# SONIFICATION AND SONIC INTERACTION DESIGN FOR THE BROADBAND SOCIETY

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**Abstract**

Imagine a huge dataset of a public census - or medical data - or the worldwide Internet traffic. What do you hear? Obviously, we are not very familiar with the use of our listening capabilities when investigating large amounts of information! The typical data analyst is indeed confronted with large visual displays showing visualizations in front of a (concerning information value) rather silent computer. This is interesting since sound plays a highly important role in most real-world contexts, e.g. to monitor complex processes, to analyze complex systems, to selectively direct our attention, to allow us to gain insight into systems beyond the surface. *Sonification*, the auditory display of information makes arbitrary data accessible by our listening skills and addresses complementary modes of understanding which put dynamic instead of static features into the fore, which are well connected to *interaction*. Sonification can play an important role for the broadband society, e.g. to increase awareness of network behavior, our virtual neighborhood, to feel connected without being bound to a visual display. The paper will introduce, demonstrate and discuss the utility of sonification in sonic interaction design from monitoring and analysis tasks, interactive biofeedback to interfaces for visually impaired, introduce the concept of *Sonic Overloading*, and furthermore relate sonification to expected trends in the broadband society.

**Keywords**

Sonification, Sonic Interaction Design, Auditory Display

## 1 INTRODUCTION

Human activity in the world can be regarded as often very *tightly closed-loop interaction* with the environment which is perceived via our *senses* and manipulated by our *actions*. Arbitrary interactions give examples, e.g. brushing teeth, setting the table, driving by car or drinking a cup of coffee. Obviously, we are evolutionary well adapted to integrate the available multi-modal information in order to show adequate task-oriented behaviour. Important factors for this degree of adaptation are (a) the *constancy* of the underlying physical laws which is even responsible for the way evolutionary forces have optimized our shape and organized our brain, and (b) the *directness* between action and reaction, which helps us to tune action-perception loops and to learn to predict the consequences of our actions. Further observations are (*i*) that we typically manipulate the environment in rich ways (think of claying, grasping or any other manual interaction), that (*ii*) several modalities are involved in most interactions (e.g. to put a cup on the table involves tactile, auditory, visual responses), and (*iii*) that we build up and adjust an internal model of our environment via interaction – which could also be rephrased as 'to gain understanding and insight' on aspects of the world.

The above observations on real-world interaction deliver an interesting perspective for inspecting the way that we perceive and interact with computers, complex data, information spaces and networks: the typical workplace of a data analyst is largely dominated by visual display of text and graphical information on a computer screen. Sounds occur only as side effect of typing the keyboard or clicking the mouse. Interaction is indirect and often disrupted in query-reply sequences. There is little constancy in action-perception loops since reactions depend on the application and context, and the output modalities are only marginally coupled. Perhaps the strongest deviation from the above observations on real-world interaction is the *lack of sound* and thereby the lack of all information layers that acoustic information gives us in natural interaction where we are permanently embedded in an informative multi-layered sonic scenery.

Sound can serve many different *functions*, from creating an awareness of the processes in our environment (e.g. wind and rain sounds, singing birds, traffic sounds), allowing us to monitor systems (e.g. boiling water), drawing our attention (e.g. alarm clock, crying baby, approaching car when crossing a street), or analysis (e.g. shaking an opaque box to listen what could be inside, to tap a melon to judge its quality). Beyond these often-neglected functions in physical and environmental interaction, sound serves important functions as music and language for entertainment and communication, which are quite obvious.

How can we shape information technology to be in better overlap with naturally experienced interaction loops? How can we use sound to enhance the understanding of complex information? What technical infrastructure is required to establish largely accepted use of these techniques? *Sonic Interaction Design* [11] emphasizes the importance of sound as a means to structure interaction and suggests to actively consider the value of sound and its organization in the course of interaction. Design comes into play at several levels, from the aspect of interaction design to the design of media such as sound synthesis and mappings. *Sonification* plays the role of delivering structured ways to couple data to sound so that sound can be used as a reliable carrier of information. Beyond this information aspect, however, sound serves also many purposes beyond information such as emotion, branding, entertainment which are also addressed in Sonic Interaction Design.

This paper will focus on the information level of sound in interactions and outline the opportunities for sonification in technical systems from wearable/portable device to computer-based applications. Application fields will be discussed with carrying in mind the specific potential for the broadband society. The paper closes with some ideas about the relation between technologies and scientific culture to forecast future trends for sonification and sonic interaction design.

## 2 SONIFICATION AND SONIC INTERACTION DESIGN

Sonification is a rather young research field, which is concerned with the auditory display of information using primarily non-speech sound. A short definition is: 'Sonification is the data-dependent generation of sound, if the transformation is systematic, objective and reproducible, so that it can be used as scientific method' [1]. Details on definitions and taxonomy can be found in [2]. Basically, sonification is a subset of *functional sounds* [12], since the well-defined coupling between data and sound allows interpreting the sound for the underlying information. Sonification refers both to the technique and thus the algorithm, and to the resulting sound. However, some sonifications will only make sense as direct response to an excitatory process. Sonification is the general term under which several sonification techniques are subsumed, such as *Audification*, which uses the sequence of data values as sound samples and thus creates a very direct auditory representation of the data, *Parameter-Mapping Sonification*, which maps data values to acoustic parameters of a sound synthesizer (e.g. pitch, attack time, level, brightness), *Auditory Icons*, *Earcons* and *Spearcons*, which are all event-based techniques that use specific acoustic signals to signify a message or signified by using sound, and *Model-Based Sonification*, where data are used to configure dynamic processes that generate sound in reaction to excitatory interaction from the user, allowing the user to shake, hit, pluck or squeeze data sets to make them sound. The latter technique, developed by the author, serves as a suitable mediator to couple interactions to sonic reactions in close analogy to how we actively receive sound in the world as a response to interactions, and MBS will be explained in more detail in the following.

A good characterization of closed-loop systems can be given in terms of how tightly the interaction loop is closed between the human and the sonification system. Figure 1 depicts the modules of sonification systems, that is (a) the data source, (b) the sonification module which renders sound in dependence of the incoming data and internal parameters and (c) the auditory display front-end, depicted as a speaker, that refers to the fact that any sonification needs a conversion into real physical audible sound to bridge the gap between the synthesis system and the ears of the user. This encompasses sound cards, amplifiers, speakers, headphones, etc. The user is the listener of the sonifications and equipped with means to interact in one of several ways. The typical action path can be used to distinguish and categorize the different types of sonifications.

As the most passive and straightforward reaction, the user might normally not do anything at all. This is the case in *monitoring* applications, where the sound is perceived to maintain awareness of changes in the underlying data. This could certainly lead the user to take action if some critical event is detected, e.g. if the sonification pattern in network traffic data changes so that a DOS-attack is detected. However, in normal situations the user simply perceives the sound and may take actions that do not have any connection to the data, such as e.g. reading a book. More interaction occurs when the user interacts with the sonification system and its internal parameters. This is the realm of *interactive sonification*. The user actively manipulates the way in which external and independent data are involved into sound computation. For instance, in parameter-mapping sonification, the user might adjust the pitch range for a variable mapped to the pitch of sonic events, or associate another variable to control the attack time while the data are converted to sound. The higher the directness of these interactions, the faster the user will be able to arrive at useful and satisfying sonifications.

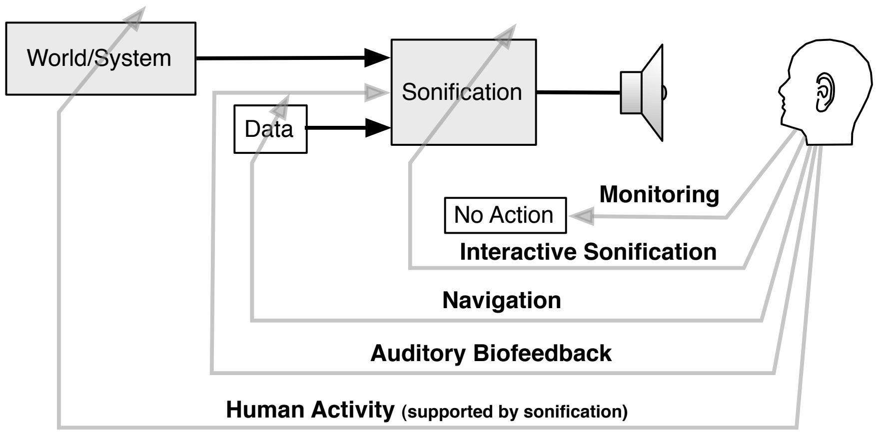


**Figure 1: Characterization of Sonifications according to the closure of the interaction loop.**

Model-Based Sonification (MBS) represents a particular instance of these interactive sonifications, since here the interaction with the sonification system occurs as an excitation. To give an example for MBS, imagine that the data points are used to configure a setup of masses and springs in data space, and that by shaking this data space, the masses start to oscillate around their position, which defines in turn the real-time sonification. Then the interaction is not very different to how we interact in the physical world: we drive a physical system by putting energy in it, which causes oscillations that become audible as sound. Energy loss causes an acoustic system to reach a silent equilibrium state after some time. In MBS, likewise data can be hit, shaken, squeezed, etc. to actively acquire informative acoustic responses that correspond to the structure of the underlying data. Different sonification models according to MBS are explained in detail in [3].

In many cases such as the analysis of data, the data set is given. The user might interact with the data instead of interacting with the sonification system. For instance, selecting a subset of data or features to be used for the sonification is such an interaction, which might also be called *Navigation*. Navigation is mostly driven with some interest in the data, e.g. to search an item or group of items, or to discern differences between groups of data, such as for instance benign and malignant tumors in case of sonification of biological tissue.

There is another class of sonifications, which are classically not called so but auditory feedback systems, which nicely emerge as a category here if one assumes that the incoming data to be sonified are not externally given, but instead measurements of the user or his/her behaviour. For instance, if the user's body motion data is measured and sonified according to how much a movement sequence deviates from a model (or: correct) movement this can be a useful feedback to train coordinated body movements such as in sports or for patients in rehabilitation [13]. There are also systems that sonify the human brain waves by means of real-time sonification, under the assumption that totally paralyzed 'locked-in' patients may increase better control over their brain waves to control brain-computer interfaces [14].

However, we need to acknowledge that in many situations the interest of the user will reach beyond the sonification or data into the world or a system to be controlled. This is indicated as 'Human behavior' in Fig. 1. As a real-world example, typically we close a door in order to close the door, and not for the 'clack' sound that we hear while the latch locks the door. However, the sound itself can be used to refine our activities, in the example, to acknowledge completion of an action unit so that we can proceed with the next action step. In the same direction, in sonic interaction design it will be useful to pay attention to the primary goals, and to structure a sonification so that it provides useful information for that. A good example is the computer desktop sound for dragging a file into the trashcan. This sound acknowledges deletion of a file, yet it gives only binary information. In contrast, if we dump different object in the real-world, the sound depends on size, weight, shape, content. Why don't computer sound designers appreciate the information level of sound and design interaction sounds such that the deletion of larger folders sounds different? If done well, it would increase the degree of immersion and have perhaps indirect positive effects such as higher engagement or more fun. *Parameterized Auditory Icons* [4] offer this potential and it is questionable why this old technique is so rarely used.

As an interesting branch of applications in this regard, all sorts of interactive games are candidates for closed-loop auditory display systems. For instance, we have developed a game called *Blindminton*, a Badminton that is played by sound alone, using a ball that only exists in the virtual world and handheld rackets in the real-world [13]. The state of the system (here: the ball, its position, velocity and acceleration relative to the player) is only represented by a real-time sonification so that the player can learn how to coordinate his/her movements to replay the ball. Such games do not only promise access to ball sports for visually impaired players, they also allow to test and train auditory skills or to induce movement patterns in rehabilitation games.

## 3 APPLICATION FIELDS

The previous section has already outlined important application fields for sonification and sonic interaction design. Obviously there are many specific applications that can be named for each of these categories. For monitoring applications, for instance, EEG sonification can be a great improvement for clinical monitoring personal. Stock market sonification might be able to shift some of the cognitive load from the visual domain (traders inspect typically more than half a dozen high-resolution visual displays) to the auditory domain while improving the reaction time to critical changes. Traffic data sonification may offer the potential to quickly discover qualitative changes in the traffic flow in cities or highway graphs, allowing to better control measures to counteract traffic jams or emergency conditions. It has been shown in experiments to the simulation of a coca-cola factory, that error detection profits from acoustic monitoring [5].

For data analysis, the audification of seismographic data is very suitable to characterize seismic activity; it is even possible to discern earthquakes from non-natural events such as nuclear detonation tests [6]. For the challenging task of detecting structure in high-dimensional data, techniques have been demonstrated that allow perceiving the intrinsic dimensionality of data [7]. In our lab we work towards a multi-modal data exploration workplace that combines visualization, sonification, tactile and tangible user interfaces for better bridging the gap between our perception/action modes and complex information spaces [8].

There is a body of work on sonification systems that aim at a sensorial replacement by using sound. For instance, visually impaired users may hear a sonification of a camera image to experience visual shapes or environments via listening [9]. Blindminton has been mentioned before as supportive applications in the same line.

Ambient Information Displays promise to augment natural environments by data-driven stimuli that allow us to experience data of interest in a subtle way [15]. Sonifications, structured as an unobtrusive backgrounding sound stream may serve this purpose, e.g. to be in touch with activity in RSS newsfeeds of interest via the purl of a stream or fountain. Likewise, administrators may profit from an ambient soundscape that correspond to network traffic. In this direction, sound may serve to enhance the sense of presence of another not-physically present person or entity. E.g. sonification can help to better couple rooms – you might hear sounds such as slamming the door as it would be if the room would be next door.

## 3.1 Sonic Overloading for Sonic Interaction Design

As a largely neglected and very promising idea, I'd like to promote the concept of sonic overloading: Let us define *Sonic overloading* as the process to augment physical interactions in the world which generate a sound anyway by sonifications that convey relevant information about some underlying data. This idea comes already into application when Model-Based Sonification is applied and physical interfaces are shaken. The Pebble Box [10] already demonstrated a technique to connect rendered sound to physical interactions (e.g. manual interaction in a pebble box was connected to fluid sounds), yet they did not couple (data-driven) sonifications to these interactions. *Sonic Overloading* is a promising approach to better interweave sonifications and real-world sounds, and we currently investigate its applications in the context of our Ambient Intelligence Lab.

# 4 SHARING MEDIA AND SCIENTIFIC CULTURE

If sonification has so many profitable applications as reported, why is it yet so rarely used in products and technological systems? On the one hand, sonification is already used in some existing products, yet not always called so. For instance, the Geiger counter is an auditory display for radioactivity. The metronome is a sonification for rhythm; the alarm clock is nothing but sonification via Earcons to draw the sleeper's attention. There are more informative sonifications in mobile devices, ranging from caller-specific ringtones to structured to data-driven interaction sounds in computer games. There are already commercial systems for visually impaired users that use sonification [9]. The reason why sonification has been developed and used relatively late is, to my opinion, due to two different reasons: (a) the dominating visual scientific culture (b) the technical premises for sonification.

Visual information has the largest bandwidth among our senses and is the dominating sense for our everyday behaviour. In turn our scientific concepts are largely coupled to spatial concepts (e.g. we talk about geometry, vector spaces, etc.) and thereby we are trapped in visual metaphors, which we created to organize of knowledge and scientific theories. This went probably hand in hand with the available media to *document* or *communicate* ideas, which has been paper and pencil or other 2D graphical/visual forms. It is interesting to speculate how our scientific ideas would have evolved if Euclid would have postulated axioms in the auditory domain instead of geometry. The development of techniques to reproduce and distribute visual media forewent the development of corresponding audio techniques by centuries and it is no wonder that sonification is in a relatively young stage compared to visualization which has had centuries of development of scientific culture from Gutenberg to zillions of graphics in newspaper to scientific journals.

Actually, the technological ability to create accurate data-driven sonifications is perhaps less than 30 years old, and publically available since about 15 years with the massive spreading of personal computers in households. It does not only demand the technical premises for sonification to establish but also the convincing of people that are used to certain culturally established practices for the inspection of data. This altogether gives sonification a difficult starting position, despite the fact that listening is indeed superior to seeing in several aspects (such as spectral and temporal resolution, or that sound can to be perceived from any angle).

The argument that techniques to generate and share data representations are the essential prerequisite for the establishment of new media to investigate data leads to the speculation what might be the next step in the evolution of techniques to grasp complex data, particularly in light of the development of information society and the evolving broadband society. Obviously we already have enough bandwidth to access sound and even video with sound, and thereby now the basis is laid for sonification to be used more widely.

Taking into account the principles observed in real-world physical interaction (see Sec. 1), the *directness of interaction* and *multi-modality* point towards the development of more interactive ways to explore data. Today we can share sound and video files, but the capabilities to share interactions are very limited. I would expect another development step if the technological basis is laid for users to better share *joint interactions* via the Internet. This means both to share the algorithms and techniques to directly experience complex data, and to compare the experiential process within the interaction loop directly. For that, users need to be able to have access to interaction devices far beyond the currently existing computer mouse, they need low-latency audio-visual connections and need to cooperatively connect to jointly explore a data set from different locations on the planet. With the situation today, where the first steps are taken towards shared reality and distributed musical performances, where more and more sensor-equipped interaction devices are available such as Nintendo Wii [16] and accelerometers in mobile phones, where web 2.0 technologies enable more mediated interactions, it looks like that the first steps in this direction are currently taken. Before interactive sonification establishes more widely, however, it demands standards, not only in how to couple sound to interactions but also on how to share, use and evaluate their use.

## 5 CONCLUSION

This paper gave some motivation for using sound in human-computer interaction, and particularly for alternative exploratory data analysis techniques. Everyday interactions served as example to demonstrate how we use everyday sound and how neglected sound is in interactions with technical devices. Sonification and Sonic Interaction Design can fill the gap, and *Model-Based Sonification* is a suitable approach since it puts interaction into the fore for closing the interaction loop. The applications of sonification have been reviewed according to the closure point of the loop, and the idea of *Sonic Overloading* has been promoted as a principle to couple informative feedback to already-existing interactions. The ever-increasing complexity of networks and information space in the information society can profit from these techniques and even define new application fields. In turn, another perspective on the relation between the broadband society and sonification has been taken, by relating technological prerequisites and use/acceptance of scientific techniques. This discussion indicated that they go hand in hand, and if we forecast from actual technological developments, the anticipated next step is the sharing of direct multi-modal interactions with complex data. Our ongoing research activities in sonification and Cognitive Interaction Technology will contribute to shape interaction techniques and exploration methods in this area.

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