Sonify: Making Visual Graphs Accessible

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Abstract. Data visualizations are an essential strategy for summarizing and comprehending large datasets. However, it is challenging for visually impaired people (VIP) to access visual representations of data. Current accessibility solutions fall short in providing comprehensive access to such visualizations. Most VIP must listen to datasets one cell at a time with a text-to-speech tool, which does not allow the user to gather the "gist" of the dataset. To address this gap, we designed and evaluated Sonify. Sonify is a sonification tool that makes data visualizations accessible to VIP through audio and tactile interactions on a mobile app. VIP use Sonify's scrubbing interaction to explore patterns in data through pitch changes in sound. We evaluated Sonify's interactions through contextual inquiries, with (n = 8) VIP. Through Sonify, we demonstrate how a novel scrubbing interaction technique makes 2-variable linear graphs accessible to a broader range of people, including VIP.

Keywords: Human computer interaction · Accessibility · Assistive technology · Iterative design · Human centered design · Sonification · Usability testing · Assistive technology for persons with disabilities

1 Introduction

The ability to collect, interpret, and analyze data has long been integral to professional fields such as science, technology, engineering, mathematics (STEM), finance, and marketing. This has become even more important in recent years due to the increased availability and usage of large datasets. Professionals dealing with data analysis often make use of data visualization techniques such as charting and graphing, but visualizations are often inaccessible for visually impaired people (VIP) [8]. In initial research for this project about accessibility at large, we conducted contextual inquiries with 8 VIP, and found that a common pain point was the inability to understand visually complex interfaces such as graphs and charts. All 8 people with visual impairments reported that they struggle with 'getting the gist' of complex data.

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The population of blind and VIP constitute 6.8 million adults in the United States [16], which has led to an increase in the amount of assistive technology to help VIP access computers [10]. Despite improvements in general accessibility, data visualizations remain relatively inaccessible for people with visual limitations. At present, screen-readers like JAWS [10] allow VIP to access content via text-to-speech technology (TTS). However, screen-readers often skip over graphs or read only the title and axes labels. If a VIP has access to the dataset, they can manually tab through each cell in a spreadsheet to try to find and understand trends in the data.

Existing technologies in data accessibility utilize tactile and haptic feedback as well as auditory interpretations of chart data, which are prevalent methods for representing visual knowledge in alternative modalities [13, 17]. Tactile solutions have been integrated as standard tools for VIP [11] and sonification of visual information has been used in tools ranging from TTS to blood oxygen monitors [15, 17]. Sonification of data, graphs, and other visual content allows VIP to understand visual content using audio patterns [8]. The Web Sonification Sandbox, a tool developed by the Sonification Lab at Georgia Institute of Technology [14] takes in a static dataset and returns customizable audio output of a single line chart. Sonification can also be used in data representations that are compelling to sighted people, like the work of the Data Driven DJ [5].

While our solution is scalable to all fields that make use of data visualizations, we chose to focus on VIP working in the field of finance, which includes traders and analysts. Prior research reports that, of individuals willing to work, 79% of those with severe visual difficulty and 64% of those with extreme visual difficulty were employed, but only 2.2% of these professionals fell under the category of "Technician or Associate Professional (inspector, finance dealer, etc.)" [9].

We followed an iterative design and testing process over 4 months, which resulted in Sonify, a sonification tool that makes 1 or 2 line graph visualizations of stock price data accessible to VIP. In this paper, we outline details about Sonify and the iterative design cycle we followed while developing the product, and the qualitative evaluation of interactions with (n = 8) users with visual limitations. Through Sonify, we demonstrate how a novel scrubbing interaction technique makes 2-variable linear graphs accessible to a broader range of people, including those with visual limitations.

2 Iterative Design

In this iterative design process, we went through 4 phases of designing and evaluating prototypes of increasing fidelity. To evaluate our prototypes in different stages of the product, we recruited 8 VIP, who constitute potential users, 14 accessibility experts, and 13 finance experts. VIP included 5 VIP with complete blindness, and 3 VIP with partial (mild to severe) visual impairments. In order to gain meaningful user insights, we kept several potential users involved through each stage of design [6]. Methods include varying combinations of contextual inquiries [3], think aloud sessions [20], and cognitive task analysis [19].

2.1 Design Phase 1

In Phase 1, we conducted think-aloud sessions with 10 finance experts in which participants were presented with a static line graph of the NASDAQ stock price graph, and asked to evaluate it in 1 min. Financial professionals reported that, when quickly reading a financial line chart, they look for: (1) overall pattern or trend, (2) high/low price of the stock for that day, (3) the current price of the stock, (4) graph labels and units, and (5) any spikes in the price over time. They may compare the chart with another related one or with relevant news events. After establishing this key information, we designed 5 low-fidelity prototypes and tested them with accessibility and financial experts. While we observed that both tactile and auditory solutions showed promise, tactile interfaces typically require a separate piece of custom hardware that is expensive and cumbersome. Thus, we chose to pursue a combined auditory and tactile solution that could be built into users' current workspace.

2.2 Design Phase 2

We chose to test pitch variation in Phase 2 based on well-documented research on pitch perception indicating that people are able to connect changes in information with changes in pitch [4, 12, 16]. Beyond audio, we recognized that the interactive aspect of tactile interfaces was compelling and effective. And existing sonification tools allow the user to play the audio version of a graph by pressing a button [14]. We sought to combine auditory and tactile interfaces to provide greater interactivity and understanding of the data. We developed and tested 3 prototypes:

1. Trackpad Scrubbing: A desktop application that allowed users to interact with an audio graph via scrubbing (dragging your finger left and right) on a computer trackpad. With X-values (dates) on the horizontal axes and Y-values (prices) corresponding with the pitch.
2. Keyboard Audio Navigation: An application that allowed people to use keyboard shortcuts to play the trend of a line and reveal important summary information such as highest, lowest, and current price.
3. Sound Preference: A system to test sound preferences using an open-source tool built by the Sonification Lab at Georgia Tech [14] to experiment with different sounds for line graphs.

Participants who used the scrubbing prototype were more successful at quickly drawing the "gist" of the graph. While participants who used the keyboard prototype took longer but drew more detailed and refined graphs. We then combined the positive elements from the two interactive prototypes: (1) interactive "scrubbing" control for line audio and (2) key data values from the keyboard shortcuts. Four out of the six participants agreed that they were able to gather the trend of the graph using the scrubbing and keyboard shortcuts. As a participant stated, "I would periodically press the spacebar as I moved through to have a more exact understanding." To address the problem of trackpad disorientation, we chose to switch from using a desktop trackpad to using a touchscreen. The absolute spatial mapping of smartphone and tablet devices would allow users to drag their finger across the graph without losing their place. We specifically chose devices with iOS over Android because our VIP participants emphasized that iOS is widely used by VIP given the accessibility friendly features.

2.3 Design Phase 3

In phase 3, we assigned a set of gestures to provide relevant pieces of information in an iOS application. For sonification of the line, we mapped values to pitches between the data points [2, 7, 17]. Participants were able to correctly describe the general movement of the line graph and identify spikes in the data. All the participants were able to identify changes in data patterns such as crests and troughs. When participants were first given the prototype, there was some confusion on what gestures they should use. We tested on both an iPhone and a larger iPad. While we had hypothesized that using a larger device would provide more granular insight, we found that participants preferred the smaller device because they could constantly feel the edges of the phone and understand where their finger was relative to the edges of the graph.

2.4 Design Phase 4

Based on results in Phase 3, we redesigned the gestures intended for gaining data insights through the GUI to match VoiceOver (iOS built-in screen reader) [1] for improved discoverability and fluidity. We divided the screen so that the top ½ would recognize VoiceOver gestures to provide supplementary info and controls for the graph while the bottom ½ would support scrubbing through the graph and single taps to read out values for that specific point (Fig. 1).

Fig. 1. This is the final design of Sonify, displaying the two stocks with the current, high and low stock prices. The interface also displays the current date range of the data and options to switch between date ranges. Finally, it includes dual stock graphs.

To compare the stocks to the market trends, we added a second line to the graph to allow for VIP to have access to similar data points. The hypothesis was that less complex sounds would be easier to distinguish while listening simultaneously, so we used sine (pure) and square (rougher) wave sounds. One line plays into the left ear audio with a sine wave sound while the second line plays into the right ear as a square wave sound. The user can swipe up and down in the graph section of the screen to switch between playing line 1, line 2, or both. If both lines are selected, Sonify plays both tones corresponding to the user's finger position as they scrub; if they tap, it reads out the current value for each line. We sought to test users' ability to distinguish between the lines and identify points where they cross/diverge, which is an important use case in analyzing stock price charts.

Based on our tests (1) users were able to pick up the Voice-Over gestures well, (2) users were able identify when the 2 lines intersected or spiked, and (3) users were able to gather a gist of the dataset. Finally, we built a barebones visual graphical user interface (GUI) for the application because our VIP participants revealed how important it is to be able to collaborate with sighted peers. We tested this UI to ensure accessibility for people with color blindness and/or low vision.

3 Discussion

In Sonify, we introduce a novel interaction technique that allows VIP to quickly build an understanding of data represented on a line graph, which was previously near difficult or impossible. Sonify's scrubbing interaction combined with standard Voice-Over interactions allows VIP to quickly gather the gist of a line graph, describe its movement, and access key values about the graph. These interactions set the groundwork for interactive data sonification and lay guidelines for designers wanting to expand to other types of graphs or datasets. We exhibit that playing two pitches of different sound quality simultaneously in either ear, when combined with tactile scrubbing, enables VIP to describe movement and crossing points of two different lines on a graph. We also demonstrate the importance of iterative design and working closely with the target users when designing for accessibility, which led us to make key design decisions like focusing on mobile phones over tablets for the VIP audience specifically. We make Sonify an open-source technology, to democratize this technology in the larger spirit of accessibility. Further, we advance the field of comprehending complex data to alternative modalities besides data visualization, and make graphs accessible to users who could not access graphs in the past.

4 Limitations and Future Work

In this paper we outline how we used user-centric iterative design methods to design Sonify, making visual graphs accessible to VIP. While we did multiple rounds of usability evaluations with potential users, there were some stages in which we could not work with VIP. As very few individuals with visual disabilities work in finance, we were not able to recruit individuals who meet both criteria.

While we qualitatively validated the design and accessibility of Sonify, the tool can also be made useful across non-finance domains. We must allow users to upload their own datasets. Sonify can also allow greater dimensions of data to be conveyed by using more complex sound interactions such as loudness, pitch, and frequency, as opposed to the current version, which only uses pitch. The current version of Sonify can be downloaded from the Apple app store found with this link.

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