Auditory Displays Article xx: Sonification

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1 INTRODUCTION

Sonification is the use of nonspeech audio to present data. Sonification is typically used in situations where the user's eyes are busy elsewhere, such as in a laboratory or production line; where extracting temporal information is important; or where the data presentation requirements exceed the bandwidth of visual presentation means. The most successful example of an eyes-busy sonification application is the Geiger counter, wherein radiation measurements are presented to the user in the form of a clicking sound, with more clicks representing higher radiation levels. The auditory thermometer, where a changing pitch is used to display temperature, is a good example of a simple sonification. Complex monitoring tasks, such as those found in surgery, for example the pulse oximeter, are other venues for sonification. Analysis of multivariate scientific data is another active area of sonification research which has begun to show some promising results (Kramer 1994).

Sonification is most common, and most effective, in situations where the change in data values and relationships between different values are more important than absolute quantities. If, for example, the pitch of a tone is being used to represent temperature, it may be easy to tell if the temperature is rising or falling by listening to the tone (a task known as trend estimation). The effectiveness of sonification displays in such tasks is a result of the excellent temporal acuity of the auditory system, and its ability to detect changes in various parameters of a sound (pitch, tempo, timbre, etc.). This is useful for exploring transient phenomena, discerning temporal patterns, and rapid detection tasks (especially in high-stress environments). Other strengths of sonification include the ability to monitor and process multiple data sets, ease of learning and high engagement qualities due to affective responses to sound, and the automatic formation of auditory gestalts which help users discern relationships or trends in data streams. If, on the other hand, the exact values in a data set are of interest (point estimation), sonification can still be effective, so long as appropriate auditory context cues are available (discussed later).

2 DEFINITIONS

The use of nonspeech audio to present data is a nascent field. Until recently, even the definition of such basic words as sonification varied greatly. Sonification is a subset of the field of auditory display (see *Auditory Display*). AQ1
The National Science Foundation *Sonification Report* defines sonification as:

> the use of nonspeech audio to convey information. More specifically, sonification is the transformation of data relations into perceived relations in an acoustic signal for the purposes of facilitating communication or interpretation (Kramer *et al*. 1999). AQ3

Audification, a subset of sonification, is the direct translation of data samples into sound. Examples of audification include shifting into the audible range subsonic waveforms such as seismic data, or supersonic waves such as radio telescope data. Auralization, a term originally used interchangeably with sonification, has come to refer to the synthetic rendering, via digital signal processing techniques, of room acoustics, including such features as reverberation characteristics, and, where relevant, the location of the listener in the synthetic space (see *Spatial* AQ2
Auditory Displays).

3 PERCEPTUAL ISSUES IN SONIFICATION

Central to sonification design is the display user and the task the display is intended to support. Sonification designers must take into account the abilities and limits of human auditory perception and even music comprehension, and how these are affected by culture, age, and experience. Research in auditory perception to date has focused primarily on speech audio and highly controlled pure tones and noise bursts. This has resulted in a good understanding of auditory thresholds and psychophysical scales. Research in intensity, frequency, and temporal discrimination of static sounds, the effects of masking, and auditory localization abilities may all be brought to bear on sonification design. More recent investigations in auditory streaming and pattern recognition are well suited to ascertaining the effectiveness of complex sounds to convey information. Research with sonar operators has shown that learning can significantly enhance the display user's ability to discern auditory patterns. Users of assistive technologies for the blind exhibit surprising abilities using auditory displays. Sonification has also been used to enhance visual or haptic displays by providing an additional channel of information. The combination of visual and auditory information has been proven to enhance display effectiveness for many applications.

4 SONIFICATION DESIGN AND DISPLAY VARIABLES

Sonification design is based around the task for which the display is being used (i.e. the task domain) and the psychology of the display user. Design solutions may make use of simile, wherein the display sounds like the source of the data being represented. One example is the use of breath-like and heart-like sounds in an anesthesiology workstation, where the pitch of the breathing sound as well as its rate are used to present physiological data. Metaphor is used in sonification where changes in an auditory variable such as loudness are intuitively understood by the user to represent changes in, say, quantity.

Other sonification design techniques include: the use of auditory "beacons," where a fixed auditory state, representing a system state or specific set of data values, is learned by the user then used as a reference to orient the user in the data and compare system states; the use of a three-dimensional timbre space modeled after the Hue-Saturation-Lightness color model used in data visualization; mapping single data variables to multiple auditory variables to produce a more compelling display; correlating changes in the sonification with the display user's expected affective response to sounds; enhancing data visualizations with complimentary sonifications; and presenting auditory equivalents of bar graphs, X-Y plots, and scatter-plots. In all of these examples, it is important to provide the user with auditory context. When presenting data visually, it is impossible to extract information about a line representing, say, average daily temperature, unless there are axes, tick marks, labels, grid lines, and so on. Auditory equivalents must be included in auditory graphs and sonifications. As an example, a series of clicks can be added to the sonification to mark time passage (e.g. one click for each week in the temperature graph). Care must be taken in this, since, just as with visual displays, sonifications can become cluttered with superfluous sounds.

5 DISPLAY SYSTEMS AND SONIFICATION DESIGN TOOLS

Until very recently, most sonification systems have been very device dependent. That is, they have been designed and built for a particular sound generating system. The advantage of this is that the display designer controls all facets of the display. The disadvantage is that an entire system, from data source to the sound synthesizer the data is controlling, must be fully specified for every application. Varying the synthesis system may result in incorrect parameter ranges (e.g. all pitches being too high), inappropriate timbres, or other disruptive display artifacts. Different sound synthesizers may be capable of generating different sounds and may afford control over different variables. Thus, any list of sonification display variables will be incomplete. Simple auditory variables are pitch, loudness, and brightness (spectral centroid). A more complex synthesis system may provide higher-level variables based, for example, on a physical model of a sounding device. In addition to pitch and loudness, timbral variables might be derived by recalculating virtual tube length or the gauge of a virtual vibrating string. The relevance of application of such variables to a sonification display are not established. Specific display variables and design environments are defined by the hardware and software tools employed.

With the increasing power and flexibility of computers, and the push toward standardization in hardware and software interfaces, it is becoming more common to see multi-purpose sonification systems. Software-based synthesizers and sound cards are the most common resources in personal computers. In such situations, the data source to be sonified can be mapped, via data-to-sound mapping software, to control inputs at the sound source. The audio is typically presented to the user via headphones or speakers, sometimes in a 3D audio display in conjunction with a 3D virtual environment. If the display is interactive, either the graphical user interface or external hardware devices (e.g. data gloves, special pointers) provide access to sonification controls.

When precise or sophisticated manipulation of the sound parameters is not required, sonification systems may be built on top of the industry standard MIDI (Musical Instrument Digital Interface) control. In this case, the data to be sonified is reformatted as a string of MIDI messages and passed to the sound synthesizer. Sonification systems with dedicated sound generating capabilities — that is, without peripheral sound cards, software, or MIDI devices, are more likely to be found in special purpose devices such as the pulse oximeter, Geiger counter, printing press, or video game.

The tools for designing sonifications have largely been drawn from the field of computer music. Different approaches to sound synthesis include: systems of sound synthesis building blocks such as simple pure tone generators, transient generators, and filters; frequency modulation and amplitude modulation synthesis; granular synthesis; massively parallel additive synthesis, wherein large numbers of tone generators are carefully controlled in tandem; and wavelet-based models. Sound spatialization systems have also been integrated into sonification systems (see *Spatial Auditory Displays*).

6 RECOMMENDATIONS

Sonification displays have distinct advantages for certain tasks, environments, and user populations. The design and application of sonification displays requires expertise in sound design, consideration of delivery systems, and knowledge of auditory perception and the task domain. There are many unanswered questions regarding displays that rely entirely upon sonification and regarding the use of sonification in multi-modal displays. Demanding tasks and complex data, and support by increasingly capable and ubiquitous sound-related technologies, are creating a shift in display and interface design. The notion that engagement of the powerful human auditory perceptual system will offer meaningful solutions is rapidly taking hold.

REFERENCES

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