Towards the Combination of Visualization and Sonification for Cylindrical Displays

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Abstract

Immersive environments provide a physical space for audio-visual data analysis. An example of such an environment is the Norrköping Decision Arena, which provides a cylindrical display together with a circular sound system. This paper sets recommendations on what kinds of visualization would benefit from being displayed in this kind of environment and how sonification could be used as a complement to enable exploratory data analysis. Three visualizations are presented as potentially interesting for the presentation on a cylindrical display: theme rivers, radial visualizations, and parallel coordinates.

Keywords

Information visualization, Sonification, Audio-Visual Analytics, Interaction, Cylindrical displays

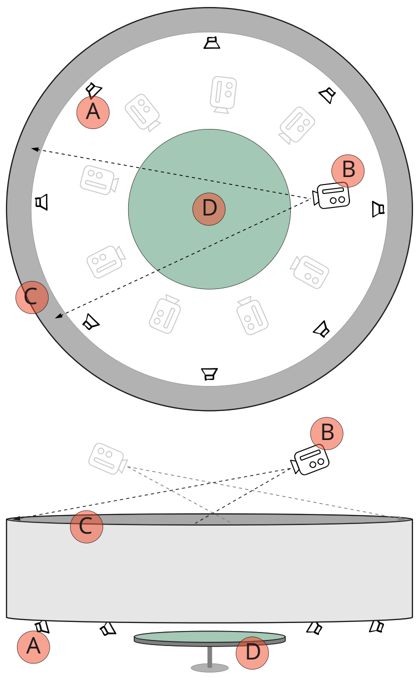

Figure 1: Sketch of the Norrköping Decision Arena from a top-down and side view. (A) shows one of eight speakers that are equally distributed over the 360° of screen space. (B) shows one of nine projectors that create the cylindrical display (C). A round desk (D) stands in the center of the room.

1. Introduction

Most conventional data analysis systems use visual representations to convey information to human analysts [1, 2]. While information visualization techniques use our human visual system to present information, sonification is "the use of non-speech audio to convey information" [3]. In recent years, audio-visual data analysis has gained interest in both the visualization and the sonification communities [4, 5, 6]. The combination of sonification and visualization (referred to in this paper as a SoniVis integration) uses both human auditory and visual perception to convey information.

Immersive environments, such as dome theaters [7] and CAVE systems [8], often enable the presentation of audio-visual media. With dedicated hardware for visuals and audio, they provide a physical environment in which users can experience audio-visual material. Through immersive analytics [9], users can intuitively explore data sets in a more tangible way.

The Decision Arena in Norrköping, Sweden[1] is an interactive facility designed to encourage collaboration and decision making. By providing a cylindrical display and eight horizontally spaced speakers (see Figure 1), the arena could be used not only as a conference room, but also as an immersive environment enabling exploratory data analysis with a SoniVis system.

To investigate the potential of the arena in terms of audio-visual analysis, we invited visualization, sonification, and interaction experts to gather ideas on the usage of the arena as an immersive environment. Topics of these semi-structured workshops included different types of visualizations, interactions, and data that would

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[1] Norrköping Decision Arena: https://liu.se/en/research/norrkoping-decision-arena

be suitable in the environment. Through the analysis of this feedback and our own findings, we propose three potential SoniVis integrations that could be beneficially used in the arena and in cylindrical displays in general.

2. The Arena

The technical possibilities and limitations of the arena need to be determined before one can set recommendations for potential SoniVis integrations. This section therefore covers (1) a description of the technical setup in the room and (2) a reflection on the ergonomical implications emerging from the setup.

2.1. Visual Setup

In the arena, a cylindrical display of six meters in diameter creates a 360° display around the user, something that would commonly only be possible through a head-mounted virtual reality display. The display system consists of nine projectors mounted in the middle of the ceiling that project their images onto the cylindrical wall (see Figure 1). The images are seamlessly stitched together to create a projection without any bezels that would otherwise be present if an array of display monitors was used. The disadvantage with a projected display is that it creates a shadow on the displayed surface if something is obstructing the projected imaging, for example a user pointing to something on the display. The resolution of the cylindrical display is sufficient when seated at the table in the center of the room, but less so for close observations on the display, which should be considered when developing towards the arena.

2.2. Audio Setup

The audio system of the arena consists of eight speakers that are mounted equally spaced beneath the cylindrical display at the ear level of people sitting around the table (see Figure 1). Although it is not possible for a user to be positioned an equal distance from each speaker (because of the table being centered in the room), having eight speakers allows for a more discrete sound positioning that is less dependent on how one is positioned in the room. An audio interface controls the output of each speaker individually, which enables two paradigms for sonification: One, using the speakers as individual mono sources, displaying sound distinctly from the direction of a speaker, or two, using the system to position and move sources between the speakers. The geometry of the arena also imposes a drawback regarding audio reproduction. The cylindrical wall used for image projection also acts as a reflective surface for the audio output of the speakers. The resulting flutter echo is most prominent when a listener is standing and is therefore vertically aligned with the cylindrical wall, while the effect diminishes when a listener is seated.

2.3. Interactivity and Ergonomics

A circular table is placed in the center of the room where up to 10 people can sit facing each other. The circular table together with the cylindrical display allows participants to look at the display while still keeping an eye to eye contact. However, it is not possible to see all of the screen at the same time. Using a SoniVis system, the main form of interaction a user will have in the arena is turning their head to see different parts of the visualization. The act of turning around is partly supported by the accompanied chairs in the arena, as they can swivel around 360°. The need to turn around also creates challenges regarding the user's interaction with the system. If a user would interact with the display via a regular mouse and keyboard on the desk, they would need to take an uncomfortable posture while moving the mouse on the table and seeing the visualization behind them at the same time. A favorable way for interaction in the arena would therefore be to use some kind of device that is not dependent on the desk but can instead be held in the user's hand and be pointed towards the area of interest. In a virtual reality setup, this would be achieved with a VR controller. The same type of interaction could be achieved by using a smartphone and its gyroscope features to make it act as a VR controller [10]. Other interaction devices could be a wireless touchpad or remote.

3. Combining the Modalities

In the context of a combined design of visualization and sonification, a 360° speaker setup has an advantage over conventional stereo systems: the locatability of sound sources. The spatial resolution of our auditory perception is lower than the one of our visual perception [11]. In a SoniVis system that uses conventional displays, such as computer screens with headphones or stereo sound setups, it will be problematic to perceive visual and auditory information from the same spatial position. With the technical setup in the arena we can spatially align the visual and the auditory information.

A sonification can convey additional information, or it can redundantly convey the same information to counteract shortcomings of the visualization. Common shortcomings in visualization are, for example, visual clutter and color perception. By using the spatially distributed loudspeaker layout in the arena, the sonification can at the same time guide the user's attention to areas of interest in the visualization.

Adding interaction to a SoniVis system is what enables exploratory audio-visual data analysis. The interaction should feel integrated with the SoniVis system, such as providing both auditory and visual feedback when a user interacts with the system. Considering the available screen space, the visualization could be displayed in its entirety on the display, meaning that no other form of navigation (such as scrolling or zooming) would be needed.

4. Potential SoniVis Integrations

The arena offers multiple possibilities to combine visualization with sonification. Through workshops with visualization, sonification, and interaction experts, three types of visualizations were chosen as potential candidates for future SoniVis integration. These were theme rivers, radial visualizations, and parallel coordinates.

4.1. Theme River

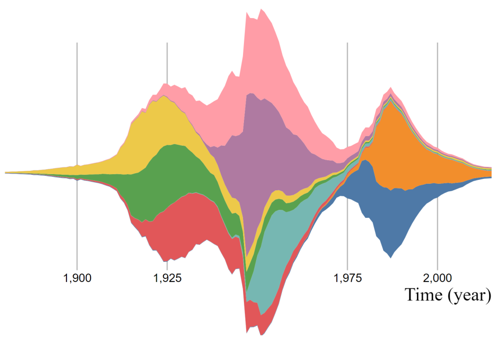

Figure 2: An example of a theme river, which displays the evolution of attribute values over time from left to right for a categorical dataset. Color hues encode different categories.

The theme river or streamchart (see Figure 2) is another example of a visualization that could be applied in the arena. Through the large horizontal screen space, a theme river can be projected over a large surface, enabling a closer look at the visualization.

With theme rivers, it is difficult to visually compare the width of two streams that are not adjacent with each other. Sonification could support a theme river visualization by conveying information about the width of selected streams. A user could then scan over the visualization horizontally and compare selected streams with greater detail. This would enable them to find the exact spot where one stream becomes wider than another. A sonification could also convey other statistical data such as the mode of the distribution at a certain position.

While the wide screen allows displaying especially long theme rivers, its circular design causes an essential drawback. The horizontal axis of theme rivers is usually a temporal axis. Connecting the beginning and end of a theme river, which the cylindrical display encourages, would result in the display of a temporal discontinuity. We therefore argue that a visualization technique conveying time on a horizontal axis should do so continuously on the cylindrical display. Therefore, even though sonification could support users working with theme rivers, the decision arena doesn't seem to be the right environment for this combination.

4.2. Radial Visualizations

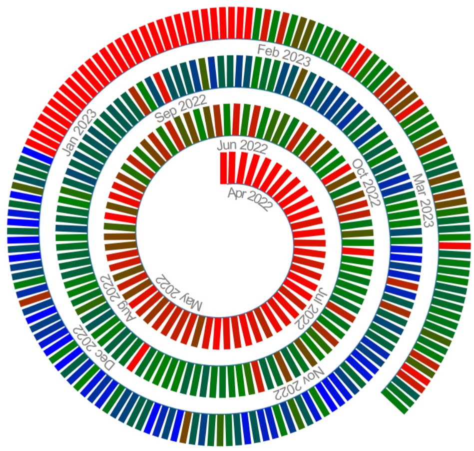

Figure 3: A spiral plot encoding attribute values over time via spatial position and color hue for a synthetic dataset.

Radial visualizations are viewed on a circular area [12, 13] (as seen in Figure 3) and have the advantage that one can present an otherwise stretched out visualization in a more consize view. The disadvantage of radial visualizations is that they are spatially distorted, in that they need to use more space for the data that is shown at a greater radius of the plot. Unwrapping a radial visualization and displaying it on a cylindrical display would eliminate this issue. However, in a radial visualization it is possible to get an overview of the visualization at a glance, which would not be possible in the arena. Radial visualization techniques are especially powerful for the display of cyclical data via spiral plots [14], which a cylindrical display can present seamlessly. Spiral plots can convey cyclical data over many iterations, often using color coding to display individual data values. Visual patterns are likely to emerge whenever periodic structures in the data align with the periodicity of the spiral plot's circumference. In an interactive visualization, users could change the display's periodicity until they detect a pattern.

For spiral plots, we imagine a sonification that supports users in the process of finding harmonic structures in their data. One way to design such a system would be to calculate the correlation coefficient between the individual cycles and to continuously sonify it to the users during their interaction. A periodic pattern aligned with the circumference of the arena would lead to a high value of the correlation coefficient. If that function controls the harmonicity of a complex sound, this could convey the impression of tuning an instrument by changing the periodicity of the display.

4.3. Parallel Coordinates

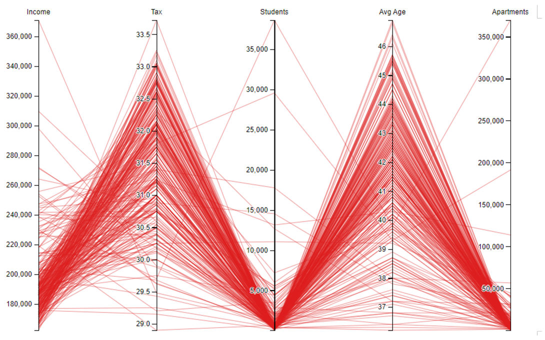

Figure 4: A parallel coordinate system displaying multivariate data items via polygonal path for a social science dataset.

Parallel coordinate visualizations are used to visualize multivariate datasets. Each of the attributes in the dataset is assigned to one of several vertical axes that are placed horizontally next to each other. Individual data items are represented by polygonal path linking the individual attribute values on the parallel coordinates [15, 16, 17]. Conventional parallel coordinate visualizations have the disadvantage of not being able to connect the first with the last axis. This is possible in the arena because of its cylindrical display. It can be argued that this additional connection does not substantially improve the visualization, since users of parallel coordinates can only compare two adjacent axes anyway. However, the connection enables users to drag and drop an axis with a shorter distance than with conventional parallel coordinate visualizations. Also, with respect to interactivity and the accompanying sonification, such a connection seems valuable. The circular display enables us to use sonifications that pan in circles around the users, without any spatial or temporal discontinuity in the auditory display. By displaying the parallel coordinates on the cylindrical screen, it would no longer be possible to overview the visualization. However, with parallel coordinates, there is no added value in seeing the entire parallel coordinate plot at the same time. Instead, only adjacent axes are important to observe, which is beneficial for the use in the arena.

As the decision arena offers eight equally distributed loudspeakers around the display, one possibility is to match these eight positions to eight parallel axes on the display. The sonification could then add contextual information about each axis in a discrete way. On the other hand, the visualization can be rotated so that the loudspeakers align with the connections between the axes. In such a case the sonification could represent additional information about the connections between two axes. We argue that accompanying sonification can support common challenges and tasks with parallel coordinate visualization, such as helping with visual clutter, detecting correlations and outliers, and allowing the comparison with more axes. Rönnberg and Johansson [6] have shown that sonification can improve the perception of visually dense areas in parallel coordinate visualizations. Sonification can also assist with conveying correlations between axes, even when there is visual clutter.

5. Conclusion

After discussing several possibilities for visualizations in the Norrköping Decision Arena, we argue that, in general, visualizations that need more horizontal space with increasing amount of data are feasible for this environment. A visualization that does not require the user to have an overview of the entire visualization is also beneficial in the arena and, whenever working with temporal data, one should display the time axis in a continuous manner. A spatially distributed audio system will help users of SoniVis systems to localize auditory information aligned with visual information, and while a cylindrical display can be simulated using virtual reality, a physical facility such as the arena has advantages regarding collaborative work.

In our future research, we will first implement a SoniVis integration for parallel coordinates in the Norrköping Decision Arena and evaluate its ability to help participants with exploratory data analysis tasks.

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