Sonification of Multi-Channel Image Data

T. Hermann
Neuroinformatics Group
Faculty of Technology
University of Bielefeld
Bielefeld, Germany

T. W. Nattkemper
Neuroinformatics Group
Faculty of Technology
University of Bielefeld
Bielefeld, Germany

H. Ritter
Neuroinformatics Group
Faculty of Technology
University of Bielefeld
Bielefeld, Germany

W. Schubert
Neuroimmunology and Molecular Pattern Recognition Research Group
Institute of Medical Neurobiology
MELTEC Ltd.
University of Magdeburg
Magdeburg, Germany

Abstract *This paper presents a method to inspect multi-channel image data by creating audible* sonifications*, which are 'sound images', computed from a stack of image data. While visualization of multi-channel image data is limited by the available three color channels, our perception of sound is sensitive to a potentially much larger number of frequency channels or dynamic patterns, that can be perceived simultaneously. Browsing the image stack while listening to the sonifications facilitates the identification of intensity patterns and the discrimination of similar patterns. Some sonification designs which use different organization principles of acoustic elements derived from the data in the image stack are presented and sound examples are given. The evaluation of Multi-Parameter Fluorescence Microscopy Data is presented as a well suited application of this sonification method.*

Keywords: sonification, auditory display, multi-channel data analysis, fluorescence microscopy, functional proteomics

1 Introduction

The comprehension of complex and high-dimensional data and the detection of regularities in such data is an important aspect in many research questions. To approach this goal, Exploratory Data Analysis aims to provide human experts with methods to inspect their data in various ways in order to discern interesting patterns. Often the data are presented as a visualization to bring to bear our very high developed pattern recognition capabilities. However, we also have comparably high-developed pattern recognition capabilities in the auditory domain, which is shown to a high degree in our ability to interprete complex auditory signals like human speech correctly even in very noisy environments (cocktail-party effect). In some domains, our auditory sense is routinely used: for example in electrophysical laboratories, audio monitoring of single cell recordings is a standard procedure for single cell identification; or in medicine, where the stethoscope still provides valuable guidance to the physician. The research field of *sonification* [5] focusses the development of methods to bring arbitrary data into an acoustic form that allows us to invoke our auditory senses to improve data comprehension.

One frequent data type, e.g. in medical research, geography or biology, is a stack of images where each image provides different information about an object. Consider, e.g. the mapping of an area in geography, where infor-

mation like climate, rainfall, soil composition, etc. are shown in different maps from the same area. Similarly, many biomedical applications like Multi-Parameter Fluorescence Microscopy or Multispectral Magnetic Resonance Imaging (MR) lead to a stack of images. The usual way to inspect these images is to arrange them in a grid as shown in figure 2. However, to perceive the data for one specific point, the eyes have to browse through all images and to compare the corresponding positions. A prominent method is to assign up to three different intensity images to the RGB-channels of a color image. In an alternative approach [2], the colors are transformed to a hue-saturation-luminance color model. However, while visualization is limited to the number of color channels, our auditory sense is sensitive to a larger number of frequency channels which are processed in parallel. Therefore, we suggest to employ the color-based channel coding strategy *in the auditory domain* leading to a new sonification strategy aimed at assisting the perception of subtle correlations in image data stacks by utilizing the multi-channel processing capabilities of our auditory system simultaneously to vision.

The paper is structured as follows: section 2 discusses auditory maps and presents some strategies to sonify localized data. In section 3, evaluation of Multi-Parameter Fluorescence Microscopy data is presented as an example application and the specific requirements for the examination of these data are listed. In section 4, different sonification designs are presented and sound examples are given. The paper concludes with a discussion.

2 Auditory Maps

In a printed stack of images or maps, information can only be accessed sequentially as the eyes need to attend the corresponding points on the individual images one by another. The access of the information can be strongly enhanced through the usage of computerized maps, as they don't have to be static, but can use windows, dynamically created to show, e.g. detailed information around the pointer position through the image stack, or RGB-color channels used for a combined display of up to three mono images. However, these and alternative ways to enhance the visualization require extra space on the display and increase its complexity, eventually overloading it and thus complicating comprehension. Auditory maps [6] offer an alternative by using our auditory channel to distribute the perceptual load more evenly among our sense modalities. For the visual channel, this entails as a second important benefit less disruption of the view of the underlying image.

There are different ways to access the information of the image stack, either (i) by browsing a map, which leads to a sonification of the local data at the mouse pointer, (ii) by selecting a path in one image along which the data is sonified, (iii) by selecting an area, to get a sonification which summarizes all included data. Each method offers particular benefits and must be selected dependent upon the task at hand. In this paper, we concentrate on (i). Sonifications for the other access types can then be derived by a suited composition of the individual point sonifications.

For each of (i)...(iii), the sonification can be generated by one of the following methods:

- **Parameter Mapping:** a single sonic event (i.e. a single tone) is generated whose acoustic properties (pitch, volume, duration, timbre, envelope, modulation, etc.) are controled by the components of the image data vector [7].

- **Model-Based Sonification:** the data is taken to parametrize a "virtual resonator", which is then excited to vibrational motion. This motion is determined by differential equations and leads to the sound. Thus the transformation from data into the sound is now implicitly [4].

- **Auditory Scene Generation:** an acoustic scene with one or more "streams" is controled by the data. For instance, a

set of events is generated while the data controls the temporal or harmonical relations between these events or streams [1].

In the presented biomedical application, the comparison of intensity vectors at different points of the image stack is important. Therefore, memorization and learnability of the sound play an important role. As people are usually good in remembering musical phrases (short melodies) and distinguishing rhythmical and harmonical structures, we chose the auditory scene generation approach, using musical elements. Details of the design are described after introducing the biomedical application.

3 Multi-Parameter Fluorescence Microscopy

As an example application, we consider the evaluation of biomedical image data from organic samples. In our collaboration, Multi-Parameter Fluorescence Microscopy data of immunofluorescently labeled lymphocytes has to be analyzed. One experimental data set consists of n intensity images of the sample. As a result of a specific immunolabeling technique [8, 9], in each image different subsets of the lymphocytes appear with high intensity values, indicating the existence of a specific cell surface protein. Because the positions of the cells are not affected by the labeling process, the n fluorescence signals of a cell can be traced through the image stack at constant coordinates as shown in figure 1.

The analysis of such stacks of images by an expert user is limited to two strategies in most laboratories: the images are analyzed one after the other or up to three images are used for a correlative visualization as described in section 1. Figure 2 shows a typical subset of images and the averaged intensity histogram for 2 cells. Comparison of the fluorescence patterns in this visualization is rather time-intensive. In contrast, sonification of the stack of images allows to perceive the complete pattern of *all* markers. In the experimental setup considered here, the number of markers is much larger

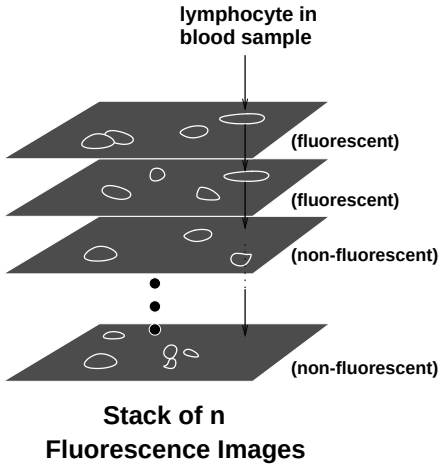

Figure 1: A sketch of a fluorescence microscopy image stack. Each image represents the data of one channel. See text for details.

than 3. For our first sonifications, we decided to omit the spatial profile of the cells and computed an average intensity on a p pixel circle around the pointer position.

To enable an efficient evaluation of an image stack, the sonification was designed to satisfy the following requirements:

(a) cells with identical fluorescence patterns should very easily be perceived as identical sounds,

(b) similar cell fluorescence patterns should lead to sonifications that sound similar,

(c) the sonification should be extensible, so that the further addition of new marker substances does not change the sound characteristics given by the previous markers,

(d) the whole sonification should last only a short time of about 1,5 secs to allow fast browsing of the image stack.

(e) a sonification of a selected area should give both the information about the patterns that occur and their relative frequency.

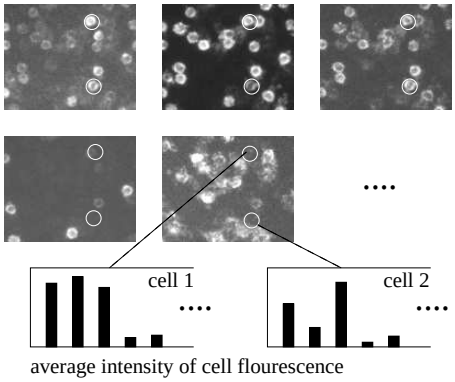

Figure 2: A subset of 5 images of the stack are shown on the grid. The average fluorescence intensity is summarized for two cells in histograms.

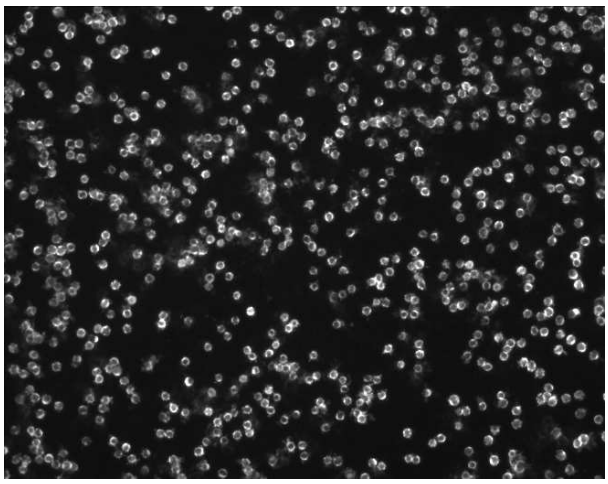

Figure 3: A typical Fluorescence Microscopy Image, here for a blood sample with marker cd_03

4 Sonification Design

As mentioned above, we chose the auditory scene approach to render the sonifications. A good example for an auditory scene is the sound of an orchestra, where each instrument represents one stream. This scene is a good choice since instrumental sounds are easier to synthesize and to control than many environmental sounds. However, we first restricted ourselves to a single acoustic stream for the representation of single cell fluorescence patterns. To increase the memorization of the patterns, it proved reasonable to restrict the pitches of the tones to the musical diatonic scale, thus leading to rhythmical, resp. harmonical patterns which are familar to the average listener of music.

Rhythmical Sonifications:
The first approach was to generate a chain of events, where the onset is driven by the marker number and the pitch is controled by the intensity, leading to a rhythmical structure. Extension of the set of markers can be done by prolongation of the event chain. We used a percussive sound resembling a "conga drum" in such a way that fluorescent markers lead to a higher pitched sound than non-fluorescent markers. However, if an activation pattern is just a shifted version of another pattern, these two patterns are semantically very different but the sound still is rather similar. Another disadvantage concerns the duration: if we allow for less than about 100 ms between two events, the memorization suffers, but for separations longer than 100 ms, the total duration of the sonification is getting too long, violating (d).

Harmonical Sonifications:
Whereas the former sonification simply leads to a rhythmical pattern, the next design exploits harmonical relations. The different markers now are differentiated by different pitches of a decaying tone. Playing the tones of all activated markers results in a chord. To get chords which can be easily discerned by humans, it is important to make a good selection of the assignment from markers to tones. A simple diatonic mapping could lead to tone clusters which are difficult to distinguish. Additionally, if the number of markers gets too large, the chord is too complex and thus is also difficult to memorize.

Melodical Sonifications:
Combining the previous two approaches, the pitched tones that correspond to the activated markers are played in a sequence and we obtain short musical phrases, which are more easy to

memorize and to distinguish. However, there are many other ways to get melodical sonifications. An interesting variant is to divide the sonification into three chunks: the first is an arpeggio of the tones for all activated markers, the second chunk plays all sounds for markers whose intensity is in between 'on' and 'off'. The third chunk plays all tones of markers which are 'off'.

Multi-Stream Scenes:
The previous sonifications allowed to perceive the pattern of activated markers. However, the correspondence from pitches or rhythmical positions to the markers must be learned. This can be facilitated by the usage of different sound classes for the markers, e.g. using percussion instruments, sounds of string instruments, animal sounds, etc. for the different markers. Every marker then is presented by a different auditory stream. This approach allows the extension by simply adding further streams to the soundscape. However, our experiences have been that more listening time is required with increasing number of streams to be aware of all markers.

Sound examples for all different approaches can be found at [3]. The sounds present pairs of cells with different, similar and identical activation patterns using the different sonification methods. An additional sound example presents a sonification along a path through 8 cells, where two of them have different fluorescence patterns than the rest.

The melodical sonifications proved most useful for the task of making comparisons between cells. They have been optimized using synthecially generated cell images. Then they were tested with real data from Multi-Parameter Fluorescence Microscopy Experiments.

5 Discussion

Sonification of Multi-Channel Image Data was presented as a method to inspect high-dimensional data by listening to their sonifications. In contrast to the visualizations which are limited to 3 color channels, the sonifications allow to draw correlations from data of much higher dimensionality. As a second benefit, the sonifications provide this information without disrupting the view onto the image.

The described sonifications have proved useful in the presented biomedical application for the recognition of frequent patterns, the identification of rare patterns and to perceive similarity of patterns. Surely, interpretation of the sonifications has to be learned. Therefore, establishing standard sonification procedures, which allow the biomedical expert to accoustom to the sonification will result in learning effects that improve his/her abilities to interprete the sonifications. However, such a standard has to include ways to extend the sonifications without changing the previously learned patterns. The presented sonification are extensible in different ways: on the one hand, new markers can be easily integrated into the sonification, on the other hand, completely different information like the cell's radial intensity profile can be integrated, for instance in form of the events' acoustic substructure.

The described sonifications give a localized view to the image stack. However, the described point sonifications build the basis for area sonifications, which give a summary of all cells in a selected area. These sonifications could be rendered as a sequence of differing single cell sonifications, where the relative volume corresponds to the relative number of cells in the image stack with a similar pattern.

Systematic evaluation in form of empirical experiments which measure the usefulness in terms of error rate, cognitive work load and processing time to browse a set of cells are certainly required and will be the scope of future research.

References

[1] R. Bargar. Pattern and reference in auditory display. In G. Kramer, editor, *Auditory Display.* Addison-Wesley, 1994.

[2] C. Gawbay, G. Brugal, and C. Choquet. Application of colored image analysis to

bone marrow cell recognition. *Analyt. Quant. Cytol.*, 4:272, 1981.

[3] T. Hermann. Multi channel image data browsing by sonification - demos. http://www.techfak.uni-bielefeld.de/~thermann/projects/index.html, 2000.

[4] T. Hermann and H. Ritter. Listen to your Data: Model-Based Sonification for Data Analysis. In M. R. Syed, editor, *Advances in intelligent computing and mulimedia systems*. Int. Inst. for Advanced Studies in System Research and Cybernetics, 1999.

[5] G. Kramer, editor. *Auditory Display - Sonification, Audification, and Auditory Interfaces*. Addison-Weslay, 1994.

[6] E. P. Glinert M. M. Blattner, A. L. Papp III. Sonic enhancement of two-dimensional graphics displays. In G. Kramer, editor, *Auditory Display*. Addison-Wesley, 1994.

[7] C. Scaletti. Sound synthesis algorithms for auditory data representations. In G. Kramer, editor, *Auditory Display*. Addison-Wesley, 1994.

[8] W. Schubert. Antigenic determinants of t-lymphozyte $\alpha\beta$ receptor and other leucocyte surface proteins as differential markers of skeletal muscle regeneration: detection of spatially and timely restricted patterns by MAM microscopy. *Eur. J. Cell Biol.*, 58:395–410, 1992.

[9] W. Schubert. Molecular semiotic structures in the cellular immune system: key to dynamics and spatial patterning? In W. Zimmermann J. Parisi, S.C. Mueller, editor, *A perspective look at nonlinear media in physics, chemistry and biology, Lecture notes in physics*. Springer, Berlin, 1997.