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 correlates for data series such as EEG channels, 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 channel objects are used to select how salient the channels' sonic representation is in the overall sonification. Selector objects serve for the specification of datasets. 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.

Figure 1: Stock data scenario

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 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 represention, 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 that are coupled to meaning within the data exploration system. In summary, the spatial organization of several tangible objects on top of an 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.

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 multifader systems like MIDI mixboards, where the topographical organization can not be maintained appropriately since the channels are here typically organized linearly.

In terms of control dimensionality, our system is open for extensions that make full use of high-dimensional controls, for instance, it is quite closeby to use malleable objects [2] and their internal degrees of freedom to control additional sonification parameters. On the interaction level, it is even possible to use activity like 'shaking data objects' to temporally excite their contribution to the sonification and thus an intuitive on-the-fly focus setting.

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 the price of a stock product. The standard (visual) analysis of real-time data is via stacked plots of function plots as shown in Fig. 2 so that some information in time remains visible. While such a display is suited to judge the over-

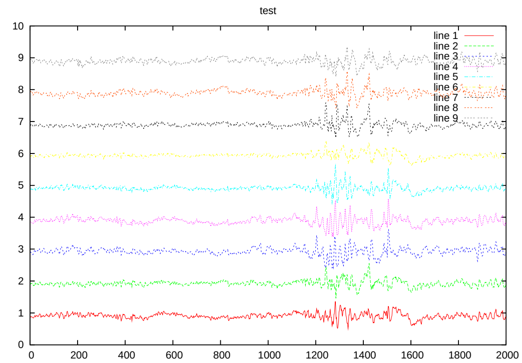


Figure 2: Standard Multi-Time-Series Plot of EEG data, the same data are used for interactive sonification in Sec. 5

all characteristics, 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

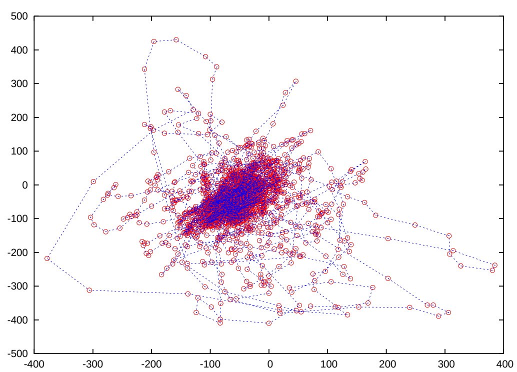


Figure 3: Plotting projection of the state trajectory on the first two principal components, data same as in Fig. 2.

allows to estimate the 'typicality' of the state, it may obscure the dynamics over time.

The above described case of multivariate data covers scalar function 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 the latest value, 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.

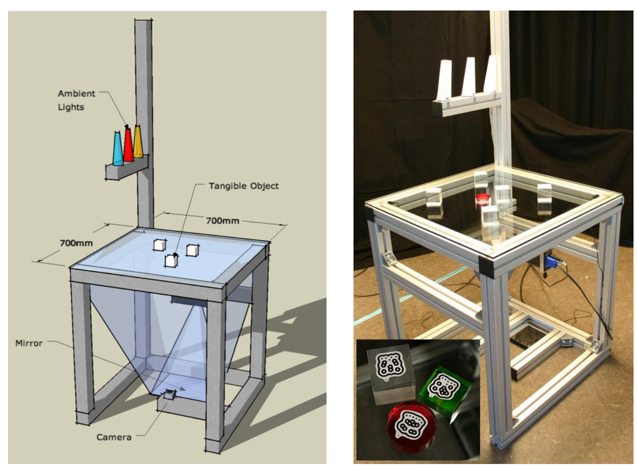
We see that multivariate data exhibit multiple features of interest that are difficult to display in a single visualization in real-time, however, the use of several visuals in parallel is not a solution since there is only one visual focus at a time. Sonification, however, allows to extend and complement visual displays without disrupting any 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 figure 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 pereption already reflect the status 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. The glass surface is easily exchangable for instace 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 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. Concerning auditory display, Loudspeakers are located around the tDesk to enable spatialized sonification and additional elements like ambient RGB-LED lamps (shown in Fig. 4) [4] or force sensors to enable tactile interactions with the desk surface complement the basis tDesk hardware setup.

3.2. Tangible Computing Architecture

Most of the used software has been implemented in SuperCollider[5]. Information like the ID, position and orientation of used tangible objects are acquired by a visual tracking system based on fiducial markers [3] and send via the TUIO protocol [3, 6, 7] to the sonification control system as 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 implementation is thus 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. While offline data can be read directly into SuperCollider, to be played at arbitrary speed, we also implemented an interface for real-time data acquisition 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 below-described, otherwise to be arbitrarily specified modeling and mapping. 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 of the displayed multivariate data. Their relative position to the Sonification Objects determine level by reciprocal distance as well as the direction of the associated sound source.

Sonification Objects represent the different Sonifications as they are described in Sec. 4. Their orientation determines the value of additional parameters as described below.

The Selector Object allows meta-controls of the tangible sonification system: by turning it for instance from one side to another, the data set under exploration can be exchanged. If this object is not found on the tDesk, no sonification is rendered at all. In non-realtime mode, the orientation of the objects relative to the tabletop coordinates determine the playback speed.

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.

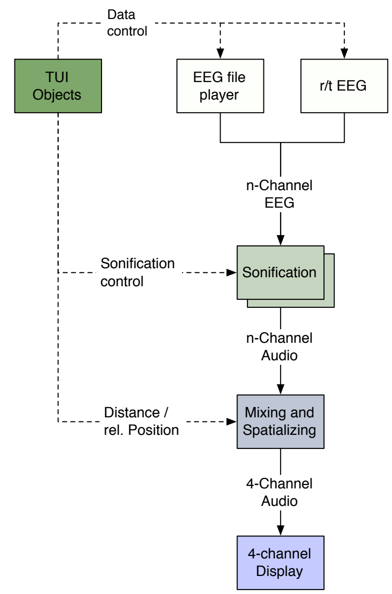


Figure 5: Data Flow Scheme

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);
```

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.

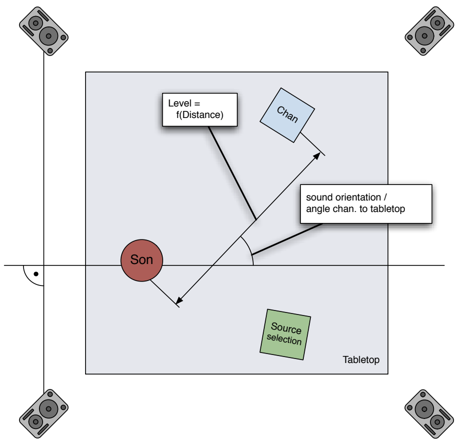


Figure 6: Tangible Channel Sonification Mixing Interface

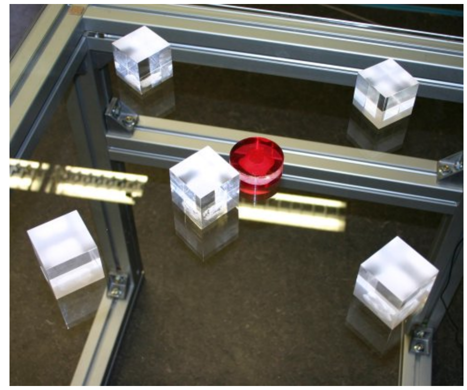


Figure 7: EEG data scenario: Glass cubes represent the channels Fp1, Fp2, O1, O2, the red object is a listener. The nearest object is the data selector which may be rotated to exchange between two different data sets recorded at differing conditions.

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 (called "Ambient Lights") 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 the multi-modal display options.

5. EXAMPLES

In this section we present two example scenarios to demonstrate the versatility of our setup. On the one hand we use real-time EEG data streams as a 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, all processing and transformation into sound is implemented in the TUIO implementation mentioned in Sec. 3.3. The Mindset24 supplies up to 24 EEG channels at frame rates of 256 samples per second.

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 thought of.

Let us review on of these many ways to get appropriate results from the sonification: The user could for instance start with the sonification object in the middle 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 thus emphasized chosen channel while the other channels set the background. 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 exploit 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 hour.

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.

Note to the referee: this is subject to be modified for the ultimate demonstration.

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 [8]. 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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