SONIFICATION OF LATTICE OBSERVABLES ACROSS PHASE TRANSITIONS

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Abstract
Sonification is defined as the use of non-speech audio to extract information from data and it represents the sound analogue to graphical visualization. The method is applied in several disciplines from economy to medicine to physics. Sonification might also help in analyzing lattice data. It could assist, together with graphical display, to examine the behavior of lattice observables as a function of parameters like gauge coupling, quark mass, etc. Sonification might further be used to identify unique characteristics of single gauge-field configurations out of many such as, for example, the topological content. In order to demonstrate the methodology for quantum chromodynamics (QCD) we analyze the eigenvalues of the Dirac operator from the confinement to the deconfinement phase. We are adapting a program package for audio browsing of baryon spectra from quark models developed at the University of Graz within the interdisciplinary research project 'SonEnvir'.

1 Visualization and Sonification

In modern science and economy a vast amount of relevant data is stored and made available for evaluation. Techniques to locate the numbers of interest like data warehousing and data mining have been developed together with program packages for visualization in order to extract the hidden information. The question arose if methods of auditory display could help to get further insight into the structures behind the data. This discipline is called sonification, and a definition can be found in the wikipedia: Sonification is the use of non-speech audio to convey information or perceptualize data [1]. The International Community for Auditory Display (ICAD) [2] was established in 1992 and has been organizing international conferences since then; this year's conference took place in Limerick, Ireland, a few days before the lattice conference in Dublin and the workshop on extreme QCD in Swansea. At the request of the NSF in 1997 the ICAD provided a Sonification Report [3].

2 Sonification Package

Sonification needs a realization on software and hardware platforms. We shall first provide a short description of the program package SuperCollider developed by James McCartney from Austin, TX. It originated as proprietary software and was released in 2002 under the free software GPL license. The name SuperCollider is said to have its origin from the Superconducting Super Collider (SSC) in Waxahachie, TX, which was planned and begun to be constructed but was then abandoned and never finished.

The SuperCollider environment consists of two applications, a client *sclang* (being the language) and a server *scsynth* (being the audio) which communicate using Open Sound Control. The SuperCollider language (*sclang*) is an interpreter language and combines the object oriented structure of Smalltalk and features from functional programming languages with a C programming language family syntax. SuperCollider runs on the platforms Mac OS X, Linux, and Windows. Relying on Linux, the program code can interactively be edited and executed using the *emacs* editor. The synthesizer (*scsynth*) can

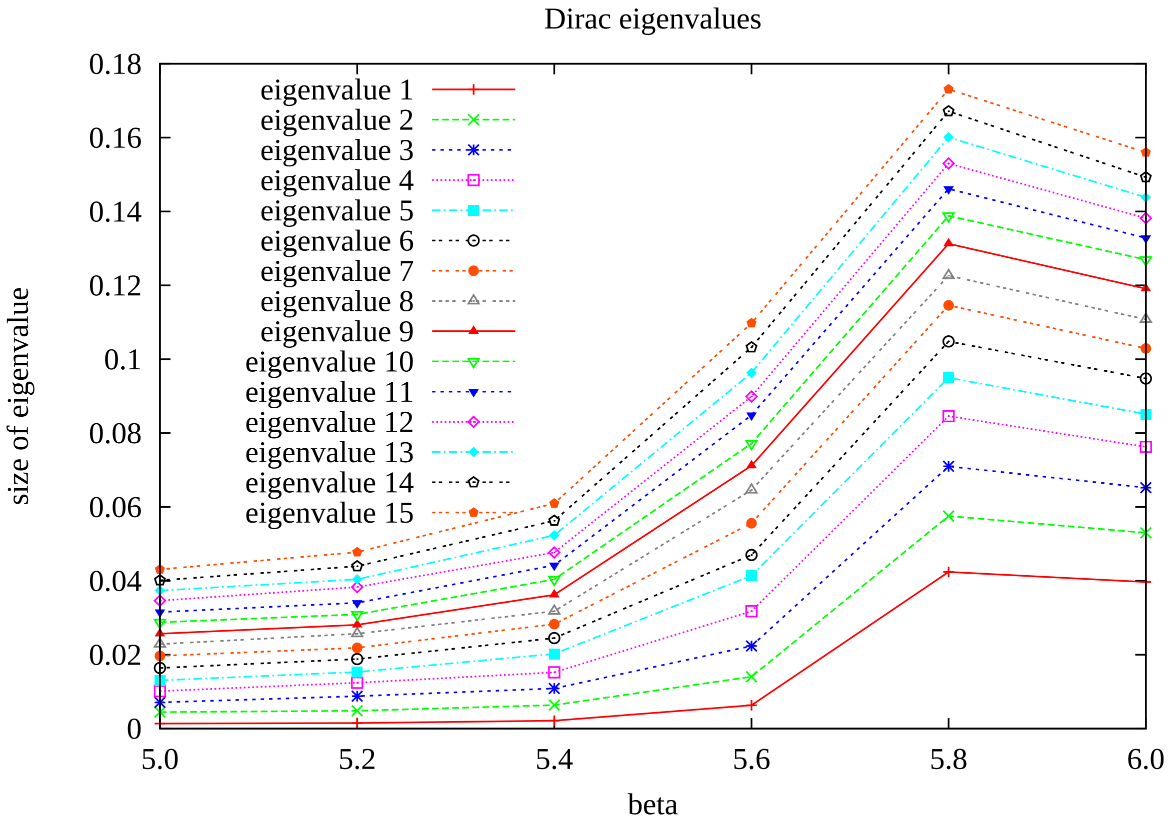

Fig. 1: Confi guration-averaged values of the 15 lowest levels of the eigenvalue spectrum of the Dirac operator as a function of the gluon coupling β.

make use of the ALSA sound system. We mention that beside this professional solution there is a simple sonification tool implemented in newer versions of Mathematica. Also MATLAB supports treating data vectors as if they were audio signals and thus allows to play them.

3 Application to Lattice QCD

Becoming interested to learn about the possibilities of sonification in lattice field theory, we took as an example the eigenvalue spectrum of the Dirac operator from existing data [4]. We generated gauge field configurations using the standard Wilson plaquette action for SU(3) and constructed the matrix of the Dirac operator using the Kogut-Susskind prescription. The Dirac matrix is anti-hermitian so that all eigenvalues are imaginary and occur in pairs with opposite sign. We worked on a $6^3 \times 4$ lattice with various values of the coupling strength β. Typically we produced 10 independent configurations for each value of β. In a first sonification attempt we analyzed the spectra for ascending eigenvalues keeping β fixed [5]. The present paper is devoted to the sonification of fixed eigenvalues as a function of the coupling β.

Figure 1 shows a graphical presentation of the 15 lowest eigenvalues as a function of the gluon coupling from $\beta = 5.0$ to $\beta = 6.0$. The phase transition to deconfinement occurs around $\beta = 5.7$ where the quasi-zero modes disappear. One observes that all eigenvalues independent of their topological content are influenced at the transition point.

For the auditory presentation we multiplied the raw data by a factor of 10000 and added the standard pitch of 440 Hz. In Fig. 2 we depict the frequencies obtained for six of the lowest eigenvalues from the confinement to the deconfinement phase.

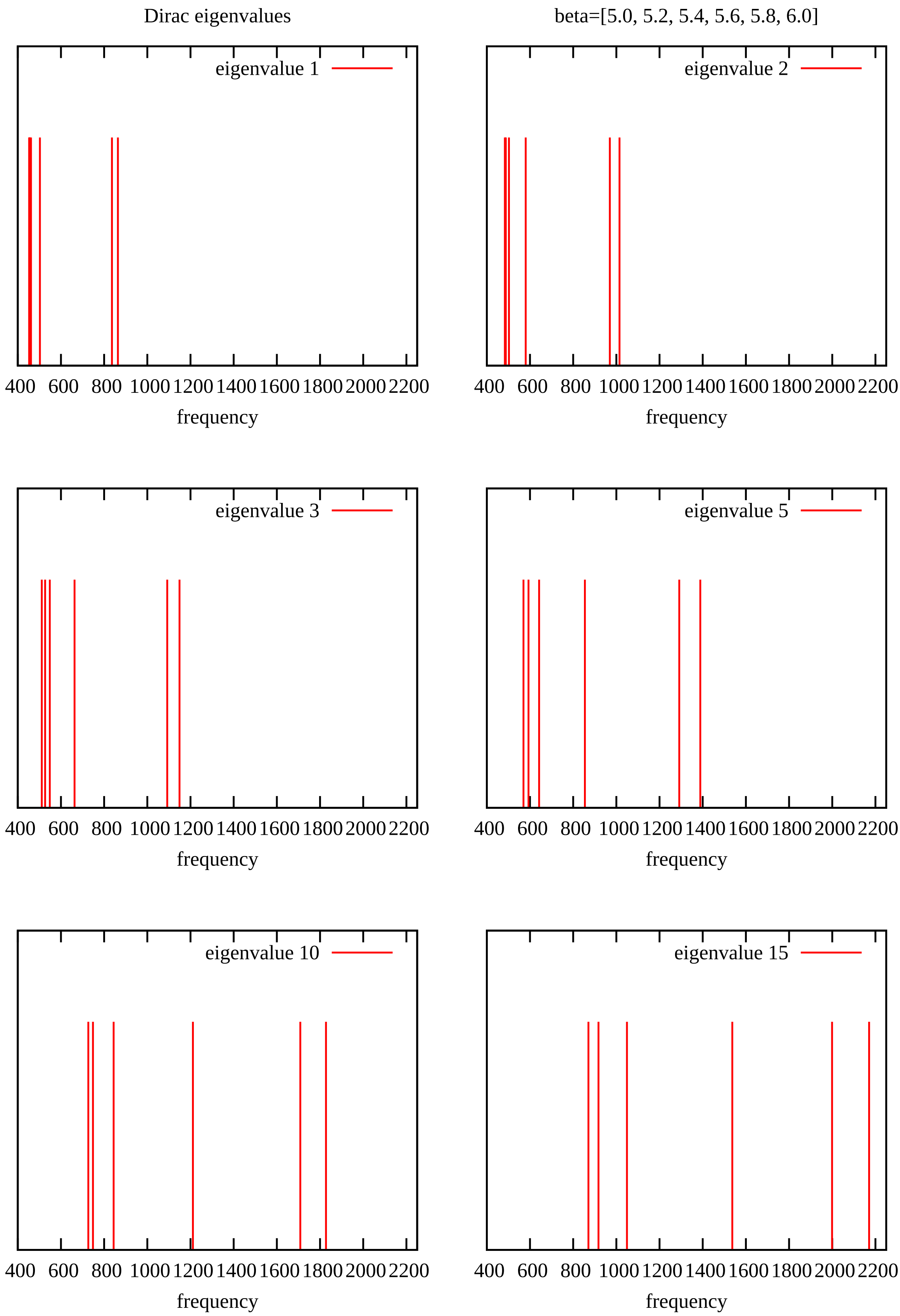

Fig. 2: Six selected eigenvalues transformed into the audible region for values of β across the phase transition from quark confi nement to the quark-gluon plasma.

Fig. 3: Screenshots of the lowest and the 10^{th} eigenvalue of the Dirac operator from the confinement to the deconfinement regions.

In the sonification process we modified a *sclang* code from another sonification project treating baryon spectra obtained from different constituent quark models [6]. In Fig. 3 we present screenshots of the 1^{st} and the 10^{th} eigenvalues from $\beta = 5.0$ to $\beta = 6.0$. Listening to the sound files one can hear that the so-called melody is changing clearly to higher tones around the critical β-value. Both eigenvalue sequences behave similarly. Only the quasi-zero mode of the lowest eigenvalue starts around 440 Hz whereas the higher eigenvalue begins correspondingly higher. This means that one can hear the restoration of chiral symmetry when increasing the coupling beyond the phase transition to the quark-gluon plasma. These sample results are stored on the SonEnvir server and can be accessed there [7].

3.1 Concluding Remarks

This contribution reports on further attempts of applying auditory display to data from lattice QCD. The aim has been to find possible advantages in the data analysis through sonification. Using the example of the eigenvalue spectrum of the Dirac operator some primitive sound files have been generated that allow to hear evident features, which have been familiar already from other kinds of data analysis, in particular, from graphical visualization. In this regard, sonification as applied here can be seen as an additional tool of data representation. Of course, one should find more refined means of auditory display in order to make further qualities apparent in some given data sets. Sonification offers the chance to detect structures in the data sets that have been hidden to the methods applied so far. Data analysis through sonification might especially be useful for displaying results depending on multiple parameters and/or belonging to higher space-time dimensions. In the context of lattice QCD one could think, e.g., of the investigation of the topological content of certain gauge field configurations.

Acknowledgments

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