PROCEEDINGS OF SCIENCE

Sonification of lattice data: The spectrum of the Dirac operator across the deconfinement transition

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Sonification is the use of non-speech audio to extract information from data. 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 the analyzation process of 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. It might further be used to point out unique characteristics of single gauge field configurations out of many. 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'.

XXIIIrd International Symposium on Lattice Field Theory
25-30 July 2005
Trinity College, Dublin, Ireland

∗Speaker.
†The project 'SonEnvir' (http://sonenvir.at/) is fi nanced by the Future Fund of the Province of Styria, Austria.

PoS(LAT2005)152

1. Visualization and Sonification

In many areas of 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 warehouse 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 insight into the structures behind the data. This discipline is called sonifi cation and a defi nition can be found in the wikipedia: Sonifi cation is the use of non-speech audio to convey information or perceptualize data (http://en.wikipedia.org/wiki/Sonifi cation). The International Community for Auditory Display (ICAD) (http://www.icad.org/) 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. At the request of the NSF in 1997 the ICAD provided a Sonifi cation Report.

2. Sonification Package

Sonifi cation needs a realization on software and hardware platforms. We will describe 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 fi nished.

The SuperCollider environment consists of two applications, a client *sclang* (that is the language) and a server *scsynth* (that is 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, e.g., the *emacs* editor. The synthesizer (*scsynth*) can make use of the ALSA sound system. We mention that beside this professional solution there is a simple sonifi cation tool implemented in newer versions of Mathematica, and MATLAB supports treating data vectors as if they were audio signals and playing them.

3. Application to Lattice QCD

In order to study the possible use of sonifi cation in lattice fi eld theory we took as an example the eigenvalue spectrum of the Dirac operator from existing data [1]. We generated gauge fi eld confi gurations 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 β and typically produced 10 independent confi gurations for each β.

Figure 1 shows a graphical presentation of the 15 lowest eigenvalues from $\beta = 5.0$ to $\beta = 6.0$. The phase transition to deconfi nement occurs around $\beta = 5.7$ where all quasi-zero modes vanish.

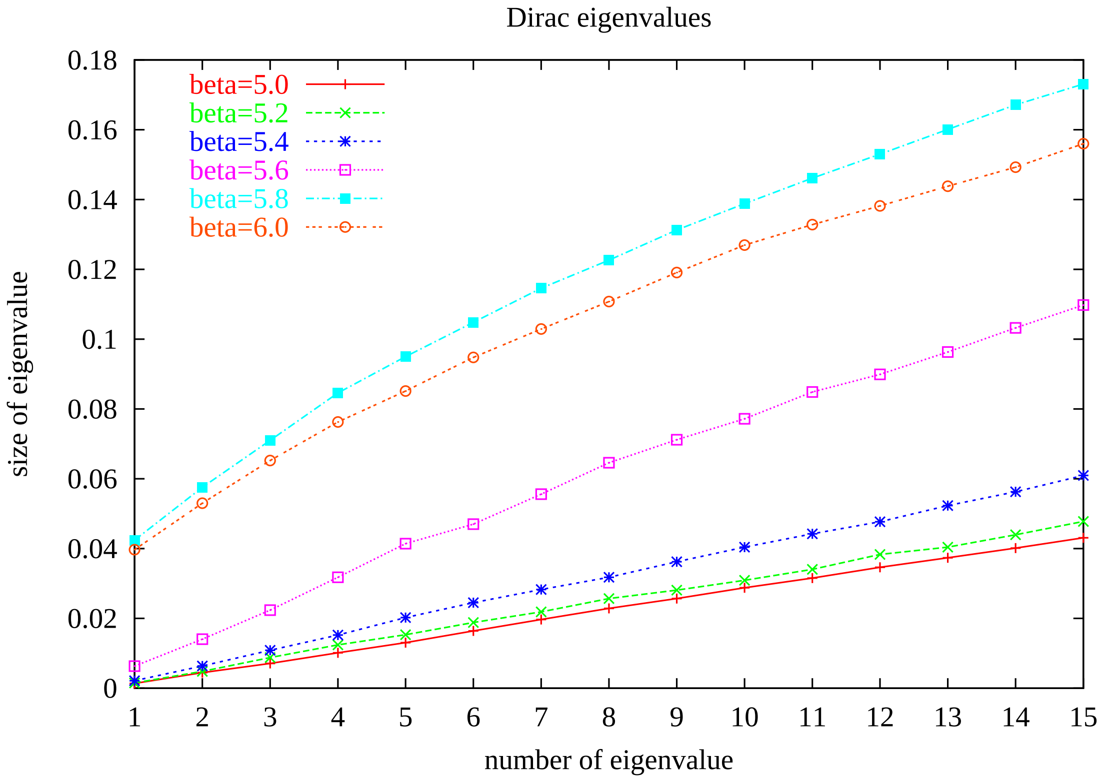

Figure 1: Configuration averaged values of the 15 lowest levels of the eigenvalue spectrum of the Dirac operator for 6 different couplings β.

For the auditory presentation we multiplied the raw data by a factor of 10000 and added the standard pitch of 440 Hz. The outcome is shown in Fig. 2 for the spectra from the confinement to the deconfinement phase.

In the sonification process we modified a *sclang* code from another sonification project treating baryon spectra obtained from different constituent quark models [2]. In Fig. 3 we present screenshots of the 15 lowest eigenvalues for $\beta = 5.0$ and $\beta = 6.0$. Listening to the sound files one can hear that the so-called melody is rather similar for the β-values in the confinement phase with a slight increase towards higher coupling. The quasi-zero mode of the lowest eigenvalue stays around 440 Hz. After the transition to the deconfinement region the melody changes clearly to higher tones. The lowest eigenvalue starts above 800 Hz. This means that one can hear the restoration of chiral symmetry when increasing the coupling to the quark-gluon plasma-phase. These sample results are stored on the SonEnvir server and can be accessed there.

4. What One Has Learned

This contribution reports first 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

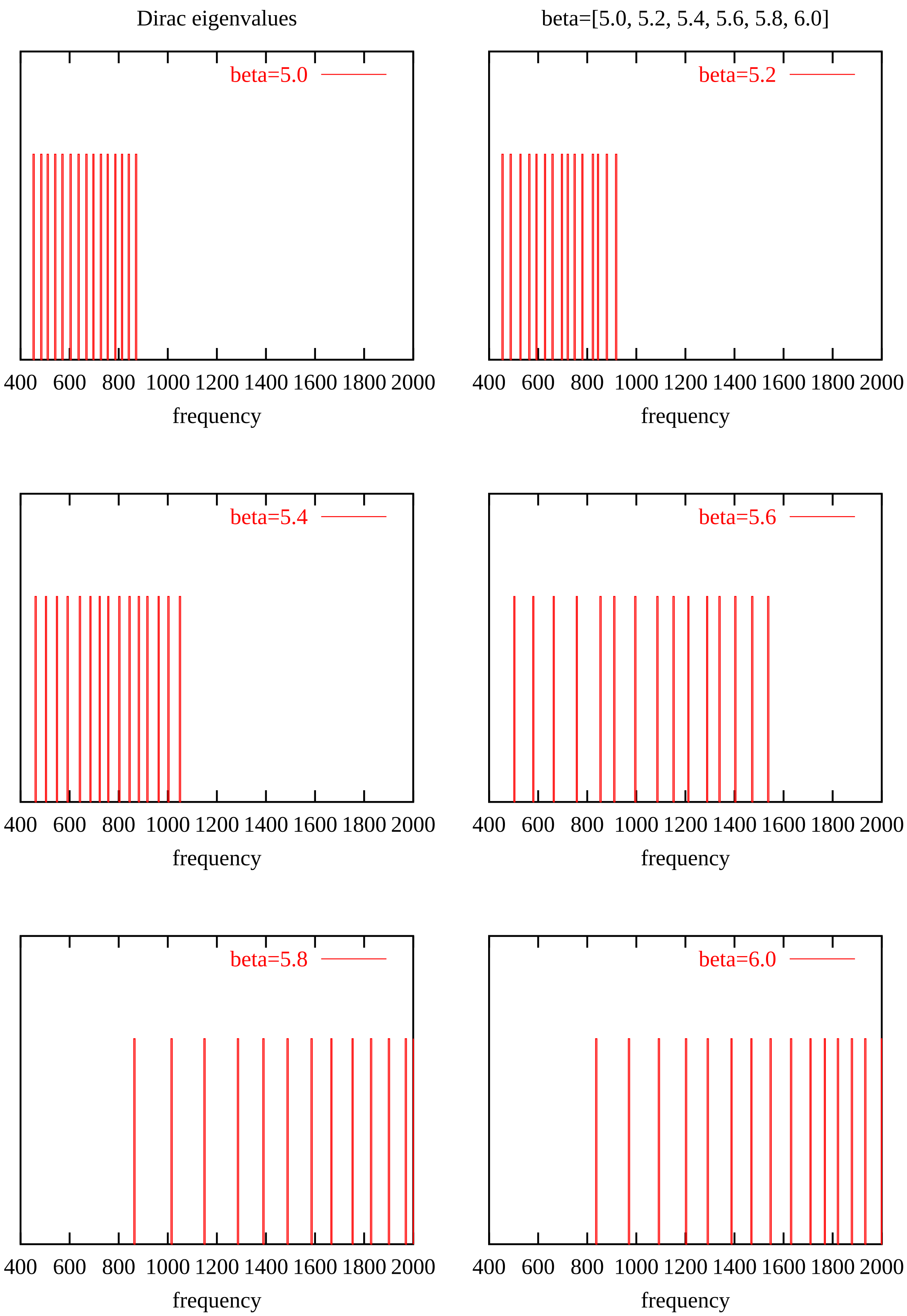

Figure 2: Eigenvalue spectra transformed into audible region for β-values across the phase transition from quark confinement to the quark-gluon plasma.

Figure 3: Screenshots of the low-lying part of the spectrum of the Dirac operator in the confinement and deconfinement regions.

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.

Acknowledgment

We acknowledge the assistance of Rainer Pullirsch in producing the eigenvalue spectra of the Dirac operator. The speaker thanks Philippe de Forcrand for making him aware of the sonification tool in Mathematica.

References

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