

The Data Sensorium: Sonifications

A Collaboration between cDACT and BNL

Dr. Margaret Schedel

Department of Music and
The Consortium for Digital Arts Culture & Technology
Stony Brook University
Stony Brook, NY
gem@schedel.net

Timothy Vallier

Department of Music and
The Consortium for Digital Arts Culture & Technology
Stony Brook University
Stony Brook, NY
tvallier@gmail.com

Abstract—The Consortium for Digital Arts Culture and Technology (cDACT) paired with Brookhaven National Laboratory (BNL) to create the Data Sensorium, a center focused on the development, evaluation and implementation of multimodal visual and auditory interfaces for the analysis of large scale data sets.

Keywords—sensorium, sonification, tides, waves, nano, fMRI, drug addiction

I. INTRODUCTION

Imagine manipulating a three dimensional animation of a dataset—stretching it with a gesture, tilting and twisting it, seeing it from all sides, erasing unwanted information, and foregrounding particular bits of data. Imagine further—you can simultaneously hear the data transformation in three-dimensional audio. In this imagination, data is immersive, offering information concurrently to all of your senses—visual, aural, and haptic. This experience of data, drawing on interactive multidimensional graphics and sound, would be able to offer the possibility of spontaneous leaps in cognition, emphasizing new associations and understandings, and drawing attention to previously invisible relationships. This is the Data Sensorium.

In this paper we will discuss four sonification projects by the Data Sensorium. We will explain three previously completed sonification projects 1) Song of the Tides, 2) Sonifying the Seismic Signature of Ocean Surf, 3) Sonification of Nano-Structures, and present a work-in-progress 4) 3D Sonification of fMRI Data. When sonification is done correctly, hearing, as a non-linear, complex process, can be used to gain further insight into data, including intuitive leaps that suggest further avenues of investigation [1]. There are precedents in the literature for scientists discovering new phenomena based on sonification of data: for example, a new current deep in the Pacific Ocean was discovered thanks to the sonification work of Bob Sturm [2]. While the center is only three years old, we have already made connections within Stony

Brook University (SBU) as well as to Brookhaven National Laboratory (BNL), and created sonifications which have yielded new insights into data.

II. SONG OF THE TIDES

Song of the Tides was a collaboration with Professor Tony Phillips from the SBU Math Department and percussion doctoral student Levy Lorenzo from the SBU music department. Phillips wanted to sonify data that represented magnitude and time information for extrema of tides over a one month period. These tidal maxima and minima are a function of gravitational forces from the Sun and Moon, as well as other geographical factors. In general, there are two high tides and two low tides per day (i.e. semi-diurnal). However, there are some days where only one low and one high tide (i.e. diurnal) occur due to a particular alignment of the Sun and Moon. The times and heights associated with the extrema vary daily. The goal of *Song of the Tides* was to get a sense of the movement and trend of the data by listening to the resulting sound, rather than performing traditional graphic analysis. The height (relative to sea-level) was mapped to relative pitch; time was scaled such that one day was compressed into one second.

Typically, in one day a grouping of four relative pitches is heard in the sonification; High1, Low1, High2, Low2. The height of the two high tides in a single day are rarely equal, and such a relationship is highlighted when one of the high points sounds at a clearly higher pitch. The same is true conversely for the two low tides of the day. Further, from day to day there is a small, almost linear, relationship between High1 of Day 1 and High1 of Day 2, etc. Thus four individual melodic voices occur in the music, which facilitates isolated analysis of an individual daily tidal extrema. In other words, the listener can easily pick out the movement of Low2 throughout an entire month. Diurnal occurrences are very clear when two of the voices disappear. The time intervals between consecutive extrema also varies. This time irregularity among four daily extrema is made very clear by the irregularity of the rhythms of the four-note groupings.

Phillips and Lorenzo sonified the tidal data for two Italian cities: Venice and Ancona. The percussive, pointilistic nature of the marimba highlighted the angularity and irregularity of the data from Venice, while the Ancona data was sonified by a

woodwind quartet where one instrument was dedicated to one of four daily extrema (e.g. Bassoon played points for Low1). This sonic representation highlights artifacts and tidal trends more clearly than simply looking at the graph or table of data [3].

III. SONIFYING THE SEISMIC SIGNATURE OF OCEAN SURF

Ocean surf conditions are difficult to monitor; harsh and energetic waves take a toll on instrumentation in the surf zone. In addition, long-period, infragravity waves are especially elusive, and not easily detected among the incident surf, yet they carry substantial energy which fuels coastal processes, such as erosion. To overcome these instrumentation and detection problems, Professor Henry Bokuniewicz, SBU Oceanography Department, undergraduate student Megan Bednarz, SBU School of Marine and Atmospheric Sciences, and doctoral composition student Timothy Vallier, SBU Music Department, sonified seismographs recorded in the coastal zone to record incident wave energy as well as infragravity waves. Seismometers have the advantage of being a reliable and robust technology safely installed on dry land. Seismologists often find their records contaminated by noise, called microseisms, some of which are generated by ocean waves. The interpretation of microseisms in terms of surf conditions requires considerable data processing and analysis.

Microseisms generated by the surf can be detected by a seismometer within 60 meters of the shoreline with a high correlation between the square of the incident wave height and the strength of the seismic signal. In addition, seismic energy also corresponds to the long periods of infragravity waves associated with the occurrence of flash, and rip currents [4].

Seismic readings of the surf were collected with a Guralp Systems Limited CMG-3TD digitizer stationed at the Maidstone Club in East Hampton, NY. These readings were recorded with *Scream! 4.3* continuously and stored in hour-long segments. The seismic readings are a string of numbers that represent the amplitude of the vibrations recorded by the digitizer paired with time information. The sonification process compresses the data so that an hour's record translates into two minutes of audible signal. The sonification of this data is completed with the program *Max/MSP*. The data's range is compressed so that it may be interpreted as literal measurements of pitch, using a comfortable listening range of 600–1200 Hz and created with 1,000 data points per second.

All of the sonified samples share two distinctive features. As expected, they were dominated by a nearly continuous high-frequency chirping created by the incident surf with periods of 5 or 6 seconds. In addition there were distinct lower frequency waves that created a popping sound, like a percolating coffee pot. The lower-frequency sounds represent the infragravity waves with approximately 20-second periods. Flash rip currents that might be associated with coastal, infragravity waves had lifetimes of only a few minutes. In the compressed mode, these short-lived phenomena appear as isolated punctuations in the audio record.

This sonification is still in its formative stage; distinctions between sound representing storm and calm conditions can

clearly be heard, but the sonification algorithm needs to be optimized to better distinguish and resolves differences in surf conditions. Further work will emphasize the beats that occur when two water-wave trains of similar period approach the shore, equalize the audio so that the amplitude of low frequency waves are distinguished from incident waves, and apply the Doppler Effect on superposition of high-frequency, incident waves on low-frequency travelling waves.

IV. SONIFICATION OF NANO-STRUCTURES

The first project completed by the Data Sensorium in collaboration with BNL was the sonification of nano-materials by Dr. Kevin Yager, materials scientist (BNL) and musician Dr. Margaret Schedel (SBU). Dr. Yager uses X-ray scattering to determine the structure of nano-materials. These datasets are normally visualized using two-dimensional false-color images (see Figure 1). Although these images are an extremely valuable tool for researchers, they have limitations: scattering data can have a very large dynamic range, which is difficult to represent in a single image, and researchers must look at the computer screen to understand the data, often interrupting workflow such as preparing new samples. Sonification can help with both of these issues, since the human ear has a large dynamic range [5], and researchers can use ambient data analysis (e.g. hearing the samples) while concentrating on other visual tasks.

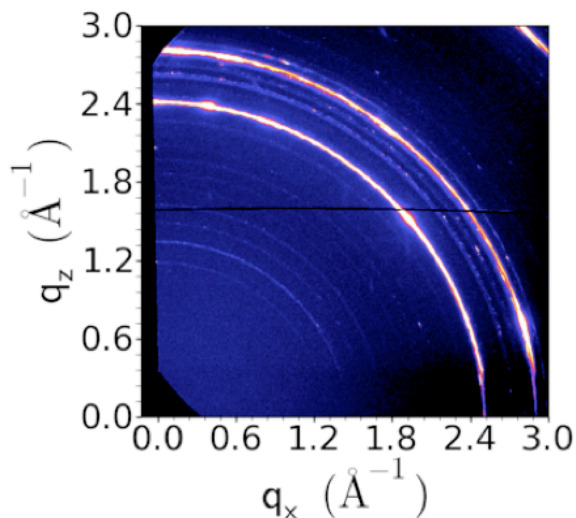


Figure 1. Example of X-Ray Scattering Data

Scattering data can be thought of as the Fourier transform of the real-space density structure; this implies a natural pairing with additive synthesis. In scattering experiments, a given feature (e.g. at q_0 ; where q is position in scattering space) will frequently have harmonics (at $2q_0$, $3q_0$, etc.). Interpreting this axis as frequency in a sonification naturally generates audio overtones. The human auditory system is exceedingly well-equipped to detect these timbral variations; timbre can be

defined as “the presence or absence, or relative strength or weakness of overtones [6].”

The other sonification procedures described in this paper utilize temporal datasets. Indeed most of the existing work in sonification involves conversion of time-series data, which discounts the vast majority of datasets, where some non-temporal variable is of interest. Although sonification of more abstract datasets is necessarily less intuitive, one can nevertheless learn to analyze the generated sonic material to provide useful information. In this case, we interpret one axis of a multi-dimensional data set as time, generating time-varying series from a static data set.

The sonification of nano-materials procedure (see Figure 2) consists of reformulating the two-dimensional scattering image into an (q, angle) array, where ‘angle’ is the arc angle with respect to the vertical axis of the image. In so doing, rings of scattering (which have a constant q -distance from the incident x-ray beam) are turned into straight horizontal lines in the $I(q, \text{angle})$ matrix. Doing so highlights any variation in the ring intensity, which corresponds to spatial orientation of the structures in the sample. In particular, the $I(q, \text{angle})$ matrix is directly converted into an $I(f, t)$ matrix, where f is frequency and t is time. This matrix is simply a spectrogram, or sonogram, which can of course be converted into a sound waveform through additive synthesis.

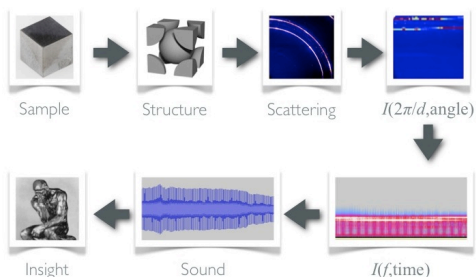


Figure 2. Sonification Procedure for X-ray Scattering Data

V. 3D SONIFICATION OF FMRI DATA

The Data Sensorium is currently creating sound from the brain scans of drug addicted individuals. Despite the prevalence and risk associated with disorders of self-regulation, little is known about their underlying neurobiological mechanisms. For the past several decades researchers at BNL have conducted basic studies in drug-addicted populations. These studies culminated to empirically inform a theoretical model of human drug addiction, characterized by Impaired Response Inhibition (RI) and Salience Attribution (SA) (hence, I-RISA) [7]. The model posits that underlying addiction to drugs, a hallmark of poor self-regulation, is the impaired ability to attribute appropriate salience to emotional cues (e.g. drug cues are overvalued while other emotional cues are undervalued) with a concomitant inability to inhibit disadvantageous behaviors. This I-RISA model is widely accepted by the neuroscience community.

Computer scientist Dr. Dimitris Samaras (SBU) has been applying machine-learning techniques to fMRI data in order to extract information automatically, by computational and statistical methods. Brain scans are treated as spatial patterns and learning methods are used to identify statistical properties of the data that discriminate between groups of subjects (e.g. addicted vs. controls). Results of machine-learning tools previously developed by the research group to automatically classify addicted individuals from controls utilizing fMRI during monetary reward have been previously published with classification accuracy of ~90% [8].

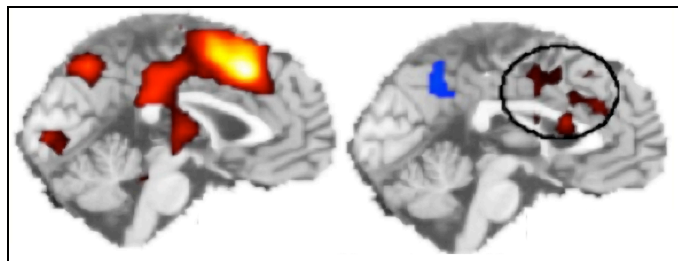


Figure 3. fMRI data in Drug Addicted Individuals (left) and Control Group (right)

An ongoing problem with brain-scan data is that it is inherently very noisy. Musicians Dr. Margaret Schedel (SBU) and Dr. Daniel Weymouth (SBU) propose sonifying data in three dimensions, with the use of a multi-speaker array. The location of sound within such an array, as well as the placement of the speakers, is an area of ongoing research [9] and will require experimentation. Nonetheless, the ability to finely localize sound in three dimensions, including behind the subject, using inter-aural differences as well as the shape of the head, pinna, etc. (the HRTF, or Head-Related Transfer Function) is well established [10]. MRI scans have low time, but high spatial, resolution, thus each data point could be assigned to a particular virtual location in a 3D sphere. Data points would not have to be connected for patterns to be perceived in the auditory domain.

VI. CONCLUSION

Experimental science, from the atomic level to the cosmic, is generating data at an ever-increasing pace. As the pace of scientific discovery increases, new methods to deal with large datasets become increasingly important. We have created a collaborative center that explores different ways that data can be converted into sensory experience. Tools developed for image analysis, visualization, machine learning, and sound processing (among others) can be fruitfully applied to allow researchers to explore their data more quickly and intuitively. In this paper we focused on the sonification experiments the Data Sensorium is conducting. Sonification is not a substitute for other methods of data analysis, either computational or visual, but is rather an additive channel which aids in data investigation. Our work supports the notion that many

problems in understanding rather abstract scientific datasets can be ameliorated by adding an auditory modality. We further emphasize that sonification need not be limited to time-series data: any data matrix is amenable. The Data Sensorium has proven to be an exemplary model of inter-disciplinary collaboration and we look forward to more exciting discoveries at the intersection of arts and sciences.

REFERENCES

- [1] S. Barrass, "A perceptual framework for the auditory display of scientific data." *ACM Transactions on Applied Perception* 2:4 (October 2005): pp. 389-402.
- [2] B. Sturm, "Pulse of an ocean: sonification of ocean buoy data." *Leonardo Journal of the Arts Sciences* 38:2 (April 2005): pp. 143-149.
- [3] L. Lorenzo, "Song of the Tides" http://www.levylorenzo.com/projects_2.html accessed March 12, 2012.
- [4] M. Slattery, Assessing the nature of rip currents along the south shore of Long Island, NY: Dominant rip type and insights into possible forcing mechanisms. Ph.D.Dissertation, School of Marine and Atmospheric Science, Stony Brook University: 2010.
- [5] T. Fitch & G. Kramer, G, "Sonifying the body electric: Superiority of an auditory over a visual display in a complex, multi-variate system. In G. Kramer (ed.), *Auditory display: Sonification, audification and auditory interfaces*. Proceedings of the First International Conference on Auditory Display (ICAD) 1992, pp. 307-326.
- [6] D. Howard, and J. Angus, *Acoustics and Psychoacoustics*. Oxford: Focal, 2006.
- [7] R. Goldstein, and N. Volkow, "Drug addiction and its underlying neurobiological basis: neuroimaging evidence for the involvement of the frontal cortex." *American Journal of Psychiatry* 159:10 (2002): pp. 1642-1652.
- [8] J. Jean, D. Samaras, D. Tomasi, R. Goldstein. "Simple fully automated group classification on brain fMRI." In *IEEE International Symposium on Biomedical Imaging 2010*, pp 1145 – 1148.
- [9] D. Malham and A. Myatt, "3-D sound spatialization using ambisonic techniques." *Computer Music Journal*, Vol. 19, No. 4 (Winter, 1995), pp. 58-70.
- [10] M. Morimoto, M. Itoh, and K. Iida. 3-D sound image localization by interaural differences and the median plane HRTF. In *Proceedings of the 2002 International Conference on Auditory Display*, Kyoto, Japan, July 2002.