A FRAMEWORK FOR MUSIC-BASED INTERACTIVE SONIFICATION

Nuno Diniz, Alexander Deweppe, Michiel Demey and Marc Leman

Institute of Psychoacoustics and Electronic Music
Ghent University
Ghent, Belgium
`nuno.diniz@ugent.be`

ABSTRACT

In this paper, a framework for interactive sonification is introduced. It is argued that electroacoustic composition techniques can provide a methodology for structuring and presenting multivariable data through sound. Furthermore, an embodied music cognition driven interface is applied to provide an interactive exploration of the generated output. The motivation and theoretical foundation for this work are presented as well as the framework's implementation and an exploratory use case.

1. INTRODUCTION

The development and application of processes that allow the transmission of information using sound has always been a main concern of music composition practice. Particularly in the 20th century, several theories have been suggested for establishing a meaningful and coherent binding of individual sound streams or events. However diverse these approaches might be, they all address the same problem: how to establish a unified context between hierarchical levels of communication that are exposed simultaneously through time. As in music, it is relevant to take this problem under consideration when presenting multivariable data through sound. For illustration purposes, consider the situation where three variables are sonified at a given moment with the C, E and G musical pitches. The presence of a higher level of meaning (a major chord) as well as the intermediate ones (such as the intervals formed by the combination of the individual elements in the pitch set) should be taken into account with the same degree of importance as the individual pitches.

Therefore, the work presented here is focused on the design of a framework which provides a simultaneous encoding of such interrelated levels.This process is a key element in the definition of structures that allow the constitution of contexts in sound data presentation. Furthermore, it is argued that a system that proposes a scalable approach to content should include an interface that provides both a top-down and bottom-up inspection perspective from the outset in order to facilitate the interactive access of these musically structured levels.

In the following section, an overview of some compositional views of Pierre Schaeffer and Karlheinz Stockhausen is discussed in order to establish a relation between musical composition practice and multilevel sound communication. Afterwards, we present the motivation underlying the use of embodied music cognition theory as an interface paradigm for interactive sonification, followed by the main concepts concerning virtual object-based mediation. Then, the framework's design, the technological aspects and the evaluation of an exploratory use-case are addressed. Finally, a discussion of the present work is provided.

2. MUSICAL COMPOSITION AND MULTILEVEL SOUND COMMUNICATION

The application of music-based approaches in non-speech sound communication has been present in the auditory display since the early stages of this research field as, for example, documented in [1, 2, 3]. Furthermore, there has been an evolving interest in on how the compositional processes can be adopted in the sonification domain. By underlining its systematic validity, aesthetic added value and capacity to generate context, the focus has been on how some of these techniques can help provide design options for improving the perceptual cognition of sonification processes' output [4, 5]. Nevertheless, a brief review will follow of some compositional theory and processes that constitute the point of departure for this work.

In the two main initial trends in electroacoustic music, the french Musique Concrete and the Electronic Music from Cologne, the search for ways for establishing relations between material and form is present in the theoretical and compositional production of their leading advocates, Pierre Schaeffer and Karlheinz Stockhausen. According to Michel Chion's Guide to Sound Objects, the sound object, as defined by Schaeffer, is perceived as an object only in an enclosing context. This dependency between individual and group is further developed in the sense that "every object of perception is at the same time an object in so far as it is perceived as a unit locatable in a context, and a structure in so far as it is itself composed of several objects" [6]. One can extract from such postulates that the dialogue condition that is imposed to the sound object and the structure holds a dynamic perspective shift, that reassures the relationship between these two concepts. From his part, Stockhausen's concept of unity addressed the possibility to trace all musical parameters to a single compositional principle [7]. This concept envisioned the unified control of the musical structures in a given work through the establishment of inherent relationships between the micro and the macro level of the musical discourse. Initially driven by the aims of integral serialism, his search for such mechanisms of scope transposition continued throughout his career. Of such techniques, one can highlight "moment form", a structuring paradigm based on a non linear distribution of "gestalts" known as moments, or the "formula composition", in which all aspects of a given work derive directly or indirectly from an initial short composition. As an example, his over twenty-nine hours long opera cycle "Licht" is based on a three-part, eighteen-bar only score formula.

Although, as argued by Vickens, one can establish a close relationship between sonification and musical composition through a perspective shift [8], it is surely arguable that these concepts can be fully applied outside the art and music realm. Nevertheless, it is our claim that they can encapsulate a set of guidelines that can be of service in functional sound based communication, as defined in [9]. As Delalande pointed out, there is a communality of processes in electroacoustic composition practice that concern the relationship between singularity and regularity of events used in the musical discourse which underlines their structural dependencies [10].

As such, the aim of this work is to transpose the above mentioned compositional concepts to the interactive sonification domain and apply the relationships between material and structure to the micro and macro sound levels of data presentation. As a result, functional contexts are generated by data-dependent hierarchical levels that still preserve their informational identity and significance. As highlighted in the work of Scaletti concerning the specification of the Kyma environment [1], the adoption of Schaeffer's concept of sound object as a base structuring concept is a fundamental design directive for allowing the manipulation of multiples levels of complexity under one unifying abstract structure [11]. On the other hand, and in agreement with Childs, the application of these techniques should synthesize these data structures in such a way that the information transmitted is not cluttered by the presence of non functional musical elements and conveyed to the user in a clear and effective way [12].

Given this conceptual perspective, the next section will present the argumentation for the need and advantages of incorporating an embodied music cognition driven interface in the presented framework in order to more efficiently connect the bi-directional top-down/bottom-up processes of human cognition [13] to this scope variation.

3. INTERACTIVE SONIFICATION AND EMBODIED MUSIC COGNITION

As defined by Hermann and Hunt, interactive sonification is "the use of sound within a tightly closed human computer interface where the auditory signal provides information about data under analysis" [14]. Being so, several questions immediately arise, namely, "how to make these multiple levels of sonification both perceivable and meaningful to the user in order for him to take full advantage of their interrelated nature?", and additionally, "how should this composed information be made available in such a way that the user can interactively manipulate it".

In order to address these issues, the proposed interface for interacting with the framework's musically structured output follows an embodied music cognition perspective [15]. In electroacoustic music, the concept of musical gesture as materialization of the composer's inner musical intention has always been present at different levels of conception, both within the non-realtime compositional and realtime performance levels. For example, one can point out the expressive use of the mixing board's faders in both the mixing and spatialization processes. It is a trivial but nevertheless good example of an embodiment-based discourse that incorporates the physical factor in the creational process. Even more interesting is the fact that this process can be used across different levels of granularity throughout the work, ranging from individual amplitude envelope of a sound object to post-production panning of entire sections. This process is in tune with the concept of variable resolution [16]in which the hierarchical nature of the human motor system allows a context coherent variation in the resolution of performed actions.

Thus, it is only natural that this architectural similarity between sound objects and gestural/physical behavior is included in the framework's interface design. In other words, an interface that stimulates a user centered approach should be adopted from the start of the design and implementation process, in order to address the impact of context on identification of data structures. With the objective of promoting a fruitful dialogue between the user and the data, an approach based on the expansion of the mediating role of the body through virtual entities is considered within an immersive environment (in relation to [17]). First, virtual objects can act as mediators representing multilevel mapping layers that conform with the premise of a hierarchical object oriented decomposition of sound entities. Second, through the immersion of the natural communication tools of the actors involved, a virtual reality based framework presents itself as an appropriate setting for the investigation and development of interfaces between body and music. More details concerning this methodology will be provided in the next section. By enabling a configurable location and form representation of the data in space, this methodology invites the user to a physical approach for the inspection process through a shared space of multilevel interaction. As such, an embodied cognition approach is expected to further enable a perceptual link between the data under inspection and the semantic high level representations of the user.

4. VIRTUAL REALITY AS AN INTERFACE FOR SONIFICATION

In this section, the main concepts regarding the virtual object's role in the data exploration are introduced: the inspection window and the inspection tool (Figure 1).

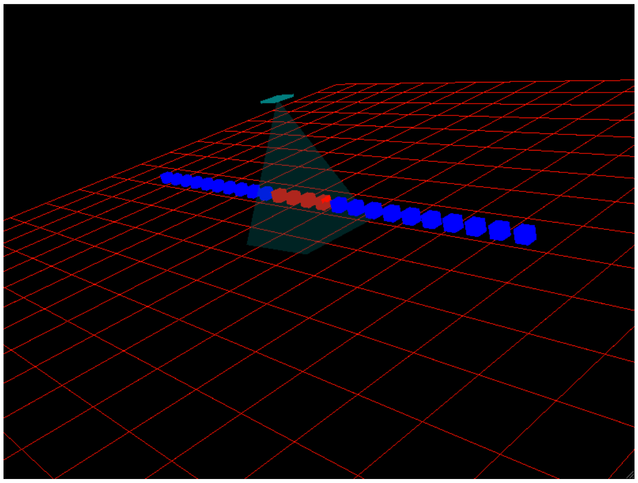

Figure 1: Visual feedback illustrating the inspection window and the inspection tool controlled by the user's hand.

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

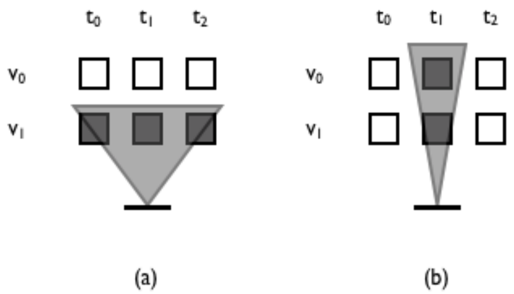
4.1. Virtual objects as metaphors for data representation

As mentioned in the previous section, the interface paradigm adopted is based on the interaction with virtual objects, which constitute access points to the variables belonging to a target dataset. To be able to represent datasets of $N > 3$ order in a tridimensional environment, these objects represent an inspection window to the variable's values. For illustration purposes, consider the following example. A dataset containing last year's average day temperatures in 5 cities of a given country is to be sonified. Instead of representing every value for every variable simultaneously, which would easily cause a congestion of the virtual scene and, consequently, difficulties to the inspection process, the representational virtual objects can be configured to allow simultaneous access to a subset of these values. For instance, an array of 30 spheres can be assigned to each variable constituting a temporary access to a period of approximately 1 month. The remaining values of each variable can then be accessed through sliding of the inspection window, which can be controlled by an auxiliary device (Ex. a WiiMote). Furthermore, the 5 arrays can then be placed in various arrangements in order to allow the multiple views of the dataset's content. Besides the previously described advantage, this approach constitutes a viable option in the analysis and comparison of real-time data. The values can be made available to the user for a certain amount of time (dependent on the generation rate) and then "hidden" from him, being available for later inspection. Moreover, the morphology of the virtual object(s) that is assign to represent a variable in space can be data dependent, conveying a more informative visual representation of the values being analyzed.

4.2. The virtual inspection tool

The inspection procedure is conveyed to the user through the inspection tool. This virtual object, composed by a flat surface (that visually represents the user's hand in the virtual space) and an inspection volume, allows the user to interactively investigate the data. This inspection volume behaves as a sonic magnifying glass or virtual microphone, allowing the user to zoom in and out in order to investigate either one element's output, or its relationship with other members of the set. This interaction mode was strongly inspired by Stockhausen's Mikrophonie I [19] composition where the active use of microphones is a base concept in the performance of the piece. Each independent virtual sound source is activated through collision detection when the inspection volume intersects the virtual objects. Then, the activated items are fed into the sonification levels responsible for calculating the respective sonic outputs according to their specific implementation. At this point, the virtual objects, their structure and their relationship with the sonification layers are addressed. Going back to the example described in the last subsection, only the individual virtual elements that compose the inspection window are subject to sonification procedure (i.c. the day's average temperature). As mentioned, the inspection window (the parent object) is composed of 30 spheres (the child objects). Here, the manipulation of the parameters involved in the sonification comes into play. As one gets the inspection tool closer to the activated elements, the distance between them has an effect on the amplitude and depth of the reverberation in the sonification process. As the distance to the user's hand is reduced, loudness increases and reverberation's depth decreases. Although this behavior is sonically implemented by the individual elements, it conveys information about the activated set as a whole. Following the previously referenced theoretical guidance of Schaeffer and Stockhausen, it stimulates a perceptual interpolation between the whole (a month) and the individual nodes (the days). Furthermore, through the use of the inspection tool and the spatial arrangement of the inspection windows elements, the user can group several consecutive "day" and have a "on the fly" composed sound object which conveys the progression of the temperature in one city. On the other hand, several "days" from different "cities" can be grouped, sonically illustrating the relations between different locations' temperature. Being so, the adopted interface paradigm can convey multiple perspective views between different levels in the form domain, by representing the evolution of the sound object in time, and in structure, by establishing and comparing different groups of N variables (Figure 2).

The framework's implementation and an exploratory use case are the subject of the following sections.



(a) (b)

Figure 2: Interactively grouping variables' values in form (a) and structure (b)

5. FRAMEWORK

5.1. Introduction

The present framework's ongoing implementation is a consequence of the need for generic data sonification tools for research and application [18]. As such, it aims to provide a software infrastructure where issues concerning portability, flexibility and integrability are addressed. Furthermore, given the current state of the art in frameworks for sonification, as presented in [5], the framework's design reflects the authors' perspective for the need of incorporating, together with compositional guidelines presented in Section 2, the users interaction mechanisms as a fully integrated structural paradigm.

The following subsections address the framework's architecture and the choice of Java as its core technology.

5.2. Architecture overview

The design is based on a functional division of modalities into individual branches around a virtual scene representation. Following a top-down approach, a first level is composed of abstract managing cores and their respective elements per modality - visual, auditory and human interface. A second level is then obtained by concrete implementations of these cores in correspondence to the external libraries chosen by their particular capabilities. A similar decomposition process is also applied to the elements that map the targeted functional implementation. Both the cores and the corresponding elements that they manage implement generic interfaces according to their role in the desired platform. The resulting abstraction layer, combined with a command-based access, enables the simultaneous use and undifferentiated access between elements through their specific cores independently from the specific library that implements them. In addition, such abstraction layer is also extended to other auxiliary managing cores and their respective elements such as Open Sound Control (OSC) drivers for connection with other software platforms.

So, as a result of this encapsulation, the concrete implementations of the virtual worlds, their visual and auditory representations and the human interfaces that enable the manipulation of the virtual objects can be either refined or substituted according to the desired performance, access or functional needs of the intended use cases. The user configured binding between the elements in play follows the observer design pattern. It is provided through the implementation of custom tracker objects that read and update the relevant entities through event triggering or user defined refresh rates. Furthermore, this modular design allows both static and realtime processing of data as well as physical model based interaction.

To further illustrate the framework's design, a concise description of the sonification package structure follows.

- Core/Element - Both core and elements implement generic interfaces concerning the frameworks kernel (ISoundCore; ISoundElement) and the external library used in the implementation (Ex. ISoundCoreSC3). It is segmented per library and functional task and contains the implementation of the synthesis controller. Ex. SonificationIntervalSC3 class.
- Sonification - Implementation of the sonification levels.These provides the triggering algorithm for the synthesis controller instances. Ex. SonificationLevel0 class.
- Model - Provides in real time the data for sonification. Defines the specified model for data conversion and source connectors. Ex. WiiPitchValueToFreqConverter class.

Being so, the development has its focus on providing a set of basic elements for non experts to construct a fully functional sonification use case while being open for expansion and more demanding scenarios. In the latter case, the basic interconnection between the elements implemented using different technologies is guaranteed through the generic interfaces. As an example, a sound element class for rendering a string-like physical model implemented using SuperCollider 3 can be swapped for an implementation using JavaSound for web deployment reasons. Since both implement a generic interface IPluckedDataString that specifies the functionality for both cases (Ex. play()), this change has no effect in the remaining elements (visual and HI elements, triggering observers) of the system.

5.3. Java Technology

The framework's kernel was implemented using Java technology [2]. The primary reasons for this choice are Java's object oriented paradigm, cross-platform support, a wide range of modular freely available open source libraries and a robust integration oriented framework with virtually every IT application area. Particularly relevant are databases connectors, mobile and data mining frameworks, web service based access, web start deployment technology and support for various functional and/or interpreted languages (Ex. Python). In the case of specific performance and/or compatibility demands, it is possible to make use of C/C++ code through component wrapping via Java Native Interfaces. Finally, a strong argument in favor of the implementation of real-time software in Java is the continuous evolution in the Real-Time Specification for Java's implementations (RTSJ).

6. USER EVALUATION

6.1. Description

The presented use case consists of the interactive exploration of a one dimension dataset through sound. The main goal was to present the test subjects with a simple use-case in order to extract preliminary issues concerning the framework. The sonification levels' specification and the technologies used are described in the next sections followed by the user evaluation where both the methodology, the tasks performed by the users and the results are presented.

6.2. Sonification Levels

Three independent sonification levels were define in which the data mining processes are driven by musical relations present in the data (Figure 3 and 4).

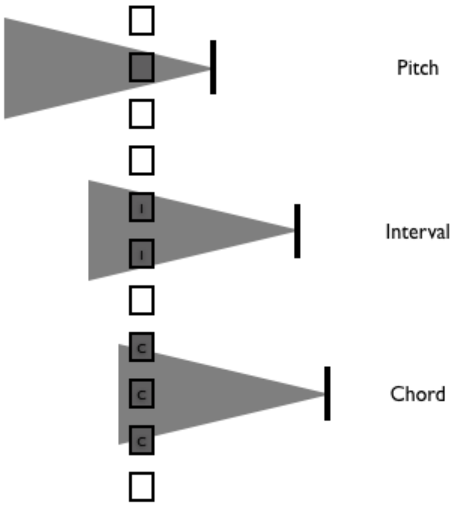


Figure 3: The interactive grouping process and the levels of sonification

- Level 0 - This level manages the sound output concerning the individual entities in the scene. It updates and triggers the assigned pitch of the activated items. This level was implemented through individual sine wave oscillators for each activated element.

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[2] http://java.sun.com/

- Level 1 - This level is responsible for detecting and sonically activating musical intervals between two virtual entities under inspection. These relations are defined as a ratio between two given frequencies and used used to highlight degrees of variation of the data. For example, a perfect fifth interval can be used for detecting a relation of 3/2 between two elements within the array. This level was implemented through the use of a resonant filter bank per intervals. Its application consisted in a percussive type activation each time a given interval was detected.
- Level 2 - This level establishes a relation between several elements and their frequencies in the inspection scope. The presence of a music chord is calculated through the detection of N ratios or intervals from a base frequency. For example, a C major chord is detected through the simultaneous presence of three frequencies: the base F0 and two other that, in relation to F0, respect the 5/4 and 3/2 ratios conditions. By defining and sonically highlighting these relations, further information is provided through a wider view of the data's progression. This level was implemented through the use of a set of delayed sine wave oscillators per chord detection.

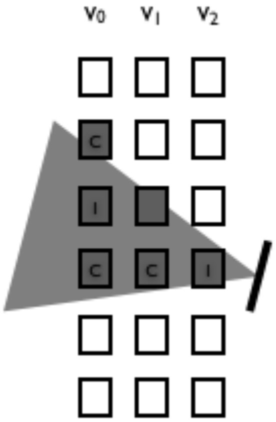

Figure 4: Finding relations through the sonification levels in multivariable inspection.

6.3. Technology

The technologies used were:

- Java 3D Library was selected for the visual engine for its high level scene graph based implementation, well structured overall design and functionalities (e.g. the included support for stereo view).
- The sound engine has been implemented using Supercollider 3 through JCollider, a Java based SCLang implementation [20]. The latter allows not only the instantiation and control but also the definition of the synthesis elements from within the framework's core.
- The NaturaPoint's OptiTrack motion capturing system provided the tridimensional position and orientation tracking through an OSC custom client using the NetUtil OSC Java library [20].

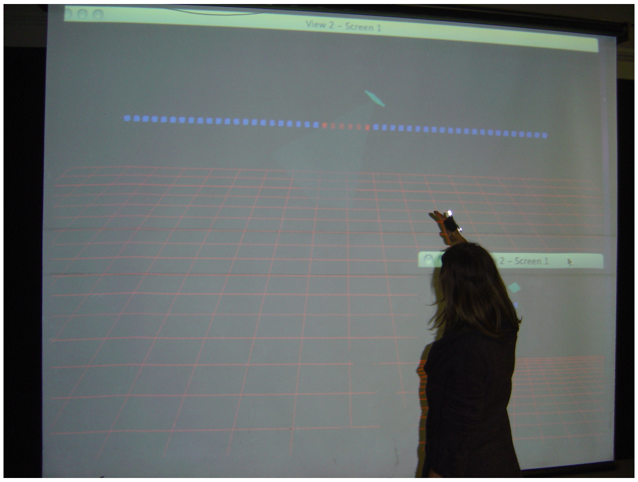

Figure 5: Test subject performing the required tasks.

6.4. User evaluation

To investigate whether the platform functioned as envisioned, two basic user-tests were performed. These consisted of both observations, documenting users' appraisal and feedback regarding the interface. In the latter test, a measurement of their performance was taken while conducting an experiment with a set of predefined tasks. The methods used were adopted from the field of HCI-usability studies [21] [22] and based on techniques such as heuristic evaluation [23] and cognitive walkthrough [24].

The initial and exploratory investigation was performed by a small number of evaluators and consisted on free interaction with the prototype while all the three levels of sonification were activated. They were asked to inspect its basic operation and to comment on it. No further instructions were given at this time. Most users found the interface to be quite responsive and its operation to be intuitive. However, only a small percentage of the test-subject mentioned the different levels in the sonification, so the purpose of these different levels had to be clarified. Other problems that were reported with the prototype included the fact that movements of the inspection tool parallel to the screen were visualized a certain inclination, which complicated the interaction with the virtual objects. This was due to the use of a perspective based visualization. Finally, some of the users complained about problems concerning their depth-perception within the visual representation. The addition of the second screen which conveyed depth perception improved the spatial awareness of the users and other suggestions that were made by the participants were considered for further implementation. The actual interface, however (i.e. the MoCap-system), was not substituted.

For the second test, a more thorough evaluation of the platform was made, and users were required to perform a series of tasks in which they evaluated the different levels of sonification and the relations between them (Figure 5). The aim of this test was to investigate whether perceptual abilities of the participants were increased by the different sonification levels or not. The proposed tasks were comprised of the exploration of a predefined one dimensional dataset through the use different combinations of the sonification levels. Within each test, the user would be asked to find a certain relation present in the presented dataset with only the lowest level of sonification after which the same user would be asked to repeat this task using the first level combined with one of higher degrees of sonification to explore a differently ordered representation of that same dataset (Ex. Level1). The test that focussed on the combination of the level 0 and level 1 sonification did not show a rise in effectiveness for any of the participants. This test proved to be problematic because of the fact that a number of different relationships within the dataset (i.e. intervals) were sonified, and it was too difficult for participants that did not have any specific musical training, to discern which. The combination of the level 0 and level 2 sonification, however, in which the test subjects were required to find a set of relations (i.e. chord) did yield good results. The addition of the level 2 sonification proved to be very valuable in the discerning task, and it improved the performance of every participant (i.e. the time consumed in performing the task).

After exploration of the interface and performance of the set tasks, participants were required to evaluate the human interface they had used in terms of performance, maneuverability and precision much in the same way as the initial evaluation. Moreover, participants were asked to comment on the completeness of the improved visual output (in order to find the requested relations and to interact with the virtual array) and on the sonification output in terms of distinguishability, information carrying potential and aesthetic qualities. Additionally, a number of remarks and requests were recorded that are being considered for further implementation. A first issue that was raised was that the different sound levels (i.e. the different sound-relations within the data) should be made selectable. Directly related to that, one of the respondents pointed out the need for a test with non-prepared dataset. Admittedly, this was a just critique, which on the other hand indicates that the platform functioned properly as means to evaluate the dataset, because otherwise, the test-subject would not have been able to notice the fact that the values had been retained and only their order had been changed. Finally, some of the test-subjects suggested a number of changes that should be made to the inspection tool, namely the fact that a rectangular as opposed to a square base of the inspection tool would allow for more accuracy in the exploration, and that making the edges of the pyramid-shape visible would enhance the perception concerning the orientation of the tool and thus the precision in the exploration task.

The overall evaluation of this prototype revealed that all participants were able to properly operate this platform. Concerning the sonification's output, the users reported being able to perceive all the sound-levels and were able discern the information that was conveyed by them, although they were not always able to fully perform the set tasks. Furthermore, their performance was considerably improved by the use of the different levels of sonification, and in that respect, the findings of this initial user testing are promising in view of further development.

7. FUTURE WORK

The future development of this project will progress in several aspects. First, we will focus on the expansion of the sonification levels and their intercommunication in order to progressively incorporate higher levels of representation. These will developed not only as a function of the simultaneous data streams at a certain point (in Schaefferian terminology, a Structural analysis) but a time based analysis (Form analysis) in which the result of the sonification process takes into account previously examined samples. Such development will contribute to a more global, musical form inspired perspective of the data's inner relationships by sonically placing its local behaviors within a broader context. Other modes of interaction with the sonification levels will be explored. For example, besides the regulation of the amplitude and reverberation parameters, the relative distance of the virtual microphone and the object(s) under inspection could also be used for the activation and mixing of the sonification levels. Furthermore, in order to the morphology and sonic feedback of the virtual elements to reflect the data's behavior, further investigation in incorporating physical model based interaction will be carried out. As Stockhausen commented about Mikrophonie I, "Someone said, must it be a tam-tam? I said no, I can imagine the score being used to examine an old Volkswagen musically, to go inside the old thing and bang it and scratch it and do all sorts of things to it, and play Mikrophonie I, using the microphone" [25]. Second, spatialization features will be implemented to assist the user's interaction with the virtual objects and to further convey information about the data (Ex. when inspecting N variables, sound spatialization can be useful in informing the user to which variable(s) correspond the heard sonic events). Third, concerning the interface, future testing will include the real time configuration by the user for positioning the inspection window in the dataset, adjusting the inspection tool dimension parameters and the activation of the sonification's levels. Third and finally, all of these features will be subject of a more comprehensive usability study in order to validate the present and future modes of user interaction in new inspection scenarios (Ex. the simultaneous inspection of N variables datasets).

8. CONCLUSIONS

The presented article aims to establish relationships between the interaction sonification field and musical composition practices. Although the present development is still in an initial stage, preliminary testing has shown that the progressive inclusion of the discussed concepts and its related techniques, combined with an embodied music cognition interface approach, can contribute to close the semantic gap between the user and data through sound.

9. ACKNOWLEDGMENTS

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