Bridging the Gap Between Sonification and Visualization

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Abstract
Extensive research has been carried out both on auditory and visual representation of data. Still, there is huge potential for complementary audio-visual analytics environments. This position paper works towards a research agenda for interdisciplinary work.

Author Keywords
Multimodal user interfaces, information visualization, sonification, visual analytics.

ACM Classification Keywords
H.5.2 [Information interfaces and presentation (e.g., HCI)]: User interface—*Graphical user interfaces, Auditory (non-speech) feedback*

Introduction
Data analysis, especially in an exploratory setting is a process that cannot be automated completely but needs to be steered by human analysts. For this, analysts need effective ways to reconcile their knowledge about a subject with the collected data [1, 6]. The research field of information visualization is building a growing body of research and guidelines regarding visual mappings [4, 15] and how multiple views can be combined [14, 18, 23]. However, the visual channel is limited by perceptual constraints [24]. Recent work in information visualization and in particular in visual

analytics has focused on intertwining visual representations with user interaction and automated analysis techniques in order to push these limits further [12, 22].

An enormous potential to improve data analysis on top of that, lies in the auditory channel. The human ear is an effective perceptual organ, which the psychologist Bruce Walker describes as “the best pattern recognition system that we know of” [5]. *Sonification* is defined as “the use of nonspeech audio to convey information” [13] and is studied by the research community of auditory display (ICAD). In particular, the methods of auditory exploratory data analysis [8] and model-based sonification [9] focus on interactive data analysis. In model-based sonification, parameters of multi-variate data sets are assigned to tonal and acoustic attributes, which require user interaction in order to be excited. Other than in more well-known parameter mapping sonification, sound is not created by play back but by user interactions (e.g., browsing in vectorized data space) comparable to playing a musical instrument, which without action remains silent. While there has been extensive research on data sonification for more than 20 years, the majority of studies in the field is constricted to comparisons of auditory, visual, and redundant perception of data displays and the evaluation of users’ performance and perception in order to demonstrate the legitimacy of auditory display in scientific terms.

Although extensive research has been carried out both on auditory and visual representation of data, comparatively little is known about their systematic and complementary combinations for data analysis. Far too little attention has been paid to the interrelation of these modalities. Existing research on combinations has often focused on one modality while neglecting the other. A methodical approach to combine information visualization and sonification in regard to a complementary framework is still missing. This position paper aims to highlight some relevant state-of-the-art and starts the formulation of a research agenda for a joint work in audio-visual analytics.

Related Work

In the visualization literature, we found surprisingly little research that included the auditory channel. Most of the sonification research surveyed includes some form of visual display or interface, but only either as a static representation of the otherwise volatile auditory display or in order to compare the perception of auditory vs. visual vs. both of them combined representations of the investigated data sets [20]. However, actual multimodal approaches, that are based on complementary and supportive interplays between data represented on the visual, auditory, or any other domain, are rare. Hildebrandt et al. [10] showed how the additional use of sound could facilitate anomaly detection or root cause analysis of irregularities and errors. Rönnberg et al. [19] successfully used musical sounds to support the interpretation and comprehension of visualized complex data. Martens et al. [16] enhanced visual displays of proteomic data by sonifications to compensate visual overload. Zhao et al. [25] augmented choropleth maps with sonification to assist users with visual impairments. Férey et al. [7] developed a multisensory system to investigate protein-docking interactions including visual, auditory, and haptic feedback. Surprisingly, Katz et al. [11] found that the 3D spatialization of sounds did not yield significant benefits over the usage of non-spatialized displays in an exploration task based on single stream sonification. The authors, however, expect significant benefits of 3D spatialization for scenarios with augmented complexity. Concerning interactivity, Bovermann, Hermann, and Ritter [2] extended model-based sonification to the Tangible Data Scanning Sonification Model using a tangible user interface object for data exploration.

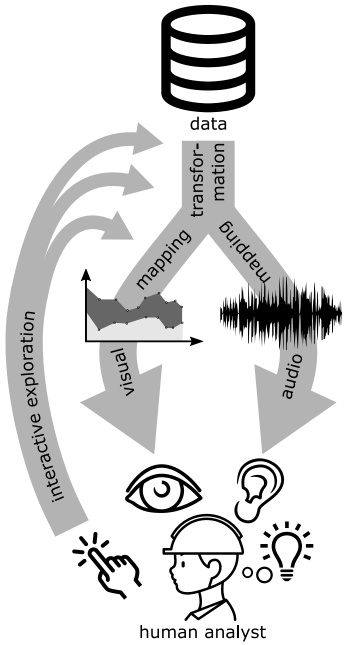

Figure 1: Conceptual process of an audio-visual analytics environment: Data is transformed to images and sound for the human analyst who interactively steers the transformations.
Figure created using work by H Alberto Gongora and Pawinee E. from the Noun Project.

Towards a Research Agenda

Based on the analysis of the scientific literature and our experience from conducting projects in both visualization and sonification, we formulate a preliminary agenda for joint research on audio-visual analytics:

- Characterize the unified design space for complementary parametrizations of visual and auditory data displays (Figure 1). A potential groundwork could be the concept of visual multi-level interface design [14] and multiple views [18, 23].
- Investigate the role of user interaction within an audio-visual analytics environment, e.g., can low-level action taxonomies be unified [17].
- Analyze the training or onboarding needs for users of an audio-visual analytics environment: Does application-tailored training increase the quality of multimodal user perception? Can generalized systematic training methods be derived?
- Develop a study design including tasks, data, and apparatus to experimentally compare different complementary audio-visual displays of data. Conduct first studies for promising combinations and make the study design open for future replications and benchmarking new work.
- Apply audio-visual analytics environments in design studies [21] to collect practically evaluated reference examples and to reflect the learnings.
- Develop principles and guidelines for effective complementary design of visual and auditory displays [3].
- Broaden the scope to other channels such as haptics and towards multimodal input such as speech.

This position paper set out to raise awareness of other modalities within the visualization community. The capabilities of data sonification go far beyond simplistic beeps. What is now needed is more interdisciplinary collaboration with sonification experts. Our first investigations as such an interdisciplinary team identified a huge potential for complementary audio-visual analytics environments.

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