Designing Accessible Visualizations: The Case of Designing a Weather Map for Blind Users

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Abstract. Major strides have been made to improve the accessibility of text-based documents for blind users, however, visualizations still remain largely inaccessible. The AISP framework represents an attempt to streamline the design process by aligning the information seeking behaviors of a blind user with those of a sighted user utilizing auditory feedback. With the recent popularity of touch-based devices, and the overwhelming success of the talking tactile tablet, we therefore suggest that the AISP framework be extended to include the sense of touch. This research-in-progress paper proposes such an extended design framework, MISD. In addition, the article also presents the preliminary work done in designing an accessible weather map based on our theory-driven design. A discussion and an outline of future work conclude the manuscript.

Keywords: Accessibility, Universal Usability, Auditory Information Seeking Principle, Multi-Sensory, Sonification, Spatial Sound, Visualizations, Weather.

1 Introduction

Modern computing, with its easily available text-to-speech applications, has improved a blind user's access to textual and graphical information by creating an experience that is comparable to that of a sighted user. However, text-to-speech techniques remain limited in their use at providing meaningful information about complex visual representations. These visual depictions of data, better known as information visualizations, still remain inaccessible to the blind. Data visualizations are typically used to improve comprehension of large quantities of data [1]. A central challenge in accessibility is devising alternative modes of representing such visual data for blind users, which frequently does not easily translate into textual equivalents.

A common method, to develop accessible visualizations, is to provide a reading of the data table upon which the visual representation is based [2]. In theory, the data presented to a sighted and non-sighted user is equivalent; however, it does not allow the blind user to obtain a high-level overview of the data and identify points of interest, which is the strength of information visualization [3]. Accessibility researchers have proposed that equivalencies may be accomplished through approaches such as haptic visualization, force feedback, and/or sonification, ([1], [4]) however, such research has typically been theoretical and also somewhat fragmented. This ongoing

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research attempts to fill the gap by exploring the possibility of developing a theory driven, integrative design framework for generating accessible visualizations. Specifically, we use the guidelines proposed by Walls et. al. [5] to develop a design theory. In addition, we also report on the preliminary steps for applying the design theory to develop an accessible weather map for blind users.

2 Research Background

Sonification represents the technique that has found significant resonance in the efforts to develop accessible visualizations. This technique is characterized by "the use of non-speech audio to convey information about data" [6]. The general concept of sonification is to provide feedback on the dataset through sound, allowing the user to develop "nominal, qualitative, or quantitative judgments" about the underlying information [7]. Unlike the static reading of a data table or pie chart, the exploration of a sonified visualization is more interactive, allowing the user to experience the dataset on a deeper and more meaningful level. [8]

Research has provided evidence regarding the usefulness of sonification in developing accessible visualizations, particularly in the context of graphs, scattergrams, and tables [2]. There is indication that sonification is useful in conveying a value measure. Pitch is the most commonly used auditory property for providing a distinction between values. In the most extreme cases, finding the lowest bass note or the highest treble note is a relatively simple activity for the average user.

However, at the same time there are indications from research that sonification by itself is not completely adequate for the visualization of complex data sets. In fact there are significant challenges in using only sound to provide feedback to a user [6]. Precision is a concern because the user must be able to interpret data values and value differences between data points. Research has shown that users have had trouble making such comparisons [6], as it becomes more difficult to judge the magnitude of difference between the notes of A and C as compared to A and D.

Another challenge for sonification is that certain visualizations of data are essentially spatial in nature. A particular challenge is that spatial data must be approximated within the azimuth plane since "users are unable to accurately locate the position of the sound source as accurately as they could locate the information in an equivalent graphical visualization" [7]. Duraiswami et al. [9] found that while pitch is acceptable for conveying the east to west location, or north to south locations, it is problematic to try and denote both at the same time. There is an indication that attempts to represent spatial and value data simultaneously using sound, tend to overwhelm the user as the cognitive effort shifts from mere perception to that of remembering the exact interpretation of the sound sequences.

The above discussion provides some indication about the necessity for the development of an integrative, multi-modal approach to visualization.

2.1 Developing the Theory Driven Design Theory

Our approach toward developing a design theory has been guided by the framework proposed by Walls et al [5]. Walls et al [5] propose four important components for the development of a design theory artifact: *kernel theories, meta-requirement, meta-design, testable design product hypotheses.* In this framework, kernel theories represent theories from natural and social sciences that provide governing principles for the design theory. These theories inform and facilitate the formulation of meta-requirements - global goals that the design theory needs to satisfy. The meta-requirements in turn lead to the development of a meta-design framework which meets the needs specified in these requirements. Finally, the testable hypotheses allow for the explicit testing of the appropriateness of the meta-design. As this research does not extend to the evaluation of the design, we have stopped at the development of the meta-design.

2.2 Kernel Theory

The Auditory Information Seeking Principle (AISP) [9] lends itself as an appropriate theoretical framework for informing our design theory. The goal of this principle is to provide a blind user with the same strategy that a sighted user would take to gather information using auditory clues. The underlying principle of AISP is to model the auditory seeking behaviors on that of the visual seeking behavior [9]. The model uses four activities to highlight the mental process related to interpreting visualizations: *gist, navigates, filter, and details on demand.* The first two of these processes model the cognitive behavior of a user as he/she begins with the development of a high level overview of the data and then navigates through it to gain a deeper understanding. *Filter* and *Detail on demand* on the other hand describes the users need to focus on relevant information to reduce information overload and also to access specific parts of the data as and when necessary. The AISP then suggests the use of auditory techniques of information presentation that would enable the user to emulate each of these activities. Space limitations constrain us from a broader discussion of AISP and we refer interested readers to Duraiswami et al. [9] for a more detailed discussion of this framework.

The benefits of AISP include the matching of the visual and non-visual information seeking behaviors to maintain one user experience and providing a consistency for sonification of information visualizations. However, while AISP represents a significant step for developing accessible visualizations, it remains limited because it implicitly proposes a unimodal sonification based approach. Therefore, application of AISP is challenging for the visualization of data that has intrinsic spatial characteristics. There is an imperative to extend AISP into a multi-modal domain. In this endeavor, the components of AISP: gist, navigation, filter and details-on-demand, and their underlying principles represent the *meta- requirements* that inform and constrain the development of our design theory.

2.3 The Meta-design - Multi-Modal Information Seeking Design

The development of the design theory is predicated by the rationale that additional modalities are essential to provide a more equivalent information seeking process for the blind. By designing the visualization using multiple channels of feedback, such as sound, tactile, and haptic, we would be to provide the user with more information simultaneously and therefore more closely approach the experience of a sighted user. We therefore propose that a multi-modal approach should be taken, and in this section present our preliminary conceptual development, the Multi-Modal Information Seeking Design Approach (MISD).

In the initial implementation of the AISP, there are allusions to the incorporation of touch into their sonification [9]. They suggested, however, that a goal of their approach was to minimize the requirement of specialized hardware, such as external haptic and tactile devices [9]. However the need for such specialized hardware has reduced with the advent of tablet-based computers and touchscreen phones. These devices are now available to the public at a lower cost than standard PCs, which moves the inclusion of haptic and tactile features back into the realm of mainstream possibilities.

Research indicates that touchscreen exploration is the preferable method of interaction as it allows for a “direct interaction of haptic-spatial cues and sonification” and that “a combination of sound and touch will work better than a single modality for non-visual display of spatial information” [10]. In addition this also conforms to the premise that users should interact with spatial data by means of a spatial interface [7]. There is also empirical evidence that touchscreens and tablets are tools that may supplement comprehension of data through supplementary sensory perceptions, and that the usability of visualizations depicting spatial data would be vastly increased by a more multi-modal approach [11]. Belardinelli et al., [10] suggests that there are immense possibilities in the dynamic integration of auditory and haptic capabilities, and that it may usher in new frontiers for the study of new effective non-visual displays.

The MISD is an extension of the AISP which strongly incorporates the sense of touch as the user’s primary method of interaction with the system. The purpose of extending this principle is to take advantage of existing research which has proven the AISP to be a reliable design approach which maps the behavior of a visual user onto that of an auditory feedback strategy. The incorporation of touch incorporates a familiar form factor which can be used to provide additional information in a consistent and simultaneous manner for all visualizations.

The integration of auditory feedback with touch based navigation is done based on the following principle. The design framework suggests that a) magnitude or value based information be provided using auditory feedback, b) spatial information be provided using incorporation of touch based interaction, and c) spatial points of interest be identified through haptic feedback. We describe the main elements of MISD in the table below. One should note that the multi-modal aspect does not extend to all the components of AISP, but only to those where it represents a significant design benefit. For example, we believe that auditory feedback would remain appropriately useful for providing the *gist* of the visualization to the user, on the other hand an explicit multimodal approach would benefit the requirements of *navigation, filter* and *details-on-demand.*

Table 1. MISD tactics for multi-modal equivalency of visualization

	Multi-Modal Information Seeking Design (MISD)
Gist	Gist of information may be provided primarily through Auditory feedback mechanisms (e.g. pitch of sound, stereophonic sound production) that provide the user an overview or summary of the data
Navigate	Navigation should be implemented using touch-based interaction designed to allow the user a sense of the spatial information underlying the data
Filter	Filtering mechanisms may be implemented through use of device-based control mechanisms (e.g. volume rocker of phones/tablets) to allow user to choose specific information presentation modes. In addition, filtering mechanisms could also be implemented through allowing user variations of auditory feedback. Finally, filtering may also be implemented through haptic feedback intimating the user of points of interest.
Details -on-Demand	Details on demand may be achieved through the synchronization of touch based interaction and auditory feedback, such that the user can select points of interest and demand additional information. Selection would be enabled by the tactile interaction, and the demanded information would be conveyed through the mechanisms of auditory feedback

3 Applying MISD – The Accessible Weather Map Project

In this section, we discuss the details of the accessible weather map project that has been undertaken to apply and evaluate MISD. Weather maps are a very common visualization which can be relatively simple or incredibly complex. Casual users are familiar with simple maps that illustrate temperature and precipitation, but weather maps can also include lesser known attributes, such as humidity, isobars, and dew point. This data can be shown individually, but it is more common to appear in a single view. Weather maps are often animated to describe the movement of storm systems, but they can also portray a static context. In addition to discrete information, it is also possible to display more complex information such as trends on maps in a static context.

Weather is a domain in which visualizations are readily used. In large part, the weather information is summarized and then presented with visuals to give meaning to the user. This domain is overly complicated because it is an intersection of many areas including geography, territorial boundaries, and atmospheric data. Therefore, the weather map represents a very suitable domain within which to apply MISD. The assumption being that if an accessible data visualization could be prepared for this complicated domain using an inherently multi-modal approach, it could be generalized to other complex domains and provide initial support for MISD.

Below, we provide the design and implementation details of the prototype weather map. This implementation of the weather map is the extension of an earlier prototype of a desktop PC-based sonified weather map is described in [11]. Figure 1 denotes a high level architecture of the application

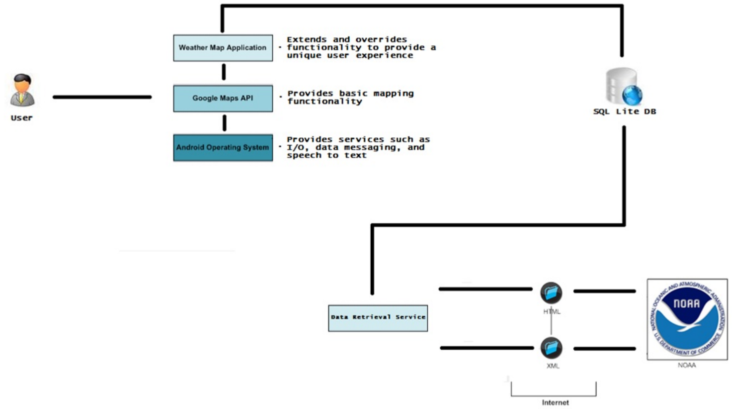

Fig. 1. Application Architecture of the Weather Map Visualization

3.1 Application Stack

The system was designed using a layered architecture approach. This allows for modularity of design and allows for collaboration through various levels of abstraction. We discuss below the different components of this layered architecture.

The basis of this application is the Android operating system (AOS). The AOS supports an application-based environment. Typically these are compiled Java bytecode developed using the Android SDK. The weather map application uses a number of services that are native to AOS, e.g.

- text-to-speech engine for voice output
- message handling and bundling services for communication
- input and output through a touch-based user interface

The second layer of the architecture is the Google Maps application. This is a closed-source application written by Google, Inc. however Google exposes the mapping functionality through an API, which provides basic services such as access to Google Maps servers, map display, and response to map gestures. The application utilized the Google API to generate the map, to allocate pixels to GPS coordinate mapping required to position the weather station data, and to map the user input into the global positioning system. In addition, weather map application overloads the interaction methods to include additional or modified behavior. For example, the standard gestures including drag, zoom, and fling have been ignored and substituted with alternative actions. Another such important change was the modification of the application

I/O to make it compatible with the usability enabled mode of the AOS. Android devices now offer an accessibility mode which allows usage of the devices by all users. Blind users touch the screen and the data is read to them. Further selection of choice may be done by a double tap of the appropriate option. The UI for map application incorporates such interaction behavior. Finally, unlike the standard Google Map application, the weather map has its location fixed at a point in the center of the United States.

To create this behavior, transparent overlays were placed over the map. There are two overlays used in the application. The first is the state, or territory, overlay which responds to the user input as they move their finger across the map. This overlay is created from XML files which describe each of the United States and their boundaries. The overlay responds to the user's touch by announcing the state names as they cross the state boundaries. If the user double taps on a location, the application zooms into the state, to focus on an area of interest. The state overlay contains a list of state objects which are used to represent the United States. As the user touches the overlay, a polygon algorithm is used to detect if the user touches within the state or not. If they do, the Android text-to-speech engine speaks the name of the state to the user.

The second overlay represents the weather data. This overlay is created from weather data stored in the application database (we describe the nature of our data service in the next section). The weather overlay contains a list of weather station objects which hold the weather data values. When a station is pressed, the station is identified and the data value is extracted for the specific weather mode. The tone is chosen from the predefined scale and the media player is used to play the tone to the user. The separation of these two overlays introduces flexibility to the design by allowing us to modularize spatial information and the weather data.

Figure 2 shows the communication structure used when interacting with the weather application. The Google map is the underlying component which is providing the GPS to pixel conversion and the background map images. The overlays lay on top of the map to prevent the user from interacting directly with it. These contain new and overloaded functionality to accomplish the goals of the application. Between the overlay and the data, is a gesture handler which detects new behaviors.

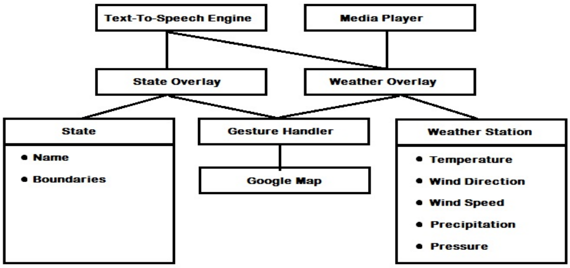

Fig. 2. Map Component Hierarchy

3.2 Data Service

In addition to the application, a data service has also been created as a background process. During the initial load of the application, an initial data fetch will occur, however, during subsequent loads of the application, the data will be fetched directly from the SQLite database. The use of a background process, allows the application to load quickly while retaining currency of weather conditions. Figure 1 displays the data retrieval process in graphical form.

Each of the weather stations serves as a data point within the map. The data is provided 3rd party from the National Oceanic and Atmospheric Administration (NOAA). NOAA maintains and allows access to the readings of their weather stations throughout the country. The data retrieval is accomplished using the data handling and message bundling services of the AOS. These can be identified using unique ids, which are packaged and sent via an HTML request to NOAA. The data is returned to the message handler in XML form. The data is then processed in the database, where it can be retrieved as a station object to place on the map as a marker as part of the weather station overlay.

3.3 Application Usage - User Story

After the application has loaded, a user can initiate touch based navigation of the map in geography mode or press the volume rockers on the phone/tablet to navigate between the weather modes. After selection of the desired mode (e.g. temperature see Figure 3 for temperature screen), the user can begin to explore the map with their finger. As the user traverses the map they can hear state names announced via the text-to-speech engine. This allows the user to take note of their location as they explore the map. If the user drags their finger over a weather station a tone will be played based on the magnitude of the weather value. For example, the coldest temperature will play a deep bass note, while the hottest temperature will play a high treble note. This sonification of the data allows the user to listen to the data set as they explore the map with their finger. The notes are spaced evenly across the musical scale to prevent confusion when comparing values. This technique allows for an easy selection of the statistical outliers. The device also vibrates if the user selects or passes geographical locations containing minimum and maximum values. As the user listens to the sounds played, they will notice that the left and right speakers are playing sounds based on the side of the screen that the user's finger is positioned. This is the technique of spatial sound, using the origination point of the sound to provide additional feedback to the user. This directionality is intended to provide positive reinforcement of the data being transmitted through the sound and touch. The application speaks the state name only once until they press on a different state. This allows the user to explore the shape of the states and their neighboring territories. If the user is specifically interested in a state, they may elect to double click on it which forces the map to reposition to a closer view of the state. When the map is finished the transition, the application will alert the user and they will be free to explore in closer detail the desired area. When satisfied, the user can double-click the state once again to return to the full view of the United States.

Fig. 3. Weather Map – Temperature Mode

4 Future Directions and Contribution

The next step of this research will involve conducting a formal usability test of this prototype. The usability testing will be designed to explicitly evaluate hypotheses derived from the propositions formulated in the earlier section of this paper and will compare the performance of the prototype to an accessible weather map developed using a uni-modal sonification approach.

Data visualization remains an area that has faced significant challenges in developing equivalent presentations for blind users. This research in progress contributes to this area by proposing MISD, an integrative multi-modal design framework. While significant work remains in terms of formally evaluating MISD, we feel that it represents a small, but important step, towards developing truly equivalent accessible data visualizations for the blind.

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