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Designing Nonvisual Bookmarks for Mobile PDA Users

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Abstract

Mobile users of information systems are not always able to view needed information because visual attention is required elsewhere. Personal data assistants (PDAs) and other mobile information devices used by the typical mobile knowledge worker support mechanisms that allow for the "hearing" of information stored on these devices. However, few of these nonvisual mechanisms provide a way to save, organize, and retrieve portions of the information being reviewed, i.e., no type of information bookmarking is readily available for the visually occupied mobile users of PDAs. This paper presents a design and implementation of nonvisual bookmarking. The key part of the paper describes multiple design options laid out in a human-computer interaction style design space. This paper discusses the resulting design space for nonvisual bookmarking and its implications. Because of its inherent ability to guide design choices and tradeoffs when creating new interaction styles, the design space serves as an appropriate tool for confronting the unique problems inherent in nonvisual bookmarking.

Keywords: Bookmark, interface for mobile device, PDA, audio-tactile interface design, nonvisual interface, design space

Introduction

The wide range of functionality offered in personal digital assistants (PDAs) has made these devices more ubiquitous in both academic and industrial settings (Albers, 2000). Perhaps one of the more useful functions afforded by PDAs is the ability to use various Internet services in an anytime / anywhere fashion. The convergence of PDAs and wide area network (WAN) communication devices allows even mobile users to receive and send e-mails and browse favorite web sites where an adequate connection is available. Hence, in addition to personal information, such as contacts and calendars, mobile PDA users can have access to the largest source of remote information – the Internet.

In addition to the increasing pervasiveness and information content of these devices, the literature also indicates that PDA interaction styles will be as varied among users as their functions (Hindus, 1995). Whether the user is tapping hyperlinks whilst browsing web pages, dialing a telephone number with a virtual phone pad, or jotting down notes with a PDA's handwriting recognition capabilities, user visual attention is a limiting mandate in the current crop of PDA interaction styles. Further aggravating this limitation is the inherently small screen users are forced to work with, which the literature has criticized as being too "confusing and cumbersome (Buyukkokten et al. 2002)." This is not likely to change because additional screen size means additional weight and cumbersome carrying mechanisms, the antithesis of a PDA's mobility.

With this, the current PDA paradox becomes prominent: the state of technology has given personal digital assistants users access to both personal local and vastly remote information stores, yet the form factor users are forced to deal with can dilute overall accessibility. A natural approach to this problem would be to build an interface that relies on the audio and tactile capabilities inherent in PDAs. This has been done, but it does not support the full interactivity of a visual interface, in particular, that of bookmarking "heard" information for future access. A nonvisual interaction space is very apt for the PDA platform. Mobile devices are designed for mobility. The literature notes that visually interacting with a PDA while performing non-stationary activities (driving or walking) leads to very "awkward [and] inconvenient" (Hindus, 1995) dialogue with the device. Additionally, as mentioned above, the current form factor of PDAs is far from suitable for even effective stationary use. Jones et. al. (1999) studied the impact of display size with information retrieval tasks performed using a 640x480 resolution vs. a larger 1047x768 resolution. The group receiving the smaller display treatment where 50% less effectiveness than the group with the larger display. Note that the study's display size of 640x480 towers above current display size of most current PDAs (at an average of 120x120). This study clearly indicate that information retrieval "tasks [with PDAs] will be harder to complete" (Jones et. al. 1999) when the user is pegged to a minute display. Indeed, bypassing the visual woes of modern PDAs via a more direct interaction space - i.e., the proposed audio and tactile space - can lead to a more comfortable and effective PDA experience.

This paper will present a design solution, a nonvisual bookmarking mechanism for PDAs. It will do this through the use of a design space analysis. This type of analysis is recommended for multi-modal designs for which large numbers of input and display possibilities have not been adequately explored. The technique is borrowed from HCI research, but has been used mostly in the design of input styles. We extend its use in this paper and begin by describing the design tool before presenting the audio bookmark design it elicited.

The Design Space Analysis: A Design Tool Primer

We chose the design space analysis methodology because of its appropriateness as an initial design tool (MacLean et al. 1991). In essence, a design space is a multi-dimensional table in which design possibilities are laid out against the desired functions in an interface. Figure 1 gives a simple example of a design space for selecting elements of text in a document, using a mouse for the text selection. Our goal of designing a purely nonvisual bookmarking interface for PDAs is a specific component of a larger research effort, that of building a comprehensive portable, nonvisual display PDA. Developing a design space for the bookmarking task will drive the design for the entire interface approach, primarily because the bookmark design involves all of the interactivity that will belong to the other functions of the design. In addition, the mechanism for visual bookmarking is well documented and standardized in today's web browsers.

Function	Design 1	Design 2
Select insert point	Point to position, click left mouse button	Point to position and let pointer dwell for 250 msec
Select word	Point to word, double click left mouse button	Point to word and single click left mouse button
Select paragraph	Point to paragraph, triple click left mouse button	Point to paragraph and double click left mouse button

Figure 1. A Simple Example of a Design Space for Selecting Text Elements with a Mouse

This paper has three major sections. *The Knowledge Base* Section discusses the research related to nonvisual bookmark design on PDAs. The research results are looked on as a knowledge base that contains necessary - yet integrated - knowledge for the design. *Generating The Design Space* Section delineates a design space for nonvisual bookmark design of PDAs. The design space is proposed as a framework for integrating knowledge in the related fields. And *A Comparison Between Alternative Designs* Section illustrates two designs that are generated and compared in the proposed design space.

The Knowledge Base

The design of nonvisual bookmarks crosses two meta-areas: (1) how people organize information and (2) how users and nonvisual systems interact with each other. We look on the rich research results in these areas as a large knowledge base. We now discuss the studies in each area, and describe how they can be accommodated into the design of nonvisual bookmarking systems.

How People Organize Information

Essentially, bookmarks are a tool for facilitating people's organization of useful information for fast retrieval. Existing research studied how people organize papers in an office (Malone, 1983), files on a computer (Barreau and Nardi, 1995; Jones and Dumais, 1986), and web pages (Pitkow, 1996; Abrams et al. 1998). The research results indicate that by organizing information into focused groups, people create personalized information spaces that contain structured shortcuts to information that is highly relevant to them. The names and locations of these groups serve as external memory helping people to relocate certain pieces of information. As the relevance and relationship of information to people's interests change over time, people re-organize the archiving structure according to their new needs. These studies delineate a collection of functions that a bookmarking system should have. The functions include allowing people to build focused information groups, to name and rename the labels of groups and bookmarks, to modify the established information sets, and so on. Based on these functions, we will analyze the interactions between users and systems, and will obtain the categories of user and system dynamics.

Interaction between Users and Nonvisual Systems

The interaction is a dialogue agent connecting users and nonvisual applications. It consists of the following three elements:

(1) Auditory representation of information. Auditory representation is a promising alternative form of output in that it releases users from reading screens with low-resolution and screens in visual-distracting and mobile contexts, e.g. (Brewster and Cryer, 1999). As auditory outputs, speech and non-speech audios are used to convey both primary and peripheral information. Speech display is a "learned repertoire of language and cognitive meanings," while non-speech display is exploiting "evolutionarily acquired environmental adaptations, including cognitive and preattentive cues" (Kramer, 1994, p. 1). Speech output is powerful in displaying text information such as contents of a web page and tags of graphs (Williams and Tremaine, 2001; Mynatt and Edwards, 1992). Non-speech audios are efficient in providing cues such as positions of information items on a hierarchy (Leplatre and Brewster, 1998), and states of system processes (Walker and Brewster, 2000). Physical properties of sounds such as timbre, pitch, and intensity are manipulated to compose different representations. All these variations of auditory output form one dimension of nonvisual bookmarking design.

(2) Input mechanisms of nonvisual systems. A wide range of input mechanisms is available for existing nonvisual systems. They include voice input (Savidis et al. 1996), gestural control (Brewster and Walker, 2000), input through special keypads and standard keyboards (Asakawa and Itoh, 1998), touch input including input via touch pads (Williams and Tremaine, 2001), and via touch screens (Roth et al. 2000). Among these mechanisms, gestural input fits the situation that no many other body movements are occurring which are prone to confuse the system with gestural inputs. Controlling the system through special keypads and standard keyboards requires a higher level of physical focus and memory load. With this in mind, the needs of a PDA user become well suited to voice and touch input when confronted with physically and mentally distracting mobile environments. These input mechanisms are considered another dimension of the design. We will analyze touch input in detail later.

(3) Dialogue between users and nonvisual systems. Dialogues transform user actions to system operations and give rise to further user actions. They keep the interactions between users and systems in a continuous flow. While the research on the dialogue design for nonvisual computer interface is sparse, some efforts have been focused on the dialogues of voice-response systems. The dialogues of voice-response systems are similar to those of nonvisual bookmarking systems in that both are transaction-based and both have definite starts and ends (Hindus et al. 1995). Halstead-Nussloch (1989) pointed out that the design of the dialogue flow is critical to the success of voice-response interfaces. We adopt the dialogue-flow approach in our study for analyzing user actions and system effects during their use of the functions suggested in *How people organize information* section.

Table 1 summarizes how the studies of above areas are accommodated in the design of nonvisual bookmarking.

Table 1. Accommodation of the Existing Studies in the Design of Nonvisual Bookmarking

Foundations for the Design of Nonvisual Bookmarking		Existing Studies as Resources
Design approach:	User-system interaction analysis (Dialogue-flow analysis)	• *Dialogue between users and nonvisual systems*
Basis for user-system interaction analysis:	Functions of bookmarking systems	• *How people organize information*
Embodier of user actions:	Technologies supporting user input	• *User control over the nonvisual systems*
Embodier of system effects	Techniques of auditory representation	• *Auditory representation of information*

Generating the Design Space

Having extracted the major factor units of the design, we needed a framework for assembling the aforementioned knowledge systematically. The design space we propose is a mechanism for integrating knowledge from different research areas onto a single design. It consists of one encompassing space composed of four sub-spaces. Each sub-space focuses on the details of a particular aspect of the encompassing space. The combination of these spaces is a complete framework for the systematic design of nonvisual bookmarking. In this section, we discuss the sub-spaces, and then present the encompassing space.

We begin by analyzing the dialogue flow between the user and the system. The dialogue flow is formed by a series of dialogue passages. Each passage starts with a user action and ends with a system reaction. User actions are transmitted to the system via a variety of input forms. System reactions are presented to the users through different kinds of auditory output. Thus, a [user-action – input-of-user-action – system-reaction – output-of-system-reaction] passage is formed. Since the design of dialogue flow can be decomposed into dialogue-flow passages, we propose *user action*, *input form*, *system reaction*, and *output form* the four dimensions for designing nonvisual bookmarking, and the four dimensions of the design space. We discuss these dimensions in the following subsections.

Dimension I: User Actions

Each user action is a step toward a goal of adding or manipulating a bookmark. According to their aimed system consequences, we classify the user actions into two categories: movement actions and state change actions.

Movement actions are users' actions that initiate system movements between system objects. These objects can be information items or operations available in a nonvisual bookmarking system. Examples of information items are folders that contain bookmarks inside, and existing bookmarks created by the user. Examples of operations are "add a bookmark" and "delete a bookmark". In a Graphical User Interface, a movement action moves the mouse from one object to another. In a nonvisual bookmarking system, a movement action moves an "invisible mouse" to an object for further manipulation. Some examples of the movement actions are shown here. When the system is in the state of displaying the bookmark folders, the movement action "next" points the invisible pointer to the next folder for display. The movement action "previous" points the invisible pointer to the previous folder. Similarly, "repeat" and "go-to" move the pointer to the current and the appointed folders.

State change actions are users' actions that take the system from the current state to another. A state of a nonvisual bookmark system is a mode that the system is currently performing a particular task, or that the system is ready for a particular type of user manipulation. For example, a "delete" action may change the system state from displaying a bookmark label to the process of deleting the bookmark. There can be a number of state change actions that put the system into a carrying-out state. We use "execute" as the epitome for them. "Initiating" can also change the system state. "Initiating" the bookmark function can change the system state from displaying an auditory web page to displaying the operations related to bookmarking. "Data-entry" is another kind of state change action. For example, the data-entry action "assign label to a bookmark" can change the system to a state that is ready for data entry. One more state change action is "Terminating". It stops any execution state. We enumerate these user actions in the sub-space for user actions in Figure 2.

Design Dimension of User Actions	Possible Values of User Actions
Movement Actions	Next Previous Repeat Go-to Forward Back
State Change Actions	Initiate Execute Data-enter Terminate

Figure 2. The Sub-Design Space For User Actions

Dimension II: System Reactions

System reactions correspond to user actions. They are categorized as movement reactions, state change reactions, and other reactions.

Movement reactions are any achievements obtained through the user's *movement actions*.
State change reactions are any changes with the state of the system initiated by user's *state change actions*.
Other reactions can be corresponsive to either users' *movement actions* or users' *state change actions*. They include displaying a confirmation message, a prompt, and an error message.

The possible kinds of system reactions are enumerated in the sub-space in Figure 3.

Design Dimension of System Reactions	Possible Values of System Reactions
Movement reactions	Point to an object Display an appointed object
State Change reactions	Initiate a process Execute Display an execution state Display an execution result Prepare system for data enter Terminate an execution
Other reactions	Display a confirmation message Display a prompt message Display an error message

Figure 3. The Sub-Design Space for System Reactions

A user action can cause one or more system reactions. A movement action of a user can cause movement reactions or other reactions of the system. Similarly, a state change action of a user can cause state change reactions or other reactions of the system. For each user action and system reaction, designers can choose proper input and output forms in the encompassing design space that will be shown later.

Dimension III: Input Forms

Due to the reasons stated in *The Knowledge Base* section, speech and touch are two proper input forms for mobile PDA users. Speech input is enabled by an embedded or external microphone, speech-recognition software, and a small grammar representing the possible user actions. Touch input is more complicated and involves position, pressure, and timed actions of a human finger or a stylus.

Touch input on a PDA involves a touch screen or a touch pad, and a set of physical buttons. It can be designed along two dimensions: the operations that the user can perform through touch input, and possible user manipulations with the touch media. A sub-space for the design of touch input on PDAs is implemented in Figure 4.

Users' manipulations can be gliding through (i.e. dragging a finger through a designated space), dwelling on (i.e. staying in one location for a specified time period), lifting off from the touch screen, and hitting (i.e. pressing and releasing quickly) either the physical buttons or the virtual buttons on the touch screen.

Operations for the user to perform	User manipulation with touch pad/touch screen				User manipulation with physical buttons
	Glide	Dwell	Lift off	Hit	Hit

Figure 4. The Sub-Design Space for Touch Input on PDAs

Dimension IV: Output Forms

Speech and non-speech audios are both used to present nonvisual information on mobile PDAs. Speech output is used to convey textual information, such as the titles of the information items on a list, and the text of an article.

Non-speech audio has been used as cues to convey various types of information. It has three categories: musical notes, synthetic sounds (e.g. a series of incrementally varying beeps), and real-world sounds (e.g. the sound of turning pages of a book). Non-speech audio can be used to represent four categories of bookmark information: an object (e.g. a folder containing a set of bookmarks inside), a property of an object (e.g. the number of items in a bookmark folder), a system state (e.g. an error occurring), or a tactile feedback (e.g. a "beep" on the boundary of two virtual buttons on the touch screen). We call each item of information that is represented by non-speech audio a "representee".

Designers manipulate the values of physical properties of non-speech audio to generate distinct sounds. Experimentally, some physical properties, used individually or as a combination, are effective in distinguishing the sound they represent from other sounds. These properties include timbre, pitch, duration, register, tempo, intensity, and spatial location (Brewster et al. 1995). A combination of specific values of these physical properties embodies a "representor" of a piece of information.

Figure 5 shows a sub-space for the design of non-speech audio.

Representor

		Description of the representee	Physical properties of the non-speech audio							Musical notes/ text description of the representor
			Timbre	Pitch	Register	Duration	Tempo	Intensity	Spatial location	
Representee	Object									
	Property of an object	subsection								
	System state	subsection								
	Tactile Feedback	subsection								

Figure 5. The Sub-Design Space for Non-Speech Audio Output

The Combo! – The Encompassing Space

In the previous sections, we presented the four dimensions that constitute the design space for nonvisual bookmarking. The four dimensions are user actions, system reactions, input form, and output form. We assemble them in an encompassing space, shown in Figure 6.

		Value of User Action	**Input Form**			**Output Form**			Value of System Reaction		
			Speech	Touch pad/ Touch screen	Button	Speech	Non-speech audio	None			
User Action	Movement Action									Movement Reaction	**System Reaction**
										Other Reaction	
	State Change Action									State Change Reaction	
										Other Reaction	

Figure 6. The Encompassing Design Space for Nonvisual Bookmarks

In order to build design tradeoffs in the design space, we need a notation for the limited table space. We use numbers (subsection ①, ②, ③, etc.) to identify different designs. We use triangles (▲) to represent input. Three symbols are used to represent three types of outputs: a circle with a black dot inside (⦿) is the symbol for synthetic audio; a hollow circle (○) is the representation of real-world audio; a musical note (♬) indicates that the output is a piece of melody. A single line (____) represents a synergistic relationship, which means the items at the two ends of the line are used together to represent a single input or output.

An example of a design for one bookmarking function is deployed on the encompassing design space in Figure 7. This example illustrates two possible designs for a user's movement action toward the next bookmark folder. When a user performs "next folder" action, his input can be either speech input or touch-pad and button combined input. The resulting system reactions can be either displaying the label of the next folder, or displaying an error message in case there is no next folder. For both design one and design two, the output form for the label of the next folder is a combination of synthetic speech and a piece of musical melody. The output for the display of the error message is a real-world non-speech audio. To design the details of the touch input and the non-speech output, the designers can use the proper sub-spaces.

User Action		Value of User Action	Input Form			Output Form			Value of System Reaction		System Reaction
			Speech	Touch pad/ Touch screen	Button	Speech	Non-speech audio	None			
	Movement Action	"Next folder"	①▲	②▲	▲	①&② ◉	♬		Displaying the label of the folder	Movement Reaction	
							①&② ○		Displaying an error message	Other Reaction	

Figure 7. Illustrating the Design Alternatives on the Encompassing Design Space

AComparison between Alternative Designs of a Nonvisual Bookmarking System

Having the design space as a framework, we are able to implement and compare several distinct designs of a bookmarking system on a nonvisual news browser. Briefly, the news browser is a prototype of a purely nonvisual system on a PDA that can 'read' web pages, contact lists, and other hierarchically organized information sources. Two dissimilar bookmarking designs will now be compared to illustrate implementation of the design space.

Design 1 uses the glide property of the touch pad to allow users to find and execute commands, respectively. Output is received via a combination of text-to-speech (TTS) and non-speech audio. Design 2's input is full speech recognition, i.e., the entire command set is recalled and spoken. Unlike Design 1, output is limited to TTS. Effectively, this interaction design is not only eyes-free, but hands free, as well.

Dimension I: User Actions

The goal is to add a bookmark. The user actions required for this goal are shown in Table 2.

Table 2. The User Actions for "Add Bookmark" Function

Order	Action Description	User Action Category
1	Initiate the system into the **add bookmark** state.	State Change Action
2	Execute the actual addition of the bookmark to the system.	State Change Action

Dimension II: System Reactions

The system reactions associated with adding a bookmark include changing the system state to the add bookmark state and issuing a confirmation of the state change. The system reactions for executing the add bookmark command include executing the command, a confirmation that the bookmark was added, or an error message, and a return to the previous system state. These system reactions are listed in the sub-space for system reactions in Table 3.

Table 3. The System Reactions for "Add Bookmark" Function

User Action	System Reaction	System Reaction Category
Initiate the system into the **add bookmark** state.	Change to the add bookmark state	State Change Reaction
	Confirmation	Other Reaction
Execute the actual addition of the bookmark to the system.	Execution	State Change Reaction
	Confirmation of execution or error message	Other Reaction
	Change to the previous state	State Change Reaction

Dimension III: Input Forms

Design 1 and Design 2 adopt distinct input forms. Figure 8 presents the touch-input design subspace for Design 1, the dual use of a touch pad and buttons. The bookmarking commands are found by sliding a finger along the middle row of demarcated touch pad. As the finger slides, speech output tells the user what command the user has his or her finger over. When the correct command is found, a physical button is pushed to select the command.

Operations for the user to perform	User manipulation with touch pad/touch screen				User manipulation with physical buttons
	Glide	Dwell	Lift off	Hit	Hit
Find Command	X				
Execute Command					X

Figure 8. The Input Form Of Design One

Design 2 requires the user to articulate voice commands, e.g., "bookmark item." Design 1's dual use of a touch pad and buttons requires more time than Design 2's speech recognition. However, Design 2's lack of recognition memory requires more mental effort from the user.

Dimension IV: Output Forms

Output varies slightly between each design. While each design uses TTS for output textual information, Design 2 also uses TTS for other system cues, such as confirmations and error messages. Design 1 employes non-speech output for these same cues, as well as for tactile feedback cues. These non-speech cues are given in the sub-space for non-speech output in Figure 9.

Representor

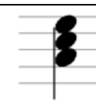
		Description of the representee	Physical properties of the non-speech audio							Description of the Representor
			Timbre	Pitch	Register	Duration	Tempo	Intensity	Spatial	
Representee	**System State**	Confirmation	Synthetic electronic music	Mode-rate	C	1.5 seconds	–	moderate	–	
	System state	Error	Human voice	Mode-rate	–	1 second	–	moderate	–	"uh-oh"
	Tactile Feedback	Tactile feedback for gliding through the boundaries between two virtual sections on the touch pad	Synthetic	low	–	0.5 second	–	low	–	"click"

Figure 9. The Non-Speech Audio on Design One

The Designs In the Encompassing Space

We have illustrated the details of two designs in our nonvisual bookmarking prototype system in the four sub-spaces. We now assemble the complete picture for both designs in the encompassing design space in Figure 10.

<table>
<tr><th rowspan="2"></th><th rowspan="2"></th><th rowspan="2">Value of User Action</th><th colspan="3">Input Form</th><th colspan="3">Output Form</th><th rowspan="2">Value of System Reaction</th><th rowspan="2"></th><th rowspan="2"></th></tr>
<tr><th>Speech</th><th>Touch pad/ Touch screen</th><th>Button</th><th>Speech</th><th>Non-speech audio</th><th>None</th></tr>
<tr><td rowspan="6">User Action</td><td rowspan="2">State Change Actions</td><td rowspan="2">Initiate the system into the add bookmark state</td><td rowspan="2">②▲</td><td rowspan="2">①▲ ———</td><td rowspan="2">▲</td><td>① ◉</td><td></td><td>②</td><td>Contextual change into the add bookmark state</td><td>State Change Reaction</td><td rowspan="6">System Reaction</td></tr>
<tr><td>① ◉</td><td>② ♬</td><td></td><td>Confirmation</td><td>Other Reaction</td></tr>
<tr><td rowspan="4">State Change Actions</td><td rowspan="4">Execute the actual addition of the bookmark to the system</td><td rowspan="4">②▲</td><td rowspan="4">①▲———</td><td rowspan="4">▲</td><td></td><td></td><td>①&②</td><td>Execution</td><td>State Change Reaction</td></tr>
<tr><td>① ◉</td><td>② ♬</td><td></td><td>Confirmation of the execution</td><td>Other Reaction</td></tr>
<tr><td>① ◉</td><td>②○</td><td></td><td>Error message</td><td>Other Reaction</td></tr>
<tr><td></td><td></td><td>①&②</td><td>Contextual change of the add bookmark state and into the previous state</td><td>State Change Reaction</td></tr>
</table>

Figure 10. Two Designs of a Nonvisual Bookmarking Prototype System, Illustrated in the Encompassing Design Space

A Comparison of the Designs

Using the design space evaluation set forth by this paper, the authors have evaluated that Design 1 has practical advantages over Design 2. The primary benefit of Design 1 is a minimal requirement of recall memory. In order to access the system's bookmarking commands, the user only needs to 'remember' how to use a touch pad with buttons. Though ergonomically graceful, Design 2 depends entirely on recall memory. The most obvious drawback in this is the system's functionality is limited to what a user has memorized. The use of an online help facility can remedy the reliance on recall memory, but searching such a system with only speech input may put the user in yet more difficulties.

Conclusion and Contributions

Overall, the realm of eyes-free mobile information systems is still in an immature, but promising, phase. In this paper, we have not just presented a design for developing a nonvisual interface, but demonstrated how designing for these new types of multi-modal systems can be carefully structured and used for design investigation. We illustrate this via a design space created for the design of nonvisual bookmarking for PDAs. We have demonstrated the usefulness of this design space by applying it to several candidate nonvisual bookmarking sub-systems of an overall larger mobile nonvisual information system. This design space is meant not only to be a useful reference for the development of nonvisual mobile systems, but a generalizable tool to advance the development of audio-tactile human computer interaction.

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References

Abrams, D., Baecker, R., Chignell, M. "Information Archiving with Bookmarks: Personal Web Space Construction and Organization," in *Proceedings of the SIGCHI'98 Conference on Human Factors and Computing Systems,* pp. 41-48, April 18-23, 1998, Los Angeles, CA, USA.

Albers, M. and Kim, L. "User web browsing characteristics using palm handhelds for information retrieval," Proceedings of IEEE professional communication society international professional communication conference and Proceedings of the 18th annual ACM international conference on Computer documentation: technology & teamwork, pp. 125-135, September 24-27, 2000, Cambridge, Massachusetts.

Asakawa, C. and Itoh, T. "User interface of a Home Page Reader," in *Proceedings of the Third ACM International Conference on Assistive Technologies (ASSETS)*, pp. 149-156, April 15-17, 1998, Marina del Rey, California, USA.

Barreau, D. and Nardi, B. A. "Finding and Reminding: File Organization from the Desktop," SIGCHI Bulletin (27:3), July 1995, pp. 39-43.

Brewster, S. A. and Cryer, P. G. "Maximising Screen-Space on Mobile Computing Devices," in *Extended Abstracts of CHI'99 Conference on Human Factors and Computing Systems*, May 15-20, 1999, Pittsburgh, PA, USA.

Brewster, S.A., Wright, P.C. and Edwards, A.D.N. "Experimentally derived guidelines for the creation of earcons," in *Adjunct proceedings of HCI'95*, August 1995, Huddersfield, UK.

Buyukkokten, O., Kaljuvee, O., Garcia-Molina H., Papcke, A. and Winograd, T. "Efficient Web Browsing on Handheld Devices Using Page and Form Summarization," ACM Transactions on Information Systems (20:1), January 2002, pp. 82-115.

Halstead-Nussloch, R. "The Design of Phone-Based Interfaces for Consumers," in *Proceedings of the SIGCHI'89 conference on Human factors in computing systems*, pp. 347-352, April 30-May 4, 1989, Austin, TX, USA.

Hindus, D., Arons, B., Stifelman, L., Gaver, B., Mynatt, E., Back, M. "Designing Auditory Interactions for PDAs," in *Proceedings of the 8th Annual ACM Symposium on User Interface and Software Technology (UIST*), pp. 143-146, November 15-17, 1995, Pittsburgh, PA, USA.

Jones, M., Marsden, G., Mohd-Nasir, N., Boone, K., Buchanan, G. "Improving Web Interaction on Small Displays," Proceedings of W8 Conference, Toronto, May 1999 (Also reprinted in International Journal of Computer and Telecommunications Networks, Vol. 31 (1999), pp. 1129-1137).

Jones, W. P., and Dumais, S. T. "The Spatial Metaphor for User Interfaces: Experimental Tests of Reference by Location Versus Name," ACM Transactions on Office Information Systems, Vol. 4, 1986, pp. 42-63.

Kramer, G. (editor) "Auditory Display: Sonification, Audification, and Auditory Interfaces," Addison Wesley Publishing Company, Reading, MA, April 1994.

Leplatre, G. and Brewster, S. A. "An Investigation of Using Music to Provide Navigation Cues," in *Proceedings of the fifth International Conference on Auditory Display (ICAD)*, November 1-4, 1998, Glasgow, UK.

Malone, T. W. "How Do People Organize Their Desks? Implications for the Design of Office Information Systems," ACM Transactions on Office Information systems (1:1) January 1983, pp. 99-112.

MacLean, A., Young, R., Bellotti, V., Moran, T. "Questions, Options, and Criteria: Elements of Design Space analysis," Human-Computer Interaction, Volume 6, 1991, pp. 201-250.

Mynatt, E. D. and Edwards, W. K. "Mapping GUIs to Auditory Interfaces," in *Proceedings of the 5th Annual ACM Symposium on User Interface and Software Technology (UIST*), pp. 61-70, November 15-18, 1992, Monteray, California, United States.

Pitkow, J. E. and Kehoe, C. M. "Emerging Trends in the WWW User Population," Communications of the ACM (39:6), 1996, pp. 106-108.

Roth, P., Petrucci, L. S., Assimacopoulos, A. and Pun, T. "Audio-Haptic Internet Browser and Associated Tools for Blind Users and Visually Impaired Computer Users," in C. Germain, O. Lavialle and E. Grivel eds., *COST 254 Intelligent Terminals, Workshop on Friendly Exchanging Through the Net,* pp. 57-62, March 22-24, 2000, Bordeaux, France.

Savidis, A., C. Stephanidis, et al. "A generic direct-manipulation 3D-auditory environment for hierarchical navigation in nonvisual interaction," in *Proceedings of the Second ACM International Conference on Assistive Technologies (ASSETS)*, pp. 117-123, April 11-12, 1996, Vancouver, British Columbia, Canada.

Walker, V. A. and Brewster, S. A. "Spatial Audio in Small Screen Device Displays," Personal Technologies (4:2), 2000, pp. 144-154.

Williams, C. and Tremaine, M. "SoundNews: An Audiobrowsing Tool for the Blind," in *Proceedings of the International Conference on Universal Accessibility,* August 2001, Elsevier, The Netherlands.