Sonification in science and art

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Abstract

We present an example of interaction between research and music composition. The research aims towards a flexible and intuitive audio representation of complex, multi dimensional data. Music offers an example where a listener is able to track simultaneous changes in variables and integrate them into a comprehensive mental image. We experimented with sonification of oceanographic and stock market data by creating vowel-like sounds using filters, mapping dimensions to the center frequency and bandwidth settings of filters anchored around a typical vowel sound. In another experiment dimensions were mapped to onset and duration. These methods also serve as a departure point for composition activities. One approach was to apply the same filter settings, derived from the data, to various different sound sources. Another approach was to use the data to generate the timing information for a piece of music, varying the timbral identity of individual events such that the representational aspect is diminished. In our talk we describe and illustrate these sonification methods and their compositional byproducts, and raise some resultant thoughts on creativity.
Introduction

Computer music in general, and sonification in particular are domains in which the interaction between applied research and creativity is inevitable and symbiotic. Our research on the use of auditory display of data is rooted in this dual interest. In this paper we describe creative artistic extensions of our research. The driving force of our research is to approach the domain from a specifically musical, rather than a more general 'sonic' perspective. In the section that follows we summarize our rationale for musical sonification.

Musical sonification as a scientific tool

Sonification has been applied to:

- The interpretation of highly dimensional data;
- Interpreting data when visual clustering is confusing;
- Topological structure analysis;
- Revealing data and learning trends;
- Finding patterns in long term dynamic temporal data (such as seismic or astronomical data);
- Interpreting short term data in which compression or expansion may be readily achieved acoustically.

A number of types of sonification are currently used. These include:

- Alarms;
- Acoustic representations of place within a data tree [Blattner99];
- Metaphorical use of sounds to represent a state [Walker97];
- Acoustic feedback in human computer interface [Friedlander97];
- Parameter mapping (in which a sound's attributes are driven by data values) [Kramer94];

We approach the issue from a musical perspective noting specific features of music that address the needs of these applications. The act of listening to music involves tracking simultaneous changes in variables (such as frequency, amplitude, or spectral distribution) and
integrating them into a comprehensive mental image. This dynamic assembling of mental images can be utilized in many ways - to track dynamically changing trends in an immediate and intuitive way, or to draw abstract connections between patterns obviating relationships that may be otherwise difficult to perceive. The resulting patterns emerging out of the sonic continuum need not be static themselves thus music can represent multiple identities and similarities simultaneously. Salient features enable the listener to prioritize and attend to specific aspects of the data-intensive stream that reaches the ear - which often result in a hierarchical organization which can be used to extract structurally salient information from complex multi-dimensional data. Last but not least, music is (sometimes) pleasing to hear.

To interpret sonified data listeners draw upon their powers of auditory abstraction and categorization in order to identify patterns and detect trends. In this sense, sonification involves engaged creative listening similar to the active listening demanded by music. A critical aspect of such listening is that of categorical perception, in which a continuous variation in one or more parameter yields perceptually discrete categories. This phenomenon was originally detected in speech processing but was later identified in other aspects of listening. Timbre is generally classified by listeners according to best-fit strategies involving abstraction and categorization that account for time and frequency domain properties. One such example is phonemic categorization in speech processing which is often also called upon to describe non-speech timbres (as, for example, 'the nasal sound of an oboe'). We thus hypothesize that vowel like sounds could be effectively used as a basic timbral language for representing data in which similar vowels share similar data properties. In initial experiments, mapping data dimensions to the filter bandwidth and center frequency of a formant filter resulted in auditory display in which trends and patterns could be interpreted according to the proximity of the resultant sound to any one of the cardinal vowels.

Examples of Musical Sonification

We experimented with sonification of oceanographic and stock market data using vocal formant filters. Two important variables of stock trade are the price of a stock and the volume of trade. In one approach these two variables were mapped to the center frequency and bandwidth settings of the filters anchored around a typical vowel sound. This resulted in changes in the inflection of the vowel if the range was chosen to be relatively small or, if we chose to use larger ranges, a shift between contrasting vowels. In a separate experiment the variables were mapped to timing information: price was indicated by the number of attacks in a given time, while volume was represented by the duration of each attack. Thus, in addition to experimenting with
timbral categorization we relied upon temporal abstraction and grouping that, like timbre classification, is an inherent aspect of musical listening.

Compositional uses of musical sonification

We proceed to describe how these methods were used in music composition and provide examples of their implementation.

Both sonification methods described above (by filter settings, and by timing information) are highly dependent on the specific values used and on minimizing changes in other variables. By using very different values the first author was able to use these same methods in composition – masking their representational aspect. The filter setting sonification uses short, evenly spaced coloured noise bursts. By applying the same settings to other sound sources (musical instruments) and considerably varying the timing a rich sound texture can be achieved. Likewise, with the timing based sonification: replacing the short similar bursts with much longer (thus overlapping) sounds, with varying envelopes and filter variables results in an organic seeming musical fabric. In both cases the complex trajectory is controlled by selecting the portion of the data used. Since stock data fluctuates considerably on the local level but often exhibits trends over the larger scale the composer has a virtually endless repertoire of interesting contours to work with.

Another method used compositionally was an extension of the time-based representation to granular synthesis. In granular synthesis a sound source is chopped into small 'grains' which are then recombined to produce a different sound. In addition to the choice of sound source, the end results depends on many variables including: grain size and density, the starting point from where the grain is extracted from the source, and the sampling rate at which the grain is read. Each parameter can be controlled dynamically when producing a sound. Mapping stock data, this time including highest and lowest daily price, as well as volume of trade and closing price, to these four granular synthesis variables the composer created a variety of sound materials.

Another example of the use of sonified scientific data is the second author's work, Haiku, for trombone and electronics. Haiku is based upon the 5:7:5 proportions of the poetry form. These proportions permeate the piece's temporal and pitch worlds. The trombone is subjected to real time signal processing and accompanies a prepared sound track played on a compact disc. The soundtrack uses solar activity data collected by the Michelson Doppler Imager (MDI), mounted on the SOHO spacecraft, circling the Sun over a million miles from Earth. Unlike the other examples in which numerical data was mapped to musical parameter, the solar data was taken 'as is', down-sampled into the audio range, filtered to remove instrument noise, and directly
sent to digital analogue converters. The direct audio representation of solar activity by Alexander Kosovich - a Research Scientist at Stanford's Solar Oscillations Investigation group, was used as source material for Haiku. The composer used convolution and formant resonators to shape the sound and emphasize the pulsations of the detected solar flares. Although there is no immediately apparent intrinsic scientific value to the sonification, the processing emphasized the temporal 5:7 ratio that subsequently inspired the compositional goal of abstracting the formal proportions of haiku.

So what about creativity?

Our line of work casts interesting glances at creative processes. We propose that listening is, in itself, a creative process in that a meaningful mental image is elicited from a stream of air pressure changes. Our sonification tools offer a unique perspective on listening because:

- The stimuli are relatively simple but not as sonically impoverished as the simple sine-tones commonly in listening experiments.
- Listeners have a relatively well defined task of extracting meaningful interpretation of data as opposed to the more vague task of appreciating music on its own terms.
- We base our approach upon a restricted and somewhat controlled context in which abstraction and categorical perception can be easily assessed in terms of a listener's ability to interpret the output.

Another aspect of evaluating creativity is the interaction between research and composition activities. Music and musical ideas served as a starting point for our search for sonification methods, which in turn were re-applied to composition. The later is especially interesting as it allows a glimpse at the sources of inspiration. For both authors the starting point was a sonic impression. There was by no means a moment of 'revelation' or inexplanable 'inspiration' but rather compositional decisions resulted from a conscious and protracted process of experimenting with auditory data display in searching for effective sonification.
Conclusion

Listening involves the creative tasks of identifying patterns and detecting trends. The facility to create abstractions and categorical perception are critical aspects of listening, whether it be to speech, music, or sonified data.

Our paradigm for creating meaningful sonification rests on anticipating the abstraction and categorization processes invoked by the acoustic signal. In this sense we view listening to sonified data as related to listening to music (but with less 'cultural baggage'). Effective sonification demands understanding something about the pattern detection and categorization processes of the listeners.
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figure 1: 3 days of trade sonified by mapping price and volume to center frequency and bandwidth of a formant filter (top) and to onset and duration (bottom)