SONIFICATION AS AN INTERDISCIPLINARY WORKING PROCESS

A. de Campo[1], C. Dayé [2], C. Frauenberger[3], K. Vogt[4], A. Wallisch[5], G. Eckel[1]

[1]University of Music and Dramatic Arts Graz, Institute of Electronic Music and Acoustics
[2]University of Graz, Institute of Sociology
[3]Graz University of Technology, Signal Processing and Speech Communication Laboratory
[4]University of Graz, Institute of Physics, Division of Theoretical Physics
[5]Medical University Graz, Neurological Clinic

decampo@iem.at, ch.daye@uni-graz.at, frauenberger@iem.at,
katharina.vogt@uni-graz.at, annette.wallisch@utanet.at, eckel@iem.at

ABSTRACT

This paper describes the progress of an interdisciplinary project that aims to develop a general sonification software environment. The approach taken is interdisciplinary; a number of target sciences form an integral part of the work process. Within the first year, we have made good progress in some areas, while others have turned out to be more difficult. We describe the project background, the work done so far in the target sciences, the general software framework, and what we have learned about the interdisciplinary work process.

1. INTRODUCTION

Perceptualization of scientific data by visualization has been extremely successful. It is by now completely established scientific practice, and a wide variety of visualization tools exist for a wide range of applications. Given the different set of perceptual strengths of audition compared to vision, sonification has been considered to have a similar potential as an exploratory tool for scientists that is complementary to visualization and statistics.

One strategy to realize more of this potential of sonification is to create a general software environment that allows for fast development of sonification designs for a wide range of scientific applications, a design process in close interaction with scientific users, and simple exchange of fully functional designs. This is the central idea of our project, as described in detail in [1].

There are a number of interesting software packages for sonification and auditory display ([2, 3, 4], and others), all of which make different choices about which data formats can be used, what sonification models are implicitly assumed, and what kinds of interactions are possible. We found that none of them would be adaptable for the broad parallel approach we had in mind, so we chose to build on a platform that is a full-featured modern programming language and a very efficient realtime performance system for music and audio processing, SuperCollider3 [5].

2. APPROACH

Sonification as a scientific field involves a variety of disciplines, which is reflected in this project by including a very diverse group of target scientists: Neurology, Theoretical Physics, Sociology, and Signal Processing and Speech Communication.

In each of these fields, we started by building basic sonification designs to begin the discussion process. The key question here has turned out to be learning how to work in such a highly interdisciplinary group, how to build bridges for common understanding, and to develop a common language for collaboration.

Currently, we focus on building sonification designs that demonstrate the usefulness of sonification by showing some substantial, practical benefit for the respective scientific field. Identifying good research questions at this intermediate level of complexity is not trivial, but being able to come up with compelling examples to reach this audience is very important

Finally, generalizing all the approaches that worked well in one context into a single software framework that includes all the software infrastructure, thus making them re-usable for a wide range of applications, should result in a useful contribution to the sonification community. The diversity of the research group and their problem domains should force us toward very flexible and re-usable solutions. By making our collection of implemented sonification designs accessible, we hope to capture much of what we have (and will have) learned, and to make it easily accessible.

3. TARGET SCIENCES

3.1. Neurology

3.1.1. Background

At the Department of Epileptology and Neurophysiological Monitoring, sonification of EEG data is intended to enhance multimedia diagnostics of epilepsy. Currently, the use of video in addition to standard visual EEG data presentation is already one aspect of this multidimensionality of the software used, *alphatrace*. This kind of video monitoring is useful to observe the correlation between clinical fits, the brain waves in the EEG and the behaviour of the patient, in order to get information about the source and the detailed location of epilepsy. Sonification potentially offers new ways to improve both diagnostics and monitoring functions.

3.1.2. Data

We started with normal data (i.e. non-pathological EEG records) in order to have a reference. Traditionally, the electric oscillations recorded in EEG are classified by the frequencies of the rhythms that are dominant in specific brain areas: Beta from 14 - 30 Hz, Alpha from 8 - 13 Hz, Theta from 4 - 7Hz, and Delta from 0.5 - 3 Hz. These normal recordings contain a number of common reactions like closing the eyes - the so called alpha-blockade - and artefacts caused by moving the head, swallowing, chewing or raising the eyebrows.

Currently, we work with pathological EEGs, i.e. epileptic fits or simple epileptic potentials. We concentrate on patients with temporal epilepsy, who show a clear focus where their fits occur.

3.1.3. Sonification Models

A number of different sonification approaches have been implemented so far for experimentation, which are geared toward different possible applications:

Straightforward audification with variable playback speed, which is useful mostly for data screening at higher speed. It allows bringing the low frequency range of EEG data into the audible range leaving the time signal intact. It is also useful for realtime monitoring by allowing time-lapse playback of the most recent e.g. 60 seconds within 5 seconds.

Granular time-stretching / pitch-shifting is useful for data exploration at real-time speed, which allow raising the frequency range (with different artifacts for different variants) while keeping the time scale independent. Modulation synthesis employs the EEG signal at realtime speed to modulate an ensemble of carrier signals: one option is to modulate the frequencies of an array of sines for the (typically 5) channels, which keeps polarity information (i.e. whether spikes in a channel are positive or negative) intact.

Mixed approaches use e.g. a "scrubbing" variant of pitch-shifting multiplied by the EEG signals' amplitude envelope, which helps to keep the sense of rhythmic activity intact (because pitch shifting pulls together longer signal segments, it tends to smooth out transient detail).

The most complex and sensitive model so far separates the EEG signals into multiple bands, and employs both the bandpass signals and their extracted envelopes to modulate formant-like carriers; it is intended to highlight dominant frequency band activity while still representing a high level of continuous signal detail.

3.1.4. Aims

Our immediate next aims at this point in the project are:

a) Designing a suitable realtime monitoring sonification, and integrating it with the EEG recording/database software used, alphatrace.

b) Developing a sonification model which can be used investigate prediction of epileptic fits by screening large amounts of existing data, and retrospective patient-specific analysis.

c) Designing practical auditory screening tools for recordings of so called absences (short epileptic fits that occur in children). These recordings are made with special portable devices, are typically from 24 hours to several days long, and thus very tiring to inspect visually.

3.2. Theoretical Physics

3.2.1. Background

In physics, sonification has already proven useful in some cases. For instance, Pereverzev et al. [6] have detected quantum oscillations in superfluid ^{3}He only by audifying experimental data, which were masked visually. Hermann and Ritter developed an interesting tool for investigating complex data sets with model-based sonification [7, 8]. The collaboration with a physics group in Vienna on aspects of lattice quantum chromodynamics (QCD) used sonification for investigating phase transitions in the Dirac spectrum [9].

3.2.2. Current Research

Within our project we are exploring the possibilities of sonification with regard to a better understanding of complex data sets of various systems in particle physics. Our studies aim both at a didactic and a research outcome.

We started out from the sonification of baryon mass spectra as reported in [5]. Baryons, such as the proton and the neutron, are understood as bound states of three quarks and may be described within relativistic constituent quark models (CQMs). One obtains their quantum-mechanical spectra containing information on the particle characteristics such as energies (masses), flavor contents, total angular momenta, and spatial parities. In order to make these qualities perceptible by sound we have developed a Quantum Browser. It has turned out as a practical tool to discriminate between the excitation spectra as generated by CQMs relying on different dynamical ingredients. By listening to sound sequences one can then compare, e.g., the level orderings characteristic of the assumed quark-quark interaction. The spectra of energy levels consist of about ten tones. Thus they are highly complex, and it was found that they are better studied in changes in the melody of successive energy levels.

In a second attempt we designed a Level Splitter allowing the study of splittings of the energy levels due to a variable strength of the hyperfine interaction inherent in the CQMs. The hyperfine interaction is needed in order to describe the binding of three quarks more realistically, i.e. in accordance with experiment. If it is absent, certain quantum states are degenerate (meaning that the corresponding energy levels coincide). In a demonstration example, we chose the excitation levels of two different particles (the Neutron n-1/2+ and the Delta d3/2+), calculated within the same CQM, the Goldstone-Boson Exchange model (gbe) [10]. These two particles are degenerate when there is no hyperfine interaction present. Mapped into sound this means that one hears a chord of three tones for the ground states and the first two excitation levels, which are the same for both particles. Here, auditory perception is more challenged than in the Quantum Browser, as complex spectra are being played as continuous chords, and the hyperfine interaction may be turned up gradually (to 100 percent). Thereby, the energy levels are split, and one hears a complex chord of six tones. The particles can be distinguished now, as they are in nature. With the Level Splitter, the dynamical ingredients leading to these energy splittings may be studied in detail, and likewise the quantitative differences in distinct CQMs.

3.2.3. Outlook

In our further research work we will concentrate on higher dimensional problems. A very intriguing case is the sonification of lattice QCD, the modelling of QCD on a discrete, four-dimensional lattice, where every lattice point is characterized by a multiplicity of quantities. In this case visualisation is not feasible, and exploration by auditory means may lead to substantial progress in the field.

3.3. Sociology

3.3.1. Background

Social (or sociological) data generally show the characteristics that make them promising for sonification: They are multi-dimensional, and they usually depict complex relations and interdependencies [11]. We consider the application of sonification to data depicting historical (or geographical) sequences as the most promising area within the social sciences. The fact that sound is inherently time-bound is an advantage here, because sequential information can be conveyed very directly by mapping the sequences on the implicit time axis of the sonification.

In fact, social researchers are very often interested in events or actions in their temporal context. The importance of developmental questions is even growing due to the globalized notion of social change. Sequence analysis, the field methodologically concerned with these kinds of questions, assembles methodologies that are by now rather established, like event history analysis, and appropriate techniques to model causal relations over time ([12, 13, 14, 15]).

Like most methods of quantitative (multivariate) data analysis, sequence analysis methods need to be based on an exploratory phase. The quality of the analysis process as a whole essentially depends on the outcome of this exploratory phase. As the amount of social data is continuously increasing, effective exploratory methods are needed to screen these data. On higher aggregation levels (global or UN member states), social data have both a time (e. g. year) and a space dimension (e. g. nation) and thus can be understood

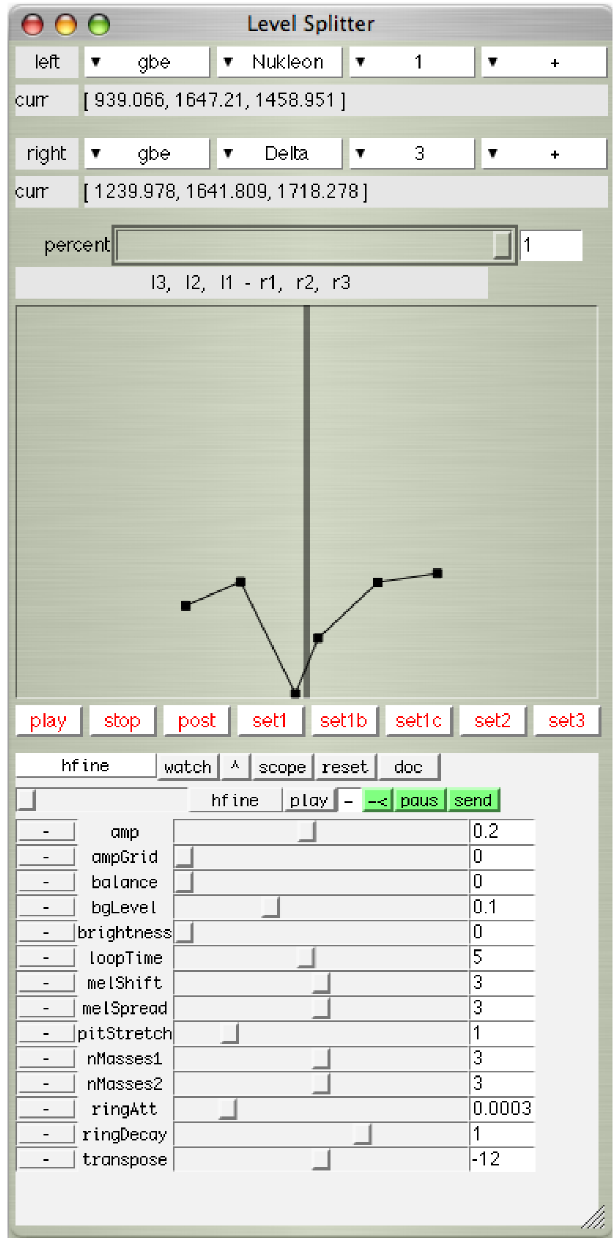

Figure 1: *The Level Splitter user interface*

both as time and geographical sequences. The use of sonification to explore data of social sequences is the current focus of the sociological part within our project.

3.3.2. Sonification Design

With the sonification design presented here, we are able to explore geographical sequences. It represents election results from the 2005 Styrian provincial parliament election. Styria is one of the nine federal states in Austria. It consists of 542 communities in 17 districts, and about 1 190 000 people live here. In autumn 2005, more than 700 000 of the Styrians elected their political representatives. Beside the fact that the result of this election was in some sense remarkable - the ruling conservative party ÖVP (Österreichische Volkspartei: Austrian People's Party) for the first time since 1945 has been defeated by the left socialdemocratic party SPÖ (Sozialdemokratische Partei Österreichs: Social-democratic Party of Austria) - our interest focused on the attempt to display social data 1) in their geographical distribution and 2) at a higher spatial resolution than usual. Whereas usual displays of social data focus on the level of the 17 districts, we wanted to design a sonification that displays spatial distances and similarities in the election results among neighboring communities. The technique we chose here was adapted from a demonstration implementation by Till Bovermann, MBS_Sonogram (available at [16]), initially developed at the University of Bielefeld, Germany [7, 8].

The mind model is that of a journey through Styria. A journey can be defined as the transformation of a spatial distribution into a time distribution. A traveler who starts at community A passes first the neighbouring communities, and the longer she is on the way the more space is between her and community A. Hence, in this sonification, the spatial distances between communities are mapped onto the time axis.

The communities are displayed in a two-dimensional window on a computer screen (see figure 2). For each community, the coordinates of the communitys administrative offices were determined and used as the geographical reference point of the respective community. The distances as well as the angles within our data thus correspond with the real distances and angles between the communities administrative offices.

This sonification is interactive in the sense that it can be played like a musical instrument. Clicking the mouse anywhere in the window initiates a circular wave that spreads in two-dimensional space. The propagation of this wave is shown on the window by a red circle. When reaching a data point, this point begins to sound in a way that reflects its data properties. In our case, these data properties are the election results within each community. The researcher can select particular parties to listen to, and the percentage the respective party achieved at the election is represented by the tone's pitch.

Further, the researcher can choose a direction in which to look. In figure 2, this direction is North, indicated by the line within the circular wave. The line begins at the point where the researcher has initiated the wave. Data points along this line are heard from the front, others are panned to appropriate directions. While this sonification was designed for a ring of twelve speakers surrounding the listener, it can be used with more standard equipment as well: For a stereo speaker setting (or headphones), one changes to a ring of four, and listens to the front two channels. Then, data points along the main axis are heard from the center, those on the left (or right) are panned accordingly, 90 degrees being all the way left (or right). The points at more than 90 degrees off axis progressively fade out, and those above 135 degrees off axis are silent.

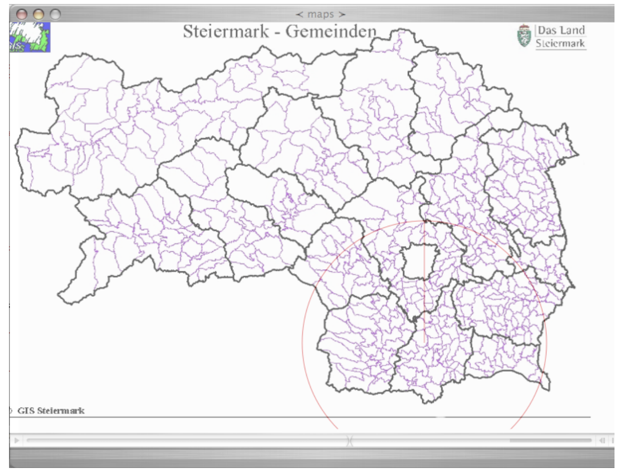

Figure 2: *The interaction window for the sonification design*

3.3.3. Conclusions

This sonification is an excellent tool for outlier analysis. It works rather fast at a low level of aggregation (communities), and outliers are easily identified by tones that are higher than their surroundings. These are local outliers: in an area that has a local average of say 30% for one party, you can hear a 40% result 'sticking out'; when analysing the entire dataset statistically, this may not show up as an outlier.

Note that this sonification design is not restricted to election data: Other social indicators that are assessed at the community level (unemployment rates, labor force participation rate of women, and others) will be included. To represent them in conjunction with e.g. election results promotes the investigation of local dependencies that might be hidden by higher aggregation levels or by the mathematical operations of correlation coefficients.

Finally, this sonification design is of course not restricted to the geographical borders of Styria.It can be used as exploratory tool enabling researchers to quickly scan social data in their geographical distribution, at different aggregation levels. The adaptation to different geographical scales, i.e. European and worldwide levels is planned, with nations as the aggregation entity.

3.4. Signal Processing and Speech Communication

Data in the field of non-linear signal processing and speech communication is often highly complex and demands sophisticated methods for analysis and exploration. The most commonly used techniques are, as in most other scientific fields, statistics and visualisation. However, there are problem fields in signal processing and speech communication in which these traditional methods fall short due to certain limitations, and alternative ways to access the data are necessary. This is, for example, the case when data spans over multiple dimensions or temporal features of the data are the most important. In SonEnvir we focus on two different applications of sonification: The qualitative analysis of time-series data produced by non-linear processes, and the simulation of ultra-wide-band wave propagation in reflective environments.

3.4.1. Time-series data

Time-series data may be obtained from any sort of process that is most commonly unknown and defined only by the relation of input and output. Signal processing often aims at modelling these processes in order to compensate for their effects, but therefore good knowledge about the properties of such processes is a prerequisite. Traditional methodology would employ highly sophisticated statistics to describe processes and classify their properties. This, however, could be a very complex and time-consuming undertaking and does not always result in reliable models. The aim for sonification is therefore to be able to classify properties of processes through their output without deploying statistical methods.

As a starting point we took a closer look at stochastic processes that are well understood. The logistic equation defined by equation 1 is a process that produces time-series data with either constant values, periodic changes or may fall into complete chaos depending on the input variable. It is a model for the development of any populations given a certain growth rate.

$$x_{n+1} = rx_n(1 - x_n) \tag{1}$$

A direct audification of the time-series obtained from this process allowed us to study the temporal features of auditory perception. We were particularly interested in the range of r in which the process would turn from being periodic into chaos. Although the value for this transition is known ($r \approx 3.54$) in this case, it would be hard to determine this value from visualisation. A typical visual representation would show a very chaotic signal and revealing periodic elements in a chart is very difficult. Audification, however, seems to provide this feature implicitly: Playing back data at various speeds, makes periodicities in the data perceivable instantly.

Subsequently, we plan on investigating whether properties determined by higher order statistics (HOS) can be heard in sonified data. Besides the spectral properties of time-series data, the distribution of amplitudes is as well crucial and often described through HOS. While the first two cumulants are trivial for audification (mean and power), it remains unclear what impact cumulants of higher order have on the perceived sound. In a series of perception tests we aim at finding out about sound properties that may reflect these properties and might provide robust and instantaneous feedback as we saw in the example above.

3.4.2. Ultra-Wide-Band Communication

Electromagnetic wave propagation and the propagation of sound waves share many principles and the theoretical foundations are similar. This suggests that the propagation of electromagnetic waves may be simulated by using sound making simulations very easy to realise and accessible through a built-in measuring device, the ear. Considering the ratio of the propagation speed of sound and electromagnetic waves which is approximately $1:10^6$, GHz radio waves would be transposed to kHz sound waves which are audible. This way, multi-path propagation and interference patterns in reflective environments can easily be simulated using loudspeakers instead of radio antennas.

There is, however, an important limitation to this: the properties of materials reflecting the waves do not change in this transposition. Absorption factors for materials in the simulation have to be adapted to mimic the behaviour of the reflection of electromagnetic waves in the real world. We approach this problem by using virtual audio environments for simulations where we have full control over the properties of any obstacle or wall. As part of SonEnvir we developed an extension to SuperCollider3 called AmbIEM that allows for creating virtual audio environments with multiple sound sources. It also supports the input of any tracking data so that the listener could explore the virtual environment while moving in a tracked, real-world space.

Using such virtual environments we intend to simulate the propagation of narrow-band, wide-band and ultra-wide-band signals in different environments and allow researchers to investigate the interference patterns interactively. This way we can demonstrate which effects multi-path propagation has on different techniques and prove that ultra-wide-band signals are more robust in such environments than others.

4. THE FRAMEWORK

The main goal of SonEnvir is the development of a sonification framework that will allow for the creation of meaningful and effective sonifications more easily. Such a sonification environment supports designers of sonifications by providing a consistent and re-usable approach and extensive tool support. It combines all important aspects that need to be considered: data representation, interaction, mapping and rendering.

In order to develop a generic framework that provides the desired functionality, we created sonification prototypes in each of our four participating target sciences. Extracting common tasks and recurring solutions allowed us to design the framework as generic and flexible as possible. We aimed at refining our designs in an iterative process through instantly using them in the next prototypes in order to evaluate their usefulness and effectiveness in the solution.

The subsequent sections describe the overall structure of the proposed framework and the design and implementation of the data representation module.

4.1. Structure

The SonEnvir framework is the implementation of a generic sonification model that consists of four parts:

Data Model The data model unifies the view of data for the use in the framework and deals with the diversity of types of data that can be used for sonification.

User-Interaction model Deals with all aspects of interactive model for exploration and analysis of data.

Synthesis model The mapping onto properties of sound or the creation of more complex structures of sound by a sonification model.

Rendering model This model takes care of the audio rendering of the designed sonification for different requirements and playback environments

All those models taken together allow for designing sonifications in a flexible way. So far, only the data model is specified in greater detail and implemented.

4.2. The Data Model

The aim of the data model is to provide a unified representation of different types of sonification data in the framework. This demands a highly flexible and abstract model as data may have very different features. The data model also provides functionality for input/output for the original form the data is available and includes various statistical functions for analysis.

All models are object-orientated in design and classes and interrelations are described using UML (Unified Modelling Language) charts. In order to avoid conflicts with other definitions on any target platform, all classes in the SonEnvir framework have the prefix ”SE”. Figure 3 illustrates the design of the data model.

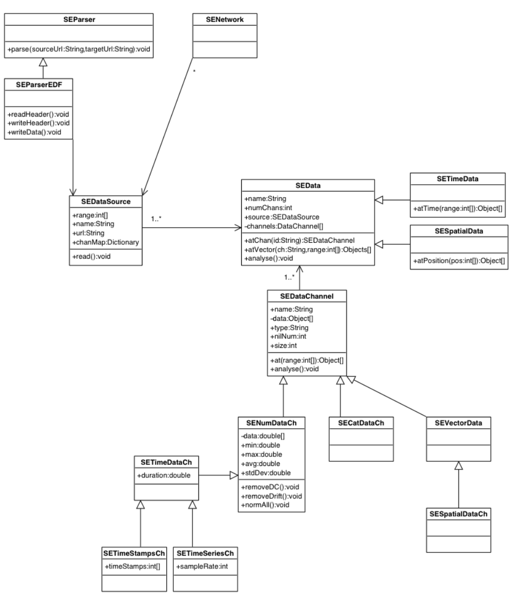

Figure 3: *The UML diagram of the data model*

Central to the design of the data model is the **SEData** class. It is the highest possible abstraction of any kind of dataset for a sonification. Besides providing properties for the name and the data source, the actual data is organised in channels. SEData refers to **SEDataChannel** which is the base class for all different types of data channels and represents a single dimension in the dataset. Data channels can be numerical data, but also any sort of nominal data with the only restriction that they are organised as a sequence.

SENumDataCh specifies that the data is a row of numbers and therefore provides a basic set of numerical properties of a set of numbers. Besides the usual minimum, maximum, mean, and standard deviation values, it also implements functions that proved to be useful in sonifications for removing an offset or a drift and normalising the numbers.

Another important subclass of numeric data channel is covering all time-based data channels. These basically refer to the two types: time series (**SETimeSeriesCh**) providing a sample rate and data with time stamps (**SETimeStampsCh**). Although basically a numeric data channel as well, we decided to introduce another basic type for vector based data with a subclass for 3D spatial data. Any of the data channel types mentioned above may be combined in order to form a dataset described through SEData. For convenience, there are two predefined classes derived from SEData that cover the most frequently used combinations of data channels: **SETimeData** and **SESpatialData**.

Every SEData instance is associated with a **SEDataSource**. This class abstracts the access to the raw data material. It takes care that the needed ranges of big datasets are available when needed and uses different parsers in order to read different file formats. In future versions this should also include network resources and realtime data. Each SEDataSource also provides information about the type of each data series that is contained in the raw data. This might be available from headers of some data formats or it might be necessary to set them explicitly to be able for SEData to create the appropriate SEDataChannels.

4.3. Implementation

The data model is implemented in SuperCollider3 [5], an object-orientated language similar to Smalltalk. SuperCollider3 is a highly sophisticated system for real-time sound synthesis consisting of a server application acting as a OSC (Open Sound Control) controlled synthesiser and a language implementation that would allow for high-level, object-orientated programming.

The framework is provided as a class library that once brought into place is compiled at startup of SuperCollider3. The following listing illustrates the use of the SEData objects in SuperCollider3:

LISTING

```
{(
    // read data file
~vectors = FileReader.readInterpret(
    "~/data/C179_T_s.dat",
    true, true
);
    / data channel names
~chanNames = ['temperature', 'solvent',
    'specificHeat', 'marker'];

    // make SEData object
```

```
~phaseData = SEData.fromVect(
    'phaseData',
    ~chanNames,
    ~vectors,
    SENumDataChan
);
// statistics
~phaseData.analyse;
~phaseData.means.postln;
~phaseData.stdDevs.postln;
)}
```

5. LESSONS LEARNED

The approach to develop a generic sonification framework with such a multi-disciplinary group is indeed challenging. Our concept was confirmed that working in many different scientific fields would give us the diversity we needed to determine which problems, solutions and methods were universal and therefore should be compiled into the framework. While we still find that this is the best way toward achieving our goals, the composition of such a research group also exposes problems in such interdisciplinary research settings.

First of all, the participating target scientists experience scepticism towards sonification within their communities. This might be partly because the idea of using sound for analysis and exploration is still unconventional and uncommon in most of the fields, but also because there are still very few convincing examples of sonifications which show a major improvement over existing methods. This scepticism is justified, and trying to find or create convincing sonifications has become a major goal in our project.

Even a convincing sonification encounters problems when it is to be disseminated within a specific target science. Considering publications in journals or books, the main problem is how to describe sounds by means of language to persons who did not hear these sounds. This applies particularly to scientific areas that have no tradition of talking about sound or wavelike phenomena, like sociology: here, fundamental terms from acoustics and physics cannot be assumed to be familiar to the reader. Though Information & Communication Technologies and on-line journals could overcome these restrictions by offering selected sound files to the reader, it is a fact that paper is still the most important information carrier. At conferences or workshops where sonifications could be demonstrated directly to the audience, the technical facilities (amplifier, speakers) most frequently are insufficient. Consequently, they do not allow for a serious demonstration in a way that invites an audience to listen carefully.

A related problem is to gain recognition for sonification as a science in itself. This is important for raising funds for sonification research and convince funding bodies and experts in peer-reviewing processes of the necessity of finding alternative methods for data analysis and exploration.

Working in a interdisciplinary research group also implies that there is little overlap between different researchers' expertise. This means that such a group must learn a common language in order to facilitate communication: Sonification experts must learn about the problem domain of the target scientists while target scientists must be able to articulate needs and valuable feedback on the developed solutions. We approached this problem by organising a SIG (special interest group) sonification with regular meetings and exchanging introductory literature and workshops on specific fields of interest, like the history of electronic music.

Since first submission of this paper, we have organized an interdisciplinary workshop called 'Science By Ear', for which we invited 8 international experts in sonification and 14 external target scientists to work with the SonEnvir team on a collection of different problem datasets. This workshop has turned out to be a wonderful learning experience, and we got very positive feedback from most participants. It brought many of the issues we encountered in daily work into sharper focus; we are currently documenting the results of the work sessions, and analyzing all the audio and video recordings for a deeper understanding of the interdisciplinary work process in these sessions. This analysis will be material for later publications; much of the work sessions material will be made accessible online on the project website.

6. CONCLUSIONS

This project has turned out to be rather complex, and has taken a number of unexpected turns. Nevertheless, we find the overall approach to be working well, and we hope that our experiences contribute to a better understanding of the interdisciplinary work process involved in sonification.

7. REFERENCES

[1] A. de Campo, C. Frauenberger, and R. Höldrich, "Designing a Generalized Sonification Environment," in *Proceedings of the ICAD 2004, Sydney*, 2004.

[2] O. Ben-Tal, J. Berger, B. Cook, M. Daniels, G. Scavone, and P. Cook, "SONART: The Sonification Application Research Toolbox," in *Proc. ICAD, Kyoto, Japan*, 2002.

[3] B. Walker and J.T. Cothran, "Sonification Sandbox: A Graphical Toolkit for Auditory Graphs," in *Proceedings of ICAD 2003, Boston*, 2003.

[4] S. Pauletto and A. Hunt, "A Toolkit for Interactive Sonification," in *Proceedings of ICAD 2004, Sydney*, 2004.

[5] "SuperCollider3," `http://supercollider.sourceforge.net`.

[6] S. V. Pereverzev, A. Loshak, S. Backhaus, J.C. Davies, and R. E. Packard, "Quantum Oscillations between two weakly coupled reservoirs of superfluid ^{3}He," *Nature*, vol. 388, pp. 449–451, 1997.

[7] Th. Hermann and H. Ritter, "Listen to your Data: Model-Based Sonification for Data Analysis," in *Advances in intelligent computing and multimedia systems*, Baden-Baden, Germany, 1999, pp. 189–194, Int. Inst. for Advanced Studies in System research and cybernetics.

[8] Th. Hermann, *Sonification for Exploratory Data Analysis*, Ph.D. thesis, Bielefeld University, Bielefeld, Germany, Feb 2002.

[9] A. de Campo, N. Hörmann, H. Markum, W. Plessas, and B. Sengl, "Sonification of Lattice Observables Across Phase Transitions," in *International Workshop on Xtreme QCD, Swansea*, 2005.

[10] L.Ya. Glozman, W. Plessas, K. Varga, and R.F. Wagenbrunn, "Unified description of light- and strange-baryon spectra," *Phys. Rev D 58, 094030*, 1998.

[11] A. de Campo and M. Egger de Campo, "Sonification of Social Data," in *Proceedings of the 1999 International Computer Music Conference (ICMC) Beijing*, 1999.

[12] A. Abbott, "A Primer on Sequence Methods," *Organization Science*, vol. 1, no. 4, pp. 375–392, Sept. 1990.

[13] A. Abbott, "Sequence Analysis: New Methods for Old Ideas," *Annual Review of Sociology*, vol. 21, pp. 93–113, 1995.

[14] H.-P. Blossfeld, A. Hamerle, and K. U. Mayer, *Ereignisanalyse. Statistische Theorie und Anwendung in den Wirtschafts- und Sozialwissenschaften*, Campus, Frankfurt, 1986.

[15] H.-P. Blossfeld and G. Rohwer, *Techniques of event history modeling. New approaches to causal analysis.*, Lawrence Erlbaum Associates, Mahwah (N. J.), 1995.

[16] Till Bovermann, "MBS-Sonogram," `http://www.techfak.uni-bielefeld.de/~tboverma/sc/`, 2005.