Sonification and particle physics.

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Abstract

Sonification is a new method of data display and is defined as the use of audio to convey information. It is an alternative and complement to visualisation. In recent years, it emerged in different fields, pushed by the development of real time audio synthesis software and the increased consciousness of human audition. The growing amounts of data in society and science ask for new approaches in data analysis and display. One of these rapidly prospering fields is the computational approach to problems in physics. The rapid development of computers and algorithms has led to new quantitative and qualitative insights, but the typically multi-dimensional data sets are very large, and only a few simple observables are considered. Our interdisciplinary research project **QCD-Audio** suggests applying sonification techniques to data of numerical models in physics.

This paper will introduce the concept of sonification, describe the motivation and goals of the project QCD-Audio and discuss first results stemming from a preliminary study.

1 Background

During the last centuries, science focused on visualisation. Scientific data is usually presented in scientific graphs or animated graphics. A complementary approach to perceptualisation is auditory display, which has emerged in the last 20 years for a number of reasons. Firstly, data amounts have been increasing both in science and society due to growing CPU power. Thus new techniques of perceptualisation are being explored. Secondly, the study of music and with it the sense of audition under various scientific aspects became popular. Finally, audio synthesis has only reached sufficient quality and realtime efficiency in the last decades. In 1992, the first International Conference on Auditory Display (ICAD, www.icad.org) took place. Its community consists today of a core of some 100 scientists, stemming from different disciplines, mostly psychology, computer science, sound engineering, science and music. Against this background, the interdisciplinary research project SonEnvir – Sonification Environment - took place at the Institute of Electronic Music and Acoustics (IEM) of the University of Music and Dramatic Arts Graz from 2005-2007. The Institute of Physics of the University of Graz collaborated with data stemming from models of computational physics. This collaboration is now continued with the project QCD-Audio, funded by the FWF Translational Research program.

In the course of the predecessor project SonEnvir (http://sonenvir.at), different sonifications have been developed in the field of physics. We did research on energy spectra of baryons (e.g. the proton or neutron; ref. [3]) and spin models, the Ising and Potts model ([11]). A smaller project was done on the chaotic double pendulum. In the last phase of SonEnvir and its aftermath, a pilot study on the sonification of data from lattice QCD was done [12].

In the following section, we will give an introduction to sonification. Then, in Section 3, also the background of lattice QCD is shortly described. In Section 4 we explain the sonifications of a first pilot project. Sound examples are described. In Section 6 we give an outlook.

2 Sonification

2.1 Definitions

Some scientific methods address our ears - e.g., the clicks of the Geiger counter or the heartbeat listened to through a stethoscope. These are examples for sonification - defined as the use of non-speech audio to convey information. Two basic methods shall be discussed here:

Audification - This is a mapping of any data to a one-dimensional data stream that can be heard. E.g., bats communicate with ultrasound; if these signal are shifted to the (human) auditory domain, with have a very simple example of audification.

Parameter-Mapping - Here, different aspects of the data are linked to parameters of sound, as shown in Figure 1. The amount of available parameters is a clear benefit in comparison to visualisation, even if it has to be taken into account that these are not independent parameters.

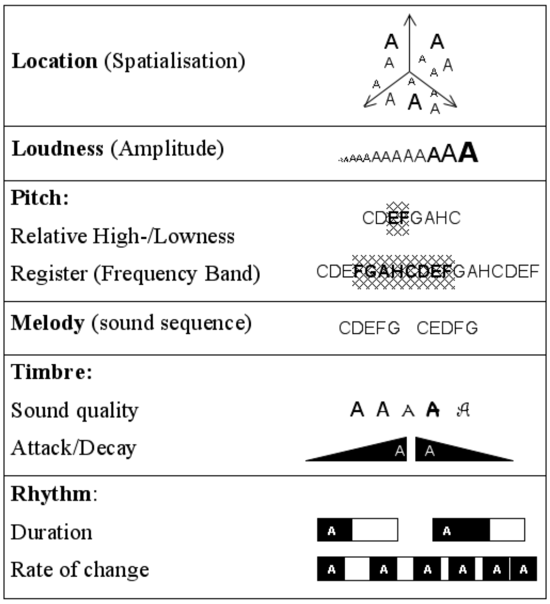

Figure 1: *Scheme of sound parameters usable in a parameter mapping sonification. Source: http://spdf.gsfc.nasa.gov/ research/sonification.*

2.2 Aims of sonifications

Three main goals of sonification can be identified.

1. Data is represented alternatively. Auditory graphs and respresentation of multi-dimensional data can be used for didactic purposes, help visually impaired people and create multi-modal displays.

2. Sonification can be used in order to analyse scientific data. It is a complementary tool to classical analytical methods, and in some contexts it is even a crucial one.

3. Sonification is an element of algorithmic composition or media art.

2.3 Examples in various scientific fields

Historic evidence - An early but historically interesting example of research using sonification is the experiment of the inclined plane by Galileo Galilei. Following Drake [6], it seems plausible that Galilei used auditory information to verify the quadratic law of falling bodies. He attached little bells in quadratically increasing distances on an inclined plane, which were hit by a ball rolling down; this resulted in a completely regular rhythm.

Seismology - Earthquakes are studied by listening. Already in 1961 Speeth [10] showed that subjects were able to classify bomb blasts and earthquakes in the audification of seismic data.

Noisy data / Experimental physics and Astronomy - One example of audification is given in a paper by Pereverzev et al. [9], where quantum oscillations between two weakly coupled reservoirs of superfluid helium 3 (predicted decades earlier) were found by listening to the amplified raw signal.
Also data from space missions (in radio and plasma wave science) are often analyzed in a first step as audio signals.

Microbiology - Oscillations of living (healthy/ ill) and dead yeast cells can be listened to with the help of an atomic force microscope [8].

Neurology / EEG data - Sonifications allow for better real-time monitoring and examination of EEG data of epilepsy patients [1].

Social Sciences - There is also sonification in the social sciences (for an overview see [5]) and in economy allowing for a better overview of market exchange data.

Arts - Electronic (algorithmic) compositions are sometimes based on sonifications. E.g., [4] is based on UN data, allowing critical comparisons of the worlds resource distributions in a musical piece.

In the examples cited above, the term sonification was not always used, as systematic research in this field started only recently. The first International Conference on Auditory Display (ICAD) took place in 1992.

3 QCD data and research questions

In the research project QCD Audio, we will use sonification to perceptualize data from lattice QCD, a branch of computational elementary particle physics.

The following section gives a quick overview over the research questions we want to address.

3.1 Quantum Chromodynamics

Quantum Chromodynamics (QCD) is the field theory of quarks and gluons: quarks, the fundamental building blocks of matter, and gluons, the particles 'gluing' the quarks together. Both, quarks and gluons, carry so-called color-charges (thus *chromo*). Observables are color-neutral, which means that no single isolated quark can be observed. This neutrality is an analogy to additive primary colors that will appear white when combined – compare the project logo on page 1. E.g., three different-colored quarks form protons or neutrons, which are color-neutral objects.

QCD is a field theory, like electromagnetism, defined on 4-dimensional space-time. Calculating observables in this framework in a non perturbative approach requires calculating integrals at each of the (infinitely many) space-time points. To make this approach well defined a regulator of the theory is necessary.

3.2 Lattice QCD

Since about the 1990s, the classical physics disciplines have a new counterpart: *Computational physics* is using innovative formulations of physical problems such that they can be attacked numerically. Thus computational physics belongs neither really to the theoretical nor to the experimental branch. One of its major fields is lattice QCD. With growing CPU power, results of simulations more and more match the results of real measurements in physical experiments.

In lattice QCD one replaces continuous space-time by a hypercubic, periodic lattice with the spacing a between nearest neighbors. In this way the necessary regulator, discussed in the last section, is introduced. The quantum fields of the theory of the quarks and gluons are described by sets of numbers assigned to the points of the lattice. The interaction between the fields gives rise to terms that link the fields on neigboring lattice sites. A complete set of values for all variables on the lattice is referred to as a configuration.

Typical lattice sizes nowadays contain at least 16x16x16x32 sites. Such a lattice already has 131072 lattice sites and a configuration on this lattice consists of 24x131072 real numbers. Obviously this is a rather large amount of information that has to be analyzed and interpreted.

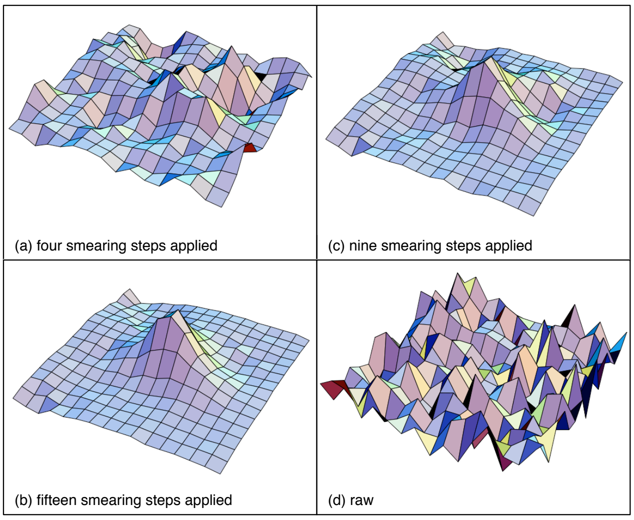

Figure 2: *Two dimensional cut through the 4-d lattice showing the topological charge density of one configuration. We compare a sequence of filtering steps (plots (a)-(c)) to the original configuration without filtering (plot(d)).*

3.3 Data and hidden structures

In a first approach, we reduced the complexity of the data and studied a physical observable which corresponds to a single number on every lattice site – the topological charge density. It is defined as

$$|q| = \frac{g^2}{16^2\pi^2}\epsilon_{\mu\nu\rho\sigma}F_{\mu\nu}(x)F_{\rho\sigma}(x), \tag{1}$$

where g is the coupling constant, ϵ is the anti-symmetric tensor and F is the field-strength tensor. We aimed at displaying the topological charge density in a meaningful and intuitive way, and compared the raw data with numerically treated data, revealing long ranged structures hidden under the background of short-ranged quantum fluctuations.

These structures are often interpreted as topological excitations (e.g., instantons). There exist filtering methods to reveal them from raw data, one of which is smearing [2]. It may be questioned if the filtering methods generate unphysical artifacts, thus a direct study of topological excitations in the raw data would be clarifying. Interestingly, also a Fourier analysis of the raw data failed. Thus the seen fluctuations cannot be decomposed in a superposition of different frequencies, due to non-linear effects.

The data sets we were exploring consist of different configurations, each available as raw data and three different degrees of smeared data. (See Fig.s 2.)

4 The Pilot project

4.1 Sonification design

In order to cope with the huge amount of data we decided to sonify small regions one after the other. These were sub-hypercubes, containing information on all 4 dimensions.

The first sonification was done with an audification as input signal. It is generated with a space filling curve [7], that sequentializes information on all neighbors in 4d. Then this signal is amplified using different (e.g., random) frequencies, thus we amplify non-linearly. Obviously, the resulting sound depends on the resonator frequencies. The scheme is illustrated in Fig. 3 on the left-hand side. We called it *resonated audification*.

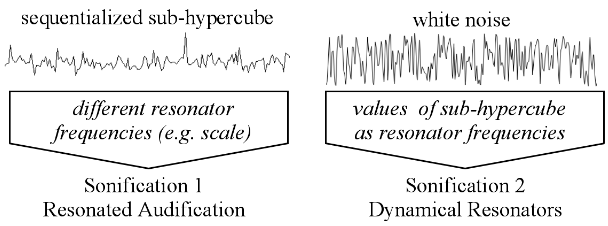

Figure 3: *Schemes of the two basic sonification approaches.*

In the second approach we put the cart before the horse: each lattice site in the sub-hypercube provides a value of the topological charge density. These values are taken as resonator frequencies for a white noise input signal. This sonification scheme is illustrated on the right-hand side of Fig. 3 and we called this approach *dynamical resonators*.

4.2 Interaction

Interactive navigation through the datasets is one possible way to cope with huge and multi-dimensional data sets. The data is explored actively, via - in our case - acoustical feedback. We tested several interfaces and finally chose a simple GamePad with 2 push sticks, each having 2 axis representing two dimensions. With this, one can navigate through the 4d space and listen to the sonification of the neighborhood.

Also, our system lets the user adjust parameters of the sonification interactively, in order to take into account the structure searched for. The path and extent of the sequentialization are very determining for the resulting sound, as well as the frequencies used for the resonators.

4.3 Audio examples

For sonification, we work with the free programming language SuperCollider3, see http://supercollider.sourceforge.net.

To test our concepts we generated idealized data sets for testing our sonification designs. They contain a pseudo structure (a 4d Gaussian bump) that is hidden under random noise. In this pseudo data, the hidden structure can easily be heard. The acoustical method is superior to searching for it in a visualisation, because all neighbors in four dimensions are taken into account, whereas in the visual approach only two dimensions can be displayed.

The real data sets are much more complex and at the moment it is not clear if the instantons may be located acoustically with our current approaches. The main challenge is probably the fact that the amplitudes of the quantum fluctuations are one or two orders of magnitude larger than the amplitudes of the topological excitations.

Sound examples can be found at:
http://qcd-audio.at and
http://sonenvir.at/data/ (where also examples of other disciplines can be accessed).

5 Discussion

We accept visual interpretation in many scientific fields as an analysis tool, which is often superior to or preceding mathematical treatment. Sonification is a logical continuation of such analysis methods.

There is a cultural bias towards visualisation because it has a longer history than representation of sound. Visualisation techniques and our learnt understanding of them have been refined since the very beginnings of modern science itself. Compared to visual display, scientists are not trained to work with auditory display, so they first have to learn how to interpret sound before a sonification will show full its benefits.

A strong argument in favour of sonification is the sophistication of audition. The properties of the human auditory system make it an especially well-suited sense for the representation and exploratory analysis of - eventually multidimensional - data in the context of sonification.

In Physics, sonification is relatively new, but has special advantages. The data is often multidimensional, and often based on time, thus any acoustic representation provides a very direct mapping.

6 Outlook

In the research project QCD-Audio, we want to explore new ways of perceptualization of data in lattice QCD. The project runs from June 2008 to March 2010 in a co-operation between the Institute of Physics, University of Graz, and the Institute of Electronic Music and Acoustics, Arts University of Graz. It is funded by the FWF Translational Research Program.

New sonification designs and programs for different numeric models will be developed. These will be used to analyze the data and also to provide didactic listening examples. Evaluation will take place in two steps – an analytic evaluation will explore the scientific gain, whereas an aesthetic evaluation will ensure that the representation is not annoying. In a last step, the sonifications will be used for a sound installation to allow new insights into the field for a broad public. Information can be found at http://qcd-audio.at.

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