Interaction with sound for participatory systems and data sonification

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CHAPTER 1

General Introduction

1.1 Background

Sound cues are immersive. If we are blessed with a good auditory system, we use sound, i.e. auditory cues and signals to orient ourselves in the environment we live in. This thesis is about using sound in interaction with data. These data can be musical elements, abstract data, scientific data, etc. But more importantly in information systems, the data can be understood through interaction with sound elements. And it is this interaction that we will explore further. In order to get insight in this interaction, we introduce the term ***dialogue*** to analyze and define the whole interactive process (cf. definition 2.1). Dialogue is typically studied in Human Computer Interaction, in which dialogue is studied at three levels: lexical, syntactic and semantic (Dix, Finlay, Abowd, & Beale, 2003). It conveys messages of how a subject communicates with an interactive system and what the system gives back. Therefore, we have included three main elements to develop this dialogue model: *verbal*, *subject* and *adjective* (cf Figure 1.1). A verbal element involves the participation and actions taken by a subject, which initiates a dialogue at lexical level. Depending on the context and scenario, the subject can be a user, a participant, an audience member or a listener in different scenarios. In the dialogue, an adjective describes how a sound is produced by the interactive system responding to subject actions. Additionally, the interaction in this dialogue model requires the user to pick up the clues that are provided by the system through sounds. The design of sounds is essential to complement a dialogue at syntactic level so that a subject can learn the interaction. The clues are given by the total dialogue that is developed between the actions of the user and how a sound is produced through interaction, which can also assist the user to understand the system at semantic level.

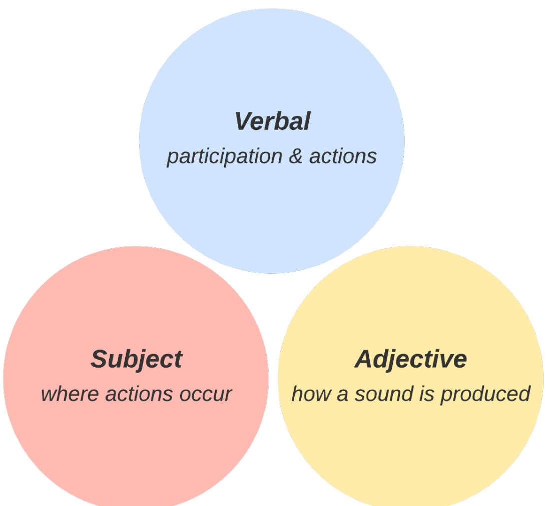

Figure 1.1: The Dialogue Model.

We will study these three elements of dialogue model to be able to propose a

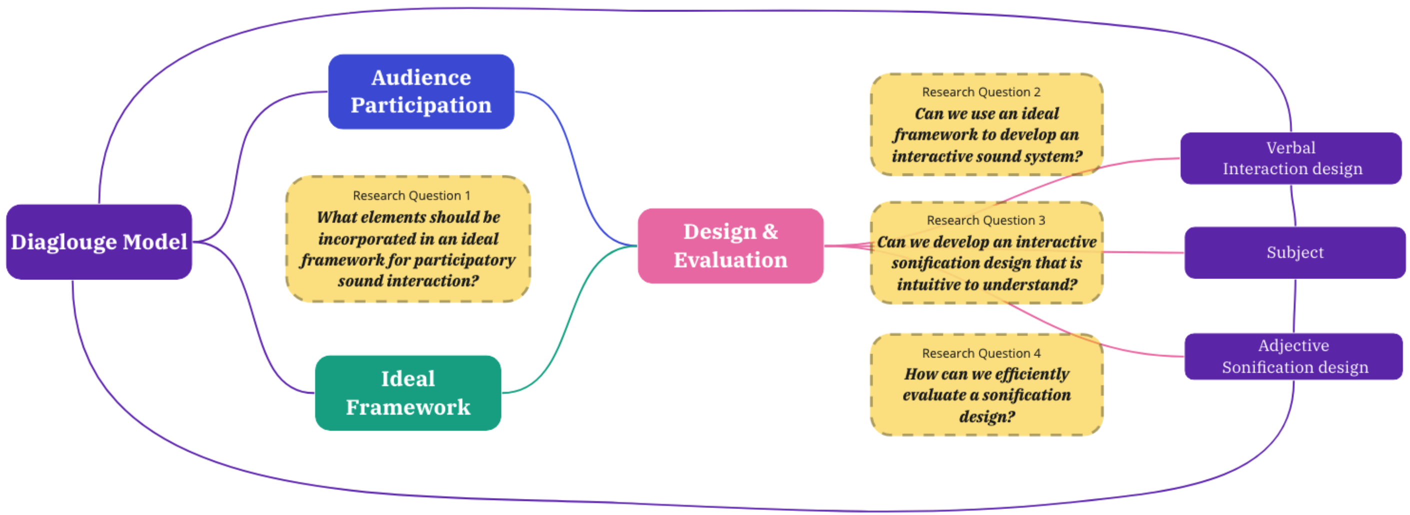

Figure 1.2: Dissertation narrative and structure. The figure presents an overview of the narrative of the dissertation, depicting the key concepts and research questions. The figure also provides a brief outline of the dissertation's structure, including the key topics, their sequence, and their interrelationship, highlighting the flow of the research inquiry.

framework that can be generally applied for sound interaction in Chapter 2 (cf. Figure 1.2). Therefore, participation of users in such interactive environment needs to be investigated first. This requires a very interdisciplinary approach. Subsequently, we intend to extrapolate our findings to an ideal but yet feasible framework. Meanwhile, we consider it necessary to study *data sonification*, in which the sounds are used to represent data in an interactive way and present users to understand data from sound. We will discuss how a sound is produced using different sonification design and how to make it learnable by a subject in Chapter 3 & 4.

1.2 Participatory Sound Interaction Models

Music interaction, as a valuable area of study, is actively used and therefore chosen to generalize concepts. In order to investigate interactive systems in the dialogue model that produce sound or relate to computer mediated music making, we start with participatory musical performance, in which audience is the main subject.

The field of Human Computer Interaction (HCI) is an important additional ingredient to this research. The universal Model-View-Controller (MVC) design pattern for interaction with computers is often used for building interactive software programs. The controller mediates input from an operator and converts it to commands for model and view; the model handles the command according to data and the rules of an application; and the view is the output that represents the data handled by the model such as charts and graphs (Gamma, Johnson, Vlissides, & Helm, 1995). Likewise, Van Troyer proposed three basic components to construct an interaction model in *participatory musical performances*: capture, effect, and performance model (Van Troyer, 2012). This is an extension to the MVC design pattern. While capture controls audience input, effect represents the outcome of audience manipulations. Next, the performance model processes and translates input to output.

In a participatory musical performance, participants are involved in the sound interaction with the intention of producing sound or music (cf. definition 2.2). From the works of Bayliss *et al.* (Bayliss, Lock, Sheridan, & Campus, 2004) and other researchers, we considered it essential to structure interaction phases in different sub-models like the audience model, the environment model, and the output mapping model. In this way, sub-models can be used to generate different interaction models. In another work, Bilda *et al.* proposed various interaction modes and phases indicated from the model of engagement (Bilda, Edmonds, & Candy, 2008), based on their observations and analysis of audience's intentions and expectations during their experience with interactive artworks. Hence, in Chapter 2, we design a participation journey map (cf. definition 2.4) to visualize the process that a subject experiences through uncovering the moments of observation, learning and interaction. This map presents a holistic view aiming to identify and analyze the audience participation form for the discussion of the interactions models. From our analysis in section 2.4 we derive a number of performance models that capture the interactions in different manners. As indicated, we study these participatory musical performances to get more insights in dialogues (cf. definition 2.1) for interaction with sound. Subsequently we will propose an ideal framework for participatory sound interaction.

1.3 Data Sonification: Interaction & Design

In the context of sonification and auditory display, sound has been used to represent complex data, enhance visualizations, as well as support the understanding of items in an educational context. Considering the MVC design pattern, sound is the view and sonification design is the model handling how data is transformed into sounds. Several approaches are distinguished from each other such as the use of earcons, auditory icons, parameter mapping sonification (PMSon) and model-based sonification (MBS) (Hermann, Hunt, & Neuhoff, 2011).

From a review on research in the area of participatory musical performance, we found that an interactive design would help a participant to understand and learn a sonification design and simultaneously the meaning of the sounds. For example, in SoundBounce, participants were able to throw and bounce a virtual ball to each other with smartphones (Dahl & Wang, 2010). The movement of the virtual ball was sonified with frequency modulation synthesis. The melodic pitch got higher, and the sound became louder as the ball rose. Additionally, the sound crossfaded from thrower to receiver. The interaction with the virtual ball is simulated with the affordances found in the real physical world by representing the changes in sounds. This example shows the possibility of an interactive slightly musical performance using a sonification approach (PMSon), which was succeeded in an intuitive interaction between the participants and the sound.

In order to study sound interaction in an audience focusing on a sound dialogue, we designed an implemented Bǎi/摆 as a research object aiming to achieve aforementioned intuitive interaction using data sonification. Bǎi/摆 is an interactive sound installation that uses a pendulum speaker as the interface to interact. The audience is free to move the pendulum speaker. The physical movement of the pendulum is sonified in a way that the control parameters for the sound synthesis are mapped (PMSon). The noticeable sound generated directly from the pendulum speaker can help the audience understand how their actions are being used for the sound and create an intuitive interaction form. Meanwhile, there are six surrounding speakers reacting the pendulum as independent entities (MBS).The sounds generated from the surrounding speakers employ both direct and indirect sonification approaches, which result in a harder understanding of the sound design. This may lead further exploration about the installation so that the audience can navigate through different types of sound composition and reach a continuous interaction. This navigation is a form of interaction to understand the sound and behaviour of the installation. The interaction is bidirectional between the audience and the system. The development process of this installation is a case study that involves both interaction design and sonification design.

In a more abstract case, we use our findings in a data sonification design where a mapping between sound and data needs to be understood. To that end, we use four sounds to represent four chemical elements (H, C, N, O). In order to understand the effectiveness of the mapping and how adjectives can influence a dialogue at semantic and syntactic level, we have designed different sonification designs and implemented an interactive sonification system which the participant navigates through the network of carbons in amino acids structures. In this study, we were interested in multiple concurrent sound sources. We assume such interactive navigation form would help the participants to learn the meaning of the sounds and understand a certain specified area of a molecular structure. Accordingly, participants can recognize and localize the surrounding chemical elements only with auditory signals. Thus navigation is an interactive method for the participants to perceive data and understand sound.

1.4 Evaluation of Data Sonification

From case studies, we learn how participants interact with a system using data sonification designs and we visualize the process with participation journey map. Subsequently, we design experiments to evaluate the system.

In the field of HCI, the System Usability Scale (SUS) has been commonly used to measure usability for interactive systems and applications. However, it is rather general and might not be applied to the field of auditory display or sonification, because of the individual differences in item interpretation. However, a usability framework can possibly be applied when evaluating the efficiency and the effectiveness of a sonification design, depending on the goals that are intended to be achieved in context of use. In previous evaluations of sonification applications, users were given various tasks during a series of experiments. Ibrahim *et al.* reviewed ten types of tasks that were used for measuring usability properties such as effectiveness, efficiency and satisfaction (Ibrahim, Yassin, Sura, & Andrias, 2011). For the experiment, such task design provides possibilities to obtain insights in factors that may influence the sonification design. We have conducted two cycles of experiments to evaluate, and further develop, our sonification design. The first experiment used a pretest-posttest design including training part to evaluate how easy the four element sounds can be identified and recognised. In the second experiment, two conditions of sound were tested using a within-subject design to investigate how many sounds can be maximally recognized and localized. In this way, we have been able to evaluate the learnability, immediacy and other aspects of this sonification design.

1.5 Research questions

Given the discussion presented in the introduction, we here formulate the research questions for this thesis:

RQ1 What elements should be incorporated in an ideal framework for participatory sound interaction?

It is essential to design an ideal framework for participatory sound interaction in the research presented in this thesis. The ideal framework can be generally applied in following research topics. We will answer this research questions in Chapter 2. Formulating the interaction models can be done through the overview of previous related artworks and research. By identifying the roles of the participants and performance models, it becomes possible to discuss related aspects such as: contribution of audience, interaction design, feedback of a system, sound production, etc. Auditory results and proper feedback, visual or otherwise, are possible to assist the audience with learning and understanding the interactive system and performance. Additionally, a responsive system can maintain the interaction between the audience and the system.

RQ2 Can we use an ideal framework to develop an interactive sound system?

Based on the ideal framework we propose in Chapter 2, we develop a sound installation Bǎi/摆 as a case study to answer this research question (cf. Chapter 3). While the audience is interacting with a pendulum speaker, the motion data collected from the speaker are sonified as a feedback responding to the audience. The diverse data and sonification design result in a stochastic system, which takes time to understand. Accordingly, the audience may involve into the interaction to learn, which makes the interaction responsive and ongoing. In order to introduce how an engaging and continuous interaction design is achieved, we will analyze the installation from three aspects: physical interface design, sonification design and experience of the audience.

We will also answer this research questions in Chapter 4, by presenting a deterministic interactive system designed for a single participant. Comparing to the stochastic system designed in Chapter 3, this system is developed in a way that is easier to learn and understand. We use atoms that are sonified in an environment surrounding the participant. In this way a participant can navigate a molecular structure through sounds. The ideal framework is applied to the system design, in which participants are expected to learn the sound mappings with the feedback from interacting with the navigation system. The participation journey map proposed in Chapter 2 will be used to analyze the experience.

RQ3 Can we develop an interactive sonification design that is intuitive to understand?

It is important that a sonification design is easy to understand and learn in an intuitive way (cf. definition 3.3). The development of Bǎi/摆 shows the sonification design of the movement of the pendulum as well as the interaction between the pendulum and surrounding speakers. It is addressed that the audience is able to explore the system or the interactive form without too many instructions (see Chapter 3). The sonification design for the molecular structures aims to achieve a faster and intuitive recognition and localization of the different concurrent sounds, which does not require too much practice and reduces cognitive load (see Chapter 4).

RQ4 How can we efficiently evaluate a sonification design?

We will answer this question in Chapter 5 & 6. Two cycles of experiments are designed for evaluating the sonification design, in order to get insight in factors that may affect individual performance in identifying and localizing concurrent sound sources.

Validation 1 includes a pretest-posttest design with a training phase, aiming at the learnability and effectiveness of the sonification design. The comparison between the results from the pretest and the posttest enabled us to look at different aspects such as element type, directions, durations, etc.

Validation 2 uses a within-subject design focusing at the identification and localization of multiple concurrent sound sources. The development of the two experiments and the analysis of the results may give clues to answer the question.

1.6 Structure of this Thesis

The structure of this thesis is as follows, Chapter 2 investigates several interaction models derived from existing participatory musical performances that are using mobile devices, *i.e.* cellphones. Several potential directions are indicated for the development of an engaging and ongoing interactive dialogue, aiming at answering the RQ1.

Chapter 3 presents the design and development of an interactive sound installation, which relates to RQ2 & RQ3.

Chapter 4 describes an interactive form of sonification in which the participant is able to navigate through a molecular structures of amino acids over the network of carbon atoms. This chapter proposes to use irregular but easy to recognize sounds for the representation of multiple concurrent sound sources.

The sound design is evaluated in Chapter 5 and 6, where two experimental approaches are involved. These two chapters pertain to RQ4.

Results obtained in other chapters are discussed in Chapter 7, answering the research questions and giving relevant perspectives for future studies.

This thesis contains examples of multimedia material, including sounds and videos. Sound samples and video fragments are referred to with a **QRCodes**. The internal camera on a mobile device such as smartphone or tablet can be used to scan the QRcodes, which will then lead to the material.

1.7 Contribution of this Thesis

- **Liu, D.**, & van der Heide, E. (2017). Interaction models for real-time participatory musical performance using mobile devices. In *Proceedings of the 2017 International Computer Music Conference, ICMC 2017, Shanghai, China, October 16-20, 2017*. Michigan Publishing. `http://hdl.handle.net/2027/spo.bbp2372.2017.051`

- **Liu, D.**, Kroese, J., & van der Heide, E. (2018). The development of bǎi: An oscillating sound installation. In *Interactivity, Game Creation, Design, Learning, and Innovation*, (pp. 69–79). Springer. `https://doi.org/10.1007/978-3-030-06134-0_8`

- **Liu, D.**, & van der Heide, E. Interactive auditory navigation in molecular structures of amino acids: A case study using multiple concurrent sound sources representing nearby atoms. (2019) In *Proceedings of the 25th International Conference on Auditory Display, ICAD 2019*, (pp. 140–156), Newcastle, UK. `https://doi.org/10.21785/icad2019.049`

- **Liu, D.**, & van der Heide, E. Evaluating the spatial sonification of the molecular structures of amino acids using multiple concurrently sounding sources. (2021) In Proceedings of the*26th International Conference on Auditory Display, ICAD 2021*, to appear.`https://doi.org/10.21785/icad2021.013`

1.8 Other publications

- Dekker, L., Peeperkorn, M., **Liu, D.**, & Verbeek, F. J. (2019) An Alternative Interaction Paradigm for DNA-Sequence Data. In *Proceedings of the International Conferences Interfaces and Human Computer Interaction 2019 Game and Entertainment Technologies 2019 and Computer Graphics, Visualization, Computer Vision and Image Processing 2019*, (pp. 343-347). IADIS Press. `https://doi.org/10.33965/ihci2019_201906C045`

- Papagiannis, A., **Liu, D.**, Zammit, A., Gultyaev, A. P., & Verbeek, F. J. (2019) Interacting with RNA Secondary Structure through Sonification. In *Proceedings of the International Conferences Interfaces and Human Computer Interaction 2019 Game and Entertainment Technologies 2019 and Computer Graphics, Visualization, Computer Vision and Image Processing 2019*, (pp. 43-49). IADIS Press. `https://doi.org/10.33965/ihci2019_201906L006`