SONIFICATION OF DARK MATTER: Challenges and Opportunities

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ABSTRACT

A method for the sonification of dark matter simulations is presented. The usefulness of creating sonifications to accompany and complement the silent visualisations of the simulation data is discussed. Due to the size and complexity of the data used, a novel method for analyzing and sonifying the data sets is presented. A case is made for the importance of aesthetical considerations, for example musical language used. As a result, the sonifications are also musifications; they have an artistic value beyond their information transmitting value. The work has produced a number of interesting conclusions which are discussed in an effort to propose an improved solution to complex sonifications. It has been found that the use primary and secondary data parameters and sound mappings is useful in the compositional process. Finally, the possibilities for public engagement in science and music through audiences' exposure to sonification is discussed.

1. INTRODUCTION

The Sonification of Dark Matter is an audiovisual work composed from the sonification and visualization of dark matter simulation data. Dark matter does not absorb or emit radiation, it is therefore invisible. We can only perceive its effects on the baryonic (visible) matter. In fact, we know that about 95% of the universe should be made up of dark matter and dark energy in order to justify the behavior of the universe according to the laws of physics. The gravitational forces in the universe are far too large if we accept that only baryonic matter is acting on them. The standard model of structure formation contains enough dark matter and dark energy to explain these gravitational effects. The simulations of dark matter such as those described here can be compared with observational data of the universe such as galaxy surveys [1]. Cognitively speaking, dark matter is not perceivable to us does not emit sound signals either. Therefore, dark matter poses a particular challenge when attempting to visualize and sonify it. The particle data used were created and visualized by Kaehler, Hahn and Abel thanks to a novel visualization method for N-body simulations [1]. A Max/MSP based implementation of the sonification of the data provides additional cognitive bandwidth for understanding the behavior of dark matter. It also increases the audience's attention engagement with the originally silent visualisations, as we have come to expect 'sound to accompany animated images' [2]. By increasing the sensory dimensions of the display, the effectiveness of information transmission is increased.

The aesthetical requirements for a successful sonification are discussed, as well the compositional opportunities resulting from it. Furthermore, the challenges of interdisciplinary music composition with sonification are identified. *The Sonification of Dark Matter* is presented as a practical example of the implementation of a sonification algorithm for dark matter.

2. RELATED WORKS

The sonification of particle physics data has been of increasing interest to scientists, particularly since the discovery of the Higgs Boson particle by CERN [3] and the gravitational waves by LIGO [4]. They have proven to be popular with the general public and scientists, for their accessibility and novelty factor respectively. The Quantizer project provides a platform for real-time sonification of the ATLAS experiment at CERN, where the listener can choose a musical style in which the sonification is mapped [5]. While these examples prove method's potential for public engagement, they do not exploit the full musical and therefore cognitive potential of sonification. In fact, they are heavily based on ideas of pitch, rhythm and harmony, as well as Western Classical musical styles. We suggest that the inclusion of further musical parameters such as timbre, spatialisation and volume can help harness the full potential of sonification. Vogt and Höldrich explore the idea of metaphoric sonification where intuitive mappings for better interpretation of sound and particle data [6]; their method has been applied to the ALICE experiment at CERN [7].

3. SONIFICATION

The intended outcome for the sonification project was an audio-visual work, the data sets was always intrinsically related to its visual counterpart. Considering the sonification as a 'concert piece' means that *musification* would be a more accurate term of the method, as it describes sonifications used 'for artistic purposes' [8]. Beyond the conscious decision of presenting and listening to a sonification as music, a musification should also use elements of the sonification process to define elements of the music. All too often, the musical thought is reduced to choice of sound mappings and instrumentation. By structuring the piece according to the structure of the data for example, the piece is not only a translation of the data but *is* the data. Therefore, if the data is organized as to create a musical structure, we are making compositional choices towards a musification. While we believe that the resulting audio-visual product could be enjoyed purely for aesthetic reasons without the knowledge of the underlying data and processes, the experience of the audience is enriched by the knowledge of its conception.
The elements that contribute to a successful sonification can be summarized by four categories: the choice of data, the choice of sound mappings, the choice of musical language and the emotional content of the data and the sonification. The combination of these parameters is unique to each data set thus there is no unique solution to data sonification [9]; only a careful combination can really transmit the information and emotional content appropriately

3.1 Data

The data used for sonification were the same as used for visualisation by Kaehler et al. [1]. The data sets are very large, e.g the simulation called 'Warm Dark Matter Halo' tracks 17 million particles which results in over 100 million tetrahedra per time step; another simulation discussed by Kaehler et al. contains 'about 134 million particles, resulting in about 804 million tetrahedra, respectively 3.2 billion triangles' [1]. Due to the size and complexity of the data sets, it was therefore imperative to filter and analyse them in order to highlight interesting patterns showing to physical phenomena. Three data sets and their respective visualisations were used for sonification; 'Warm Dark Matter Halo', 'Dark Matter Streams' and 'Dark Universe' [10]. Respectively, they simulate the formation of a dark matter halo around a galaxy, dark matter forming streams and the spatial concentration of dark matter in the universe.

The size and complexity of the data sets means that a second-order sonification is needed to express complex relationships in the data. Gresham-Lancaster describes the second-order sonification as the 'application of time bound algorithmic processes that are driven by sets or clusters of a data set' [11]. The 'sets or clusters' representing interesting relationships and patterns in the data were extracted by analyzing the simulation visualization.

3.2 Mappings

Primary and secondary data parameters were translated to primary and secondary sound mappings. 'Primary cues' were attributed to sound parameters to which we are particularly sensitive and capable of perceiving even small changes [12]; in this case pitch frequency and rhythm. Ballora describes 'supporting auditory cues' which underline the distinction between different primary cues while being more difficult to perceive; interesting examples are panning and volume. While this differentiation is useful for sonification design, it also has an interesting relation to musical composition where parameters have different cognitive levels but contribute to the overall musical structure. The hierarchy in parameters is thus a crucial element in the composition of a musification; to create a sonification which represents the data but is also structurally determined by the data.
In practice, examples of data parameters we identified were the size of a dark matter halo or galaxy, spatial particle concentration and distribution, and the movement of structures through space. As previously discussed, the data parameters used were of a higher-level nature where the relationships between the data points are explored rather than the data itself. These were mapped to sound parameters such pitch and rhythm, but also volume, spatial panning and timbre; the use of data parameters to trigger sound events was also explored.

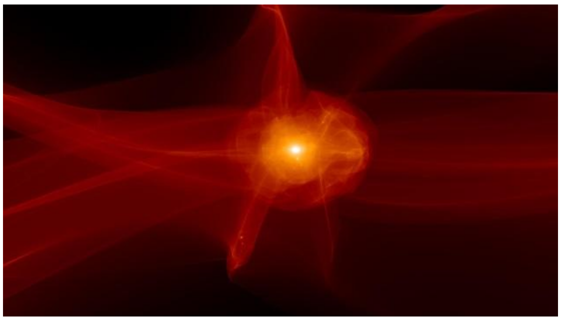

Figure 1. Visualization of a warm dark matter halo simulation. Visualization by Ralf Kaehler and Tom Abel, simulation by Oliver Hahn and Tom Abel [10].

3.3 Musical Language and Emotional Content

We know that sonification can be a powerful tool when used to harness the 'perceptual strengths that we possess as human beings' [9]. It is then surprising and counter-productive that sonification design so often relies on a well-established but limited set of sound parameters within the Western Classical musical language: pitch, harmony and rhythm. While these are understood almost universally and can be very effective, further musical parameters should also be considered for full effect. The electroacoustic or sound-based musical language focuses on sound qualities such as timbre, spatial positioning, frequency spectrum and so on; we feel that a combination of musical languages can broaden the cognitive possibilities of sonification.
The discrete nature of the musical scale is hardly appropriate to describe continuous data. For example, the mapping

of tiny differences of data to an audible frequency can be very effective as humans can distinguish tiny changes in frequency. We can see, that the variety of types of data demands that we broaden the ‘toolkit’ and that we adapt the mappings to the data. Note that these suggestions are in line with the development of music composition over the last century, during which composers have increasingly turned towards sound-based music and transcended the restrictive and discrete nature of Classical Western musical language.

Creating an emotional connection between the listener and the sonification can be another way of engaging them in the data. Vogt and Höldrich speak of ‘metaphorical sonification’ [6], the author prefers the concept of ‘empathetic sonification’ [12]. That is a sonification which ‘engages the listener’s ears and emotions in equal measure’. This is achieved by a sonification which musically reflects the emotional meaning of the data intended by the composer; the potential soundscape of the work should also reflect the data. However, the cognitive void presented by dark matter poses a challenge to this approach to sonification. A quick conclusion would be to assimilate sounds of space crafts or sounds associated to science-fiction with the sound of dark matter. This is problematic for a number of reasons. While dark matter exists in the universe and therefore has a link to space exploration, it also exists on earth. Furthermore, the music and sounds of science-fiction are ultimately a social construct of what space exploration sounds like.

While circumventing the danger of relying on stereotypical soundscapes and sonic associations in order to evoke the emotional content of the data, the listener’s innate and learnt connotations can also be harnessed to transmit a more powerful message. *The Sonification of Dark Matter* uses a mixture of Western Classical and electroacoustic musical languages for this reason. The sound sources are recordings of a piano and an array of synthesizers built in Max/MSP. Finally, some elements of we what might consider a space or science-fiction soundscape were included in the final sonification. That is to say, the use of synthesized sounds evoked these connotations for a large number of audience members. The listeners found this reference rather fitting as it provided a musical reference in what is otherwise a complex subject matter and resulting musification.

3.4 Methods

The visualisations were analyzed in Max/MSP to identify data clusters; this is because the size and complexity of the data made this approach far more effective than to deal with the raw data. By adjusting parameters of brightness, contrast and saturation of the image, specific patterns emerged which could be regarded as the visual filtering of the data. Subsequent RGB analysis calculated the amount of a specific color or its position in the image and therefore revealing the concentration and spatial mapping of particles in the image. As the colors in the visualisations correspond to the concentration of particles – the visualization effectively made artistic choices in choosing the colors - the RGB analysis resulted in a filtered and parsed data set. The data clusters were then mapped to sound parameters as previously described. The implementation of the RGB analysis and the second-order sonification in Max/MSP allowed us to produce sonifications in real-time, this was particularly useful for monitoring the results.

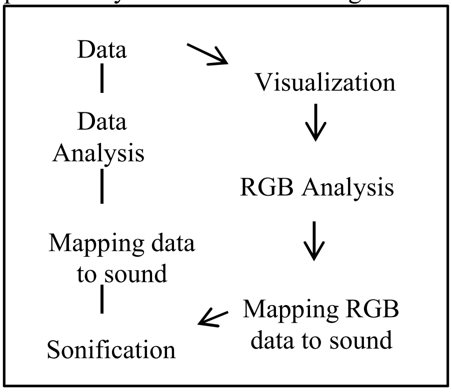

Figure 2. Process from data to sonification. The left side shows the typical method for data sonification, the right side shows the modified method needed to deal with dark matter simulation data.

3.5 Presentation

The project the piece *The Sonification of Dark Matter*, a 17-minute movie which accompanies the listener through the process of the sonification of the data from the silent visualisations to the completed sonifications in conjunction with their corresponding visualisations. As such, the final work serves as a tool to introduce the beginner to dark matter but also the process of sonification. It was felt that this was crucial for listeners to understand the full complexity of the original data, the method of sonification and the resulting audiovisual work. *The Sonification of Dark Matter* was premiered at the *Peninsula Arts Contemporary Music Festival* at Plymouth University (Plymouth, UK) on 26-28 February 2016.

4. DISCUSSION

The work with large-scale data sets of dark matter simulations highlights the challenge of using sonification as a compositional tool. The method demands musical and scientific knowledge in order to be successful; it can at times be impossible for a composer to fully understand the scientific background of the data sonified without the collaboration of a subject specialist. The discrepancy between the two knowledges has been mostly highlighted in sonification for scientific use which is often aesthetically poor and possibly unpleasant. A lack of aesthetic understanding of auditory display can render a sonification unappealing to listeners but also relay little information to the listener. On the other hand, a musification which transmits information poorly can be appreciated as a musical work but loses its purpose as a sonification. Therefore, a scientific and musical collaboration is indispensable to allow the field to progress and tackle more complex data and music.

Some sound mappings were more effective than others. As previously mentioned, pitch and rhythm parameters were particularly effective as listeners could perceive even slight variations; the use of volume was far less effective in that sense. However, the combination of the primary parameters (pitch and rhythm) with secondary parameters (volume) was crucial in creating a satisfying musification and transmitting information. In fact, the hierarchy of parameters established for the sonification mirrored the used of primary and secondary parameters in music composition. The structure of the data also informed the creative process as it determined the structure of the music. Finally, a careful choice of musical parameters and languages created a powerful piece. These elements elevated the aural display to musification.

The positive response from audiences showed that sonification can be used in public engagement in both music and science. By presenting a number of different mappings to the audience before collating them into a final version, the listeners could learn about sonification while also understanding the compositional process behind the final product. Effectively, they were involved with and gained an understanding of contemporary and electroacoustic music through the audiovisual installation. They were also introduced to the concept of dark matter in an accessible manner and had the chance to experience different aspects of the phenomenon in an educational environment. We found that the installation engaged crowds which were interested in the science aspect of the project in music, and vice-versa. In conclusion, the use of sonification and musification has widened the participation in scientific and musical outreach.

Acknowledgements

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5. REFERENCES

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