ACCESSIBLE SONIFICATION OF TOTAL SOLAR ECLIPSE 2024: ACCESSIBLE MAP AND MULTIMODAL VIRTUAL REALITY EXPERIENCE

Auralee Walmer, Nicolette Cash, Wenqing Yin, Teairis Majors, Brandon Biggs, Bruce N. Walker

Georgia Institute of Technology, Atlanta, GA, USA
auraleewalmer@gmail.com; ncash6@gatech.edu; wyin43@gatech.edu;
tmajors6@gatech.edu; bbiggs31@gatech.edu; bruce.walker@psych.gatech.edu

ABSTRACT

April 8th, 2024 marks a rare astronomical event impacting a notable portion of North America – a total solar eclipse. While this event can be witnessed by those along the path of totality, many may find it inaccessible due to their geographical location or a possible visual impairment which would exclude them from the experience. We aim to make the solar eclipse more accessible, by creating an audio-visual representation of the event that can be both educational and awe-inspiring. There are three primary components of this project, each designed to be accessible before, during, and after the 2024 eclipse: (1) accessible audio-visual maps; (2) a virtual reality simulation with educational and immersive features; and (3) a soundscape to accompany the real-time total solar eclipse event. Each component introduces intentionally designed sonic parameters, as well as narrative elements, to guide listeners through each feature of the project. We explore the challenges and benefits of expressing the total solar eclipse auditorily, and argue that an audio-visual format provides both educational and engaging benefits. Our ultimate goal is to provide an experience that is illuminating, enriching, and most importantly, accessible to anyone regardless of visual impairment or geographical location.

1. INTRODUCTION

On April 8th, 2024, a total solar eclipse occurred and was visible for a significant portion of North America, moving in a northeast trajectory across Mexico, The United States, and Canada. The path of totality, meaning geographic locations where individuals are able to experience the effect of the moon completely blocking the sun, included U.S. cities like San Antonio, Dallas, Indianapolis, Cleveland, and Buffalo. During an eclipse's period of totality, there is a darkening of the sky comparable to dawn or dusk [1,2], which is an intriguing and breathtaking effect.

However, not everyone has the opportunity to enjoy a total solar eclipse due to either geographical constraints or visual and auditory limitations. Thus, we have launched a project to make it more accessible for people to experience the solar eclipse and to learn more about how the environment and animals react during the process. Our project has several classes of components: (1) accessible audio-visual maps of two different types ("push", "pull"); (2) a virtual reality (VR) simulation with educational and immersive features; and (3) a soundscape to accompany the real-time total solar eclipse. Each component is tailored to highlight different aspects of the solar eclipse, ensuring a comprehensive and inclusive understanding and experience of this astronomical event.

This project weaves together astronomy with geography, music, sonification, environmental science, and game elements. It provides a unique opportunity for learners worldwide to understand the mechanics of solar eclipses and their effects on the natural world, making it a valuable resource for educators and students across diverse international settings. The novel use of sound, which is of special interest to the ICAD community, is something we emphasize in each component of this project. Additionally, we introduce important innovations in accessible multimodal maps.

2. PREVIOUS WORK

The Georgia Tech Sonification Lab created a unique auditory experience for the 2017 Solar Eclipse [3], aimed at making the event accessible to individuals with vision loss. The primary focus of the project was an audio track that was composed to accompany the live eclipse. The audio composition was live-streamed during the eclipse on August 21st, 2017, and was listened to by people both near to and far from the path of totality. The Georgia Tech Sonification Lab team used a variety of software instrumentation, synthesized tones, and other sonic elements to symbolize the movement of the sun and moon. The soundtrack was designed to be emotionally stirring and to build anticipation towards the moment of totality, which was represented by a segment of near silence. Additional live musical components were performed and layered onto the soundtrack during the live eclipse, representing data such as air temperature, brightness, and barometric pressure. Specifically, the 2017 soundtrack consisted of three layers: (1) a pre-composed base track reflecting the eclipse's temporal dynamics and light changes, with emotional undertones; (2) environmental sounds mimicking natural reactions to the eclipse, like cricket chirps during the false dusk and bird song during the false dawn; and (3) live-generated musical tones based on real-time meteorological data. The confluence of these layers offered an emotionally moving and multi-dimensional representation of the eclipse.

While the 2017 eclipse sonification was very well received, it was mostly about enhancing the live experience. It did not include interactive or educational elements that might provide more generalized insight about solar eclipses. Reflection on this previous work highlights a need for expansion beyond the stand-alone soundtrack concept. When rare astronomical events occur, there is a unique opportunity to inspire awe and catalyze more public interest in science. Current technology makes it possible to bring the eclipse experience to people all over the planet through immersive and engaging educational design.

3. PROJECT AIMS

A total solar eclipse is a phenomenon that receives significant visual attention, and thus potentially marginalizes people with visual impairment. By designing novel auditory and multimodal experiences, we aim to make the awe-inspiring experience of witnessing a total solar eclipse accessible to all. Further, we hope to incite further public engagement with topics like astronomy, geography, and environmental science. Accomplishing this requires the union of intentional aesthetic design and educational feature development.

Part of understanding an eclipse is by exploring the geospatial movement of the eclipse's path. Long before the eclipse happens, astronomers know precisely where and when the period of totality (and partial totality) will be experienced. NASA publishes this geospatial data along with an array of geographical representations of the eclipse's path which are available to the public. Unfortunately, these maps are almost exclusively visual and consequently inaccessible for visually impaired or blind individuals. Thus, we sought to explore options for maps that include audio for both accessibility and enjoyment. By engaging with an auditory map and sonification of the path of totality over the contiguous United States, one can understand where this particular phenomenon has occurred in a regional sense. On a more practical level, an accessible map can make it easier for a person with vision impairment to predict what the eclipse will be like where they live, or even to know where to go to experience the effect of totality.

In addition to the geospatial representation of the eclipse, another important aspect of this project involved simulating the "on-ground" experience of the total eclipse. That is, what is it like to experience a total solar eclipse as an individual standing underneath its path? We aspired to convey characteristics of the event through accessible educational features that would be easily usable before, during, and after the eclipse event. While oftentimes the educational focus would be the visual experience, we wanted to highlight that there are several distinct auditory events and environmental changes that occur during an actual eclipse. Examples include a quieting of animals in the environment who sense a shift to nighttime, and the moment of calm that naturally washes over an environment when darkness emerges. These audio features are expressed in our soundtrack, and are included in the immersive virtual reality (VR) component of our project.

4. COMPONENT 1: ACCESSIBLE MAPS AND SONIFICATION OF THE PATH OF TOTALITY

The solar eclipse presents an ideal opportunity to explore geographical representations of data. As the eclipse of 2024 approached, a myriad of geographical maps appeared across the internet, displaying the path of totality from an aerial view [e.g., 4]. Visual representations of this path are straight-forward and intuitive to generate, but how could the path of totality be expressed in the form of audio? This is one of the sonification research elements we are undertaking as part of this project.

4.1. Definitions of "Push" and "Pull" Maps

We explore and present two different classes of accessible maps: "push" maps and "pull" maps. A "push" map is a curated multimodal experience that presents relevant geospatial data to a recipient without the need for user direction or prompting. Our "push" map delivers this information in visual form with the eclipse path superimposed on a map of the United States, and in audio form through a set of speech, music, and sonification components. The experience is like playing a video, in that the information is "pushed" to the user. In contrast, a "pull" map allows the user to actively navigate around in the map, to see and hear about the data at the user's virtual location. The user "pulls" information on-demand, so the experience is dictated more by the user rather than curated by the designer. The terminology here parallels the distinction between pull and push auditory menus (see [5,6]). Push maps are useful for guiding and highlighting elements the designer wants to emphasize, and pull maps are useful for expressing detailed spatial attributes about features that interest the user. In the following sections, we focus more on the design and creation of a multimodal push map. We also created a pull map which is also presented in a subsequent section of this paper.

4.2. Multimodal "Push" Map of the 2024 Solar Eclipse

Previous explorations of geographical data sonification have often focused on navigation-based designs, or user-selected musical parameters mapped to geographical elements [7]. In our conceptual development for sonifying the trajectory of the eclipse's path of totality, we initially approached the design as a narrative playback audio-visual presentation, so users can understand the path of the eclipse the same way they might consume a chronological story.

A portion of the ideation process for this audio-visual map involved exploring which parameters should represent geospatial movement along a path. The primary data elements to capture are latitude, longitude, and time. Depending on the chosen map projection, which influences the curvature of the visualization, latitude and longitude provide a grid-like framework for aerial navigation of 2D space. Latitude could intuitively be represented by a positive mapping onto pitch. Longitude could intuitively be represented by stereo imaging: "west" at the left side of the stereo field, and "east" to the right. A listener hears a "panning" effect from the left to right speaker as a data point moves from west to east on the map. This can be captured with percentage values associated with longitude representing lateral placement from west to east. Finally, time in this scenario is marked by timestamps associated with different coordinates, as the moment of totality becomes visible for certain locations over the course of the day. Typical time-based sonifications have used a click track to mark the passing of time, like a metronome providing temporal context. In an effort to steer away from typical time-based approaches, we explored other ways to represent changing coordinates over time, elaborated below.

4.2.1. Data Source & Subsampling

Data for the 2024 total solar eclipse path of totality came from NASA: Michala Garrison, Science Data Visualizer at the NASA Earth Observatory [8,9], provided spatial coordinates, UTC timestamp values, and other pertinent values such as the duration of total totality for each coordinate, distance to the moon, and angular positioning of the celestial bodies. The original data set of 6,770 rows was trimmed to only include the 3,837 rows pertaining to locations in the United States. The original data contains geospatial coordinate measurements for every passing second across the full time range. For the purposes of an audio-visual map with an aerial view of the path of totality and accompanying sound, less precision is required. Thus, we further subsampled the data to contain regularly-spaced longitudinal value bins.

The reason for equal increments of longitude is this: as a quasi x-axis, one can imagine the fluctuating slope of the path indicated by shifting latitudinal values for each equivalent increment of longitude. By allowing equal spacing of longitude, one can capture the corresponding latitudinal coordinate bin, which may not be a 1:1 mapping depending on the slope of the path. Making an analogy of a right triangle with the path of totality as the hypotenuse, one can see this effect. Figure 1 shows this mapping idea.

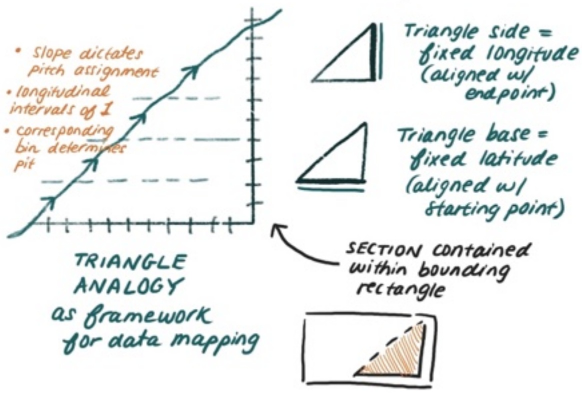

Figure 1: Exploration of the data-to-audio mapping using a "triangle analogy," where the base and side map to coordinate data.

4.2.2. *Sonification of the Trajectory*

Following the preliminary parameter mapping decisions, the next phase involved an exploration of the audio aesthetic and musicality of the data sonification. For example, design choice questions might be: should we use singular tones or chordal structures? Software instruments or acoustic renditions? What complexity of layering should be involved? Latitude is not the only data to convey; additional layering of information is required. For example, a listener might be interested in knowing where major cities appear along the path of totality. Taking this into consideration, we planned to include sonic indicators that would reflect certain major cities, such as Dallas, Indianapolis, Cleveland, and Buffalo. The sketches in Figures 2 and 3 show the ideation process of building informative layers of the sonification, with purple markings representing major city indicators. The turquoise markings in Figure 2 represent notes within the G major scale, mapped to latitude. The two triangular shapes in Figure 2 represent a fade-in and fade-out chordal foundation, intersecting at the trajectory midpoint, to improve musicality and provide temporal context.

Providing a sonic frame of reference is particularly important to ensure that a listener can understand the meaning behind auditory elements in a sonification. Designing this playback audiovisual map as a narrative story, it is important to begin the story with the information and lexicon needed to understand the main plot. To create this, we explored the idea of sonic "reference points," to be played before the path sonification. Using the analogy of the contiguous United States bounded by a rectangle, one can imagine the four corners of this bounding shape. These we considered our "extreme coordinates," which are associated with the maximum sonic expressions for our two primary parameters: pitch and stereo image. We selected the most recognizable cities nearest to the extreme coordinates of the contiguous United States: Seattle, WA; San Diego, CA; Miami, FL; and Portland, ME. This bounding box analogy is demonstrated in both Figures 3 and 4. The placement along the stereo field is derived from a longitude-to-percentage mapping, where the leftmost coordinate corresponds to 0%, and the rightmost coordinate corresponds to 100%.

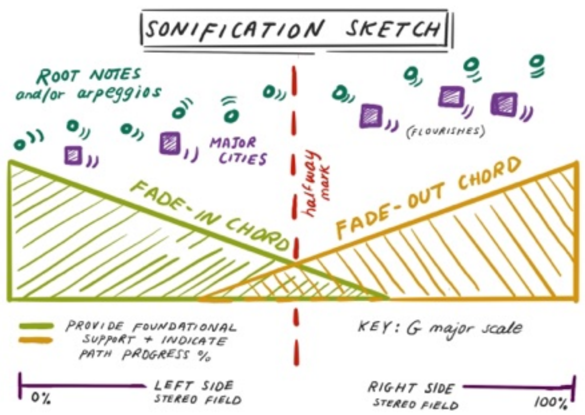

Figure 2: Sketch of the audio elements constituting the data sonification, categorized by color (to be read from left to right).

An additional developmental decision for this sonification was the degree of musicality to be expressed. Designing a sonification to be more musical can help make it more pleasant and engaging. To achieve this, we implemented a series of arpeggios (notes played in sequence) to represent increasing latitude, rather than singular notes. We also decided to limit the pitch mapping to a G major scale, to create a sense of auditory harmony. The downside to limiting notes to a musical scale, as opposed to a chromatic scale for example, is that there are fewer notes to work with and thus less data mapping accuracy. But for this case, the benefit of maintaining musicality and avoiding dissonance outweighed the need for further pitch mapping precision. Our subsampled data set contains 18 unique rows of data that can easily be aligned with audible notes on a piano constrained to the key of G. Figure 5 demonstrates the notes included in the mapping as highlighted notes on a keyboard.

Another auditory characteristic of our sonification design is its condensed nature. While many sonifications take on a longform expression, we decided that a condensed audio representation of the path of totality would be more engaging, and fit well into the context of a simple narrative presentation. By providing multiple temporal experiences of the eclipse throughout our project, we allow for engaging versatility in how a user can engage with this astronomical event. This is one of the ways that this project differs from the 2017 project. The approach to sonifying the eclipse in 2017 (referenced in Section 2) was a longform soundscape, designed as an accompaniment to the live experience of the event. We provide that experience once again with this project through the soundscape included in the VR component. This narrative-form condensed playback component is an additional aspect which allows the listener to quickly understand the path of totality.

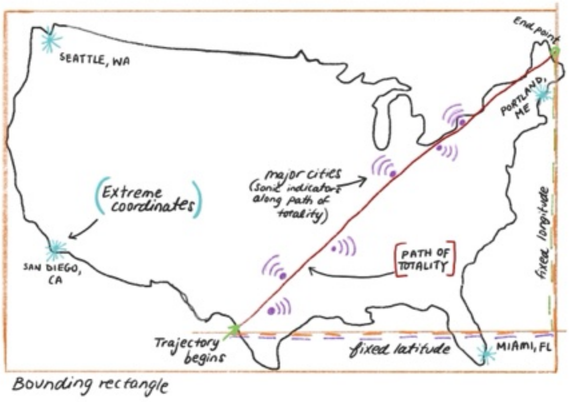

Figure 3: Sketch of the geographical map with the path of totality, bounding rectangle, and accompanying sound components.

4.2.3. Visual Development

As cartographers are well aware, there are several geographical projections available, each impacting the way earth's curved features are represented on a flat surface [10]. Regardless of the selected projection, some distortion is introduced. We selected the "Albers USA" geographical projection, because it worked best for our rectangular bounding box analogy. Additional visual elements to be expressed include the extreme coordinates (our reference points). These are marked on the map with points placed on the coordinates for Seattle, San Diego, Miami, and Portland (ME). The triangle analogy is visually represented by an array of coordinates along latitude value 29 and longitude value -68. The hypotenuse of this triangle is represented by the path of totality itself, which is visually captured by a line drawn in a northeast trajectory across the United States. Major cities are represented by additional points, which fall along the line of totality. Each categorical element corresponds to a unique color, as an embedded legend for visual clarity. Figure 6 represents a simple version of these visual elements.

The prototype development of the visual elements involved ideation sketches, static mapping and placement of the coordinates, and planning animated features to engage the audience. The visual elements appear and animate as each is referenced in the spoken narrative. For the animated aspect of this map, we also decided to include an eclipse icon that would move along the path of totality as the sonification plays, to provide visual reference for the spatial placement being represented. As the icon moves, the visual points corresponding to major cities react with movement when the icon passes in their vicinity.

4.2.4. Narrative Presentation

There is a balance to be found in the effort to make a sonification both pleasant and informative. On one end of the spectrum of "data-driven audio" is the highly musical and aesthetic composition; on the other end is the rigid, pure data mapping. Both ends of this range have the potential to convey data-driven meaning, but a beneficial augmentation to any data sonification is a preparatory sonic glossary, akin to a map's legend. By introducing the listener to certain sonic elements, and allowing her to develop familiarity and associations with those sounds, one equips an audience to understand the data sonification as a whole. These elements can be introduced in the form of a narrated chronological story, in which a listener can get comfortable with the characters involved and thus have context to understand their subsequent interaction.

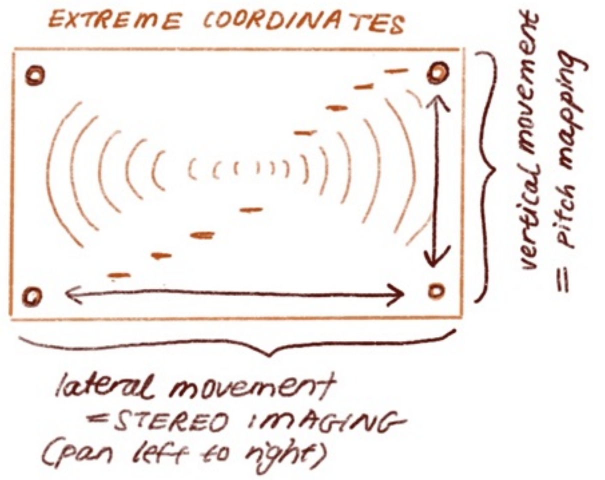

Figure 4: Sketch of the audio parameter mapping, with range determined by the corners of a geographical bounding rectangle.

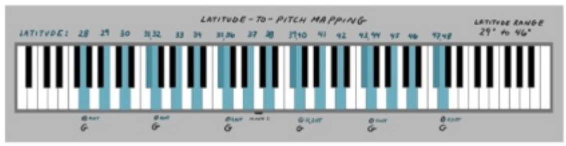

Figure 5: Latitude values mapped to notes within the key of G on the piano keyboard (in final version, value 29 is lowest G note).

The narrative piece of this audio-visual map is a mechanism to guide the listener through its elements and provide the option to rely solely on audio for full comprehension. There are four main categorical components that are referenced in the narrative structure of this audio-visual map: (1) frame of reference points ("extreme" coordinates); (2) the starting and ending coordinates of the path of totality; (3) the path of totality coordinates; and (4) major cities along the path. We wrote a script to introduce the overall concept of the sonification and its sonic elements, and to guide the listener through the holistic composition with better clarity.

4.2.5. Final Multimodal "Push" Map of the 2024 Eclipse

Putting all of the audio and visual components together, we arrive at a web-based playback format presentation of the total solar eclipse's path of totality, which provides a visual projection of the contiguous United States, paths and points associated with the data mapping involved, a narrative audio guide to understand this path, and the data sonification of the path of totality itself. By bringing the audio and visual elements together in a narrative format, we provide a well-rounded presentation of this phenomenon on April 8th, 2024 from an aerial perspective. By ensuring that the entire

Figure 6: Digital rendering of the geographical map using Flourish, implementing the triangle analogy and extreme coordinates.

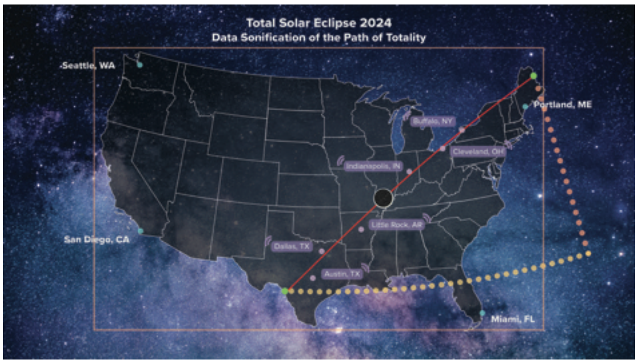

Figure 7: Aesthetics of the final audio-visual "push" map video.

playback form remains condensed and quick-moving, we minimize the risk of losing the interest of a listener. The short form approach also makes this component a convenient option for an educational setting. This digital material can also be referenced well after the event has passed, because it will remain relevant as a way to interpret a total solar eclipse in more generalized terms. This material will also be publicly accessible for any users interested in data sonification, or for students in the classroom setting.

The web-based audio-visual "push" geographical map can be accessed at: https://tinyurl.com/GTeclipse2024.

4.3. Multimodal "Pull" Map of 2024 Eclipse

The ability to independently navigate through a map and explore the data is crucial in dealing with all kinds of geospatial data. "Pull" maps that are accessible to non-visual users are rare. The Audiom system [11] has been developed by XRNavigation to support visual and audio presentation of geospatial data in an accessible, user-driven ("pull") format. We created an Audiom map of the 2024 solar eclipse using the same data from NASA. The map starts the user in Texas, where the path of totality "enters" the United States; from there, keyboard commands allow for step-by-step exploration of Texas and the rest of the country. Audiom supports many features, but most notable in this case are the visual map showing regions of full and partial totality, plus spoken information about the user's location within the Audiom map. As the user navigates around the map, she encounters parts of the path of totality in either "partial totality" or "full totality." The lines of totality use a French Horn sound to indicate the celestial majesty of the event. As the user navigates closer to positions of full totality, she receives reinforcement of a fuller musical chord with additional notes included. The chord of D was chosen because the song "Pink Floyd – Eclipse" is in the key of "D." The resulting resource is very effective in allowing a blind or visually impaired user to explore the map of the USA, understand the path of the eclipse, or even make travel plans to experience the event live.

The interactive Audiom audio-visual "pull" map can be accessed at: https://tinyurl.com/GTeclipse2024.

5. COMPONENTS 2 & 3: VIRTUAL REALITY (VR) EXPERIENCE AND ACCOMPANYING SOUNDSCAPE

The other main component of this total solar eclipse accessibility resource project is the "on-ground" virtual reality (VR) experience and accompanying real-time soundscape. Crafting a VR experience with immersive audio and visual features provides a resource that makes the total solar eclipse accessible for people with varying visual abilities in any part of the world. The VR component consisted of three thematic priorities related to visualization, audio, and education, respectively. More specifically, these priorities are: (1) Create a compelling visual simulation that allows users to feel as though they are truly witnessing a solar eclipse within a city that is on the path of totality; (2) Create an inspiring audio soundtrack that conveys the eclipse's magnitude and beauty, and makes the eclipse accessible for visually impaired individuals; and (3) Create an experience that seamlessly integrates engaging educational content related to changes in the environment during an eclipse. The soundscape portion of this project provides a real-time artistic sonic simulation of the total solar eclipse, expanding upon techniques used in Georgia Tech's previous work in 2017. Together, the VR experience and soundscape allow users to learn and explore characteristics of an eclipse in a highly interactive manner, developing knowledge that could be applied generally to similar astronomical phenomena in the future.

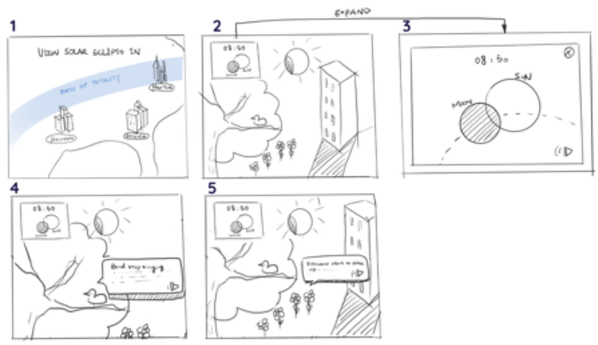

Figure 8: Initial sketches of the virtual reality experience, exploring interactive features of the map, city environment, and eclipse.

5.1. Total Solar Eclipse Virtual Reality (VR) Experience

Virtual reality experiences simulate three-dimensional environments and are generally deployed for use with either a VR headset or mobile device. As VR headsets are not available to everyone, we wanted to ensure that the virtual reality component of this

Figure 9: Comparison of light and dark themes for the virtual reality experience; dark theme was chosen for its space-like aesthetic.

project would be made available to access either through a headset configuration or through a mobile app, the latter being a more inclusive option for access. While the VR simulation is more convincing and immersive with a headset, allowing for free user movement within the simulated space, the mobile version reflects this design with similar freedom of navigation.

5.1.1. VR User Flow

The VR experience design process began with an ideation phase regarding what would be visible to the user, frame by frame. This resulting storyboard of this process is comprised of three main chapters, which can be seen in Figure 8: (a) a geographical map showing an aerial view of the path of totality as well as the different cities that users could choose to view; (b) the "on-ground" environment within a selected city as well as the educational features of objects in the environment; and (c) a close-up view of the relative position of the sun and moon in space, continuously displayed as a window in the upper left corner with the option for selection. Within the frame of the city environment, the user can navigate on their own accord, encountering objects that carry the educational information, such as trees, birds, and flowers. Figures 9 and 10 demonstrate some initial designs of this navigation framework.

5.1.2. VR Visual Design

The visual design of the VR experience involved important aesthetic designs; the first was whether to use a dark or light theme, as seen in Figure 9. We decided that a dark theme would be most appropriate for this astronomical event, because it helps to enrich user immersion, ensure the user's visual comfort, and align seamlessly with the thematic essence of a total solar eclipse.

Beyond the application theme, we ensured that certain visual cues would make the experience intuitive. The software we used is designed for swift download and immediate use by the user. Based on iterative feedback on our prototype, we integrated directional arrows and a distance bar as visual cues. These were favored for their game-like navigation model. These cues are persistently displayed on the screen, ensuring users always have clear guidance on where to go, regardless of their location within the city.

Finally, to facilitate intuitive use of the application, we implemented consistent and repeated visual elements across the virtual environment in order to streamline navigation and deepen users' understanding of the solar eclipse. Consistency across various screens and crucial interaction points aid in preventing disorientation within the application. Furthermore, these recurring elements reinforce the theme of the total solar eclipse, always ensuring that the user can access the and understand relative positioning of the sun and moon along the timeline of the eclipse event.

Figure 10: Screen captures of the virtual reality experience during the development phase, with integration of VR assets from Unity.

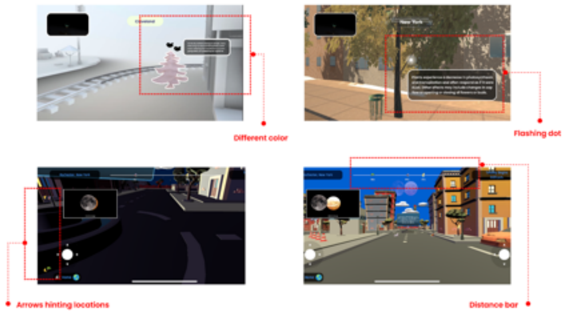

Figure 11: Identification of user experience features designed to create an educational and interactive virtual reality environment.

5.1.3. VR Prototyping Process

The primary platform used to design and develop the mobile application and VR target application is called Unity Game Engine. There are two main environmental simulations in the VR experience which required significant prototyping: the "totality view," which provides a perspective of the sun and moon's movement, and the "on-ground view" which provides the perspective of navigating a city environment during an eclipse.

The "totality view" was developed as follows. Orbital animations were created using the third party asset DOTween Pro [12]. Using its intuitive editors, we were able to create accurate, lifelike animations.While not all models were presented true to scale, we took high priority in accurately representing the path of totality during the solar eclipse, using the Mapbox SDK (Mapbox, 2021). We used a range of tools to build the initial representation of earth, including world-scale AR Maps, Geocoding, and Navigation APIs and SDKs (https://docs.mapbox.com/unity/maps/guides) for Unity. In addition, we used the data set of eclipse path coordinates provided by NASA[8] to accurately plot the path of totality, in combinations with Unity's Line Renderer component. We wrote a custom CSV parser using C# to neatly organize the path of totality data, and packaged this data a "Scriptable Object" (which is a Data Container Asset in Unity). The stored values are processed at runtime to render the path of totality accurately. DOTween's path animation functions smoothly animate the movement of the moon's shadow along the path of totality. Additionally, all data values were rigged to user interface text elements.

To develop the "on-ground view," which is the city environment that the user navigates within the application, we integrated a low-poly city environment asset in Unity. This facilitates the sensation of immersion in life-like surroundings. Building upon this baseline cityscape realm, we began to implement additional features to guide the user, such as educational pop-up panels containing informative excerpts about the environmental changes during a total solar eclipse. Examples of these informative excerpts include the decrease in photosynthesis within a tree that would normally occur at dusk, or the change in birdsong behavior or roosting activity among birds in the environment. In addition to these educational panels, we integrated a panel in the upper-left corner of the application showing the status of the total solar eclipse. The user is able to interact with this panel, initiating an expanded view of the sun and moon, and listen to the accompanying soundtrack [13] reflected by the progress of the eclipse in the simulation.

5.2. Total Solar Eclipse Soundscape (or "Soundtrack")

In creating a soundscape to accompany and/or symbolize the real-time experience of the total solar eclipse, our goal was to develop an artistic sonic narration representing this astronomical event. Expanding upon previous work done in 2017, we designed a soundscape to model the emotionally-stirring reaction to this rare natural phenomenon. The intention of this design is to inspire a feeling of awe for people that may have never experienced a total solar eclipse. Inspired by the descriptive term "natural phenomenon," we considered the analogy of planetariums, in which disembodied sounds place listeners in an immersive sonic scenario. Planetariums catalyze an emotional and inspired reaction in an audience, not only educating them about the nature of astronomy, but also activating their curiosity about science. This soundscape was designed to help stir a similar reaction for listeners.

5.2.1. Soundscape Conceptual Development

Inverting the analogy of a planetarium experience, during which an audience member is passively immersed in an audio-visual environment, we focused on the feature of interactivity. In the context of the VR environment, a user is able to navigate to the totality view, which initiates this soundtrack. Users are thus driven by their own curiosity, and then immersed in an inspiring sonic composition. To create more relatability in the soundscape, we implemented sound effects that might exist in a listener's daily life and wove dynamic musical dynamics symbolizing the anticipation, peak, and conclusion of the event. The period of totality for this instance of the total solar eclipse lasts about four minutes on average, and this is the time frame we set for the soundscape. The background layer of the soundscape builds ambience reminiscent of the daytime with birds chirping as a breezy day passes the listener's ears. During the period when the sky would completely darken, the soundscape morphs to symbolize a still night with low breeze and piercing cicadas to replace the bird calls. The primary material used in the soundscape is precomposed music selected to characterize the sun, moon, and the eclipse's evolution.

5.2.2. Design Choices Related to User Experience

Developing the soundscape raised questions about topics such as where to place a listeners' focus, the balance between realism and dramatic storytelling, and how to preserve clarity while exercising artistic freedom. We aimed to (1) effectively communicate the experiential progression of the solar eclipse, and (2) to impart the experience of environmental changes during the moment of totality. The listener's focus is intended to be on the interaction between the sun and moon. Various sound effects build an ethereal sound stage, relaying a message of relaxation, anticipation, and awe. Accessibility was also factored into our sound design. In particular, the soundscape is available as a standalone precomposed soundtrack that can be accessed separately from the visual VR experience.

5.2.3. Audio Sourcing and Data Representation

Royalty free music and sound effects for the VR city environment and spatial view were sourced from the Fesliyan Studios, Pixabay, and Freesound websites. Audio files were edited to loop cleanly in Logic Pro X and the same sound files were edited for use in the separate soundtrack. We used consistent sonic elements across the soundscape and VR audio environment to ensure sonic consistency across application frames. The audio for day and night involved light mid-frequency breeze with birds for daytime, and a heavier low-frequency breeze with crickets for nighttime. Regarding the sound design for the celestial environment, we decided to implement multiple low frequencies which created a pulsing effect symbolizing the moon. The sun was represented by the high and mid frequencies of David Fesliyan's song "Peace and Happy" [13]. Eclipse progression was mapped to amplitude, with near-silence occurring during the moment of totality.

5.2.4. Reflections

Listeners benefit from this soundtrack by being able to listen to the narrative soundscape while experiencing the eclipse. The moment of totality in the virtual simulation does not last very long. With the looping functionality, we were able to extend the ambient sounds as long as needed; however, the simulated animation of the eclipse condensed the real time 4-minute duration to a much shorter sequence. This translates to the music not being able to develop as dramatically as it does in the separate soundtrack. As a result, listeners in the VR may not have time to digest all the information that is sonified in the looped sequence.

6. USER EVALUATION OF VR EXPERIENCE

The virtual reality (VR) experience component of our project was deployed in prototype form before the event of the total solar eclipse, so that there would be an opportunity to collect feedback on our work. The aim of our formative evaluation study was to gather feedback on audio and visual cues in the application that might affect the user experience and their engagement with the solar eclipse. This preliminary study, while limited, provided useful direction in the development process of the application. More user experience research is required for future implementation of our project into a generalized format. The following is a brief summary of the formative evaluation and results.

Six staff and students from the music department, ages 22 to 38, completed the initial evaluation, including a demographic questionnaire, a task-guided interaction with the VR application, and a post-experience questionnaire. Each participant had the opportunity to see the starting frame, explore the interactive features of the map, and navigate through the virtual cityscape containing three educational pop-up panels. Participants unanimously rated the visuals as fair or good. One participant mentioned that the "lighting details [of the buildings during nighttime mode] added to the ambience of the world". They reported the user interface as easy to understand and intuitive. Participants rated the audio as "good", and said the spatial audio contributed to a sense of immersion. Music and sound effects choices were rated as "supportive" towards anticipating the eclipse. Participants liked the fully explorable 3D world with light and shadow cues of environmental changes, as well as the option to select the sun and moon panel at any point. One commented that this application could be useful for "people and museums who want to experience what the effects of an eclipse would be like live, but can't make it to the path of totality." Critical feedback was also provided by participants, and we considered this information using the framework for Universal Design for Learning (UDL) Theory. Participants commented that the "cartoon" world and unmoving sun appeared to be inconsistent with the "realistic" animal models. They also commented that some of the user interaction control design was uncomfortable for the eyes, and that more visual cues would be helpful to assist in navigating the space. Participants gave feedback that the experience could benefit from more audio dynamics from the animals in the environment, as well as additional educational information.

This feedback led to changes in the VR design: (1) increased realism of the virtually simulated elements; (2) improved animated event signifiers; (3) improved user interaction control; (4) more navigational cues; and (5) more educational elements. Leading up to the finalization of this project, these themes were iteratively implemented. As development of the VR application progresses, additional thematic improvements may be integrated. More evaluation-based research and development will be useful for further expansion of the application. We see an opportunity to continue developing this resource as a generalized simulated experience of total solar eclipses, and believe that it can be used well into the future as an educational tool to learn about environmental science and astronomy.

Links to APK file for VR headsets, mobile app, soundtrack, and assets: https://tinyurl.com/GTeclipse2024.

7. CONCLUSION

Rare and awe-inspiring astronomical events, such as the total solar eclipse of 2024, provide unique opportunities to bring data sonification and multimodal data navigation tools forward as beneficial resources for all people. These multisensory forms of exploring information have the power to educate and inspire people about the topic of science, catalyzing an interest that might otherwise not be stirred. Audio-based resources are also particularly useful for improving accessibility in science education, making content available to low vision or blind individuals. While astronomical sonification projects are emerging more and more, these projects often tend to sonify light sensor data or rely on verbal descriptions of astronomical events like eclipses. Our project components provide a multifaceted approach that could be used for research and exploration of the eclipse, even after the experience. We hope to see the implementation of more interactive data sonification and audio-visual resources in the context of education and beyond, and hope that this project contributes to the advancement of that goal.

8. REFERENCES

[1] NASA Eclipse webpage: https://science.nasa.gov/eclipses. Accessed March 15, 2024.

[2] NASA Newsletter on Eclipse: https://science.nasa.gov/eclipses/future-eclipses/eclipse-2024/. Accessed March 15, 2024.

[3] Solar Eclipse 2017 Sonification by The Georgia Tech Sonification Lab: http://sonify.psych.gatech.edu/research/eclipse/. Accessed March 15, 2024.

[4] NASA Eclipse Map: https://science.nasa.gov/solar-system/skywatching/eclipses/new-nasa-map-details-2023-and-2024-solar-eclipses-in-the-us/. Accessed March 15, 2024.

[5] Walker, Bruce N. (2023). The Past, Present, and Promise of Sonification. Arbor, 199(810): a728. https://doi.org/10.3989/arbor.2023.810008.

[6] Wilson, J. B. (2016). Push and pull menus for auditory interfaces. PhD dissertation. Georgia Institute of Technology. http://hdl.handle.net/1853/56308.

[7] Park, S., Kim, S., Lee, S., & Yeo, W. S. (2010). Composition With Path: Musical Sonification Of Geo-Referenced Data With Online Map Interface. Proceedings of ICMC. New York, USA. pp. 5-8. http://hdl.handle.net/2027/spo.bbp2372.2010.002

[8] M. Garrison, "NASA Scientific Visualization Studio | The 2023 and 2024 Solar Eclipses: Map and Data," NASA Scientific Visualization Studio: https://svs.gsfc.nasa.gov/5073.

[9] NASA Scientific Visualization Studio, Michala Garrison: https://science.nasa.gov/solar-system/skywatching/eclipses/new-nasa-map-details-2023-and-2024-solar-eclipses-in-the-us/.

[10] United States Geological Survey: "How are different map projections used?" https://www.usgs.gov/faqs/how-are-different-map-projections-used.

[11] Audiom: https://www.audiom.net. Accessed March 15, 2024.

[12] DOTween Pro, Daniele Giardini. https://dotween.demigiant.com/pro.php.

[13] Fesliyan Studios: https://www.fesliyanstudios.com/royalty-free-music/download/peace-and-happy/125. Accessed March 15, 2024.

[14] Biggs, B., Toth, C., Stockman, T., Tupy, S., Coughlan, J.M., & Walker, B.N. (2022). Audiom: An auditory web-based geographic map viewer showing COVID-19 state data and a travel map. Installation description in Adjunct Proceedings of ICAD Virtual Conference (24-27 June). pp. 163-165. https://doi.org/10.21785/icad2022.000

[15] Biggs, B., Coughlan, J.M., & Coppin, P. (2019). Design and evaluation of an audio game-inspired auditory map interface. Proceedings of ICAD, Newcastle-upon-Tyne, UK (23-27 June). pp. 20-27. https://doi.org/10.21785/icad2019.051

[16] Biggs, B., Coughlan, J.M., Toth, C., Walker, B.N., & Stockman, T. (2022). Evaluation of a non-visual auditory choropleth and travel map viewer. Proceedings of ICAD Virtual Conference (24-27 June). pp. 82-90. https://doi.org/10.21785/icad2022.027