Soundscape4DEI as a Model for Multilayered Sonifications

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Abstract. Computation emergence has impacted the development of creative musical systems, as it allows for unprecedented exploration and innovation in the realm of music composition and sound design. As data is becoming more and more complex [1], new information sharing tools and methods arise. In this paper, we present *soundscape4dei*, a system that sonifies data from the daily routine of the Centre for Informatics and Systems of the University of Coimbra (CISUC). The developed system explores and proposes a multilayered approach that succeeds in raising awareness and informally disseminating the (usually invisible) activities at CISUC. We go over the design of the system, we analyse its outputs and we discuss our sonification model.

Keywords: Sonification · Sound Design · Sound installation

1 Introduction

Humans are equipped with a complex listening system. It is capable of distinguishing sound sources, identifying melodies, recognising patterns even under adverse conditions and, most importantly, "interpret sounds using multiple layers of understanding" [2], making it a powerful and flexible instrument to explore for portraying data. Our ability to flexibly change the auditory focus and learn and improve discrimination of auditory stimuli [2] creates many possibilities when approaching sound as an information-sharing vehicle.

The study of auditory displays as a scientific field started in 1992, with the foundation of the International Community of Auditory Display (ICAD) [2]. In the past few decades, technological growth and accessibility contributed to the appearance and standardisation of new communication methods and tools. Sonification, "the use of nonspeech audio to convey information" [3], is a powerful auditory data representation based on mapping data attributes to sound parameters for user-friendly comprehension. Its merits include harnessing innate auditory pattern recognition, fostering rapid data interpretation, and aiding visually impaired individuals. Moreover, real-time feedback empowers scientific research, healthcare monitoring, and industry [2][4]. It is currently used in a wide variety of contexts (e.g., bio-medicine, seismology, interfaces for visually disabled people) and its research is associated with a wide list of disciplines, such as physics, perceptual research and computer science [2].

Be it education, research, students' activities or industry cooperation, most of the activity at CISUC (Centre for Informatics and Systems), University of Coimbra, is mediated through computers and mostly closed networks. This project arose from an attempt to locally raise awareness of those activities and informally disseminate them. By exploring the intersection of music and technology, we developed a sonification system that uses real-time data analysis and a multilayered approach to create musical compositions. The challenge of this sonification is to be able to illustrate four different types of events, each with specific and particular mappings. At the same time, the system must operate continuously, so we aimed for the creation of a non-invasive sound space.

The name *soundscape4dei* refers to DEI, the Department of Informatics Engineering, where CISUC is hosted. The created soundscapes depict events like purchases, scholarship allocations, paper submissions and researchers' missions. In this paper, we start by overviewing sonification projects that inspired this work, followed by a description of the system and its physical installation. We discuss the multilayered approach and how it can incorporate different techniques while still being successful. We end by discussing how the resulting sonic experiences may be evaluated and then we address future work.

2 Related Work

Sonification has been investigated and proven successful when explored in a vast number of contexts. In this section, we briefly describe projects addressing various fields, thus illustrating its multidisciplinary applicability. Furthermore, we envision some of their musical nuances to be either related or likely applied to routine sonifications, the domain of the presented system.

Two Trains [5] is a music composition that emulates a ride on the New York Subway through three boroughs: Bronx, Brooklyn and Manhattan. The number of instruments and dynamics of the song corresponds to the median household income in each location, revealing the economic inequality across the city while exhibiting its energy and the chaos of the subway system.

Sonic Kayaks [6] are musical instruments used to investigate nature. They use a system previously explored by Matthews on Sonic Bikes [7] and allow kayak paddlers to hear real-time water temperature and underwater sounds as they map the marine world data to a generative live composition while navigating.

Seiça *et al.* [8] developed a system that analyses social media (TWITTER) data, estimates the posts emotions and translates them into auditory language. This project explores the subjectivity of human emotions and its relationship with music as a transmedia instrument.

A sonification experience to portray the sounds of Portuguese consumption habits [9] presents a listening experiment that explores the influence of aesthetics in the perception of auditory displays. The system sonifies consumption habits from a portuguese retail company over the course of ten days.

Brian House [10] interprets a continuous year of his location-tracking data to create a recording that sonifies every moment of his daily routine. The 11 minute song, Quotidian Record, suggests that habitual patterns have inherent musical qualities that might form an "emergent portrait of an individual" [11].

Living Symphonies [12] is a sound installation based on the fauna and flora of four ecosystems in the United Kingdom. The designed model reflects the behaviour, movement and daily patterns of wildlife, translating a network of interactions that formed the ecosystem.

This sonification project is based on a developed multilayered model. This model consists of the use of direct parameterization as well as generative techniques, used to enrich the sound experience.

3 The approach

Conceptually, we focus on developing a system whose outputs focus on data transparency while taking advantage of sound expressiveness to create immersive sonic experiences. We also had to pay attention to the audio intensity and other components that could disturb students and researchers that often use the installation room to study and work. Figure 1 describes the architecture of the sonification process. In the following sections, we will provide a comprehensive overview of the data and the implemented system, while also explaining the decision-making process throughout the project.

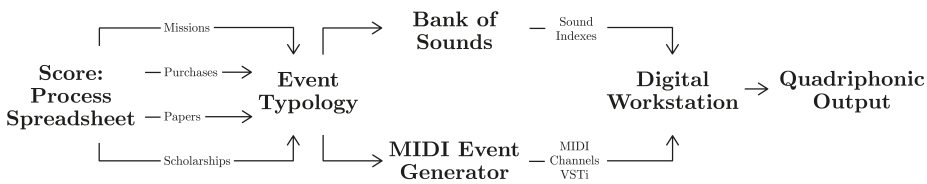

Fig. 1. The architecture of *soundscape4dei*: the Spreadsheet contains the data to be sonified, the Event Typology is described in the *Encoding* section, the MIDI events and Bank of Sounds are displayed in Table 1, and the digital workstation and quadriphonic output are detailed in the Instalation section.

3.1 Data

In this project, we propose to sonify data describing the activity of our research centre CISUC, which comprises about 150 researchers (faculty members, graduate and post-graduate students) and is organised into six research groups: Adaptive Computation, Cognitive and Media Systems, Evolutionary and Complex Systems, Information Systems, Laboratory Communications and Telematics, Systems and Software Engineering. We found CISUC activities enough diversified to be sonically explored and conceptually rich from a social and technological standpoint since the data is dense, well-structured and periodically refreshed. For the purpose of illustrating our approach, we use a small fragment of the stream of data, manually edited to assure a diversity of situations. We follow a standard visualisation pipeline to handle the data preprocessing — selection, categorisation and validation, before applying any transformations. The manual edition allowed the filtering of spelling inconsistencies.

All the activities at CISUC are chronologically registered and detailed according to their nature. We identified four meaningful categories of events to consider within the sonification: purchases, missions, scholarship allocations and paper submissions. The system must be able to create meaningful sonic scenarios allowing for easier recognition of these categories.

3.2 Software Architecture

The implemented pipeline is composed of five main stages (Figure 2). The data is firstly preprocessed by a PROCESSING sketch which checks for spelling typos and standardises every entry (setting the input to lowercase and removing its accents), before transforming and encoding them. This process is based on algorithms described in the next section. The output of this sketch is then sent as OSC messages to a MAX/MSP patch, which is responsible for playing organic sounds from WAVE files after handling equalisation, as well as for converting OSC messages to MIDI. This messages are sent afterwards through multiple channels to a LOGIC PRO project. LOGIC PRO uses Spitfire LABS VSTI to create the various hybrid soundscapes, composed of both symbolic (human) sounds and organic (nature) sounds [13,14].

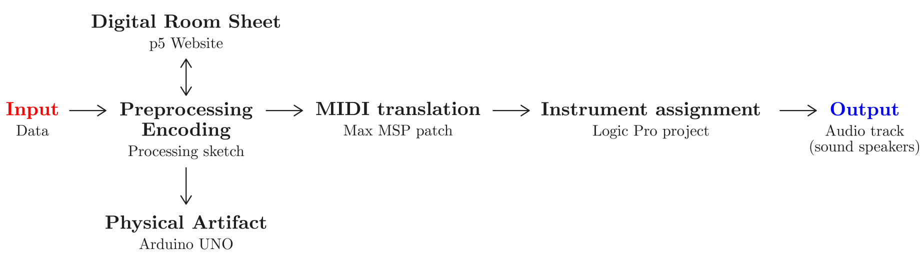

Fig. 2. *soundscape4dei* pipeline.

3.3 Encoding

Sound has a multitude of changeable dimensions that allow for many options when mapping data to audio [4][15]. This system relies on algorithms that manage and create different sound layers. They are composed of organic sounds from standard environmental recordings and by symbolic sounds (i.e. trigged by MIDI events) from a selected and specific VSTI bank Spitfire (LABS) to ensure the system creates the experiences we envision (Table 1). The criteria for choosing sounds is based on artistic intuition.

Table 1. Nature and symbolic sounds and respective description.

	Recording	**Description**
Nature Sounds	1. Underwater environment	Used together with a *Storm* recording in order to create the illusion of submersion in the *Purchase* category.
	2. Storm	Used together with a *Underwater environment* recording in order to create the illusion of submersion in the *Purchase* category.
	3. Sea waves	Used in the *Scholarship allocation* category to represent the money invested. Money flow translates to water flow.
	4. Crowd	Used in the Missions category to portray the amount of population at the destiny.
	5. Birds	Used in the *Paper* submissions category. The amount of chirping translates to the importance of the submission, based on the ranking of the targeted conference.
	VSTi	
Symbolic Sounds	6. Electric Piano	Morse code melody used in all sonifications.
	7. Granular Whalesong: Nautilus and Drone	Drone sounds used to represent pollution in the *Missions* category.
	8. Pedal Pads: Azure Piano	Synth sounds used to establish a major scale mode based on the current weather of a mission destination as well as to create harmony for the *Purchase* category.
	9. Opia: Piano Granular	Synth sounds used to intensity the flow metaphor for the *Scholarship allocations* category.

Soundscape4dei sonifies every *Score* line (see Figure 1) individually, portraying it for one minute. To allow a easier communication of multiple streams of event data simultaneously, we explore a multilayered approach, resorting not only to standard parameter mapping [2] but also to methods presented in this section and further discussed in section 5. The sonification is composed of specific encodings that differentiate and represent the different categories of events and universal encodings (general components) which aims to provide a unifying character.

Table 2 depics the structure and sound allocation of our sonification. We name the three layers that compose the different soundscapes as *Melody* (L1), *Harmony* (L2) and *Texture and Signals* (L3). Each layer concerns several symbolic and/or organic sounds, which are selected to each category encoding.

Table 2. Layer division and sound allocation for each category. Source numbers according to Table 1. *G* source stands for group instruments which are individually present in all categories but are not exclusive.

Layer	L1	L2			L3					
Source	6	7	8	9	1	2	3	4	5	G
Mission	blue	blue	blue					blue		yellow
Purchase	blue		blue		blue	blue				yellow
Papers	blue								blue	yellow
Scholarships	blue			blue			blue			yellow

3.3.1 General components For each entry on the process spreadsheet (1), there is a melody that sonifies its description field. The melody rhythm is generated from a Morse code translation of the input. The scale notes and tonality of the melody, which is always major, are chosen randomly to create more variety and avoid stagnation.

The research group associated with each entry is represented by notes from predefined VST percussion instruments: Glockenspiel for *Adaptative Computation*, triangle for *Cognitive and Media Systems*, jingle bells for *Evolutionary and Complex Systems*, kettledrum for *Information System*, chimes for *Laboratory Communications and Telematics* and cymbal for *System and Software Engineering*. We chose to use instruments from this family because they have defined and precise sounds that stand out sonically.

3.3.2 Missions Missions comprise oral and poster presentations at conferences, project meetings and other activities that require travelling. In this type of event the soundscape is composed of elements that vary depending on the destination of the mission. The system uses an API to verify the destination meteorology in real-time, which defines the major mode (for the Morse melody). The brighter the current weather, the brighter the major scale mode [16]. The population number influences the volume of a talkative crowd and the pollution level plays a drone sound, creating a pedal that lasts the entire sequence (the higher the level, the greater the presence).

3.3.3 Purchases We approached purchases from a more subjective standpoint. This soundscape means to represent how significant the transaction is, since some purchases are cheaper (for example, an arduino compared to a laptop), therefore tendentially less impactful than others. To develop this metaphor, we use water sounds. When combined, they create the illusion of submersion — the more unusual and significant the purchase, the stronger the low-pass filter applied and, consequently, the more depth is simulated. To intensify this encoding, the mode (of the Morse melody) changes depending on the same factors, creating a relationship between its brightness and the proximity to the surface [16]. The VST unifies the various sound components by playing augmented triads that share notes with the tonal center.

3.3.4 Scholarship allocations Scholarship allocations always have a certain duration and remuneration associated. The system maps this information into three independent levels and translates the money flow into water flow, overlapping sounds from various water currents. This is intensified by a modal progression that uses more chords if the level is higher. Since the parameter that is being represented (remuneration) translates into the tonality, we randomly select chords from a predefined array. The harmonic movement created provides a tonal center, no matter which chords are chosen. This is a crucial characteristic of the sonification model we are presenting. If the tonal center is established, the harmony is free to fluctuate within the options of the array.

3.3.5 Paper submissions The last type of event involves the mapping of the submission into a scale of importance according to the CORE Ranking, for conferences, and Scimago Journal Ranking, for journals. The metaphor links the paper's visibility to the sound of birds chirping as they get louder the more relevant the submission is.

3.4 Installation

soundscape4dei is installed in a room acoustically studied beforehand. The room is public and accessed by researchers and students. The sound system is composed of four speakers (Genelec 8010a) and a subwoofer (Genelec 7040a Active Subwoofer) as well as an interface (PreSonus Studio 1810c) which is connected to the desktop that runs the software (Figure 3).

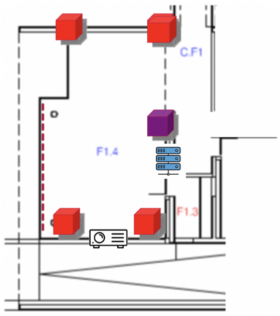

Fig. 3. Installation mapping: subwoofer as a purple cube, speakers as red cubes.

The graphic identity is inspired both by the physical dimensions of the room and the distribution of the hardware. Each CISUC group is represented by a circle and consequently a colour. In order for the listener to share a deeper understanding of the project, we developed a website that contains live encoding details and an option for a temporary mute. This usability feature allows the installation room to remain a silent place for formal meetings.

The website and the processing sketch communicate via WebSockets within the safe university network. The logo is used both on the website and on a small physical artefact that interacts with the system (Figure 4). We use an **arduino uno** to blink the led that corresponds to the CISUC group responsible for the event being reproduced. This object works as a visual clue that stimulates the audience to investigate about what they are listening.

Fig. 4. Physical artefact (left) and *soundscape4dei* website (right).

4 Results and Analysis

In this section we analyse the sonification of the *Score* line (Figure 1) represented on the website of Figure 4. We start by analysing the output's spectogram while referencing its MIDI layer L2. We analyse the harmonic movement and what sort of experience it helps to deliver. We conclude by comparing two recordings of the same *Score* line (Figure 1) by depicting the variations and identifying what differs and stands out in our sonification model.

To get a clear render of the recording we set the spectogram's scale to linear, the algorithm window size to 8192, we chose the Hann algorithm window type and displayed frequencies between 0 and 6000 Hz. Figure 5 reveals four main incidents:

1. The occasional appearance of frequencies in 3k-6k range, caused by the VSTI that represents the assigned CISUC group (glockenspiel);
2. Some initial turbulence due to the Morse melody;
3. A large cluster of low frequencies (up to 1000 Hz). This characteristic is due to the harmony emphasis, more specifically, due to the choice of chord notes;
4. The chords also split the spectrum into temporal sections. These partitions are created by the chord progression (or pulse) like for example between the red and the blue markers. However, we can argue that these divisions do not negatively impact the resonance levels, since it remains similar throughout the recording.

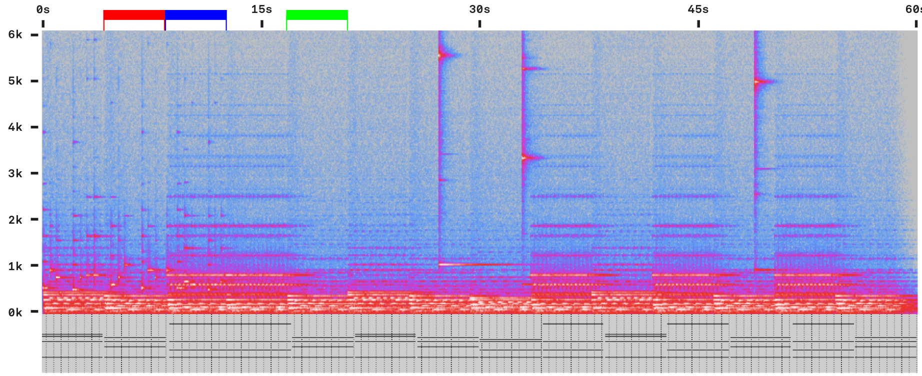

Fig. 5. Spectrogram of a scholarship allocation sonification recording (top) and respective L2 MIDI (bottom).

All the described elements reveal that, regardless of whether there are places with more activity than others (such as between the sections comprised in the blue and green marker), L2 blends with the other layers of the soundscape L1 and L3, creating a relaxing, non-intrusive soundscape.

Figure 6 represents the variations of the same *Score* line and displays how the encoding methods affect the composition. The harmonic pulse is still present but progression is different, since the bottom spectrum is more stable after the 30 seconds mark while the top spectrum is not.

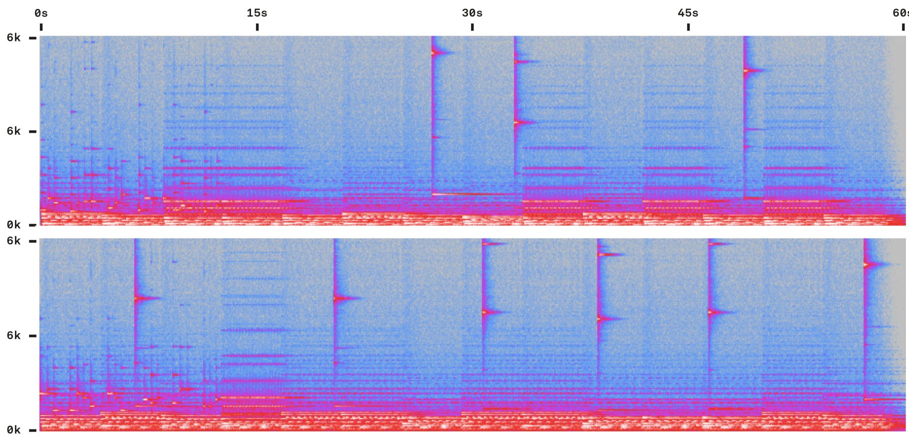

Fig. 6. Spectrogram from two recordings or iterations of the same *Score* line sonification.

5 Discussion

After presenting the system and analysing the results, we discuss our model. Baxter [17] argues that sonification may be a means to create generative music, but may not the opposite be also true?

Figure 6 revealed that the same *Score* line had two different outputs. One of the main reasons for that to happen is because the progression that is being developed is generated in real time. By having a list of possible chords, the system randomly selects which one is to be played. This does not compromise the sonification accuracy because the chord list guarantees that the outcome is always, in this case, a Dorian progression (Figure 7).

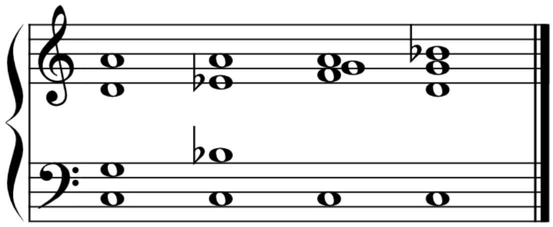

Fig. 7. Array of chords that can be selected and played in the recording portrayed in Figures 5 and 6.

We believe that combining standard parameter mapping with encoding algorithms that are partially stochastic creates and, arguably, enhances sonification systems. Our model and contribution works on top of multilayered compositions and is based both on the exploration of those stochastic processes and on testing how they may help to prevent stagnation, may create movement and surprise and may instigate and immerse the listener while they faithfully portray the intended data [3].

6 Future Work

There are several options and approaches for future work related to the development of this model regarding *soundscape4dei*. From the current state we can divide it into three major streams: system evaluation, system enhancement and system design.

6.0.1 System evaluation So far, the system's evaluation has been solely qualitative and hasn't incorporated user input. Our aim is to conduct a comprehensive assessment of users' experience and explore whether sonification enhances awareness and insights. This will involve implementing mechanisms for

[3] https://vimeo.com/824378644

gathering feedback from individuals present in the room, such as installing a tablet or providing a web page accessible via mobile devices or laptops. Additionally, we plan to collect audio descriptors from the ambient sound in the room and examine potential correlations with user feedback.

6.0.2 System enhancement *Soundscape4dei* is currently able to sonify data from a specific dataset. We envision the development of a dynamic API that would feed the implemented system from a larger group of events which take place across the department, such as classes attendance, crowded rooms, masters' and doctors' thesis defences, social network publications, among others.

To avoid repetition and stagnation, the system could also incorporate more diverse sounds. For that matter, we plan to enrich the sound bank by recording original content, not only as a standalone work but also by inviting the community to contribute.

When approaching the project beyond its software components certain enhancements may arise. We plan to build an object that allows the community to locally share their perspective on the soundscapes. By gathering those inputs we can evaluate the system, and consequently the model. Physically, the installation can also be expanded into larger and more populated areas across the campus. Broadening *soundscape4dei* helps to disseminate the sonified activities and evaluate it from a larger community sample.

6.0.3 System redesign The implemented system portrays each entry for one minute. Having the activities chronologically separated and melodically identified helps to distinguish them but it also imposes a rigid premise. This trade off hints a new approach where all activities may coexist in the same sonic mist. In this scenario, the system allows for the creation of denser soundscapes. Sounds may be added or removed at any moment since there are no time restraints, which can be used to highlight certain events creating and manipulating the hierarchy. We envision this approach to create an opportunity to further develop our model, since the premise suggests a sort of compositional freedom while raising the challenge to accurately portray data.

7 Conclusion

We presented *soundscape4dei*, a system that creates sound compositions through the analysis of data and we discussed the model we propose. Throughout the development of this project, we have focussed on balancing exploration and functionality — the outputs portray data in unconventional manners by exploring sound and musical density without neglecting events recognition through sound. There are multiple options to be explored towards new versions of this system, while extending the reach of our model when applied to multilayered sonifications. Nevertheless, the installation fulfills its purpose, as is able to produce immersive soundscapes and locally share the activities from CISUC.

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