The Planetorium: Sonic Information Design for Earthling Audiences

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1 Introduction

For millennia, humans have looked into the night sky and wondered at what they saw. This curiosity led them to develop instruments that enabled them to look deeply into space, which revealed celestial bodies in ever-greater detail. They developed new mathematics and physics to better understand and predict the cosmos and began to teach each other, pointing to what they knew to be true. Sadly, as the objective facts and figures poured in with ever-increasing precision, the oral traditions of myths, stories, and gods began to fade from view.

In the past century, some humans have worked to cultivate a new technology that would allow humans to use their ears to hear the objects that, before, they could only see. By transforming numbers into sound, humans could listen again, which made those who could hear it very happy. However, others did not comprehend it, became confused, and began to ask one another: How can I make sense of something I cannot see? How do I know what I am hearing is true? Is this some kind of music, or something else altogether?

In this paper, we use "The Planetorium" as a metaphor and context for understanding how we might best design aural celestial experiences for earthling audiences. Audiences are groups of individual humans all listening to the same thing at the same place for some length of time. And while planetariums are places they go to learn about space through stunning views and new perspectives, planetoriums (like auditoriums) are places they go to listen.

In this paper, we will present the strategies and designs behind two public-facing planetorium experiences. The first was a formal, educational planetarium show where the audience learned about the solar system by taking an auditory journey through space. The second was an informal, mobile, and live musical sonification of the 2017 Great American Eclipse that could be tuned into by anyone over the web. Our design strategies were based upon a mixture of previous research, in-person interviews, and creative interpretation, three pillars that we hope will benefit others wishing to design for groups of these diverse organisms.

2 Background and Motivation

Researchers have defined sonification as the "use of non-speech audio to convey information," or more specifically, "the transformation of data relations into perceived relations in an acoustic signal for the purposes of facilitating communication or interpretation" (Kramer et al. 1999). Although this definition fits well for the many applications of sonification that are targeted for specialists (i.e., those trained in the context of application), recent work has revealed the ways in which the experiences of non-specialists can become problematic (Supper 2014). At root, the problem is related to the homologous relation between sonification and music, socially-constructed limitations of listening, and the appropriation of the term into contexts where there is no desire for communication or need for interpretation of the data relations by listeners (Sterne 2003; Vickers 2017).

The need to challenge these intellectually retrograde conceptions of listening arises in the desire to create sonifications that are public-facing and even frequently listened to by large numbers of people. Such a "killer-app" would assist in disseminating and convincing the general public of the utility of sonification (Supper 2012). One vision for how this might occur is the transformation of sonification into a socio-cultural medium where "the general public tunes into pop sonifications for listening enjoyment as well as useful information about the world" (Barrass 2012). Another possibility arises in the form of concert music, where an audience might appreciate a sonification not just for what it purports to convey (e.g., the title), but for the experiences garnered by comprehending the relationships inherent in the data itself (Ballora 2014a). In the present work, we propose that traditionally visual experiences such as going to a planetarium or viewing an eclipse could be substituted with or enhanced by a vivid and well-designed auditory experience.

2.1 Astronomy Sonification

Astronomy sonification is a rich place to explore the application of sonification for both specialists and audiences. As a microcosm of the entire field, some sonifications have been designed for specialists to assist in the exploration and analysis of large amounts of astronomical data (Alexander, Gilbert, Landi, Simoni, Zurbuchen and Roberts 2011; McGee, Van der Veen, Wright, Kuchera-Morin Alper and Lubin 2011), and others have been made by composers for music, performance, and film (Exploratorium 2017; Ballora 2014b). Our two works contribute to this field by targeting audio-driven educational shows for the general public as well as mobile auditory experiences of live geo-specific astronomical phenomenon.

Few astronomy sonification works have explicitly designed or evaluated their system based upon feedback from users or other stake-holders. One notable exception is the work of Quinton, McGregor, and Benyon (2016). To determine the data properties and mappings to use for their auditory model of the solar system, they conducted an interview with a planetarium expert, a trained scientist, a teacher, and members of the general public. In a similar manner, we involved stakeholder and non-stakeholder members of the general public in determining both the data and mapping strategies that should be used. However, our work went a step further. Once these parameters were designed, we released them into the wild as planetorium experiences, which included marketing, publicity, live auditory experiences, audiences, and post-hoc critique and feedback.

2.2 The Missing Audience

In 2004 a sonification concert premiered at the Sydney Opera House Studio (Barrass, Whitelaw and Bailes 2006). The concert, entitled "Listening to the Mind Listening," received a submission of 27 sonification mappings of the same EEG dataset by 38 composers. To select the final 10 pieces for the concert, a blind review committee of 34 composers, neuroscientists, sonification researchers, and concertgoers rated three submissions each according to aesthetics, mapping, accessibility, and overall impression. Answers to the questionnaire revealed that different factors contributed to the overall impression of the piece, reflecting group-level differences. In particular, for the concertgoer group, aesthetics was correlated with accessibility, which was also correlated with overall impression.

In our view, the "audience" has been a missing factor in public-facing sonification design-work. In particular, current thinking in sonification aesthetics has drawn upon the phenomenological experience of individuals, including their modes of listening (Grond and Hermann 2014), their aesthetic direction (Vickers, Hogg and Worrall 2017), and their embodiment (Roddy and Furlong, 2014). While these perspectives have added a great richness to listening theory and design guidelines, they have not sufficiently addressed the experiences of groups of co-situated non-specialist listeners attending to and directed towards a shared listening experience. It is inappropriate to project on such groups the evolved, encultured, and specialized forms of listening that originate with mappers, composers and music-theorists. Instead, we advocate an "audience-centered" design strategy wherein sonification designers cultivate an aesthetic experience for audiences aimed primarily at accessibility. Access to information the audience needs to hear and aural access to the data itself through creative but accessible mapping strategies.

3 Example #1: Solar System Sonification

Our first example is the “Solar System Sonification” planetarium show that debuted at the Fernbank Science Center Planetarium in April 2016. The planetarium featured a 70-foot diameter hemispheric SciDome for video projection, originally dedicated to “teaching and public enrichment.” While many planetarium shows attracted audience members to stunning and immersive visual spectacles, ours capitalized on the planetarium's quadraphonic speaker system and advertised a listening experience mediated by sonification. Figure 1 displays a captivating visual from the projection system. A poster presenting an advertisement for the planetarium show is presented in Figure 2.

The 40-minute show included multiple sections that highlighted specific learning concepts, organized into two sections or “views.” In the “Solar View,” planets rotated around the audience, simultaneously conveying their mass, year length, and day length. Sound Example 1 plays the masses of all eight planets in their customary order, demonstrating that low mass planets were high in pitch, and high mass planets were low in pitch. Sound Examples 2 and 3 display the day length for the four inner and, subsequently, the four outer planets using the frequency of a full-range amplitude modulator. Sound Example 4 displays the relative year length for the first four planets with a stereo mixdown of the original quadraphonic sound design. The solar view ended by taking a trip from the sun to planets in an “auditory spacecraft.” Sound Example 5 displays an excerpt of the spacecraft, which would play for the duration of travel between planets as if the spaceship were travelling at 0.2 AU per second. Because the outer planets were much further away, the playback rate of the loop was sped up by a factor of 5 (1AU/sec, Sound Sample 6) to reach Jupiter and Saturn and then by a factor of 10 (2AU/sec, Sound Sample 7) to reach Uranus and Neptune.

During the “Planetary View,” the audience journeyed to the individual planets and listened to an auditory rendering of their unique characteristics. This included the presence of any moons or rings, temperature range, and gravitational pull. As displayed in Sound Samples 8-11, the number of moons was conveyed by a corresponding number of short sinusoids with random frequency randomly distributed around the hall. As displayed in Sound Examples 12 and 13, the number of rings were conveyed with a corresponding number of randomly distributed frequencies slowly fluctuating in volume. As displayed in Sound Examples 14–17, the temperature range of each planet was conveyed as a sequence of notes that ascended or descended in pitch, with lower pitches indicating the lower temperatures and higher pitches indicating higher temperatures. Finally, as displayed in Sound Examples 18 and 19, gravitational pull was conveyed by dropping a virtual ball from a small height (~1 meter) onto a virtual surface of the planet. The sonified trajectory of the ball (i.e., the decay of its bounces) indicated the strength of the gravitational pull.

Beyond the sonification, two narrators engaged in dialogue to provide context and a mapping introduction for each auditory scene. They would introduce every new scene or view and, where needed, explain how the sound represented the data. They would provide additional context cues, such as saying the planet's name. To assist in establishing conceptual anchors for the sounds, publicly available photographs of each planet were used as basic visual anchors for the audience. More details on our mapping strategies can be found in "Solar System Sonification: Exploring Earth and its Neighbors Through Sound" (Tomlinson, Winters, Latina, Bhat, Rane and Walker 2017).

3.1 Evaluation

After each of the two sections, we conducted an open-ended user experience evaluation: a series of Likert questions adapted from Matthews (2006) work on peripheral display interpretation to measure the helpfulness, appeal, and learnability of the mappings used in both halves of the sonification. The audience rated each of the sonifications quite positively, with a mean score of 4.7/6 for the mappings in the first half and 4.6/6 for the mappings in the second half. Tomlinson et al. (2017), mentioned above, describes the evaluation results in more detail.

The audience found this experience enjoyable, and many provided feedback through open-ended responses on what mappings they found most interesting, intuitive, or striking. Some found that the sonification evoked unexpected positive feelings, including feelings of how "awesome" the size and scale of the solar system really is. Attendees reported having more trouble remembering the sonification mappings from the second half. This view displayed more details specific to each planet and presented many more pairs of data comparisons than the first half. Breaking this section into smaller chunks [with more quiet intermissions??] would make it easier for the audience to enjoy and reflect on the sonification.

4 Example #2: The Great American Eclipse

The total solar eclipse that took place on the 21st of August 2017 projected the moon's shadow diagonally across the North American continent. The population of 12.25 million people living in the path of totality, combined with live-stream video watched by many people across the world, could arguably have made this event one of the most watched in history and a truly shared social experience.

One of the unique features of the solar eclipse is that in order to view it, one has to wear special-purpose solar filters (a.k.a. “eclipse glasses”) that block almost all light. Even the darkest of sunglasses transmit thousands of times too much sunlight to be safe for viewing.[1] These glasses create a special kind of “blindness,” where viewing the sun is only possible at the expense of viewing anything else. Figure 3 displays a person wearing eclipse glasses. Thus, although the primary motivation for designing an eclipse sonification was to include individuals with visual impairments who might otherwise have been left out during this rare shared experience, the reduced visual capabilities experienced by all viewers made the eclipse sonification a perceptual enhancement for everyone.

To make the sonification available synchronously to large numbers of people at different locations, the eclipse sonification was hosted on a public-facing website synchronized with the unfolding time-period of the eclipse. Although different locations experience different eclipse durations, we focused our design on two cities: Hopkinsville, Kentucky (the site of maximum total solar eclipse), and Atlanta, Georgia (a site of non-total overlap). The data was transformed into sound using the Data-to-Music sonification API (Tsuchiya, Freeman and Lerner 2015), Supercollider and sample sounds from Ableton Live.

4.1 Archived Interactive Demonstration

An archived interactive demonstration of what audience members heard during the eclipse is now available on the eclipse website, and we encourage the reader to explore this site to listen to the sounds and apprehend the mappings. The online archive includes a total of 40 minutes of audio, including different “movements” of the piece and different “events.” An information button in the upper right-hand corner allows the user to read about the sounds and mappings used in more detail. Figure 4 displays two screenshots from the interface, taken 20 seconds before and 20 seconds after totality.

The first section of the piece starts about 30 minutes before totality and represents the progression of the moon towards the sun. It develops slowly, rhythmically capturing the building anticipation with its increasing tempo. About 15-20 minutes before the totality, the

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[1] https://eclipse2017.nasa.gov/safety

excitement rises. The piece transitions into a new section, almost breaking down the rhythmic elements into a crushing soundscape, when suddenly the moon has covered so much of the sun that it starts to appear bigger. In this section, one hears what sounds like a duel between the sun and the moon – the harsh-sounding sun and the mellow-sounding moon. You can hear the moon slowly overcoming and soothing the soundscape. Finally, you hear a last retort from the sun, and then the piece builds up toward the dramatic totality. At totality, you hear nothing but a low lingering presence of the corona of the sun. Then, the sun reemerges into another hopeful post-ecliptic phase and fades into the day. A diagram displaying the data used for the sonification is displayed in Figure 5.

5 Design Strategies

Both works took a similar approach to design, utilizing creative interpretation, previous research on acoustic cues, and in-depth interviews. At the core, they were also motivated by the desire to engage blind and visually impaired members of the general public, while also attracting and engaging sighted users.

Some differences arose from the contexts of use. In the first example, the objective was to create an educational show that would premier at a planetarium and utilize a built-in sound spatialization system. In the second, the desire was for the sonification to complement or replace the experience of viewing a celestial phenomenon in a mobile, outdoor setting. Hence, the second example did not seek to "educate" its audience but rather to create a memorable aesthetic experience in which data-driven sound augmented the visual phenomenon.

5.1 Conceptual & Perceptual Research

Many of our mapping decisions were based upon previous work regarding perception by researchers in the field. Sonification designs of the mass of planets and moons drew upon previous polarity mapping research (Walker 2002). Tempo was used to create a comparable pattern for day length (Flowers 2005). By using easily referenced mappings that people can easily internalize into a mental model for comparison, we supported ease of initial understanding for these sonic representations. Physical movement, such as the revolution of planets around a sun, were scaled and mapped through vector-based amplitude panning (Pulkki 1997) to persuasively simulate movement of the planets around the audience.

Leveraging of conceptual metaphors, such as pitch representing temperature range, supported concrete comparisons between familiar and unfamiliar information (e.g., temperature on Earth vs. Neptune) (Dubus and Bresin 2013). Other uses of conceptual metaphors leveraged knowledge about physical phenomena: how a ball bounces under the influence of Earth's gravity, for example. Using this information as a reference for comparisons of gravitational strength on other planets (e.g., Jupiter or Mercury) can make it easier for someone to internalize and understand the mappings. Playing concurrent auditory streams can scaffold these comparisons, especially when representations are changing in a single dimension (e.g., pitch only) (Schuett, Winton, Batterman and Walker 2014).

5.2 Interviews

For the solar system sonification, we conducted interviews with 5 astronomy teachers, including a planetarium instructor, and analyzed data from a misconception identifier survey answered by 69 college students. In the second example, we interviewed two blind people as a basis for approaching the range of expectations and desires of the visually-impaired population. The interviews and questionnaires identified what key areas needed to be conveyed in sound, such as details for the size and scale of the solar system as well as specific characteristics of each planet.

A shift in the approach of design for the eclipse was noted after the interviews: the first interviewee had lost his vision as an adult and had seen an eclipse before, and the second was congenitally blind and had never experienced an eclipse. They both expressed interest in hearing a sonification of the eclipse but offered different perspectives on what was important to convey. The first interviewee had expectations based upon what he remembered and could imagine happening during an eclipse. For the congenitally blind individual, aspects relating to the amount of light or the colors were not as important as the tangible properties. Their understanding of the surroundings was strongly based on touch, surroundings, and sounds. They could describe the mass, temperature, and dimensions of the sun and the moon but could only imagine them as physical representations, and thinking of them as “illuminated” objects in the sky was not very meaningful. They felt that the relative brightness would be important to convey as well as the animal sounds of the environment (i.e., crickets, frogs, and birds), which often follow their usual circadian rhythms in close succession due to the “false-sunset” and “false-dawn.” More details on the planetarium interviews can be found in Tomlinson et al. (2017).

5.3 Creative Interpretation

To effectively use insights from previous research and interviews with end-users, both systems involved some degree of creative interpretation. In the solar system project, previous research and interviews had revealed particular concepts to focus on, also indicating how they might be mapped, but several factors were left to be determined. For example, although the mass, day length, and year length were mapped to pitch, tempo, and speed of rotation around the audience, decisions needed to be made about the timbre. We selected bandpass filtered pink noise to abstract the sounds from recognizable or overly-synthetic timbres, which we felt could distract the listeners' attention or bring to mind unnecessary associations. Again, from a planetary science perspective, no research could be found on how one should convey the force of gravity, so we decided to use the sound of a ball bouncing on each planet for conceptual scaffolding.

In the eclipse project we faced the task of creating a sonification piece that could capture the listener's imagination for the length of the eclipse. Our sound design therefore had two broad goals: 1) to convey the physical process of the eclipse to the listener as it progressed and 2) to induce awe and elicit an emotional reaction that one might feel when witnessing such an event. This second goal was creative in nature, requiring our sonic design to merge musical and data-driven composition techniques. The eclipse was represented as a process and abstract experience whose structure was based upon movements and events. Soundscape-inspired composition techniques were employed to introduce sounds of physical entities, and the sounds of birds and crickets marked a simulated experiential and environmental "false dusk and dawn" before and after the eclipse.

6 Conclusion

We have presented the strategies and designs behind two contrasting "planetorium" experiences. Though differing in many respects, both aimed to create engaging experiences for groups of co-situated non-specialist listeners, attending to and directed towards shared listening experiences. We presented an audience-centered design strategy founded upon accessibility and involving three parts: audience research, perceptually-informed mappings, and creative interpretation. Audience research helped determine what data should be conveyed and how it might sound, perceptually-informed mappings facilitated the audiences' auditory access to the data by privileging validated acoustic cues, and creative interpretation transformed the insights of prior research into a final acoustic form, contributing to listener engagement for the entirety of the listening experience.

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