Sounds sequential: sonification in the social sciences

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This article discusses the use of sound for auditory information display, and in particular its application for exploration of scientific data, known as sonification. Sonification can be defined as the use of sound to display data of scientific interest in order to investigate structures, trends or patterns in the data. Background is provided from several perspectives: the use of the senses in the history of science, the strengths of human hearing, the recent technological availability of auditory interfaces, the development of sonification itself, and differentiation of sonification from musical practices. In Western science, as in Western culture, the eye has become the predominant organ of sense; using the ear consciously in research thus implicitly questions the implications of the eye's predominance. As practical examples, two applications of sonification to data-sets from the social sciences are discussed in detail. We argue that the most promising areas of application of sonification within the social sciences are in the exploration of sequential data. Our two examples both concern sets of sequential data, one temporal, the other spatial (geographical). Discussion of these examples is followed by consideration of the practical and cultural implications of working with sonification. We thus hope to further the use of sonification in the social sciences, not as an alternative to visualisation or statistical approaches, but as a complementary tool of data analysis and exploration.

Presenting data or information to human beings must necessarily rely on some mode of perceptualisation: to be perceived by the human senses, data or information must be rendered in suitable form. While visual rendering (visualisation) has become an everyday affair, the representation of data or information by sound remains much less common. Nonetheless, research concerned with auditory interfaces and with related issues of psychoacoustics and design is a rapidly expanding field in the realm of information and communication technologies (ICT). The main concern in this emerging field is to investigate ways of conveying information in the form of sound generated by for example a personal computer. Because auditory interfaces offer alternative channels of communication, the first beneficiaries of these research and development activities have been people with vision or speech impairments. When such applications are designed in a satisfactory and user-friendly manner, the quality of communication with the environment and, consequently, the quality of life for such individuals can be greatly improved. This line of research, enhancing knowledge on the use of auditory interfaces as assistive technologies, or, more precisely, as technologies for 'augmentative and alternative communication' (AAC), is very active.[1]

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Besides these successful ways of using auditory interface technology to overcome the physical restrictions of specific user groups – an understanding which seems to reflect Ortega y Gasset's notion that one principle of technology is its prosthetic function[2] – a broader area of research has emerged that recognises and investigates the advantages of conveying information by auditory means for a wide variety of purposes. The idea of one subfield of this area, sonification, which has been a growing field since the early 1990s,[3] is to represent (typically numerical) data by non-speech audio events. Most challenging is the use of sonification as a tool for scientific data exploration, enabling researchers to listen to their data to search out inherent structures, trends or patterns.

The question of 'developing a feel' for one's data is a rather intangible one, and so it is hard to measure the success of a user interface – auditory or otherwise – at supporting it; yet it is also central to formulating preliminary hypotheses, and in due course attaining insights, concerning the data at hand. Sonification is, thus, not about alleviating physical restrictions, but about using additional modalities to engage with scientific data: it makes use of the ear in addition to, not as a surrogate for, the visual sense. In so doing it tries to play to the human ear's perceptual strengths. Rather than giving a comprehensive overview of these strengths, we will concentrate here on two in particular, and explain how these can be used in sonification design.

To begin with, the ear can follow highly complex properties of sound, and trace multiple streams of auditory events. Thus, it can be used to explore high-dimensional data structures or to monitor multiple processes simultaneously. An example from music may help clarify this: Imagine listening to a piece of chamber music, say a string quartet. Given some musical training, a listener should be able to discriminate between the different instruments, and to follow their paths through the piece. Translated into more scientific language, this means that the ear is able to filter a complex stream of sound events to identify single constituent streams and trace their development over time. Obviously, in standard (Western) scientific curricula, teaching how to listen analytically is not at all common practice, while teaching how to read graphs is.

Second, regarding the pitch (or frequency) of a sound event, the ear is extremely sensitive to minimal changes, variations and irregularities. Consider what musicians do when tuning their instruments, or how easy it is to detect when a piece of music speeds up or slows down. It has been argued, and we think rightly, that in certain contexts the human ear is a much more accurate 'measuring device' than the human eye.[4]

Thus, using sonification in a targeted and judicious manner can allow for a deeper understanding of complex data-sets. Conveying information by sound is understood not primarily as an assistive technology, but as a scientific technique. The researcher investigates the characteristics of the data under study by listening to their representation as sound events, and by manipulating aspects of this representation interactively. It seems reasonable to hope that sonification may help to overcome, to some extent, inequalities in the access of the visually impaired to scientific fields. But at the core of sonification lies a generally new approach to data; and the integration of sonification into the scientific toolkit would be a heuristic development the consequences of which should not be underestimated.

It is interesting to consider that in a sense, sonification also aims to countervail cultural, as well as physical, restrictions. As we will discuss in more detail below, over the course of the centuries the eye has reached the status of the predominant sense in Western culture, and thus also in Western science. A conscious opening of other ways of rendering data for the human senses at least begins to question the value of this predominance.

Being aware of cultural implications and the philosophical and historical background of the human senses in science and society is, at least in our perspective, crucial to an understanding of the meaning of sonification. The objective of our paper is therefore to investigate some of the cultural aspects of research using the human ear, before going on to introduce two practical examples of sonification realised using data relevant to social scientists. In this way we hope to further the use of sonification in science, not as an alternative, but as a complementary tool of data analysis and exploration. First of all, however, before investigating aspects of the history of the human senses in Western culture, we briefly outline the historical roots of the attempt to capture nature in music with the help of numbers and elementary mathematics.

NATURE, NUMBERS AND MUSIC

In the history of Western science, Pythagoras is traditionally credited with discovering the bridge between nature, numbers and music, by observing that subdividing strings in simple integer proportions (such as 2:3) created 'harmonic', i.e. beautiful-sounding, musical intervals.[5] One expression of these proportions was the Tetraktys, a triangular arrangement of the numbers one to four, symbolising, among other things, the four elements and the harmony of the spheres. The ensuing notion that the deep underlying beauty of Nature is directly related to simple numerical ratios became a central tenet of the philosophical school of Pythagoras, and has influenced many Western mystical and esoteric traditions up to the present. The notion of the harmony of musical sound based on these simple proportions has also deeply informed both Western tuning systems and musical theory for centuries. Many composers have used the same approach to proportions for structuring musical form as was described for architecture by Vitruvius in antiquity and by Leon Battista Alberti in the Renaissance.

The idea of embedding meaningful numbers in music has a long tradition too: many Renaissance composers encoded numbers such as birth-dates, numerological values of the names of their patrons (as a form of dedication), as well as more complex ideas into the overall scheme of notes within individual parts and sections in their scores. This esoteric practice was based on the Talmudic tradition of Gematria, which involves reading words and sentences as numbers and creating relationships of meaning between them. As Gösta Neuwirth has shown, it was a practice that developed to a quite amazing degree of subtlety.[6] However, while the idea of visually representing observed (or measured) natural phenomena has been a major practice of knowledge transfer (or science) down the ages, transformations into music have always been of a poetical nature, not meant to be directly perceived; usually the encoded information is intended to remain hidden, thereby giving aesthetic (and possibly magical) depth to these works of art.

Part of the inspiration for sonification for scientific purposes comes from experimental twentieth-century composers interested in making music that is not generated by the composer's individual aesthetic preferences, but by extra-subjective factors, by 'nature': such composers have been interested in eliminating their own subjectivity to generate music that is not designed by a human mind. For example, John Cage (1912–92) wrote the composition *Atlas Eclipticalis* by superimposing musical staves on an atlas of the stars, and by writing instructions on how to play this atlas as a graphical score. A second approach is exemplified by the works of Iannis Xenakis (1922–2001), who pioneered the idea of expressing current mathematical and philosophical thinking in music (and architecture as well). This typically entailed the algorithmic generation of data to give musical structures that would produce the desired aesthetic effects.[7]

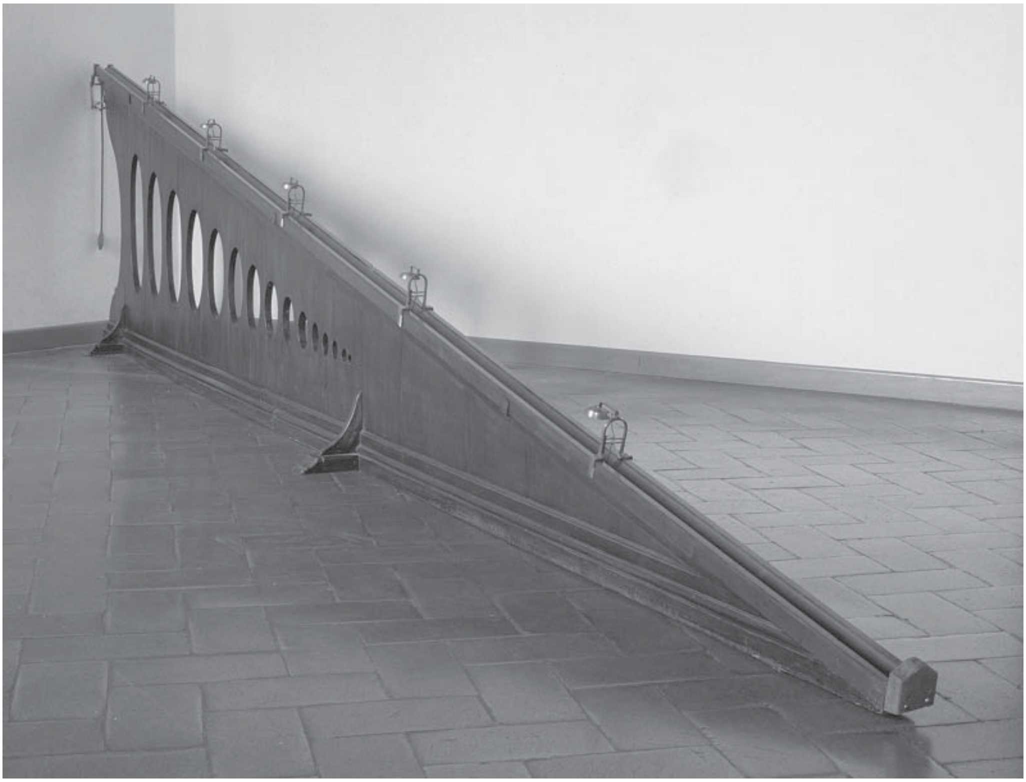
THE EAR AS AN INSTRUMENT OF RESEARCH

Research has, with cultural and historical variations, always relied on the human senses. Over the course of the centuries, however, the eye has become the dominant sense in research, displacing the others. Nowadays, Western culture as a whole is a visual culture: It is a culture of seeing, of reading, a culture of scripture and images.[8]

Science, as a part of this culture, has relied and continues to rely on the perceptual capacities of the eye. Over centuries of philosophical debate, the eye emerged as the only sensory way to the truth, in scientific, theological and social contexts. Light was, from Plato's allegory of the cave up to the Enlightenment, discursively related to truth, knowledge and humanity, both in theological and secular ideologies.[9] Medieval scholars tried to read the 'Book of Nature' in order to decipher the will of God.[10] Some hundreds of years later, 'inscription devices' are at the heart of scientific practice, transforming traces of matter into dots, lines or rows of numbers printed on paper that are seen to depict characteristics of the material itself.[11] This predominance of the written (or printed) in science should be understood as part of a wider process of cultural development, in the course of which the eye emerged as the sense to be trusted when one sets out to find the truth. Though often challenged, the disciplined eye is seen as the only sense able to find its way through the promising but deceptive jungle of life, be it life in society or in nature.[12]

Notwithstanding this dominance, early scientific experiments indicate how as a measuring device the ear has sometimes been used to compensate for a lack of adequate visualisation techniques. Galileo, for instance, conducted the following experiment with a ball falling on an inclined plane: A small heavy ball was released down an inclined plane so that as it rolled it lightly touched catgut strings that were tightened above the plane (Fig. 1). Galileo noticed that every time he repeated the experiment, the sound of the strings had the same rhythm.[13] Interestingly, he never published this methodology, instead reporting having measured time with water clocks; he may well have anticipated scepticism towards an auditory proof. Though early scientific experiments like this sometimes relied on the ear as the 'measuring device', technological developments in Europe gradually furthered the primacy of the eye over the other senses.

It is consistent with the notion of the predominance of the visual that the function of the human eye has for centuries been at the core of a variety of educated discourses. In the field of optics, a (scientific) field that experienced overwhelming scholarly interest from at least the Renaissance, people we would nowadays call physicists, physicians, epistemologists, philosophers, inventors and artists were taking the eye to be the central paradigm of their science. From the thirteenth century up to the publication of Newton's *Opticks* in 1704, all students of optics followed the tenet formulated by Christoph Scheiner, a German Jesuit and astronomer: 'Oculus, hoc est fundamentum opticum.' The eye, in other words, was understood to be the fundamental model for explaining all optical phenomena, including the *camera obscura*.[14]



1 Inclined plane with catgut strings and bells used by Galileo, now in the Istituto e Museo di Storia della Scienza in Florence (© Photo Franca Principe, IMSS, Florence)

It should not of course be overlooked that some practitioners – for example physicians and car mechanics – do indeed rely on the ear to diagnose malfunction, especially when dealing with unobservable areas: probably the most famous example of such auditory diagnosis is the stethoscope (see also below). Furthermore, it would be a serious exaggeration to conceive of sonification as aimed at initiating a wholesale change in our culture. Our basic assumption is rather that the predominance of the human eye has obscured the perceptual capabilities of the other senses. As a consequence, they are hardly ever used in research. We learn how to read graphical displays, and scientists' skills are often highly developed and sophisticated in this area. But we do not learn how to identify structures or patterns in a given sequence of sounds. While graphics exist both in art and in science, non-speech sound is almost exclusively restricted to the sphere of art.

We should also be clear that we do not intend sonification as a replacement for visualisation. The thoughtful use of *all* the human senses, making good use of the perceptual strengths of each, is a more complex, but ultimately more fruitful undertaking. Where possible, it is advisable to combine both modes of perceptual representation, vision and hearing, as has been done in the examples presented below.[15]

For centuries, then, technological developments fostered the predominance of the visual sense, and this predominance gave the direction of further research. Of course we would not wish to claim unilateral causality here: the directions of technological development themselves rely implicitly and explicitly on theoretical, partly metaphysical, considerations, and reinforce our faith in them. However, in the present case, the development of the personal computer can be seen as the basic condition for sonification. To draw a graph by hand was quite possible millennia before the advent of the PC. But to sonify a complex data-set was not within the range of remotely imaginable approaches. This needed the combination of two interdependent historical developments: first, the development of computer technology, its dissemination commercially and into scientific sectors other than those for which it was developed (for instance high-energy physics),[16] and second, the wide availability of PC software applications, particularly via the internet, to facilitate technological implementation. In addition, artists engaged in computer music established laboratories whose output links advances in computers and computing with the tradition of extra-subjective composing. Together with research done in the area of digital audio synthesis and signal processing, such work forms the basis for sonification research.

RESEARCH IN SONIFICATION

The task of sonification research is, thus, to explore new ways of understanding scientific data. Generally speaking, understanding data depends on finding ways of simplifying them structurally, as in statistical analysis, or of making them accessible to our senses, for example as graphs or as images in scientific visualisations. Sonification takes the latter approach: it aims at an understanding of the inherent structures of data-sets by making them audible, in order to let human perception detect patterns in the data. Audio signals represent elements of a data-set, and unknown structures in the respective data-set are mirrored by structures in the related sound events, which may well become perceptible.

Though discussion in the field is still ongoing on how to define sonification, it is widely accepted that it involves the use of non-speech audio to display data.[17] We would argue that at the core of this definition lies the constraint that sonification is concerned with the *data* level, and not with *information*. To clarify: data become information when they are combined, interpreted and organised within some context which thus conveys additional meaning.[18] To say that sonification is concerned primarily with the data level means that the sound events are determined by the data, and the researcher listening to the sounds can then reason about them, interpret them, form hypotheses and thus add context, so that the represented data become informative.[19] In sonification, we listen to data in order to gather information.

Sonification remains practically unknown in the realm of the social sciences. This is despite the strengths of human hearing – for example with respect to temporal patterns, the detection of periodicity, and the ability to follow multiple parallel streams of auditory events simultaneously – being well known. In the natural sciences, however, a significant effort has been made in the past ten to fifteen years to investigate the advantages of sonification, and to explore fields of application. In 1992, on the initiative of Gregory Kramer, a group of researchers founded the International Community for Auditory Display (ICAD), which has evolved as the main international forum for professionals dealing with or interested in sonification and its potential. Since then, ICAD has organised regular meetings and conferences, the proceedings of which are the main literature source in the field. Though there is a great deal of activity, however, sonification still lacks a common methodological structure, an 'applied theory of sonification' to unify sonification research.[20]

While the field of sonification is quite diverse, a kernel of techniques has emerged over the past ten years. The most significant are audification, parameter mapping sonification, and model-based sonification approaches.[21] Audification is the simplest approach. It interprets the given data as acoustical waveforms. This works best for time-series data, where certain observables (e.g. temperature) are measured at regular intervals, and the resulting variation over time (or along some other axis) can meaningfully be interpreted directly in terms of variations in air pressure, i.e. sound. Interesting audification applications deal with seismological data on earthquakes; work has also been done with EEG and stock-market data.[22]

Parameter mapping sonifications take a more symbolic approach. Here, the researcher decides how to represent the variables. The sounds are not directly generated out of the data, as with audification; only certain parameters of the sound event (loudness, pitch, timbre, duration, for example) are determined by characteristics of the data.[23] The first of the sonification examples presented below is a parameter mapping sonification.

Model-based approaches use models that mediate between the data and the resulting sound event. The objective of such models is to communicate the meaning of the data in clearer and more intuitive ways than parameter mappings can. In a way, the data become an instrument, and the user explores the data by playing the instrument. The resulting sonifications often require active interaction with the sonification software, for instance by triggering a 'shockwave', as is the case with the second sonification example described below.[24]

SOCIOLOGICAL DATA: FIELDS OF APPLICATION

Regardless of which particular sonification technique is applied, we find that social (or sociological) data in general show characteristics that make them a promising field for sonification. They are multidimensional, and they usually depict complex relations and interdependencies. This was rightly emphasised in probably the first published results of sonification of social data.[25] This research was continued some years later and led to a systematic introduction to sonification for social scientists.[26] Since January 2005, these efforts have been integrated in a project called 'SonEnvir'.[27]

The SonEnvir project involves a multidisciplinary consortium whose objective is to develop a generic approach to sonification for use in a wide variety of scientific contexts.[28] The approach is being implemented in a sonification software environment available as open source for the two most common operating systems (MacOS and Microsoft Windows). The examples we will present here have been conceived as test cases to help understand both the expectations of the target users and the heuristic value sonification has to offer for their purposes. But where are the potential fields of application for sonification within sociology, or within the social sciences in general? As the examples will indicate, the direction we consider most promising is the application of sonification to data capture of historical or geographical sequences.

Sound is a time-bound phenomenon; it only exists in time, and it takes time to perceive sounds and their interrelations. In short, time is an intrinsic quality of sound that has to be taken into account when using sound for data display. We consider this a key advantage of sonification. We would argue that as a result of its inherent temporal character, sound is an excellent carrier of sequential information. When this time factor is not just accepted as a condition of auditory display, but systematically used in sonifying data, then sequential information can be conveyed by mapping the sequences on the implicit time axis of the sonification. It is for this reason that we see a major field of application of sonification in questions concerned with historical or geographical sequences.

Many research areas within the social sciences are in fact concerned with events or actions in their temporal context. Indeed this branch of social research is currently expanding, perhaps due to the growing importance of developmental questions and questions of social change. Further, the amount of social data is continuously increasing, in both a global sense (consider the widespread use of UN social indicators) and a historical sense (more statistical agencies have gathered more sophisticated and extensive data over a longer period). Sequence analysis, the field methodologically concerned with these kinds of questions, applies well-established methodologies (event history analysis for example) and techniques to model causal relations over time.[29] Without going into detail here, all these analysis techniques, however advanced they may be, rely on a scenario where the researcher already knows where patterns are to be found in a given data-set. Comparable with other methods of data analysis, sequence analysis methods need to be based on an exploratory phase.

PRACTICAL EXAMPLES OF SONIFICATION

Sonification is a very good tool for exploring data-sets that represent sequential information. To illustrate this, we introduce two sonification designs implemented in the SonEnvir project mentioned above. The first is concerned with time sequence data, and the second investigates the use of sonification for displaying geographical sequences.

Sonification of time sequences

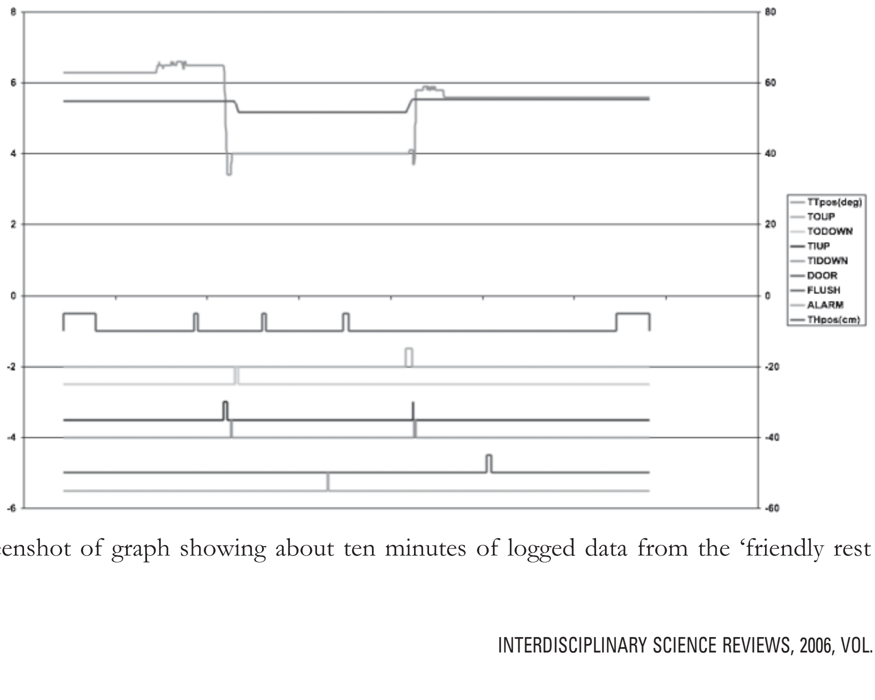
The first source of sequential data sonified within SonEnvir was a project concerned with the development of a toilet system that meets the needs of older people and those with physical disabilities.[30] In the final stage of the project, a prototype was installed at a day centre for patients with multiple sclerosis in Vienna. There, the system was tested in a setting as close to real life as possible. For ethical reasons, direct observation of the user's interaction with the toilet system was impossible. Thus, the sole data source showing the interaction of users with the equipment in this final stage was log files that were continuously produced by a computer mounted near the toilet. This computer logged the status of several sensors on the adjustable toilet prototype: the height and tilt of the toilet seat were registered, as were the status of the six buttons on a remote control (tilt up/down, height up/down, flush, alarm), and other more technical measures.

We decided to work with this project because, from the perspective of the researchers, the log data were hard to deal with. It was our impression that a standard graphical display did not allow for a clear or intuitive representation of time sequences, especially when dealing with a huge number of data files. As the computer logged about two hundred and forty hours in total at a resolution of a tenth of a second, a file containing a single hour's data comprised about thirty-six thousand entries.

The situation the researchers found themselves in when beginning data analysis after this 'real-life' testing phase was that they wanted to relate actions they had not been able to observe directly to knowledge derived from examining users' interactions in laboratory tests. Thus, a reconstruction from the log data of the unobserved users' interactions with the equipment was required.[31] The researchers wanted to know what was going on in an area they could not observe visually, because they needed this information to evaluate the usefulness of the prototype. With some restrictions – above all, the sounds constituting the sonification are generated artificially; further, real-time analysis was never intended – this situation resembles the medical practice of stethoscopy. The stethoscope transports the sounds of human organs within the living body (the unobservable area), so that another person interested in their status can listen to them. The findings of this procedure are then evaluated by relating them to existing knowledge of (post-mortem) anatomy. By analogy, we listened to auditory indicators of events in the prototype toilet system, in order to be able to relate our findings to knowledge derived from laboratory tests.

These data provide a good example for investigating the strengths of sonification above all because they record time sequences with high temporal resolution. Superficial screening of a data-set with these dimensions would be scarcely possible with a graphical display. Note that Fig. 2 shows only about ten minutes of data: if one wanted to display for example eight hours graphically, one would need to produce forty-eight similar graphs; using sonification, by contrast, the researcher could screen those eight hours in about five minutes.

The sonification technique chosen in this case was parameter mapping. A specific sound event was assigned to each variable of interest. In total, we ended up with nine variables plus time as the basic dimension. After some weeks of auditory exploration, we found that identifying interesting sequences is much easier with an auditory representation



2 Screenshot of graph showing about ten minutes of logged data from the 'friendly rest room' project of the variables: with the given data, the human ear is capable of tracking the sequence of events even when accelerated by a factor of a hundred – in other words one is able to perceive a sequential order spread over a hundred seconds even when it is compressed into one second.

Further, sonification provides a more dynamic representation of the events' sequential order. The intrinsic time factor of the auditory representation helps the researcher to comprehend the sequential ordering much better than standard, static graphical displays. It reproduces a temporal phenomenon in its natural dimension, time, not in space, as the static graph does. While dynamic graphical displays would also offer time-to-time representation, following several parameters and their timing patterns visually is much more difficult.

The conclusion we draw from this sonification example is that we were able to achieve what we set out to do: we were able to investigate the users' interactions with the equipment as indicated by the logged sensor data. Though it can be argued that data within the social sciences are seldom of such high temporal resolution, sonification offers a promising exploratory method for sequence data even when the sequences are not so continuously registered as they were in the example described.

Sonification of geographical sequences

The aim of this second sonification was to provide a representation of election results from the 2005 Styrian provincial parliamentary election, as an easily accessible and topical example of geographically distributed social data.

Styria is one of the nine federal states in Austria, consisting of 542 communities in seventeen districts, and with a population of about 1.2 million. In autumn 2005, more than seven hundred thousand Styrians elected their political representatives. Besides the fact that the result of this election was in some sense remarkable – the ruling conservative party ÖVP (the Österreichische Volkspartei, or Austrian People's Party) was defeated for the first time since 1945 by the Social Democratic Party, SPÖ (Sozialdemokratische Partei Österreichs) – our interest focused on the attempt to display social data, first, in their geographical distribution and, second, at a spatial resolution greater than usual. We wanted to design a sonification that would display spatial differences and similarities in the election results among neighbouring communities. The technique we chose was a model-based sonification approach, initially developed at the University of Bielefeld, Germany, by Thomas Hermann and colleagues.

The mental model behind our approach to the election data was that of a journey through Styria. A journey can be defined as the transformation of a spatial distribution into a temporal distribution. A traveller starting at community X passes first through the communities neighbouring X, and the longer the journey, the greater is the distance from community X. Hence, in this sonification, the distances between communities are mapped onto the time axis.

The communities are displayed in a two-dimensional window on a computer screen (see Fig. 3). For each community, the coordinates of the community's administrative offices were determined and used as the geographical reference point for the respective community. The distances as well as the angles within the data thus correspond to the real distances and angles between the communities' administrative offices.

3 Screenshot of the graphical user interface for the Styrian election sonification

The sonification is interactive in the sense that this window can be understood as a musical instrument. Clicking the mouse anywhere within it initiates a circular wave that spreads in the two-dimensional space. The movement of this wave is shown in the window by an expanding 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 one particular party at a time to which to listen. Then, the pitch of the tone represents the percentage the respective party achieved at the election among a given community's population: the higher the tone, the higher the percentage. Furthermore, the researcher can select the direction in which to travel. In the graph, this direction is West, indicated by the line within the circular wave. The line begins at the point where the researcher has initiated the wave. This line is used to support the perception of an aspect of the geographical distribution.

The sonification software was designed for a ring of twelve speakers surrounding the listener, but it can be used with more common equipment too. In a standard stereo speaker setting (or when using headphones), the communities are mixed to virtual spatial positions between the channels ('panned') according to their angle from the main axis: those located straight in front are represented by sound events panned to the centre, those at ninety degrees left of the line by sound events from the left speaker, those in between to appropriate intermediate positions, and similarly for the right side.

In addition to these fixed parameters, many others, for example the duration or reverberation of each sound event, are more or less freely adjustable by the researcher. The rationale for this adjustability is that different settings allow for a focus on different aspects of the data-set. We found, though without being able to generalise this finding, that the 542 values for a given party can be displayed in about eight to ten seconds. In relation to browsing through the tables, this is a remarkable time gain. Also, in comparison with a standard two-dimensional graph, the combination of sound and interactive graphical display allows for rapid geographical localisation of data points or areas of particular interest.

Deciding on a longer decay time for individual sound events, for instance, results in a smoother, more integrated sound texture, because the single constituent sound events overlap and merge into a broader impression. This allows for a focus on general trends in the data. Conversely, a shorter duration for each sound event results in individual communities being represented more distinctly. This allows for single communities to 'pop out'. In fact, our experience is that this sonification is an excellent tool for outlier analysis. It works rather fast at a low level of aggregation (of communities), and outliers are easily identified by tones that are higher than in their immediate surroundings. Note that these are local outliers: in an area with a typical average of say thirty per cent for one party, a forty-two per cent result can be heard 'popping out'; looking at the entire data-set statistically, this may not even count as an outlier, for example if the overall average is say forty per cent.

Application of this sonification software is not restricted to election data alone. Other social indicators assessed at the community level (for instance unemployment rates, participation of women in the workforce, and the like) can be included. As the pitch of the sound event is already used for the election result, a representation option for a further variable may be timbre, or spectral qualities in general. To represent such indicators in addition to the election results facilitates the investigation of local dependencies that might be hidden by higher aggregation levels or by the mathematical operations of correlation coefficients. This is however only work in progress, and we cannot yet report conclusive results.

Finally, this software is not restricted to the geographical frontiers of Styria; it could of course be adapted to other geographical entities. It could be used as an exploratory tool to enable quick scanning of social data in their geographical distribution, at different aggregation levels. As it is based on open source software, it is available on the project's homepage for further development.

SONIFICATION: PRACTICAL AND CULTURAL CHALLENGES

In an earlier section, we claimed Western culture to be a visual one. How far-reaching the implications of the predominance of the eye are is a source of recurrent perplexity for researchers concerned with auditory displays. Standard working environments often turn out to be quite unusable for sonification research, simply because their design follows the cultural hierarchy of the senses; what is more, the traditional carrier of the symbolic knowledge generated by science, paper, hardly begins to meet the requirements of communicating sound.

The use of sound, then, has practical implications first of all for the working environment. When using speakers, the researcher should be seated in a room alone, since it is likely that room-mates will not accept being subjected to computer generated sounds over an extended period. When, on the other hand, one is using headphones, one makes oneself more or less unavailable to other technical devices that make use of an auditory interface. This might be harmless when missing a phone call, but it could become more dangerous in the event of a fire alarm or other more general communication system relying only on the auditory channel.

The second point we want to make is concerned with scientific communication.[32] Referring above to Latour and Woolgar's famous study *Laboratory Life*, we have claimed already that inscription devices are at the core of most scientific research. As Latour and Woolgar put it, 'an inscription device is any item of apparatus or particular configuration of such items which can transform a material substance into a figure or diagram which is directly usable by one of the members of the office'.[33] Moreover, this figure or diagram is not only directly usable by a member of the same institution, but it is portable: it can be used in a paper, the best established form of scientific communication. This portability bestows the value of inscriptions: they can be directly used as rhetorical resources in the attempt to convince scientific colleagues of the truth and legitimacy of one's claims.

Since sonifications cannot be included in printed papers, their diagnostic power is therefore weakened. To put it in other words: the applicability of sonifications as rhetorical resources is significantly restricted (though ICT and online journals do increasingly allow for the inclusion of multimedia files and the presentation of selected sound examples). Again, in scientific fora where sonifications could be demonstrated directly to the audience (for instance conferences or workshops), the technical facilities (amplifier, speakers) are most often inadequate. Consequently, they do not allow for serious demonstration in a way that invites an audience to listen carefully. This too diminishes the rhetorical force of sonification.

We argue that it is partly as a result of these portability problems that sonification still lacks recognition. Another factor surely is that to do research in sonification requires a certain level of training: learning to listen carefully is fundamentally different from learning variance analysis. As this kind of recognition is important both for an individual's motivation and for raising research funds, sonification research has not yet reached the critical mass to establish itself as a valid and valuable complementary approach in the (social) scientific toolkit.

CONCLUSION

Reporting experiences from working with practical sonifications, we find that sonification offers a promising complementary approach within the social sciences, especially in the exploration of sequential data. Technological developments now allow for applications the value of which are rarely acknowledged in the social sciences. The idea of interactively exploring data depicting social phenomena is not only fascinating, but we hope also to have shown that it is heuristically worthwhile. It is so, we argue, in two respects: first, because sonification as a tool for exploring data has something new to offer social scientists; and second, because it might initiate a reflective discussion on the extent to which the perceptual capabilities of the human senses are exploited in social research.

Nevertheless, dealing with the difficulties (or – put more positively – the challenges) sonification faces on its way to becoming established as a scientifically reliable way of exploring data will be hard. The reasons for this are deeply ingrained in the fabric of our culture. And sonification of itself will not effect substantial change. However, we are confident that, in time, the heuristic value of sonification will eventually be seen to outweigh the effort necessary to cope with the practical and cultural difficulties described.

NOTES

1. To give just a few examples: so-called screen readers assist visually impaired computer users by 'reading' the text displayed on computer screens – for a critical overview see T. Stockman: 'The design and evaluation of auditory access to spreadsheets', Proceedings of the 2004 International Conference on Auditory Display (ICAD), Sydney, Australia, 2004, www.icad.org/websiteV2.0/Conferences/ICAD2004/posters/stockman.pdf; a German team developed a microelectronic system to provide acoustic information and orientation for visually impaired users in cities, see M. Kemmerling and H.-J. Schliepkorte: 'An orientation and information system for blind people based on RF-speech beacons', in *Improving the Quality of Life for the European Citizen*, (ed. I. Palacencia Porrero and E. Ballabio), 275–278; 1998, Amsterdam, IOS Press; and Scottish researchers developed a system called ScripTalker, which uses scripted conversations to help non-speaking people accomplish communication tasks more effectively, see R. Dye *et al.*: 'ScripTalker – an AAC system incorporating scripts', in *Improving the Quality of Life for the European Citizen*, pp. 310–313.
2. J. Ortega y Gasset: *Betrachtungen über die Technik*; 1949, Stuttgart, Deutsche Verlags-Anstalt (first published in Spanish as *Meditación de la técnica*, 1939).
3. cf. T. Stockman: 'The design and evaluation of auditory access to spreadsheets' (see Note 1) and G. Kramer (ed.): *Auditory Display: Sonification, Audification and Auditory Interfaces*; 1994, Reading, MA, Addison-Wesley.
4. G. Kramer: 'An introduction to auditory display', in *Auditory Display*, (ed. G. Kramer), 1–77; 1994, Reading, MA, Addison-Wesley. See pp. 6–15 for a comprehensive summary of the advantages and drawbacks of auditory displays.
5. Since Pythagoras is reported to have travelled widely in Egypt and the East, it is also possible that this observation may have been imported by him from the Orient.
6. G. Neuwirth: 'Erzählung von Zahlen', in *Musik-Konzepte 26/27: Josquin des Prés*; 1982, Munich, edition text+kritik.
7. I. Xenakis: *Formalized Music: Thought and Mathematics in Composition*; 1992, Hillsdale, NY, Pendragon Press is a major reference work in contemporary music.
8. See the works of Vilém Flusser, especially *Medienkultur*; 1997, Frankfurt am Main, Fischer, and *Kommunikologie*; 1998, Frankfurt am Main, Fischer.
9. H. Blumenberg: *Höhlenausgänge*; 1996, Frankfurt am Main, Suhrkamp.
10. H. Blumenberg: *Die Lesbarkeit der Welt*; 1986, Frankfurt am Main, Suhrkamp.
11. B. Latour and S. Woolgar: *Laboratory Life: The Construction of Scientific Facts*; 1986, Princeton, NJ, Princeton University Press (revised edition with an introduction by Jonas Salk and a new postscript by the authors).
12. T. Kleinspehn: *Der flüchtige Blick: Sehen und Identität in der Kultur der Neuzeit*; 1989, Reinbek bei Hamburg, Rowohlt.
13. This story is reported in S. Drake: *Galilei*; 1999, Freiburg, Herder; its meaning is reflected on in F. Dombois: 'Wann hören? Vom Forschen mit den Ohren', in *Chemie – Kultur – Geschichte: Festschrift für Hans-Werner Schütt anlässlich seines 65. Geburtstages*, (ed. A. Schürmann and B. Weiss), 79–92; 2002, Berlin, Diepholz.
14. W. Kutschmann: *Der Naturwissenschaftler und sein Körper: Die Rolle der 'inneren Natur' in der experimentellen Naturwissenschaft der frühen Neuzeit*, 303–309; 1986, Frankfurt am Main, Suhrkamp.
15. Building on the definition of the aim of visualisation in R. M. Friedhoff: 'Is visualization really necessary? The role of visualization in science, engineering and medicine', in *Visualization, 1993*, 343–346; 1993, Los Alamitos, CA, IEEE Computer Society, we would define perceptualisation as the attempt to substitute conscious thinking with preconscious perceptual competencies.
16. S. Traweek: *Beamtimes and Lifetimes: The World of High-Energy Physicists*; 1988, Cambridge, MA, Harvard University Press.
17. See, for instance, S. Barrass: 'Sonification design patterns', Proceedings of ICAD 2003, Boston, MA, USA, 2003, www.icad.org/websiteV2.0/Conferences/ICAD2003/paper/42%20Barrass.pdf; S. C. Peres and D. M. Lane: 'Sonification of statistical graphs', Proceedings of ICAD 2003, Boston, MA, USA, 2003, www.icad.org/websiteV2.0/Conferences/ICAD2003/paper/38%20Peres.pdf.
18. E. J. S. Hovenga and W. Sermeus: 'Data analysis methods', in *Textbook in Health Informatics: A Nursing Perspective*, (ed. J. Mantas and A. Hasman), 113–125; 2002, Amsterdam, IOS Press.

19. When we say that the sound events are determined by the data, we are not ignoring the fact that there is a translation process where the researcher has to decide how the data influence the sound parameters.
20. 'Sonification report: status of the field and research agenda', prepared for the National Science Foundation by members of the International Community for Auditory Display, 1997, www.icad.org/websiteV2.0/References/nsf.html.
21. A more detailed description of these, and other, techniques is included in T. Hermann: *Sonification for Exploratory Data Analysis*, PhD thesis, University of Bielefeld, Germany, 2002.
22. For earthquake seismology, see F. Dombois: 'Using audification in planetary seismology', Proceedings of ICAD 2001, Espoo, Finland, 2001, www.acoustics.hut.fi/icad2001/proceedings/papers/dombois.pdf; also 'Auditory seismology', a webpage maintained by Florian Dombois at www.auditory-seismology.org. For EEG data see T. Hermann *et al.*: 'Sonifications for EEG data analysis', Proceedings of ICAD 2002, Kyoto, Japan, 2002, www.icad.org/websiteV2.0/Conferences/ICAD2002/proceedings/22_Thomas_Hermann_EEG.pdf; T. Hinterberger *et al.*: 'Auditory feedback of human EEG for direct brain–computer communication', Proceedings of ICAD 2004, Sydney, Australia, 2004, www.icad.org/websiteV2.0/Conferences/ICAD2004/papers/hinterberger_etal.pdf; T. Hinterberger and G. Baier: 'Parametric orchestral sonification of EEG in real time', *IEEE MultiMedia*, 2005, **12**, (2), 70–79. For sonification of stock-market data see K. V. Nesbitt and S. Barrass: 'Evaluation of a multimodal sonification and visualization of depth of market stock data', Proceedings of ICAD 2002, Kyoto, Japan, 2002, www.icad.org/websiteV2.0/Conferences/ICAD2002/proceedings/51_KeithNesbitt.pdf.
23. The Sonification Lab at the Georgia Institute of Technology has developed some easy-to-handle software called Sonification Sandbox which supports parameter mappings. It is freely available at http://sonify.psych.gatech.edu.
24. The advantages of model-based sonifications are described in T. Hermann: *Sonification for Exploratory Data Analysis*, pp. 70–80 (see Note 21).
25. A. de Campo and M. Egger de Campo: 'Sonification of social data', Proceedings of the 1999 International Computer Music Conference (ICMC), Beijing, China, 1999, 281–283.
26. C. Dayé, A. de Campo and M. Egger de Campo: 'Sonifikationen in der sozialwissenschaftlichen Datenanalyse', *Angewandte Sozialforschung*, 2006, **24**, 41–56. See also in the same volume the reviews by C. Frauenberger (pp. 56–60) and A. Müller (pp. 61–64) and our response to them (p. 65).
27. SonEnvir: Designing a Generalized Sonification Environment for Scientific Data; for further information see the project's homepage at http://sonenvir.at.
28 A. de Campo, C. Frauenberger and R. Höldrich: 'Designing a generalized sonification environment', Proceedings of ICAD 2004, Sydney, Australia, 2004, www.icad.org/websiteV2.0/Conferences/ICAD2004/posters/campo_etal.pdf.
29. We base our comments on A. Abbott: 'A primer on sequence methods', *Organization Science*, 1990, **1**, 375–392; A. Abbott: 'Sequence analysis: new methods for old ideas', *Annual Review of Sociology*, 1995, **21**, 93–113; H.-P. Blossfeld, A. Hamerle and K. U. Mayer: *Ereignisanalyse: Statistische Theorie und Anwendung in den Wirtschafts- und Sozialwissenschaften*; 1986, Frankfurt am Main, Campus (English title: *Event History Analysis*); H. P. Blossfeld and G. Rohwer: *Techniques of Event History Modelling: New Approaches to Causal Analysis*; 1995, Mahwah, NJ, Lawrence Erlbaum Associates.
30. For a general introduction to this project see P. Panek *et al.*: 'Friendly rest room project: a toilet prototype for improving the quality of life of old people and persons with disability', in *Assistive Technology – From Virtuality to Reality*, (ed. A. Pruski and H. Knops), 8–12; 2005, Amsterdam, IOS Press.
31. C. Dayé *et al.*: 'Sonification as a tool to reconstruct users' actions in unobservable areas', Proceedings of ICAD 2005, Limerick, Ireland, 2005, www.idc.ul.ie/icad2005/downloads/f66.pdf.
32. Some considerations on this topic are included in A. de Campo *et al.*: 'Sonification as an interdisciplinary working process', Proceedings of ICAD 2006, London, UK, 2006, www.dcs.qmul.ac.uk/icad2006/proceedings/papers/f54.pdf.
33. B. Latour and S. Woolgar: *Laboratory Life*, p. 51 (see Note 11).

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