Sonification and Acoustic Environments

Scot Gresham-Lancaster and Peter Sinclair

ABSTRACT

Sonification can allow us to connect sound and/or music via data to the environment; in another sense, by "displaying" data through sound, sonification participates in creating our acoustic environment. The authors consider here the significance of certain aspects of this relationship.

There are two basic ideas of what music is or ought to be. These may be seen clearly in two Greek myths dealing with the origin of music. Pindar's twelfth Pythian Ode tells how the art of aulos playing was invented by Athena on hearing the heart-rending cries of Medusa's sisters after Perseus had killed the Gorgon. In a Homeric hymn to Hermes an alternative origin is proposed. The lyre is said to have been invented by Hermes when he surmised that the shell of the turtle, if used as a body of resonance, could produce sound. In the first of these myths music arises as a subjective emotion; in the second it arises with the discovery of sonic properties in the materials of the universe. These are the cornerstones on which all subsequent theories of music are founded. In the former myth, music is conceived as subjective emotion breaking fourth from the human breast; in the latter it is external sound possessing secret unitary properties.

—R. Murray Schafer [1]

We each create works that use raw information (data) to generate and modulate sound using the technique often referred to as sonification. Much of the material in this article comes from a series of discussions between us about the boundaries between music and sound and how this relates to sonification. To frame this discussion, and by way of an introduction, below are brief descriptions of examples by each of us that use real-time sonification techniques to engender new acoustic environments.

Peter Sinclair, *RoadMusic*: The idea is to be finished with listening to recorded music in your car and instead to have a live sonic experience in which music is created *from* your ride *for* your ride. Accelerometers gather data about bumps, curves, accelerations and braking while a camera analyzes the visual scene through blob-tracking and color analysis. This data is used by custom software, on a dedicated on-board computer (Fig. 1), to generate sound. *RoadMusic* is specific to the situation of the car ride in which we are "traditionally" estranged from the audio environment through which we travel. The road becomes the score, the driver becomes the musician and the music becomes the sound of the situation. Audio synthesis is entirely data driven, initial waveforms are in fact audification of sensor input (so in a sense the sound is literally that of the road surface), and analysis on different temporal scales—direct parameter mapping, event detection, and statistical analysis—enable an orchestration which albeit real-time stretches beyond the immediate moment [2].

Scot Gresham-Lancaster, *Trees and Vineyard on the Internet*: Starting in 1999 and until his death in 2009 Toyoji Tomita and I worked on an ongoing public sound art piece *Trees on the Internet.* The contract with the city of Oakland that Toyoji had as landscape designer of the Frank Ogawa Plaza in downtown Oakland included a percentage for a public art piece. Each tree in the plaza was wired with sap flow sensors that fed data to a small network computer in an irrigation closet. This computer communicated to an off-site computer the data from the various trees. These various streams of data from the trees, 32 channels in all, drove a threshold-based audio "mix" that was being constantly re-calibrated each time the sensor network was polled. A web page was put online that gave interested users access to eight generated sound files. Users could mix and mute the channels of audio interactively. After Toyoji's untimely death in 2008, a similar realization was made using data from a sensor network of David Tudor collaborator Mark Holler's Camalie Vineyard on Mt. Veeder near Napa, Calif. This time the data was mapped to the physical modeling characteristics of a wave-guide physical modeling synthesis engine (Fig. 2). The real-time output of the synthesizer being perturbed by the changes in the vineyard was played on three occasions as part of memorial concerts for Toyoji [3].

Fig. 1. *RoadMusic* device, 2012. *RoadMusic* is a live sonic experience in which music is created from the car ride itself. Accelerometers gather data about bumps, curves, accelerations and braking while a camera analyzes the visual scene through blob-tracking and color analysis. This data is used by custom software on a dedicated on-board computer to generate sound. (Photo © Peter Sinclair)

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See <o-art.org/music/Toyoji's_Song.mp3> for a supplemental file related to this article.

WHAT IS SONIFICATION?

In the most common definition, "Sonification is the use of non-speech audio to convey information" [4]. However, it is useful here to expand this definition into some of the different techniques that it includes:

- *Auditory Icons* have a symbolic relationship to a represented action; an example is the icon for the Trash on a PC, which, when activated, produces the sound of crumpled paper falling in a wastepaper bin.
- *Earcons* [5] are usually short tones, combinations of tones or simple melodies (e.g. the jingle preceding an announcement on the PA of a train station).
- *Mapping-Based Sonification* refers to data that directly modifies parameters of a sound such as pitch or amplitude. An example found in the medical domain is the pulse-oximeter, which monitors a patient's blood oxygen saturation as pitch, and pulse rate as tempo [6].
- *ReMapping* refers to information encoded as a perturbation of parameters in an audio source. The output of a given and possibly familiar sound source is modified by the time series data flow, giving the listener information through this channel, which is made as a layer of a familiar acoustic and/or musical environment.
- *Audification* is the direct transposition or transduction of a signal into the audio domain—think of audio-biofeedback, where sensors connected to a subject's muscles or skull capture electrical impulses, which are then directly amplified and played through a loudspeaker as an audio signal (usually crackly or noisy).

PRECURSORS OF SONIFICATION

Throughout the history of music, many composers have written pieces that allude to natural sound environments and settings, but since the beginning of the 20th century, concert hall music has moved more radically into the general acoustic space.

A milestone in this evolution was when Edgard Varèse shocked the concert world with *Ionisations* (1930), a vivid and engaging piece made only with percussion, much of it without pitch; it became the progenitor of a movement of sound examinations using timbre as the primary sound source. Varèse was pushing his music toward the acoustic realities of the world around him: "I was not influenced by composers as much as by natural objects and physical phenomena" [7].

Iannis Xenakis and John Cage also stand out as examples of the transitions into a new acceptance of the purely acoustic in the concert hall and beyond. Both composers have participated in enabling the thinking that has lead to the emergence of the concept of sonification.

Xenakis's influences can be traced to his background in political action as a active member of the resistance to Nazism in Greece, combined with his later studies of architecture. He expresses music in terms of structured blocks of confined chaos, shepherding the sound into chunks of activity, not unlike crowds or flocks of birds [8].

In his seminars, Xenakis would often state that he was using mathematics to model sound as a sculptor molds clay. He would carefully adjust the formula to obtain the sonic result that he ended up using. Many contemporary composers using software to create new sounds can identify with this process, as it is a fundamental part of making music with today's electronic and digital tools. This method approaches the creation of music from an almost purely acoustic perspective.

Constructing pieces from generative processes and equations is fundamental to sonification techniques. These methods may lead to the production of notes, melody, rhythm and harmony, but they are all incidental to the processes that address the overall sound. Thinking in terms of the sound itself was always one of the primary components of the act of composition across music history and for all musical styles, but Xenakis was one of the first to demonstrate the direct use of mathematics and streams of numbers to accomplish this goal.

Cage arrived at a similar understanding that challenged the fundamental relationship of sound and music. He declared that all sound is music and stated on several occasions that he preferred listening to environmental sound (including the sound of traffic) rather than to traditional music. "When I hear what we call music, it seems to me that it is speaking. . . . I don't want sounds that speak to me" [9].

Questioning the status of individual choice in music through indeterminacy, Cage opens multiple doors to the composer/sound artist. His compositional focus moved away from the composer's intention and toward acoustic space itself. He changed the "craft" of music by framing composition in terms of procedural approaches.

We have now discovered the acceptance of these techniques of procedural music-making end up being an unforeseen advantage for those using computers to make music. Xenakis and Cage had no way of knowing what computers

Fig. 2. Camalie Vineyard sensor station. Data is mapped to the physical modeling characteristics of a wave-guide physical modeling synthesis engine. The real-time output of the synthesizer is perturbed by the changes in the vineyard. (Photo © Mark Holler)

were going to be capable of, but what they practiced and advocated as craft fit so completely with how one can use process as part of constructing music and sound art with a computer that their work has become a natural point of reference.

In this era of readily available data, the step from procedural composition to sonification is a small one. Sonification could be considered in this context as the implication of data at some level of the procedure or compositional process. When data issues from the environment, it raises several questions.

The first concerns the time and place of the sonification: Is it real time and real place, and what does that signify? What of the permanence or impermanence of the sonification?

What is the relationship between the data, the parameters of the acoustics of sound to which it is mapped and those of the environment in which it is acted?

Real-Time Real-Data

The presence of real time in computer music is now standard practice; what we wish to discuss here, however, is the particularities of the situation created by real-time sonification.

In certain cases, sound artists or composers make use of vast data sets to reveal patterns: For instance, when compressed in time, audification can render audible elements of the environment that would otherwise be imperceptible due to their scale (e.g. meteorological or seismic data). The fact that the data itself is simply a transposition implies a "real" or un-interpreted or acoustic aspect to the sound, whereby audification may approach soundscape listening, and can increase awareness of environment. (Alternatively, sonification can be a requirement of the context to which a composer responds: for example, I [co-author Gresham-Lancaster] am working with physicists to create sounds so that they can use their eyes to observe experiments while using their ears to receive other, critical real-time information.) Even if the data is mapped, scaling of time and space can be an important aspect of the work [10].

On the other hand, and as is the case in both of the works described above, real-time sonification of data can become the basis that anchors an artwork or composition in a situation, but predictions and manipulation of scaling are integral parts of the refinements needed to make the pieces work. Reoccurring events can take place on any timescale, and so the concept of scaling into an acoustic environment becomes essential. For example, *Trees on the Internet* required scaled parameters that defined boundaries and triggers of hysteresis-based thresholds. The slow arc of change was similar every day, but one never knew exactly when during the day these imposed thresholds would be triggered, because the light and temperature changed with the seasons and weather conditions. Ultimately, the piece was manipulated on a musical timescale via these triggers, because otherwise the result was extremely amorphous, too ambient and not perceivable as a musical composition.

Another example of real-time sonification, John Eacott's *Flood Tide,* premiered at Trinity Buoy Wharf, Docklands, in June 2008. It is a musical sonification performance generated by tidal flow. By use of a submerged sensor in tidal water, the data is transformed by computer software into notation read live from computer screens by musicians, who perform *in situ* (overlooking the Thames River in London). The installation is completed by posters that give clear explications of the sonification process. The successful performance conveys the knowledge that the river below is influencing the music. This lends poetry to the piece. However, in this case, the data (and the posters) can be likened to the program in program music in the sense that they function essentially to augment the music conceptually. One cannot understand the tidal state by listening to the music, and the fact that it is driven by this data is not apparent unless one is informed by the posters.

Always on Real Time (Non-Performative)

What would happen if Eacott's piece were a permanent fixture? Imagine an orchestra playing tide-derived music on the edge of the Thames all day, every day. Everyone would then know about the state of the tide in the Thames from the sound environment—that is, how the river would sound in this hypothetical scenario. This would be completely different from having it set up as part of a concert or sound art exhibition. In this "always on" scenario, the piece becomes subsumed in the acoustic reality of the setting.

This opens up the possibility of learning the acoustic environment that a given sonification is dynamically creating. One doesn't need "program notes" if the sonification is no longer a representation but rather a process that is part of the dynamic of the acoustic environment itself. It is direct mediation.

> **Peter Sinclair:** For the sake of discussion: If you are expecting a package and you hear a moped, you will be able, after a while, to distinguish the sound of the moped of the fellow who delivers the post from the others that are just leaving the village on their bikes. I just did it this morning. I heard the postman delivering his packages on the route (Fig. 3), subconsciously, and went out to meet him because I was expecting this book to come, and that stuff is what you do all the time. It doesn't matter if the postman changed his moped, it would take me only a few days to figure out the acoustic change and begin to recognize it again. . . . By the end of a week, you would know what the new moped sounded like and you would be out there meeting him again, without even thinking about it [11].

There are resonances with the cultural memories of musics and life experiences of sound environments. These resonances are embedded in any sounding that is happening, and we are listening all the time. We are always constructing gestalts of the interrelationships of the sounds around us. The changes in the acoustic environment are perceived in the context of our memories of acoustic environments and musics that we have heard before.

Sympathetic Resonance

The concept of resonance in the acoustic environment has a very interesting relationship to sonification. Acoustic sympathy can be conceived more broadly than the literal idea of an object or a string resonating sympathetically, and from it we can progress to the idea of crafting the sound.

The resonance that we are talking about is pre-semiotic in this way. It has to do with someone understanding that a sound is linked to a process, even though it is not the sound of the actual thing but one that mediates the actual thing. We might imagine, ideally, that all *constructed* sonifications should resonate with the rest of the acoustic world in the same way that all other objects in a sound environment resonate with each other.

> **Peter Sinclair:** An example of this is my fine-tuning of *RoadMusic* over several years. I find distinctions between music and sound art are blurred in this process, as I create a new acoustic environment that does not represent but resonates with the driving experience. Both of us work to frame the sounds being produced so that they more clearly reflect the results of these various processes.

The writing of Fluxus composer and

Fig. 3. Le facteur: Mail scooter delivering Peter Sinclair's package in Niolon, 2012. (Photo © Peter Sinclair)

early Bell Labs computer musician James Tenney gives us a theoretical context for thinking about sympathetic sound. From his earliest writings of 1961, "Meta-Hodos" and the slightly later "Meta Meta-Hodos: A Phenomenology of 20th Century Musical Materials and an Approach to the Study of Form" [12], Tenney put forward a template for understanding the musical experience through cognition and perception. He referred to this form of musical analysis as temporal gestalt perception. It is musical analysis from the viewpoint of Gestalt psychology. It is a discussion of music in more universal terms of acoustics and perception, a technique that frees the observer from stylistic bias.

The term gestalt is often used to describe the clustering of experiences into single cognitive entities. In the standard definition, "The Gestalt effect is the form-generating capability of our senses" [13]. While this includes the sense of hearing, in the literature about gestalt perception, listening is too often ignored. Our minds are actively hearing the world awake or asleep. Unlike sight, hearing does not go away (one cannot close one's ears); our ears and brain are automatically and continuously polling the acoustic space around us and making preconscious decisions about actions and reactions in a framework of long- and short-term memory and deep instinctual motivations. Our conscious minds take this acoustic *bricolage* of memories and make associations to our past experiences even if those experiences are only minutes or even fractions of a second old.

We are hearing the resonance of the room as it reacts to each new sound and we compare it to the pre-delay arrival of a sudden new sound. In the distance we hear thunder and the wind in the trees, an ambulance or the howl of a wolf, and our minds are suddenly taken to that place that we imagine in the distance. Since the invention of vehicles, we have enabled a new sensation of velocity. When we hear a vehicle with a siren pass by, we observe a noticeable drop in pitch of the siren. This is audio Doppler shift. Our acuity for Doppler shift has made it so that we expect things that are hurtling past us to also drop in pitch in the same way. Phenomenon like this, part-instinctual and part in the preconscious domain, is the place where "music" emerges. Our reality is shaped by our reactions to our sensations and the order that our mind makes out of the world outside of our skin. This is the envelope that wraps around us for all our acoustic experiences. Then there is the actuality of the modern music experience and the cultural memories of music that create the interplay of our understanding of each new acoustic experience. As Tenney has said,

> For the musician, a piece of music does not consist merely of an inarticulate stream of elementary sounds, but a hierarchically ordered network of sounds, motives, phrases, passages, sections, movements, etc.—i.e., time-spans whose perceptual boundaries are largely determined by the nature of the sounds and sound-configurations occurring within them. What is involved in both cases is a conception of distinct spans of time—at several hierarchical levels—each of which is both internally cohesive and externally segregated from comparable time-spans immediately preceding and following it [14].

Tenney speaks in terms of aural gestalts, formative parameters, rhythmic inertia and morphological relations. These are all new constructions in relation to the music theory that preceded it and are based on his Cage-influenced model of understanding the overall sound experience as music.

This phenomenologically based perspective of music theory is pulled along by a strong tide of cultural understanding and memory that each individual carries as part of one's heritage and life situation; below this conscious influence are perceptual mechanisms that are first and foremost dependent on understanding the acoustics of an environment.

Each recording carries with it a "sound" that recording engineers and producers have worked hard to create and present as a fundamental aspect of every recording. As a matter of fact, many recordings fail because of the production quality and timbre of the recording itself and not the more definable musical attributes. As Adam Lockhart points out:

> Adopting a cognitive model to conceptualize musical perception may be useful for composers who wish to obtain a deeper understanding of their craft. New music such as electroacoustic music, painted on a canvas of spectrum over time, relies on these ideas of cognitive connectivity to evoke substance. When we become immersed in a musical experience, we are actually immersed in our own mind [15].

Thus, while we may believe that conscious, high-level, cultural influences are at the front of our understanding of a musical experience, when faced with new sets of sounds in an acoustic environment, there are also lower levels of subconscious cues that have evolved in us collectively as humans and in the course of all the listening we have done in our lives as individuals. These become the fundamental gauge of what we are hearing. Perceptions of style, melody, harmony, etc., are framed by the actual experience of listening to the raw acoustic itself. Of course, our intentions additionally push this perception into conscious categories of memory and experience, but the core impressions of a given audio experience remain tied to the acoustic reality.

CRAFTING

To return to sonification: Is it possible to make any arbitrary parameter linkage and end up with a functional acoustic environment? It is likely that if someone experiences sonifications on a regular basis, as in the case of the mail-deliverer's moped above, then one's cognition of the "audio scene" will come to be understood in terms of whatever one is hearing at that time.

There is the representative sound (the auditory icon); then there is the codified melodic phase (the earcon), which makes a semantic representation of what is being communicated; a sequence of notes can thus represent some distinct idea or concept. There can be a general mapping of data directly to the parameters of sound. When we assign the parameters to arbitrary acoustic elements, what we end up with is still inevitably an acoustic environment. If something is important to us, then we are going to refocus our attention to hear it; but it is the function of the designer to make the object of attention apparent and that of the artist or composer to create what she or he considers as a "just" connection between sound, situation and intention.

This means that even if one *can* map anything to anything else, it doesn't mean one would want to. We should get beyond the symbolization of things. There is a difference between something that symbolizes something and something that is sympathetic (in sympathy) or naturally resonant. This can be considered in the light of Schafer's concepts of acoustic ecology, as seen in "The Tuning of the World" [16], but it could also be considered from the point of view of Pierre Schaeffer's causal listening, which consists of listening to a sound in order to gather information about its cause (or source) [17].

Conclusion

Although sonification can be presented in consecrated space and/or time (art installation or concert), we are particularly concerned with the case of the permanent sonification of environments. This is the way in which the context of sound shifts from the exceptional, the occasion-based special finite event, to the acoustic, the environmental, the everyday.

Sound encompasses our fundamental sense of where we are and what surrounds us at any given time. It also simultaneously triggers our memories of what we have heard before. Memories of sound work to cluster all new sounds into our understandings of the world, which are connected through the gestalt of those memories to meanings and feelings from other times and places. The techniques of digital sonification of data are introduced into this ancient context and are encompassed by it.

The creation of acoustic environments that contain new channels of previously inaudible information will be discerned best in the context of this acoustic memory and the relationship to the additional memories of recordings and music. This is the reality of listening to the world, whether it is encoded with new information or not.

Part of the challenge for composers and sound artists interested in these new acoustic environments, which can convey subtle, previously inaudible information, is to craft sound environments that resonate with the broader acoustic experience. One objective could be to create acoustic environments within which listeners can intuit new information channels naturally, because these resonate with their previous experience of the acoustic and musical aspects of their reality. This can only be fully accomplished in the context of an overall new acoustic reality and not merely through the compositional techniques of the semiotics of melody, harmony, timbre and rhythm. These musical functions are just some of the myriads of acoustic interrelationships that are automatically and instinctually digested by any listener in any given acoustic environment. By consciously linking newly minted information and rich sounds into an inclusive sonic model, this new audio representation integrates the understanding of the richness of all musical and acoustic parameters. In this context, we can craft a new acoustic that takes the listener beyond the passive experience and into a new, fecund world of sound that relies on attention to yield the full meaning intended by the creator of new soundscapes.

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