is a Distinguished McKnight University Professor of Psychology and Neuroscience at the University of Minnesota, with specialization in visual perception and cognition. He is director of the Minnesota Laboratory for Low-Vision Research, and recently completed a 5-year term as director of the university’s Center for Cognitive Sciences. He is the PI on two R01 grants from NIH, an NIH MERIT Award winner, recipient of the Pisart Vision Award, and the 2003 recipient of the College of Liberal Arts Dean’s Medal. He is a member of the editorial board of Journal of Vision, and recently served on NIH’s National Advisory Eye Council.

Legge’s research has been internationally recognized for translating the principles and methods of basic visual science into an understanding of difficulties encountered by people with low vision. One practical outcome of his research is the development of the MNREAD Acuity Chart for use in normal and low vision. He was a member of a National Research Council committee involved with the redesign of U.S. currency bills. One result of the committee’s work is the large-print numerals on the new bills which are helpful to people with low vision.

Currently, projects in his lab focus on the roles of vision in reading and spatial navigation, and reorganization of visual areas of the brain resulting from different forms of vision impairment. The research on spatial navigation is a new topic for Legge. He brings his expertise in vision research and vision rehabilitation applications, to this important problem in spatial cognition.

(I) Preparation:
Massachusetts Institute of Technology, S.B., 1971, Physics
Harvard University, Cambridge, Massachusetts ,M.A., 1972 , Astronomy
Harvard University, Cambridge, Massachusetts, Ph.D., 1976, Experimental Psychology
Cambridge University, Physiological Laboratory, Post-Doc, 1976-1977, Vision Research

(II) Appointments
1996-Present: University of Minnesota: Distinguished McKnight University Professor in Psychology and Neuroscience
1999-2004: University of Minnesota, Center for Cognitive Sciences, Director
1998: Institute for Comparative Studies of Culture: Visiting Fellow, Tokyo Woman’s Christian University
1991-1997: University of Minnesota: Director of the Cognitive and Biological Psychology Program
1991: Visiting Scholar, School of Optometry, University of California, Berkeley
1984-Present: Professor, Department of Psychology, University of Minnesota
1983-84: Visiting Scholar, Physiological Laboratory, Cambridge University
1981-84: Associate Professor, Department of Psychology, University of Minnesota
1977-81: Assistant Professor, Department of Psychology, University of Minnesota

(III) Publications
a) 5 Related Publications:

b) 5 Other Publications:


(IV) Synergistic Activities

1) Co-Inventor of MNREAD Reading Acuity Chart: This new type of eye chart provides an assessment of reading vision that goes beyond the traditional letter chart. It has particular application in quantifying the reading difficulties of people with impaired vision. The chart is available commercially through Lighthouse International in New York. Japanese, Italian, French and Portuguese versions of the MNREAD chart have been developed in collaboration with international colleagues, and a Spanish version is in process.

   2) 1999-03 National Advisory Eye Council, NIH: Responsibilities of membership included oversight of NIH’s external grant programs in the area of vision and ophthalmology, with special reference to research related to visual impairment. Organizer of a series of regional workshops on research opportunities in low vision.

   3) 2000-01 National Research Council Committee on Disability Determination for the Visually Impaired: In its published report, this committee recommended standards for evaluating vision disability for use by the Social Security Administration.

   4) 2001-06 Research consortium on “Wayfinding technologies for people with visual impairments: Research and development of an integrated platform”: This multi-institutional project, headed by Sendero LLC funded by the National Institute for Disability Research and Rehabilitation (NIDRR), has the goal of developing prototype technology to support wayfinding by visually impaired people. The PI, Mike May, is a leader in developing GPS-based technology for use by visually-impaired people. Research in Legge’s lab funded by this project provides the basis for his role in the current NSF/UA proposal.

   5) 2003-2005. Consulting with Advanced Medical Electronics (AME), a Twin Cities company, on transfer of IR thermal imaging technology to applications for impaired vision.

(V) Collaborators & Other Affiliations

a) Co-Authors During Past 48 Months (2000-2004):
   MiYoung Kwon, Sing-Hang Cheung, Daniel Kersten, Christopher S. Kallie , Sarah J. Mason, Alberto Ortiz, and Paul Schrater, all University of Minnesota;
   Paul Beckmann, Beckmann LLC; Wendy Braje, State University of New York at Plattsburgh;
   Hugo Bruggeman, Brown University; Susana Chung, University of Houston; Joshua Gefroh, Dupont;
   Tom Hooven, Univ. of Michigan medical School; Jeremy Jobling, Motorola; Beth O’Brien, Tufts University;
   Timothy S. Klitz, Washington and Jefferson University; Hye-Won Lee, Ewha Womans University, Seoul;
   Dennis Levi, University of California at Berkeley; J. S. Mansfield, State University of New York at Plattsburgh;
   Brian J. Stankeiwicz, University of Texas at Austin; Bosco S. Tjan, University of Southern California.

b) Advisors: Postdoctoral Advisor: Fergus W. Campbell, Cambridge University (deceased)
   Ph.D. Advisor: R.J.W. Mansfield (Harvard University)

c) Advisees During Past 5 Years (1999-2004)
Ph.D. Students Advised (9): Paul Beckmann, Beckmann Research; Hugo Bruggeman, Postdoc, Brown University;
   Nicholas Giudice, Postdoc, UC Santa Barbara (as of Jan. 1, 2005); Jeremy Jobling, Engineer, Motorola Corp.;
   Timothy Klitz, Faculty, Washington and Jefferson Universit; Alberto Ortiz, Faculty, Inver Hills College;
   Deyue Yu, Amy Kalia, Sing-Hang Cheung in training

Postdocs Advised (8): Mark Brady, Faculty, North Dakota State University; Ming Cheong, ongoing;
   Hye-Won Lee, Faculty, Ewha Womans University, Seoul; J. Stephen Mansfield, Faculty, SUNY Plattsburgh
   Joseph Miller, Faculty, University of North Dakota; Alberto Ortiz, Faculty, Inver Hills College;
   Beth O’Brien, Tufis University ; Brian Stankiewicz, Faculty, University of Texas at Austin
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Education
Ph.D. in Computer Sciences  University of Texas at Austin  1991
M.S. in Computer Sciences  University of Texas at Austin  1988
B.A. in Computer Science, Mathematics, History  University of South Dakota  1984

Professional Experience
Associate Professor  University of Minnesota  2002-present
Principal Member of Technical Staff  AT&T Labs - Research  1996-2002
Member of Technical Staff  AT&T Bell Labs  1991-1996
Graduate Research Intent  MCC  1986-1991
Teaching Assistant  University of Texas at Austin  1985

Affiliations
Member of ACM, ACM/SIGCHI

Research Interests
Human-Computer Interaction, Computer-Supported Collaborative Work.

Selected Awards & Honors
Awarded 9 U.S. patents in various areas of Human-Computer Interaction  1995-2002
Graduate Fellowship Recipient, University of Texas  1984-1986

Professional and Synergistic Activities
Conference Co-Chair for IUI 1998, ACM Conference on Intelligent User Interfaces.
Editorial Boards: ACM Transactions on CHI, 2000-present; Knowledge-Based Systems, 1993-present; intelligence, 1998-present
ACM SIGART Conference Chair (1995-1999); originated and co-organized Doctoral Consortia held in conjunction with AAAI and IJCAI.

Five Related Publications
Ludford, P., Cosley, D., Frankowski, D., and Terveen, L. Increasing Online Community Participation Using
Dissimilarity and Uniqueness, in *Proceedings of CHI 2004.*


**Five Other Publications**


**Collaborators and Co-Editors**

Yan Chen, University of Michigan; Quentin Jones, New Jersey Institute of Technology; Sara Kiesler, Carnegie Mellon University; Robert Kraut, Carnegie Mellon University. Christine Halverson, IBM; Paul Resnick, University of Michigan; Steve Whittaker, University of Sheffield; Dennis Wixon, Microsoft.

**Ph.D. Students Advised**

Served on Ph.D. committee for:

- David McDonald (University of California at Irvine, 2000)
- Brian Amento (Virginia Tech, 2001)

**Current Ph.D. Students**

- Dan Cosley (co-advised with John Riedl)
- Pam Ludford

**Graduate Advisor:** Robert Simmons (University of Texas at Austin)