Audio-browsing of large tables

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1. Introduction

Everyday, technology becomes increasingly pervasive and ubiquitous, acting as an extension of human modalities and facilitating interactions between different entities; however, these technological tools can often be exclusively designed for majority groups, such as people with normal vision. People with visual impairments are one example of an audience that must tediously navigate our sight-reliant society. We interact with screens and displays, employing our perceptual visual system's high bandwidth, without any afterthought for how effective and convenient information is transmitted to and through these devices. As visually-impaired users cannot engage with visual information systems, such as tables and charts, in the same way as normal-sighted users, we must deconstruct current technologies and design approaches to be more accessible and universal. For example, normal-sighted users have greater advantage over visually-impaired users in parsing and navigating tabular data because normal-sighted users can quickly see patterns, trends, and structures in a table's extensive and complex data structure. Expanding off previous work in sonifying tables [3], I propose preprocessing table information to highlight important details (minimums, maximums, etc.) and intersecting visual-auditory-tactile modalities to streamline user querying and memorability in nested tables. I will also discuss my user-centered design framework and evaluation methods for validating the relevance of my design for users with visual impairments.

2. User-centered Design

While performing accessibility research and designing aids for people with visual impairments, it is important to assure that the problem is meaningful and relevant to the target audience. The research should not project experiences and instead should actively dismantle assumptions about the target users. The design approach should "[put] human needs, capabilities, and behavior first" [6] and refine a solution through repeated iterations. By including the target audience in the design and testing process, the end product will be effectively and explicitly defined with respect to the audience's needs.

My design facilitates the navigation of nested tables for users with visual impairments while contributing to a more general universal design that all humans can pleasurably use. Although I present a theoretical framework, in practice I would work and engage with my target audience from the start. I would employ semi-structured interviews and contextual inquiry to better understand my user group, learn about current interactions with tables, and deconstruct initial researcher biases; I would observe the utility and efficacy of current sonification (speech vs. non-speech feedback) tools for users with visual impairments and determine if auditory modalities are sufficient for substituting visual disparities. Then I would update and iterate my designs using obtained user feedback and realized user personas. My approach aims at keeping the user-in-the-loop in all stages of development, thus delivering a contextually relevant product.

3. Sonification Design

Sonification employs the human auditory system to aurally recognize patterns and discontinuities in data.

3.1 Related Work

Several works have identified the potential value of incorporating sonification in visualization systems.

Universal design approaches emphasize that sonification tools can help not only visually-impaired users but also researchers in general by providing another perceptual dimension for analysis; however, one case study recognizes various design implications due to the differing tensions and biases from sonification use cases between visually-impaired users and sighted listenerst [7]. Another case study proposes a "Action-by-Design-Component" framework for effectively mapping "auditory interactions" and showcases the utility and generalizability of sonification across visualizations, including charts and tables, using their iSonic tool [8].

Further, an interview study explicitly engages with visually-impaired users to need-find the next directions for current designs and developments; users recommend support between auditory and tactile modalities and haptic feedback [2]. Notably, one task-based design study showed that the use of vibrotactile aids improved performance with task-based sonification interactions in blindfolded sighted participants [5]. Similarly, one user study measures performance differences between visual-auditory and visual-tactile feedback and finds that additional modalities facilitate interactions with visual systems; this research recommends further investigation on more complex multimodal feedbacks, such as visual-auditory-tactile modalities.

Sonification designs and techniques differ by the data structure. Focusing on tables and tabular navigation, Kildal and Brewster found that grouped sonification of data is faster and more efficient without reducing accuracy in browsing tables [3]; their work also reveals that users navigate data faster with mental workloads for non-speech sonifications than speech sonifications [4]. Given the extensive and complex nature of tables, data patterns can still be revealed effectively using sonifications.

3.2 Approach and Strategy

Following Kildal and Brewster's work on tabular sonification, I aim at expanding their design and matrix reduction approach by augmenting additional features in the non-speech sonification method and employing an additional tactile modality. Their work cleverly reduces 2D tables into 1D arrays by grouping the values in a row or column and sonifying the grouping at once [3, 4]. As a result, this minimizes the overall complexity of the table data structure and provides easier navigability for users– notably, users with visual impairments. The users can use speech sonification for details-on-demand and obtain the original values associated with the non-speech sonification sequencing. For my design, I noticed that although the grouping and dimensionality reduction is more efficient, some important values, such as maximums and minimums, may not be as salient when sonified as a grouped entity. I propose emphasizing the saliency of important values further by first preprocessing the table to highlight the details. This can be achieved by attaching an additional dimension of sound, such as varying pitch levels or with frequency or amplitude. Given the short temporal nature of sound, through this modification, users can efficiently navigate through the table and recognize the most important values in the grouping. As the sonification advances with respect to positioning in the table, users can also create better mental maps of the visualization, a commonly performed action for users with visual impairments [2, 8]; through explicit sonification of important values, users will have lighter cognitive workloads from not having to distinguish between unimportant values during the sonification sequencing. The following sketch illustrates the mapping:

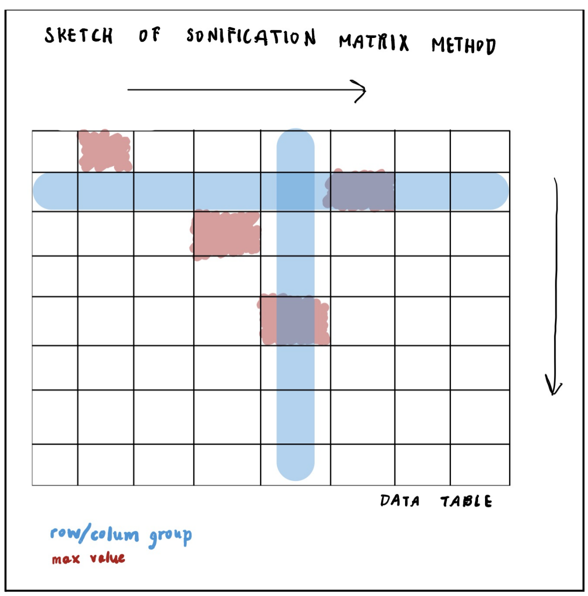

Figure 1. A sketch of pre-processed table sonification of data table where red cells indicate a highlighted value, *e.g.* maximum or minimum in the given row/column, and blue cells indicate the grouped values to be sonified. Users conventionally navigate the table: left–right, top-bottom.

As the user sonifies through the table, the highlighted cells in red are sonified with an additional sound parameter, thus explicitly informing the user about its position and value. By embedding additional dimensions of sound to the dimensionality reduction approach, the important sonified values become more salient, which may have been lost due to the grouping.

Further, since there is a natural intersection between visual and tactile modalities, such as screen readers, tablets, and Braille devices, and between visual and auditory modalities, such as with aforementioned sonification research [2], I intersected all three and aimed at designing a visual-auditory-tactile multimodal navigation of nested tables to facilitate memorability in the user's position and the table's view state. Drawing from research on vibrotactile interactions and the ubiquity of vibrotactile feedback in current technologies, I noticed that there is a subtle aural component associated with vibrations, thus mapping a natural relevance between auditory and tactile modalities. As tables may be nested thus breaking conventional 2D table structures, I propose informing the user of these changes. Users without visual impairments can clearly and immediately see how a structure is organized, but users who rely on sound navigation can only recognize structural discontinuities at the moment of occurrence, assuming the discontinuity is distinguished. through vibrotactile feedback, the user can subtly hear and feel changes in the table view and without being distracted by the active sonification of data. The vibrotactile feedback can inform the user of an approaching change in the table format and if the user enters a nested table, thus enhancing the user's mental visualization of the structure and streamlining navigability of the table. The following sketch illustrates this feature:

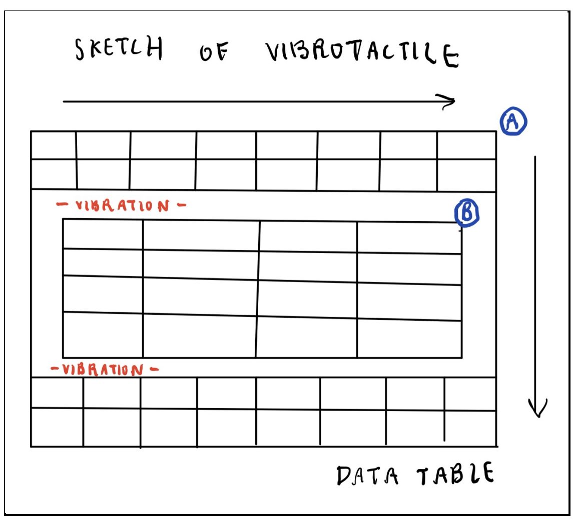

Figure 2. A sketch of the vibrotactile feedback elicited from the sonification. The vibration occurs when the user reaches the labels in red, or the nested table. In this case, the original table and the nested table are denoted by the A and B labels, respectively. Table navigation: left–right, top-bottom.

As the user sonifies through table A, the device vibrates briefly upon entering and exiting nested table B thus informing users of changes in the table's structure. An additional sound dimension can be mapped to the sonification of the data to better illustrate the changes between states.

In addition to the previous designs, I propose an "echolocation" feature for the sonification. One research study learned that users with visual impairments use "echolocation" for understanding and visualizing the space around them using ambiental auditory and tactile cues. Motivated by this insight, I emphasize the importance of recognizing the user's position while navigating a table. Given the extensive nature of tables, even for users without visual impairments, it is easy to get lost in a large table, thus I designed a sketch as follows:

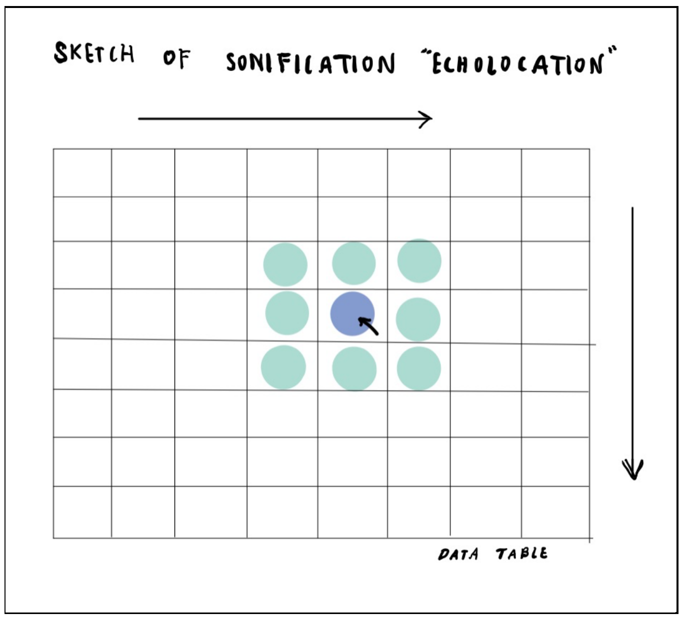

Figure 3. A sketch of "echo-location" sonification of a data table in which the blue cell is clicked and sonified at a mapped sound dimension, and the surrounding green cells are grouped and sonified/"echoed" after a short delay at a lower sound. Users conventionally navigate the table: left–right, top-bottom.

As the user sonifies through the table, the user can interact with and ping a specific value, which sounds the value and then sounds surrounding values at a lower sound parameter, *e.g.* pitch. This parallels desaturated or lower opacity visual encodings to highlight or emphasize an aspect of a visualization. The "echolocation" feature can also help inform users of the table's bounds, such as through values at the rightmost column or values at the perimeter of a nested table. This feature can improve the memorability of particularly interesting values and enhance spatial awareness while navigating the table.

4. Evaluation

For evaluating my design, I intend to create user studies in which participants will be taught how to use the system and then perform tasks associated with the features. Quantitative and qualitative methods will be used to inform future iterations. As the design emphasizes user-centered approaches and iterations, I intend to record qualitative and subjective responses toward the features; the features should be pleasurable and not confusing to use, thus it is important to capture their experiences with the system design. Then I will measure quantitative data, such as the number of accurately-completed tasks and the time spent completing a given task. The quantitative measurements will help inform whether the designed features actually improve performance in navigating nested table structures compared to without the features.

The study will be evaluated within groups. A within groups experiment is best for low-level interactions, such as the features I designed. I must evaluate interactions with each feature that I proposed: preprocessed highlights, vibrotactile navigation, and echolocation. Through this process, I can discover which features help or hinder and if one feature implementation affects the others.

5. Conclusion

For users with visual impairments, visualizations become difficult to navigate and unravel, thus other modes of interaction must be considered. Sonification is a useful technique for aurally recognizing patterns and trends in data through another modality.

Using a user-centered design approach, I designed features that help users with visual impairments effectively navigate nested table structures. As discovered in many related works, my designs emphasize a user's desire to create mental visualizations of the structures by improving memorability and navigability. By preprocessing the table and highlighting, the sonification can make the important values more salient to the user. Then through vibrotactile feedback, users can both hear and feel where changes occur in the table structure, such as when a user finds a nested table. Finally, the echolocation feedback helps the users track potentially interesting values and informs them of their position in the table. Through a within groups user study, I can determine the efficacy and relevance of these features for users with visual impairments.

6. References

[1] J. L. Burke et al., “Comparing the effects of visual-auditory and visual-tactile feedback on user performance: A meta-analysis,” 2006, doi: 10.1145/1180995.1181017.

[2] P. Chundury, B. Patnaik, Y. Reyazuddin, C. Tang, J. Lazar, and N. Elmqvist, “Towards Understanding Sensory Substitution for Accessible Visualization: An Interview Study,” IEEE Transactions on Visualization and Computer Graphics. 2022, doi: 10.1109/TVCG.2021.3114829.

[3] J. Kildal and S. Brewster, “Explore the matrix: Browsing numerical data tables using sound,” Int. Conf. Audit. Disp., 2005, http://hdl.handle.net/1853/50153.

[4] J. Kildal and S. A. Brewster, “Non-visual overviews of complex data sets,” 2006, doi: 10.1145/1125451.1125634.

[5] J. Kildal and S. A. Brewster, “EMA-tactons: Vibrotactile external memory aids in an auditory display,” 2007, doi: 10.1007/978-3-540-74800-7_6.

[6] D. A. Norman, *The design of everyday things*. Cambridge, MA: The MIT Press, 2013.

[7] B. N. Walker and L. M. Mauney, “Universal design of auditory graphs: A comparison of sonification mappings for visually impaired and sighted listeners,” ACM Trans. Access. Comput., 2010, doi: 10.1145/1714458.1714459.

[8] H. Zhao, C. Plaisant, B. Shneiderman, and J. Lazar, “Data sonification for users with visual impairment: A case study with georeferenced data,” ACM Trans. Comput. Interact., 2008, doi: 10.1145/1352782.1352786.