Sound and Meaning in Auditory Data Display

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This paper focusses on the connection between human listening and datamining. The goal in the research field of datamining is to find patterns, to detect hidden regularities in data. Often, high-dimensional datasets are given which are not easily understood from pure inspection of the table of numbers representing the data. There are two ways to solve the datamining problem: one is to implement perceptional capabilities in artificial systems - this is the approach of machine learning. The other way is to make usage of the human brain which actually is the most brilliant data mining system we know. In connection with our sensory system we are able to recognize and distinguish patterns, and this capability is usually exploited when data is presented in form of a visualization. However, we also have extremely high-developed pattern recognition capabilites in the auditory domain, and the field of sonification addresses this modality by rendering auditory representation for data for the joint purposes of deepening insight into given data and facilitating the monitoring of complex processes.

An unanswered question is how high-dimensional data could or should sound. This paper looks at the relation between sound and meaning in our real world and transfers some findings onto the sonification domain. The result is the technique of Model-Based Sonification, which allows the development of sonifications that can easily be interpreted by the listener.

Auditory Perception and Environmental Listening

In evolution, the auditory senses developed because they provide us with relevant information to survive. However, we use listening far beyond this primary purpose by developing language and music. These three sorts of auditory signals shall be distinguished by their different functions.

The elementary and oldest function of listening is the detection of sound. Sounds in our environment provide us with awareness and they are able to draw our attention to potentially dangerous events (e.g. approaching enemies). Besides this, sound allows us to extract lots of information about a 'sounding' object: its size, material, surface, tension and so on. We are able to abstract from sounds to properties of the sounding object or sound process because the connection between sound and an object is fixed, given by the laws of physics. Because the coupling mechanism (physical laws) were constant over a large time scale, evolution was able to develop 'hard-wired' mechanisms to interprete such signals and pull out relavant information from the signal without the need for conscious processing.

Sound emerges as a consequence of excitation of physical objects, thus objects/instruments in equilibrium are usually silent. Humans often excite objects consciously and thus get sound as a feedback to their actions. So they can relate the sound to their actions and learn about the world from this interaction loop. E.g. pressing a button, we know from the sound (besides haptical feedback) if our action succeeded. While these observations seem self-evident, they are often ignored when considering sonification and techniques to access data by acoustic representations. Using this relation between sound and meaning, an alternative to Parameter Mapping, the prevailing sonification technique, is developed in the next section.

Let us now focus on the relation between sound and meaning within other types of sound signals. In language, spoken words receive their meaning within a cultural context and the association is learned by each child. The relation between the sound of the word 'table' and the meaning of this word must be learned and is somehow arbitrary. Obviously, humans have also excellent capabilities in learning and accessing the meaning of learned auditory patterns. While the information within environmental sounds is analog, language emphasizes the communication of symbolic information or abstract content. In sonification, verbal messages are suited to label categorial data or provide symbolic labels within an analog auditory data display.

Musical Information lies in between these two sound types. Controlling sounding objects by human supervisors leads to sound that both gives information about the instrument and the performer. Harmonic relations find an analog in physical laws (Fourier decomposition of periodic signals) while melodic and rhythmic structures are related to prosodic patterns in language and narrative.

Data Sonification

High-dimensional data is given by vectors of numbers. The question is how to generate meaningful sounds from given data. The traditional approach is to synthesize a sonification by superimposing sonic events whose attributes (onset, frequency, duration, amplitude, etc) are mapped by numeric values of the given data vector. This technique is known as parameter mapping. The main disadvantage is, that there is no canonical way to specify the mapping and that the mapping must be known prior to interpreting the sonification. For high-dimensional data, a mapping might be long and complex. There are further problems with interfering perceptional dimensions.

Model-Based Sonification

Model-Based Sonification solves some of the problems mentioned above by providing a structured method to link data to a sounding object. Different from parameter mapping, data is taken to parameterize a sound model, which rests in a state of equilibrium without excitation. Dependent upon the model, dynamical laws are introduced which cover the temporal evolution of the model, giving rise to acoustic signals which represent the sonification.

The main advantages of this model-based approach is, that the sound and its meaning with respect to the data are connected in the same way as in the real world. Thus, intuitive metaphors can be applied to interact with the model. Think of a model where the local tension of a membrane surface is parameterized by data. It can be struck, plucked, rubbed, etc. to make it produce sound. Information about the data is given in the control loop between human excitation and system reaction. As a model definition is not bound to specific data, humans get the chance to become familiar with the sound space of a model. Furthermore, the model can be applied to arbitrary data. If dynamical laws are applied which resemble physical laws that govern sounding objects, the sonifications are likely to be sounds within the soundspace we are familiar with from our listening experience.

Sonification models emphasize acoustic signals as a feedback to human actions. This offers new perspectives for human supervision of complex data and control of data manipulations. The investigation of sonification models and their utility for exploration of high-dimensional data is the topic of current ongoing research.