Information through Sound: Understanding Data through Sonification

Mark Ballora
School of Music, Department of Integrative Arts, Penn State University
ballora@psu.edu

S. Lee Hong
Department of Kinesiology, Louisiana State University
shong1@lsu.edu

Brian Panulla
College of Information Sciences and Technology, Penn State University
bpanulla@ist.psu.edu

David Hall
Director, Center for Network-centric Cognition and Information Fusion
Professor of Information Sciences and Technology, Penn State University
dhall@ist.psu.edu

Introduction

The turning point in the film *The Hunt for Red October* occurs when the sonar expert plays an apparent recording of underwater magma displacement. When he speeds it up tenfold, a rhythmic characteristic emerges that is unmistakably human-made: a new form of Soviet submarine.

While Hollywood has never been renowned for historical or scientific accuracy, the idea of detecting valuable information through sound is neither far-fetched nor fictional. In our Information Age, new forms of gathering information are constantly being created. However, this does not necessarily lead to increased understanding. In particular, managing crisis situations or monitoring infrastructures requires the ability to interpret incoming information from multiple sources. With new sources of information constantly becoming available, the challenge becomes how to process it effectively, avoiding *cogmenutia fragmentosa*.

As we navigate our way through life, the eyes and the ears play complementary roles in giving us information about our environment. Yet in research fields, the eyes predominate, as datasets are typically presented through visualization. While composers have been using sound to represent subjective information for centuries, many researchers are beginning to look to a new form of composition, *sonification*, as a means of representing objective information. The authoritative source for this area is the International Community for Auditory Display (www.icad.org), with focused efforts being carried out in interdisciplinary facilities such as SonEnvir in Austria (http://sonenvir.at) and the Sonification Lab at Georgia Tech University (http://sonify.psych.gatech.edu/).
Here, we'll present an overview of sonification's benefits and discuss two projects currently in progress.

Sight and Sound

Visualization has the benefit of being synoptic, and has a well-established vocabulary for conveying information with different types of charts and graphs. However, studying large amounts of data with the ears offers a number of advantages. Small-scale variations may be "magnified" if they are mapped to a quality such as pitch, to which the human auditory system is particularly sensitive. The auditory system is also highly adapted for following multiple streams of information. That is, listeners can readily apprehend a number of simultaneous melodies if they are presented effectively. Thus, sonification is an effective way to display a multitude of signal processing operations simultaneously, with each being represented as a line of counterpoint, a series of chords, or a succession of musical instruments.

Sound is also well suited for representing dynamic, changing events. As in the cinematic example above, the rate of playback may be adjusted arbitrarily, allowing data that occurs over large time periods to be played back over much shorter timeframes. While multiple time series may possess similar time-dependent patterns, they may in fact be occurring on different time scales, making the differences and similarities in dynamic patterns immediately apparent. Sonification provides the benefit of a clear distinction between time series, much like discerning between a waltz and a march.

Monitoring vs. Analysis

There is a distinction to be drawn between *monitoring* and *analysis*, both of which can be served by sonifications. Monitoring refers to detection of known conditions, with obvious alerts making clear when action needs to be taken. Analysis takes detection a step further by illustrating previously unknown conditions, allowing new patterns to be recognized. The case studies that follow have examples of each of these facilities.

Case Study 1: Heart Rhythms

In an earlier work, one of our authors (MB) used sonification to study cardiac rhythms.[1] By sonifying time intervals between successive heartbeats occurring over time spans on the order of hours, sonified representations were beneficial in identifying unhealthy cyclic patterns associated with obstructive sleep apnea. These sonifications have subsequently proved useful as general introductions to physiological health, making distinctions between healthy and diseased states easy for uneducated listeners.[2]

Scientists who use complexity theory as a framework to study human health and the control of human movement are now beginning to propose that the changes in highly regular physiological and motor behavior patterns are biomarkers of ill health and disease. In particular, when presenting such ideas to audiences that are new to this conceptual framework, sonification provides a direct entry point, clearly highlighting the droning or obviously cyclic sounds of ill health and frailty.

Given the auditory system's strength in detecting patterns, there is the possibility of expanding upon this work as a means for patients to monitor their own cardiac health. Patients who have suffered from heart failure frequently need to follow a regimen of diet, medication, and exercise to maintain proper levels of blood flow. After a period of hospitalization following heart failure, patients are vulnerable to relapse — roughly $^1/_3$ of patients are readmitted to hospitals within 90 days of discharge, a situation that is both costly and a drain upon resources. Patients are often unaware that they are at risk until their condition is advanced and re-hospitalization is necessary.

At present, many patients wear small, non-invasive devices that monitor heart rate and respiration levels. Data from these devices could be uploaded to a secure Web site and sonified, allowing patients to monitor their progress. When unhealthy patterns begin to emerge, patients could consult their doctors, and routine interventions could be taken that prevent the need for re-hospitalization.[3]

Case Study 2: Songs of Computer Networks

Penn State's newly formed Center for Network-centric Cognition and Information Fusion (http://ist.psu.edu/facultyresearch/facilities/nc2if/) addresses the issue of *data fusion* — managing, combining, and correlating the ever-growing numbers of available information sources and making useful interpretations of emerging events. Along with visualization, sonification is regarded as an essential component of multi-dimensional information streams.

As an initial effort, we are investigating datasets that track computer network queries in order to identify patterns that may be associated with attacks and intrusions. Network security is a pressing and, at present, overwhelmingly complex problem in information sciences. Hundreds of alerts are recorded every minute. A small-scale attack may appear in intrusions that occur over a period of months, while a large-scale attack may have dozens of intrusions every second. The nature of the data is multi-faceted, including parameters such as the inquiry's source port and IP address, the targeted port and IP address, the attack signature (generic ping query, buffer overflow, denial of service, etc.), and the type of sensor that reports the attack.

There is some precedent for this work with the Peep Network Auralizer system,[4] which is currently "abandonware" — open source and not being developed further. This system addresses an ongoing problem in sonification, which is that the sound quality of auditory displays tends to be simplistic and thus a less than compelling listening experience. Peep ingeniously solves this by mapping network activity to nature sounds. When a network is functioning normally, there is a pleasant backdrop of waterfalls, streams, wind, and various animal sounds. When something is amiss, the sounds change in character (greater water flow, different types of animal chirps), alerting the operator.

While this is an excellent solution for a monitoring sonification, it is likely limiting for the more highly dimensional information contained in the network alerts datasets. Thus, while we are exploring appropriating elements of Peep, we are also relying on synthesized sounds, which, while sounding artificial, have the benefit of finer degrees of control and nuance. In preliminary models, we have found it easy to distinguish among attack types — from repeated network scans, which sound like sweeping glissandos, to denial of service attacks, which are monotonous pitch repetitions.

Conclusion

From an informatics perspective, sonification represents an exciting frontier of research methodologies. Creating sonifications that are both informative and compelling offers new avenues of digital artistry, and is a fruitful area for multi-media development as combinations of aesthetics and engineering are relied upon to transform dry information into actionable knowledge for decision-making.

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1 Ballora, Mark and Bruce Pennycook, Plamen Ch. Ivanov, Leon Glass, Ary L. Goldberger. 2004. "Heart rate sonification: A new approach to medical diagnosis." In *LEONARDO* 37. Cambridge, Massachusetts: MIT Press, pp. 41-46.

2 Hong, S. Lee and James W. Bodfish, Karl M. Newell. 2006. "Power-law scaling for macroscopic entropy and microscopic complexity: Evidence from human movement and posture." In *CHAOS* 16, 013135, Melville, New York.

3 Private communication with Dr. John Boehmer, Hershey Medical Center, Pennsylvania, February 2008.

4 Gilfix, Michael and Alva Couch. 2000. "Peep (The Network Auralizer): Monitoring Your Network with Sound." In *2000 LISA XIV*, December 3-8. New Orleans, Los Angeles, pp. 109-117.