TANGIBLE COMPUTING FOR INTERACTIVE SONIFICATION OF MULTIVARIATE DATA

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ABSTRACT

We present a novel tangible computing system for interactively controlling real-time and offline data sonifications. Tangible objects serve as physical representation for data series such as EEG channel time series, and their arrangement on our Tangible Desk (tDesk) surface is used to interactively explore features of interest in the real-time rendered sonifications. A listener object and its distances to the data objects are used to select how salient the channels' sonic representation is in the overall sonification. Selector objects allow intuitive specification of data sets. This interface enables the user (a) to identify groups of correlated rhythmical behavior, (b) to control multiple channels simultaneously, and (c) to explore the data collaboratively in a team. We give a full account on hard-/software of the system and we demonstrate the system at hand of offline- and real-time sonification of EEG and stock market data.

Keywords: Interactive Sonification, Tangible Computing, EEG data analysis.

1. INTRODUCTION

In most of the current data analysis problems, researchers are confronted with the challenge of identifying relevant structure in large repositories of high-dimensional data. Yet it is essential to understand what sort of structure is 'hidden' in the data before data mining techniques might be applied to proove or disproove any hypothesis. For that reason, *exploratory data analysis* techniques gain an increasing importance to catalyze the successful solution of complex data analysis problems. Particularly in case of multivariate data streams as they arise for instance in biomedical contexts such as EEG, or any other complex system such as stock market trading or network traffic, structures are likely to occur in a rhythmical organization like for instance as a change of correlation, synchronization, phase differences. These all are structures where our human listening skills are particularly strong. Thus the combination of visual data mining and sonification techniques, rendering auditory representions, may help researchers significantly to accelerate the process of getting a good overview, to discover the unexpected, and to stimulate interesting hypothesis.

Interactive Sonification puts the particular focus on the tight closure of the interaction loop between the user and a sonification system [1]. In this paper, we present an approach that uses physical (tangible) objects to establish a highly intuitive and tightly closed control-loop in which data can be experienced via manipulating object parameters such as position and orientation. In summary, the spatial organization of several tangible objects on in the interaction space determines how data channels contribute to the sonification. Moving a 'listener object' allows to interactively select what data channels are fused within the sonification and how pronounced.

Figure 1: Tangible Interactive Sonification - showing bimanual interactions while interactively tuning the sonification of stock market data. The red object is the sonification object, which here acts as listener to data streams.

Classical alternatives to our tangible, physical, spatially structured interaction system would employ GUI interactions with a very limited number of interactands (typically there is only a single mouse pointer), or multi-fader systems like MIDI mixboards, where the topographical organization is fixed (typically by a linear organization).

Our system offers a rather high control dimensionality, giving each object at least 3 degrees of freedom, and our system is open for extensions that make use of the objects' internal degrees of freedem, e.g. by using malleable objects [2] we can give control over a large number of sonification parameters. On the interaction level, the system infrastructure now enables us to use physical activity like 'shaking data objects' to temporally excite their contribution to the sonification and thus an intuitive on-the-fly focus setting, but we do not demonstrate such interactions in this paper.

2. REAL-TIME ANALYSIS OF MULTIVARIATE DATA

Multivariate data are a very common data type in science and economy. The standard representation is by using state vectors $\vec{x}(t)$, whose components represent different features $x_i(t)$ that change with variable t, typically the time. In the case of EEG measurements, each component would be a channel voltage, in case of trading data, each feature could be a stock price. Standard exploratory analysis of real-time data is often done visually via stacked function plots as shown in Fig. 2 so that the time structure remains visible. While such a display is suited to judge the overall charac-

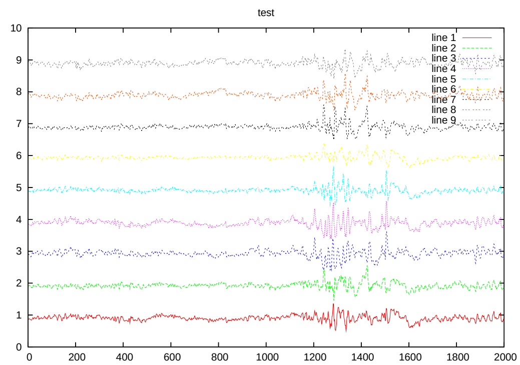


Figure 2: Standard Multi-Time-Series Plot of EEG data, the same data are used for interactive sonification in Sec. 5

teristics, it may be less suited to quickly detect changes, to discover phase shifts between channels or to judge the overall state at a single time in terms of the location in state space. State space plots as shown in Fig. 3 plot a projection of the state trajectory on specific axes (typically principal components). While this allows to see the

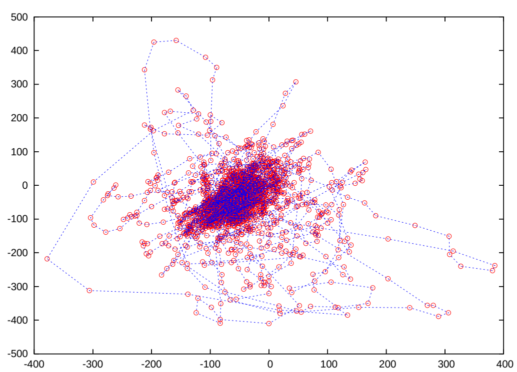


Figure 3: Plotting projection of the state trajectory on the first two principal components, data same as in Fig. 2.

actual high-dimensional state at a single time point, it obscures the temporal evolution over time

The above described case of multivariate data covers scalar functions with well-defined values over time. A somewhat different situation is that of discretized event streams like for instance individual trading transactions, or registered events in physical sensor arrays. Here we certainly have at all times values, yet in addition a density of occurences over time. Certainly, visual displays exist for this data type as well, or can be derived from the above shown displays. However, compared to the above case we here encounter an even increased complexity.

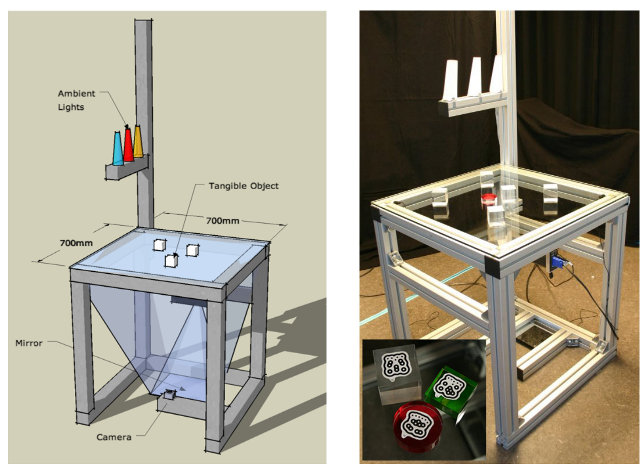
We see that multivariate data exhibit multiple features of interest that are difficult to display in a single visualization in real-time, however, the use of several visual displays in parallel is not a solution since there is only one visual focus at a time. Sonification, however, allows to extend and complement visual displays without disrupting visual analysis, and is in addition excellent at presenting multiple event streams as superposition of several acoustic grain textures.

Concerning display control, we are used to simply direct our visual focus on those elements of the visual display that find our interest, however, we lack a similar directness (of interaction) in auditory display, and here our tangible computing approach comes into play. To control the data in real-time we use a tangible environment called the tDesk (see Fig. 4) to create a novel controlling interface for real-time processing of multi-variate data. The upper limit for the number of channels is determined by the physical extend of tangible objects and the tabletop surface, and the ability of the user to handle all these objects. Our tangible computing approach suggests a solution here, allowing even complex (parallel, multi-user and multi-parameter) control activities without binding the visual focus overly: since proprioception and periphery visual perception already reflect the state of the physical setup, the eyes even remain free to inspect additional real-time visualizations. However, we here limit our interest to the tangible control system attached to the sonification.

3. THE TANGIBLE INTERACTION SYSTEM

3.1. Hardware

As interaction surface we introduce here our tangible desk (tDesk) redesign sketched in Fig. 4.



(a) schema (b) implementation

Figure 4: The Tangible Desk (tDesk) platform

Modularity of our setup and the flexibility to easily and quickly change the desk was a highly important design issue. In result, we assembled the tDesk from BOSCH Rexroth aluminium strut profiles[1]. The glass surface is easily exchangable for instance against a white plastic surface for top projection, or a semitransparent acrylglass for rear-projection. Currently we use a FireWire camera looking from beneath up to track the tangible objects. For object

[1]http://www.boschrexroth.com/

recognition we use the Fiducial Marker Tracking [3], and Fig. 4 shows some colored glass objects equipped with Fiducial markers. For visual display, we use a projector mounted downwards at the rear side of the table, so that its display fills the complete interaction space after reflection on the mirror close to the floor. For sonification, an array of 8 loudspeakers are located around the tDesk to enable spatialized sonification. In addition ambient RGB-LED lamps (shown in Fig. 4) [4] are mounted on the desk, and force sensors can be easily attached to the table to enable tactile interactions with the tDesk surface.

3.2. Tangible Computing Architecture

Most of the used software has been implemented in SuperCollider[5]. Information about tangible objects like the ID, position and orientation are acquired by a visual tracking system based on fiducial markers [3] and sent via the TUIO protocol [3, 6, 7] to the sonification control system shown in Fig. 5. Our tangible computing software architecture allows to manage object administration including events like the creation or deletion of new objects, and to control connected data exploration engines at hand of OSC messages. Sonification Techniques are implemented as classes derived from a data sink (or: display). The software is thus mainly implemented on the SuperCollider language level, and synthesis occurs via Open Sound Control (OSC) communication with the scserver.

Data acquisition is implemented specific to the data type: offline data can be read directly into SuperCollider, and played at arbitrary compressions (including real-time playback), alternatively we have implemented an interface for real-time data processing using OSC.

3.3. Interaction Design

To get an intuitive access to all channels respectively their sonifications we designed our tabletop multi-object tangible user interface as follows: the interaction space (tDesk surface) is used as a 2D-spatial representation of the (potentially higher-dimensional) data space in which the researcher explores the data. This design guideline motivates most of the modeling and mapping described below. Based on parameters such as the position or orientation of tangible objects, the mixing parameters of the various channel sonifications are computed. Fig. 6 illustrates how geometric features are related to control variables. We differentiate between three different object types:

Channel Objects represent a single selected dimension (or feature) of the displayed multivariate data. Their relative position to the Sonification Objects determine the level as a mapping from reciprocal distance, as well as the spatial direction of the associated sound source.

Sonification Objects represent the different sonifications as they are described in Sec. 4. Their orientation may be used further to determine the value of additional parameters.

The Selector Object allows meta-controls of the tangible sonification system: by turning it for instance from one side to another, a different data set can be selected, allowing thus a speedy A-B comparison. In non-realtime mode, the orientation of the objects relative to the tabletop coordinates may be used to determine the playback speed or compression rate.

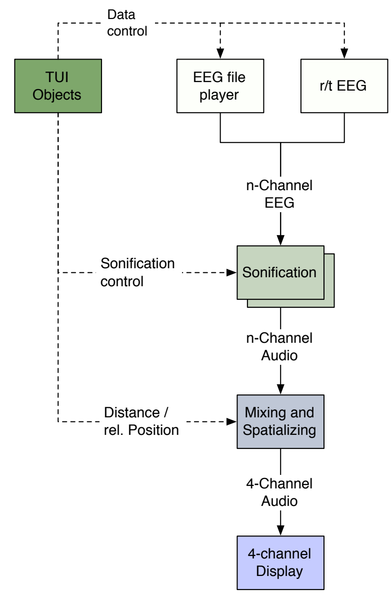


Figure 5: Data Flow Scheme

4. SONIFICATION APPROACHES

For sonification we here use two different quite straight-forward approaches applicable for all sorts of multi-variate data streams. We later exemplify operation of our tangible approach via real-time EEG data and by using some stock market data.

4.1. Multi-stream Audification

Audification is the most direct sonification of data, and often a good first choice to inspect time series data. Since, however, most data show variation in a non-audible frequency range, we here use a windowed pitch shifting technique using granular synthesis. Doing this, for instance the frequency range of interest in EEG (1-15 Hz) can be converted to better audible frequencies without sacrificing the directness of audification. A typical sound for an EEG channel can be heard in sound example S1. For sonification, the following SuperCollider code is used:

```
SynthDef("synBufRd", {
        |out=0, bufnum, rate = 1, amp=0.5, pan=0|
var sum, phase, start, end, buflen;
buflen  = BufFrames.kr(bufnum);
start   = MouseX.kr(0,buflen);
end     = MouseY.kr(0,0.1*buflen) + start;
phase   = Phasor.ar(0,
   BufRateScale.kr(bufnum)*rate, start, end);
sum     = BufRd.ar(1, bufnum, phase,-1);
FreeSelfWhenDone.kr(sum);
Out.ar(out, Pan2.ar(sum, pan, amp));
}).load(s);
```

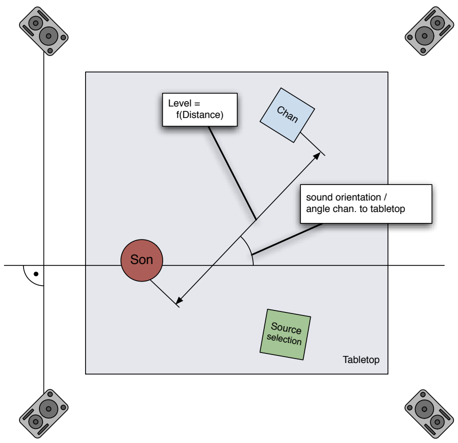


Figure 6: Tangible Channel Sonification Mixing Interface

4.2. Multi-stream sonifications

Continuous parameter mapping sonification is used here to display a single univariate channel data via a single acoustic variable, so that for instance in case of EEG data, the sonification in whole is the superposition of several continuous acoustic signal streams. We practically use a simple sinusoidal `Out.ar(SinOsc.ar(freq, mul: amp))` and regularly update freq and amp in real-time.

4.3. Non-auditory displays

In parallel to the sonification, it is easily possible to use other output display modalities. Via our AmbiD (Ambient Data Display) system described at [4], we can for instance control 3 RGB-LEDs lambs shown in Fig 4. This allows for instance to visualize activity flashes or changing colors. In addition we can use the tDesk's integrated projector to visually display activity within the channels on the table surface or the tangible objects. However, we are just starting to exploit these multi-modal display options.

5. EXAMPLES

In this section we present two example scenarios to demonstrate the sonification part of our setup. For the first example, we use a real-time recorded 4-channel EEG data stream as data source for sonification. The second example deals with pre-recorded stock market data.

5.1. Real-Time EEG Data Streams

It is quite difficult for neurologists to monitor real-time EEG data visually while medicating a patient. So we picked up the idea of real-time sonification of these data. To make use of the tangible environment provided by our tDesk, the user has the possibility to pick out and combine channels of the EEG data streams to tune the sonification for his/her needs.

While data acquisition is here realized in a custom C++-interface to a Nolan Mindset24 neuromapping EEG system [8], all processing and transformation into sound is implemented in the TUIO implementation mentioned in Sec. 3.3. The Mindset24 records up to 24 EEG channels at 256 Hz sampling rate.

In our system there are many possible ways to achieve the aim of a good sonification, because in the tangible computing approach contraints like in GUI programming are not limiting. The developer has to be aware of the freedom of this interaction concept and as a benefit of this, solutions are possible which the developer did not think of before.

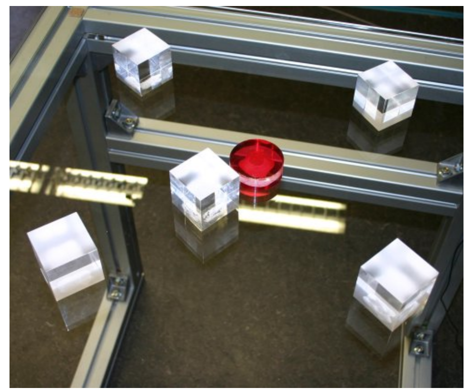


Figure 7: EEG data scenario: Glass cubes represent the channels Fp1, Fp2, O1, O2, the red object is a listener. The nearest object is the data selector which may be rotated to exchange between two different data sets recorded at differing conditions.

Let us review one of the many ways to get appropriate results from the sonification: The user could for instance start with the sonification object located at the center of the tDesk. This object may represent a multi-channel audification or another multi-channel sonification. All available channel objects are then arranged on a circle around the sonification object. Doing this all channels contribute to the sonification at equal share and join to a gentle noise. To find channels which are most interesting, the user might simply move channel objects one by one towards the sonification object in order to monitor the hereby emphasized sonification while the other channels set the background sound. Alternatively, the user may move the listener object towards the channels. The most interesting channels can then be collected into a group (cluster of objects on the table) which can then be arranged around the sonification object to explore spatial sound features. As an extention the remaining (unused) channel objects can be arranged around another sonification object which could for instance represent a multi-channel sonification at different parameter settings which works out other aspects of interest in these channels. In summary, a continuous action sequence leads to the creation and tuning of auditory displays of enhanced utility.

5.2. Recorded Stock Market Data

In this example recorded stock market data are to be explored. A typical situation would be the quick overview of over-night activity for a stockbroker starting to work in the morning, or the wish to discover dependencies and patterns over the past month's data. The user deals with recorded multi-stream data where every channel represents a single stock title. The data were recorded over a period of several weeks with one timestamp every minute.

To navigate these data we identify a single channel object with a product. To select a time window we introduce the selector object and use its (angular) orientation as navigation parameter. This object is comparable to a jog dial, turning it left results in going backwards, turning it right results in going forwards. When remaining at a specific time we use granular synthesis to play the stationary sonification located at that time.

The user might want to sort the channel objects in semantically related groups. For example, stocks of computer companies may be grouped in one pile, medics in another and so on. Now the sonification object loaded with an event-based sonification may be placed at one group and the user inspects this group's behavior through time using the selector object.

6. CONCLUSION

In conclusion, we promote tangible interaction as a novel and highly interactive method to create more intuitive human-computer interfaces for data sonification. The connection of tangible computing and sonification has so far barely been addressed, yet we regard this combination as particularly promising, since acoustic responses that are tightly coupled to object manipulations have the tendency to strengthen the perceived binding between the interactand (here: the tangible object) and its meaning within the exploratory sonification system.

As outlook on our future architecture development plans, we think of implementing more specific object types to enable the user to combine several data sources or display sinks into one object (container object). This reduces the number of objects – which can lead to a problem as pointed out in Sec. 3 – on the tDesk and simplifies the arrangement of objects on the table so that the user can focus on the central issue.

In contrast to container objects it would be useful to have the ability to copy objects (except from the selector object which needs to be unique). This gives for example the user the ability to use one data channel within different sonifications at the same time.

Another novel concept would be filters comparable to the filters implemented in the reacTable project [9]. A filter object, placed between two other objects (in our case a listener and a data channel) - would influence the data stream between these objects. Filters could be simple signal filters like band-pass filters, or more complex operations like for instance finders of local optima in the time series etc.

Different mappings of distance between objects to sonification delays instead of sonification level could make it possible. As a metaphor we could think of data waves emanating spherically from channel objects. This would give the user the possibility to explore temporal coherences like for instance phase differences between data channels.

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7. REFERENCES

[1] Thomas Hermann and Andy Hunt, "An introduction to the discipline of interactive sonification," *IEEE Multimedia*, pp. 20–24, 04 2005.

[2] Matthias Milczynski, Thomas Hermann, Till Bovermann, and Helge Ritter, "A malleable device with applications to sonification-based data exploration," in *Proceedings of the International Conference on Auditory Display (ICAD 2006)*, Tony Stockman, Ed., London, UK, 6 2006, International Community for Auditory Display (ICAD), pp. 69–76, Department of Computer Science, Queen Mary, University of London.

[3] Ross Bencina, Martin Kaltenbrunner, and Sergi Jordà, "Improved topological fiducial tracking in the reactivision system," in *Proceedings of the IEEE International Workshop on Projector-Camera Systems (Procams 2005)*, San Diego, USA, 2005.

[4] Till Bovermann, Thomas Hermann, and Helge Ritter, "A tangible environment for ambient data representation," in *First International Workshop on Haptic and Audio Interaction Design*. multivis, Aug 2006, vol. 2, pp. 26–30.

[5] "Supercollider hub," URL, July 2004, `http://supercollider.sourceforge.net/`.

[6] Till Bovermann, "Tuio homepage," URL, 2006, `http://tuio.lfsaw.de/`.

[7] M. Kaltenbrunner, T. Bovermann, R. Bencina, and E. Costanza, "Tuio: A protokol for table-top tangible user interfaces," in *Proceedings of Gesture Workshop 2005*. 2005, Gesture Workshop.

[8] Daniel Schmitzek, "Echtzeit-sonifikation von eeg-daten," M.S. thesis, Bielefeld University, 2006.

[9] S. Jorda, M. Kaltenbrunner, G. Geiger, and R. Bencina, "THE REACTABLE," in *ICMC Proceedings 2005*, 2005.