Constructive Exploration
of Spatial Information by Blind Users

Jochen Schneider, Thomas Strothotte
Department of Simulation and Graphics
Otto-von-Guericke University of Magdeburg
Universitätsplatz 2, 39016 Magdeburg, Germany
+49 391 67 11404
{josch, tstr}@isg.cs.uni-magdeburg.de

ABSTRACT

When blind people wish to walk through an area not fully known to them, they have to prepare themselves even more thoroughly than sighted pedestrians. We propose a new approach to support this preparation with the help of an interactive computer method, called *constructive exploration*. Using this method, the user is guided in physically constructing the spatial arrangement to be learned using building blocks. We describe two implementations of the concept, one with a graspable interface with object tracking and the other employing a force feedback device. We report on first tests of the implementations.

Keywords

Orientation aids, blind users, augmented reality, force feedback devices

INTRODUCTION

Information systems in general and those for blind people in particular put the user primarily in the role of a recipient of information. For example, a search for information on the web can be considered successful if a page has been found with all the required data presented in a succinct form. Indeed, many users complete their search by printing out a page or a small number of selected pages.

By contrast, students are taught not only by presenting material to them, but also by letting them actively work with it. For example, every good mathematics book will give exercises for the student to practice what they have learned. Students learn new material by the aid of physical objects: "... one learns by building artefacts — whether they be formal reports, private scribblings, Lego choo-choo trains, or computer programs, the path to learning is strewn with things, with externalizations" [17].

When pedestrians or drivers try to prepare themselves in an area not fully known to them, they undergo a learning process, even when they are not consciously aware of that fact.

One evidence for orientation as learning is that people first orient themselves by routes and landmarks, and only with experience acquire a mental overview of the full area ([2], pp. 214). In practice, when we prepare ourselves for a trip through an unknown area, we first look at a map and try to learn how to travel through it. We might take the map with us during travel, but are often too busy looking for landmarks or traffic while walking or driving to update our current position on the map. We therefore have to memorize parts of it beforehand.

If we examine how blind people have obtained access to spatial information in the past, we find that it has mostly been in a passive way: They have either listened to live or pre-recorded descriptions of an area or a route, have been lead through the actual area by walking or have studied a tactile map [4].

In this paper we propose to apply the idea of intimately involving the user in the process of building a solution to a spatial orientation problem. In particular, we propose to let the user explore spatial information by actively building certain parts of it as a model with the help of an interactive computer system. Our approach can be considered an application of the "learning-by-doing" principle. Map learning for travel planning meets the prerequisite of that principle, namely that "there has to be a real task in which the learner has some personal interest and investment" [17].

The paper is organized as follows. In section two, we talk about the background of our work. In section three, we define the term "constructive exploration" and show how we implement it in actual systems. In section four, we describe our implementations in detail. In section five, we report on first tests of our approach with blind and sighted users. In section six, we conclude the paper and comment on future work.

BACKGROUND

Map Manipulation

Letting people (re-)construct routes on maps with physical objects in connection with map learning is a well-known technique in the psychology of education: When psychologists want to assess a child's mental map of a route, one

way is to ask the child to construct the route with card board strips and toy buildings [1].

The "Tangible Bits" concept by Ishii and Ullmer aims at coupling physical objects and digital data, so that physical skills can be applied during computer use [9]. One application of the concept is the exploration of a map and the manipulation of its display with the help of physical objects.

Research on Tactile Maps

Carved maps made by the Inuit three hundred years ago can be considered forerunners of tactile maps. They are highly abstracted as shapes and can be felt in the dark ([11], pp. 229). Today, tactile sheet maps offer blind people suitable access to geographical information [4]. The choice and tactual representation of cartographic features to present constitute the main challenges in designing such a map ([3], pp. 206). Besides tactile maps for geography education, we distinguish tactile orientation, mobility and topological maps. Orientation maps provide a general overview of a certain area. Mobility maps are tailored towards travellers and include orientation points. Topological maps show a certain route. Other detail is left out, the presentation is simplified and distorted (ibid., pp. 194).

Tactile maps constitute mature means of orientation and can be carried along on trips. On the other hand, tactile map design is not fully standardized. This is one of the reasons not all blind people are able to use these maps successfully, another being that inscriptions are done in braille, which not all blind persons can read. In addition, tactile maps are not readily available for all regions or at the time they are required, because they are mostly made by hand. For these reasons, there have been efforts to enhance tactile maps through the help of computer systems.

Electronic Travel Aids

Tactile maps can be enhanced through multimedia computer systems. A tactile map is placed on a touch tablet, an absolute two-dimensional input device. The touch tablet is connected to a computer which has the map information that is depicted on the tactile map loaded as a digital map. The computer emits sound or text information on an object when the user presses the object on the tactile map and therefore the touch tablet [7]. With this approach, the exploration experience can be enhanced and braille labelling of features can be substituted with speech output, but there is still a tactile map needed.

The MoBIC preparation system (MoPS) empowers blind pedestrians to plan a walk through an urban area [15]. The MoPS can be used to both explore maps and select routes in them. Routes selected are transferred to an electronic travel aid, the MoBIC outdoor system, which then guides users during their walk outdoors. Users interact with the digital map loaded into the preparation system through the cursor keys of a PC keyboard. The system gives them information on their current position through speech and braille. Absolute spatial input is not supported.

The "KnowWhere" system is a hand gesture recognition system which conveys geographical information to blind people [11]. The system presents zoomable outlines of geo-graphical objects by emitting a sound when the hand of a user touches the imaginary objects on a tactile grid. When a map is loaded into the KnowWhere system, it can therefore be passively explored. For a test, congenitally blind subjects explored country and state maps. They were able to find absolute positions and recognize puzzle pieces of the objects afterwards.

Van Scoy et al. propose to use the Phantom force feedback device from Sensable to let blind people explore a three-dimensional model of a street block for mobility training [18]. In this approach, buildings are presented as three-dimensional models both for touch exploration and visibly on the computer screen.

CONSTRUCTIVE EXPLORATION

By constructive exploration, we mean the process of learning information through partly (re-)constructing it by following instructions. Applied to the learning of spatial information, during constructive exploration, users build parts of the spatial structure while they are given instructions on how to assemble which parts. The parts are constructed with physical building blocks.

To implement a constructive exploration system for spatial information, we need ways to let users explore spatial information with the help of the computer, let them choose parts they wish to learn in detail, let them (re-)construct these parts, and finally trace them until they have learned their positions and relationships.

The first implementation approach uses a graspable interface [5] which enhances physical objects with interactive computer technology. It consists of a rectangular tactile grid on which the interaction happens and which represents the map which is loaded into the computer as digital map data. On this grid, users move their hands to virtually touch map objects to request information on them which is given through synthetic speech. Users place physical objects on the grid to select routes and reconstruct them.

A different implementation utilizes a force feedback device which conveys the impression of touching a tactile map. In addition to letting users explore the map, the system can also give them information on objects on the map through synthetic speech and even guide them from landmark to landmark on a route. One can imagine additional implementations of the constructive exploration concept. Other input/output devices can be used, and information other than map information can be explored by users.

IMPLEMENTATIONS

Requirements

The spatial information systems described here fall into the category of orientation aids. General requirements for the design of orientation aids can be elicited by asking how blind pedestrians prepare themselves for a walk through an urban area not fully known to them. Mobility psychology has found that blind people who wish to navigate independently have to memorize the layout of a given area, learn path segments and angles between them, and have to recognize them during walking [6]. Therefore, a constructive exploration system needs to provide blind people with an overview of a given area on the one and teach them straight

route segments and angles at route succession choice points on the other hand.

To implement the constructive exploration concept, there are no large tactile input/output devices available to be used by blind people in the same manner as mice and graphics screens are used by sighted people (apart from research prototypes [16]). Therefore, new interaction techniques were devised and implemented, while consulting a mobility psychologist who is himself blind.
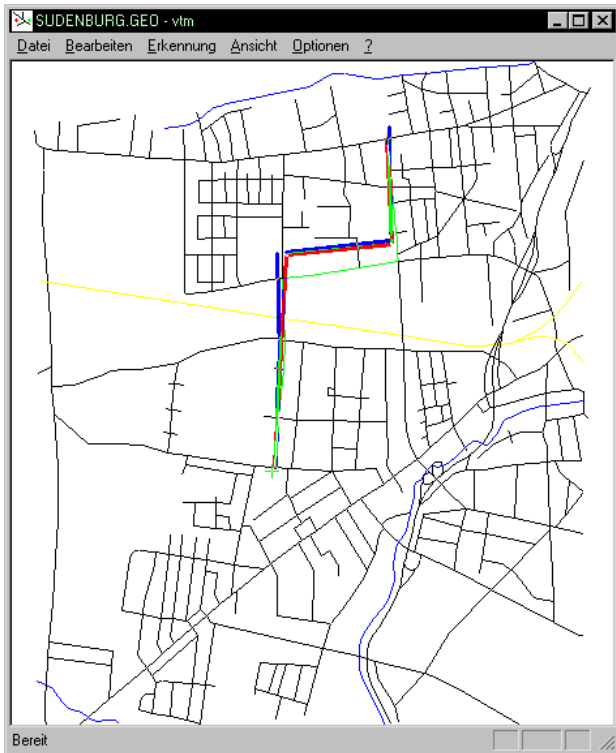

Figure 1:   Screen shot of the visualisation of a map and a route of the camera-based system

Implementation through an Image Processing System

Our first implementation of the constructive exploration concept contains an image processing system for input and speech and sound for output. Users interact with the system with their hands and physical objects, whose positions are tracked by a camera. The systems allows for the exploration of digital map data and the selection and learning of routes in it. The digital map data is not displayed explicitly, but is conveyed during interaction: Textual information is presented through synthetic speech, other information through sound.

On a table there is a tactile grid which delimits the interaction area and gives the user a sense of where the hands and objects are on this area. Objects similar to the pieces of a game serve to select the two end points of a route and to actively construct the route once it has been selected.

The systems supports free exploration and route learning in two different modes between which users can switch with the help of the construction objects, without the need to explicitly switch modes with a program command. At first,

the tactile grid is empty and the system starts in free exploration mode. In this mode, the user moves a hand freely on the grid underneath the camera. When the index finger "touches" a cartographical object on the grid, like a street or a building, information on this object (e.g., its name) is given by the system through synthesized speech.

To change into route learning mode, the user places two route end pieces on street crossings on the grid. The system then searches a route between the two crossings, careful not to select unwalkable map segments like highways, and announces to the user that it found a route. The user then constructs the route with long physical objects, guided by the system.

To construct a route, there are a number of game pieces of different lengths to choose from. The system tells the user which length the next piece to place should have. The user places the first piece next to the route start object. The system then tells the user through sound how to turn the object, with the start object as the axis, so that it lies on the route. After the first brick has been correctly placed, the system tells the user the size the second brick should have. The user then places the second brick guided by the system in a similar way as for the first brick, with the end of the first brick as the connection point, and so forth for the rest of the bricks. When the last brick is correctly placed, the system tells the user that the route has been successfully built.

In order to let the user place a brick, the system only needs to tell her or him the correct angle, because the position (actually the rotation axis of the brick to place) can be derived from the objects already placed. The angle is conveyed trough a pulsed sound once a brick is placed at the end of the previous brick: the pulse frequency gets higher as the angle of the brick gets closer to the correct angle. The sound stops once the brick is correctly placed. The route end pieces stay on the pad during the construction of the route. When they are removed from the pad, the system switches back into free exploration mode.

Once a route is chosen by placing the two route end pieces on two crossings, the systems calculates the shortest path between them. The system then simplifies the path calculated by merging two neighboring segments if no third segment leaves the node connecting the two and the angle between them is roughly 180°, i.e., one is the elongation of the other. The route is then scaled down so that it starts and ends at the border of the respective route end piece. A linear scale is used in this step, in contrast to a system for producing tactile route maps [13]. The system then calculates how each straight route segment has to be scaled so that it can be filled with route bricks. Finally, the segments are attached again to form a closed route.

All graphical information like the map, the current position of the index finger, the current object of which information is spoken, the position of the route end pieces, the current route and the route bricks placed so far are displayed graphically (see Figure 1). This allows for the cooperation of a sighted and a blind user (and facilitated the development of the system). Digital map data is loaded into the system as map files covering a certain area, e.g., a part of a city.

The physical objects used have a special design to enable the interaction just described. Bricks need to attach to the last brick already placed (or the route start piece) so that they can be turned with the previous brick as the axis. Route end pieces and bricks already placed need to stick to the pad so that they cannot be moved accidentally. Both these requirements for the bricks are met by placing magnets on both ends of the bottom of the bricks. Magnets of two neighboring bricks stick together and route end pieces and bricks already placed can be moved less easily when a metal pad is used.

The camera is mounted over a table, facing down. The tip of the index finger is marked with a colored ring, which enables tracking of its position through image processing. Due to the nature of the image processing system currently used, bricks need to be fully visible to the camera in order to be tracked correctly. On the other hand, bricks need to be tracked even when they are grabbed by a user. Bricks are therefore constructed in a way than they can be held in the middle while still leaving the top unoccluded.

Implementation through a Force Feedback Device

For a different approach to implement the constructive exploration method of conveying graphical information to blind people, a Phantom force feedback device from Sensable [12] is used. This device has the advantage that it can realistically simulate the effect of touching three-dimensional objects. (On the other hand, this effect is only applied to one finger tip and the device will generally find no wide-spread use, because it is too expensive.) In order to let users explore two-dimensional maps with the Phantom, they are converted to a three-dimensional representation, which resembles engravings in a metal plate when explored.

A three-dimensional model of a map was created, similar to a tactile map, to be explored by users with the "Haptic VRML Guide", a haptic exploration system for those models for the Phantom [10]. To create the map model, each map object was converted into a three-dimensional representation in the modelling language used by the exploration system (VRML, see [8]). Under this scheme, segments are converted to cylinders. The VRML map is then manipulated with the help of a 3D modelling system by "subtracting" it from a block of suitable size, which makes the map "engraved" into the block. To explore the map, it is loaded into the "Haptic VRML Guide" system (see Figure 2). (This system was developed by our colleague Henry König [10].)

Once the map is loaded into the system, users can trace streets will be able to listen to information on them given by the system through synthetic speech. In order to make the exploration constructive, routes can be built with virtual objects in the haptic space. The construction will start at one of the route end markers. A long, thin object the size of the length of the first segment will be attached with one end at one of the markers. It can freely rotate around that marker. The user can place the first segment by rotating it until it engages at the start of the next segment. Then, an object representing the next segment appears and can be placed in the same way, until the whole route is constructed.
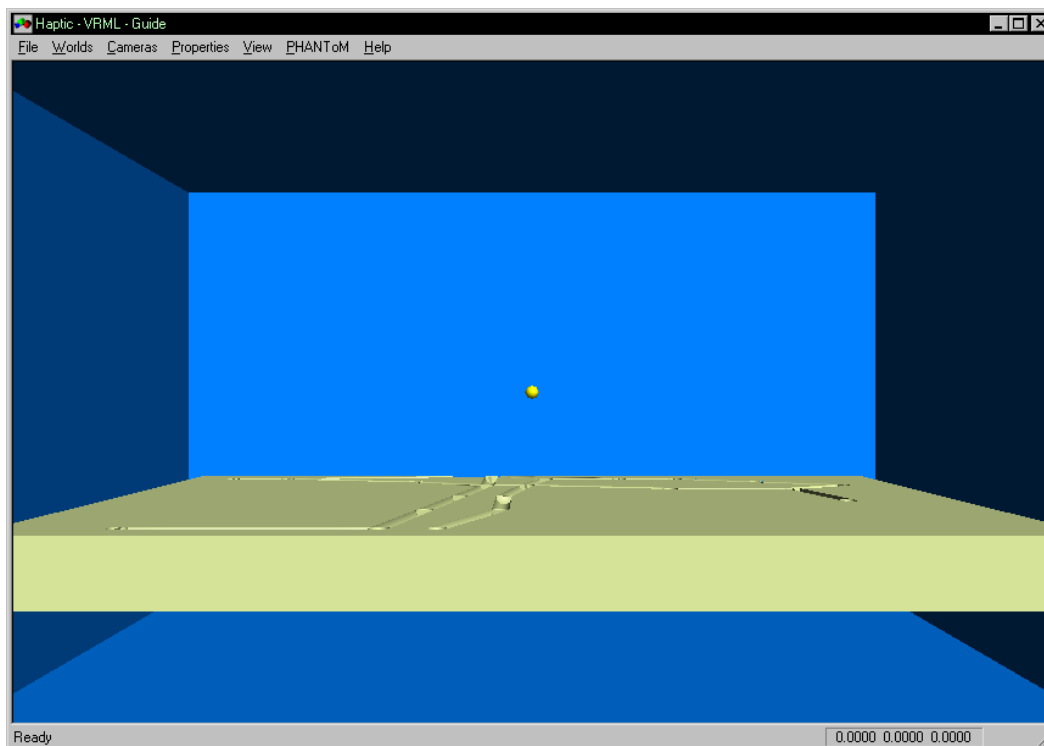

Figure 2: Map data loaded into the system to explore it with a force feedback device (front view)

EVALUATION

The camera-based constructive exploration system was first tested by a sighted user. He was able to successfully choose and build a route with the help of the system. Route construction was also tested by a congenitally blind subject. He was asked to build a route with five route bricks. He was able to place the bricks at the right position and angle. It was expected that the fact that route bricks do not snap into each others' ends would make using them harder, but this surprisingly turned out not to be the case. After a short while, the subject was also able to build a route without occluding the bricks with his hands.

The user had fun with the system. After he knew how to correctly handle the bricks, it didn't take him long to place them. The user is optimistic that he can learn routes with the system. Formal evaluations of both the camera-based and the force feedback-based implementations will be carried out in the near future. They will both be based on the hypothesis that routes can be conveyed better with the system than by verbal descriptions. In order to test this hypothesis, subjects will be divided into two groups. Each subject will construct a route with route bricks in one of two ways: by either listening to a verbal description of the route or by being guided by a virtual tactile map system. The routes constructed by the two groups will be compared.

CONCLUSION AND FUTURE WORK

Our work has focused on blind users, who are mostly ignored by current design efforts for multimedia systems. On the other hand, our constructive exploration approach and implementation methods can benefit sighted users, as well: Sighted people also find themselves in the position of learning the layout of an area they want to travel in and learn routes in it.

REFERENCES

1. Blades, M. Research Paradigms and Methodologies for Investigating Children's Wayfinding, in N. Foreman, R. Gillet (eds.), *Handbook of Spatial Research Paradigms and Methodologies Vol. 1*. Psychology Press, East Sussex, 1997, 103-129.

2. Downs, R.M. and Stea, D. *Maps in Minds: Reflections on Cognitive Mapping*. Harper & Row, New York, 1977.

3. Edman, P.K, *Tactile Graphics*. American Foundation for the Blind, New York, 1992.

4. Espinosa, M.A., Ungar, S., Ochaíta, E., and Blades, M. Comparing Methods for Introducing Blind and Visually Impaired People to Unfamiliar Urban Environments. *Journal of Environmental Psychology* 18 (1998), 277-287.

5. Fitzmaurice, G.W., Ishii, H., and Buxton, W. Bricks: Laying the Foundations for Graspable User Interfaces, in *Proceedings of CHI '95* (Denver CO, May 1995), 442-449.

6. Golledge, R.G., Klatzky, R.L., and Loomis, J.M. Cognitive Mapping and Wayfinding by Adults Without Vision, in Portugali, J. (ed.), *The Construction of Cognitive Maps*, Kluwer, Dordrecht, 1996, 215-246.

7. Holmes, E., Jansson, G., and Olsson, E. Tactile enhancement of reading a tactile map presented via synthetic speech. *Proc. Maps and Diagrams for Blind and Visually Impaired People: Needs, Solutions, Developments* (Ljubljana, Slovenia, October 1996), International Cartographic Association, 1996.

8. ISO/IEC 14772-1, Information technology - Computer graphics and image processing - The Virtual Reality Modeling Language (VRML) - Part 1: Functional specification and UTF-8 encoding, VRML Consortium, 1997.

9. Ishii, H., and Ullmer, B. Tangible Bits: Towards Seamless Interfaces Between People, Bits and Atoms, in Proceedings of CHI '97 (Atlanta, GA, March 1997), ACM Press, 234-241.

10. König, H., Schneider, J., and Strothotte, Th. Haptic Exploration of Virtual Buildings Using Non-Realistic Rendering, in *Proceedings International Conference on Computers Helping People With Special Needs (ICCHP)* (Karlsruhe, Germany, July 2000). Austrian Computer Society, 377-384.

11. Krueger, M.W., and Gilden, D. KnowWhere™: an Audio/Spatial Interface for Blind People, in *Proceedings of the Fourth International Conference on Auditory Display (ICAD) `97* (Palo Alto, CA, November 1997). Xerox PARC, Palo Alto, 1997.

12. Massie, Th.H. and Salisbury, J.K. The PHANTOM Haptic Interface: A Device for Probing Virtual Objects. *Proceedings of the ASME Winter Annual Meeting, Symposium on Haptic Interfaces for Virtual Environment and Teleoperator Systems* (Chicago, IL, November 1994), 295-302.

13. Michel, R., Computer-Supported Symbol Displacement, in Ottoson, L. (ed.), *Proc. 18th International Cartographic Conference*, Vol. 3, (Stockholm, June 1997), 1795-1803.

14. Papanek, V., *The Green Imperative: Natural Design for the Real World*, Thames and Hudson, New York, 1995.

15. Petrie, H., Johnson, V., Strothotte, Th., Raab, A., Fritz, S., Michel, R. MoBIC: Designing a Travel Aid for Blind and Elderly People. *The Journal of Navigation* Vol. 49, No. 1 (1996), 45-52.

16. Schweikhardt, W., Interaktives Erkunden von Graphiken durch Blinde (Interactive Exploration of Graphics by Blind People), in Bullinger, J.-J. (ed.), *Proc. Software-Ergonomie '85* (Stuttgart) Teubner, 1985, 366-375.

17. Soloway, E., Quick, Where do the Computers Go? *Commun. ACM* 34, 2, 29-33.

18. Van Scoy, F.L., Baker, V., Gingold, C., Martino, E., and Burton, D. Mobility Training Using a Haptic Interface: Initial Plans, in Proceedings Fourth Annual Phantom Users Group (PUG) '99 (Boston, MA, October 1999).