TOWARDS AN AUDITORY REPRESENTATION OF COMPLEXITY

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ABSTRACT

In applications of sonification, the information inferred by the sonification strategy applied often supersedes the amount of information which can be retrieved by the ear about the object of sonification. This paper focuses on the representation of complex geometric formation through sound, drawing on the development of an interactive installation sonifying escape time fractals as an example. The terms "auditory emergence and formation" are introduced and an attempt is made to interpret them for music composition, data display and information theory. The example application,. "Audio Fraktal", is a public installation in the permanent exhibition of the Museum for Media Art at ZKM, Karlsruhe. The design of the audiovisual display system that allows the shared experience of interactive spatial auditory formation is described. The work was produced by the author at the Institute for Music and Acoustics at ZKM, Karlsruhe.

1. INTRODUCTION

Unlike the generation of sound, which can be described in parameters such as volume, pitch and timbre, spectral composition, dynamic development etc., the perception of sound seems to defy simple parameterization, yielding a broad bandwidth of different acousto-psychological phenomena: The manifoldness of our spatial auditory world, involving speech, noises, music, etc.

Complexity on the other hand is a term vaguely based on the anthropomorphic concept of information density[7]. The definition of complexity that we adhere to in this presentation is the degree by which a structure creates "emergent formation" that seems to transcend or is not deductible from the description of its parts.
Famous examples are the emergence of color from the properties of atoms combining into molecules, or the emergence of "intelligent behaviours" from ant colonies[14]. Formation is a perceivable property emerging from a complex process. The process of interpreting emergent formations from complex processes by a human onlooker has been covered in much detail in the interesting works of Hans Diebner[7].
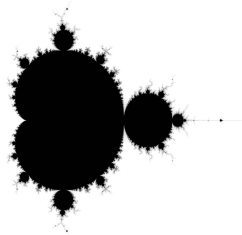

Figure 1: *The iconic z^2 Mandelbrot set*

From the polymorphism of our auditory perception it can be hypothesized that an investigation of complexity through sound is a worthwhile endeavour – an idea which is explored here employing Escape Time Fractals as an example. ETFs have been a source of inspiration for computer geeks and artists ever since their mind-boggling and colourful visual representations were widely published[8][13].
Although a number of sound pieces inspired by the beautiful images were created, many have argued that there is no successful way to generate an equivalent to the notions of infinite complexity and self similarity for the conscious auditory perception of a listener (not only for the structure of the composition) that these structures provide to the eye: Many cases of "Mandelmusic" employ the calculus in a rather unspecific fashion comparable to a strange random-number generator and carry a lot of "dead freight" by using the tempered tuning system of western music, thereby limiting the auditory outcome to "everything that can be played on a piano", covering up many very interesting and important subtleties.

2. CONCEPT

2.1. The data, the sonification and the listener

Sonification attempts to make patterns within datasets readable to the human ear. Depending on the application, this can generate various relationships between the listener, the sounds and the conveyed information, resulting in different solutions for the design of the sonification. We can roughly separate two cases: In the first case, the patterns in the data are pre-analyzed and categorized, and are represented as clearly as possible through sound. The main focus of creating such an application is the unambiguous design of the sound, comparable to the creation of a road sign or guidance system: The pre-interpretation of the data determines the information content of the sonification. This type of sonification includes the reading of parameter values from the sound, if the interpretation of the parameters is defined beforehand, such as current weather conditions.
In the second case, the information content of the sonified data is at least partially obscure – only a general categorization of the data might be known. This use of sonification to find unknown structures in the data by ear, is also called exploratory sonification[4]. In this application, the human hearing and its psycho-acoustical and acousto-psychological properties become a key issue[10].
Exploratory sonification can be a transformation of data values into a time series played back to the listener as PCM-audio (audification)[11], but may also employ parameter mapping, or apply models that may open the sonification to interaction[4]. It

attempts to optimize the emergence of those acousto-psychological phenomena, or auditory formation, from the data, which transcend the description of the sonification method itself. This means that the strategy of sonification should be as open for unexpected results as possible – as we are not certain about what we are going to find in the first place.

The medium (computer generated sound) should be allowed to create a language of its own forming instead of relying on metaphors or inferred cultural artifacts, which carry the danger of obscuring the information to be retrieved. – what we are looking for is an auditory language comparable to the formal languages of image for the display of information[9].

2.2. Auditory formations – a music excursus

In the field of sound and music, comparable abstract forms of expression developed in the 1940ies: The method of electroacoustic composition was expanding the role of the composer from writing notes to be played and interpreted by instrumentalists, to the creation of the very sound that is heard, played back through a loudspeaker. Composers were exposed to that freedom when signal generators and tape recorders as well as other electroacoustic instruments became available.

Pierre Schaeffer, one of the pioneers in the uses of these new technologies for composition, started to work in 1943 on a new type of music, which was based on sounds recorded via microphone to tape, and was to be experienced through loudspeakers.

In "musique concrete", according to Schaeffer, the sounds should unfold their own inherent language and not refer to the sources they were taken from. This mode of listening to abstracted sounds projected through loudspeakers was called "acousmatic listening", from which the term "acousmatic music" was created.

In opposition to the French Musique Concrete "Electronic Music" was created in Germany, in which only sounds were admitted that were generated electronically. After early experiments, composer Karlheinz Stockhausen introduced the possibilities of generating sounds from the superposition of sine tones to the studio in Cologne[3]. This idea roots in the Fourier Transformation and the contemporary idea of deconstructing sound into audio quanta[2]. Later, composers such as Yannis Xenakis continued along this tendency to formalize not only the musical score but the sound itself.

The "musical" language developed by these composers has at first generated confusion and earned disaffirmation by music listeners in the general public, who were unable to create an emotional or emphatic relationship with the new sounds they were unacquainted with. Nevertheless it has long since become a vital part of the sound design for films and radio plays and surrounds us now on a daily basis. It may also be noted that an emotional or emphatic relationship to the sounds is also something should not be excluded from the evaluation of exploratory sonification, as it represents a high-level acousto-psychological phenomenon. Schaeffer's envisioned abstract language of sound is akin to what we would like to call "auditory formation". What a composer of Musique Concrete tries to bring forward in his composition is very much related to what we would like to emerge from exploratory sonification: Perceivable abstract auditory structures. In accordance with Schaeffer, we would like to avoid abusing the structures of traditional music such as the tempered tuning system or sampled piano sounds, unless they emerge from the data at hand. What we are working toward with the concept of "auditory formation" is to bridge the gaps between composition/sound design, data display and information theory – disciplinary crevices that need to be overcome by a successful sonification to make audible nothing but the data.

As a side note, Schaeffer's "postulates and rules" which he formulates in his "Lettre a Albert Richard" are partially very relevant to the design and application of sonification - A more detailed analysis of the relationships between sonification and the historic developments of Acousmatic Music is worthwhile, especially concerning the description and uses of timbre, as well as the strategies of temporal and spatial organization of sound. It needs to be continued elsewhere, as it is beyond the scope of this presentation.

3. INSTALLATION

3.1. Representing Escape Time Fractals

The installation "Audio Fraktal" is an interactive audio-visual display of exploratory sonification. The visitor sees the visual representation of an Escape Time Fractal projected onto a pedestal in the center of the room, in which a graphics tablet is embedded. Using an interaction device (wireless 5-button mouse), the visitor is able to navigate freely through the two dimensional structure, zooming in and out.

The visitor can activate the sonification by pressing a button on the interaction device. A spatialised sound spectrum fills the exhibition space that corresponds to the current location of the interaction device within the visual representation. Moving the mouse while keeping the button pressed results in a spectral and spatial glissando to the new location of the mouse, allowing the visitor to continuously scan across the fractal to investigate transitions.
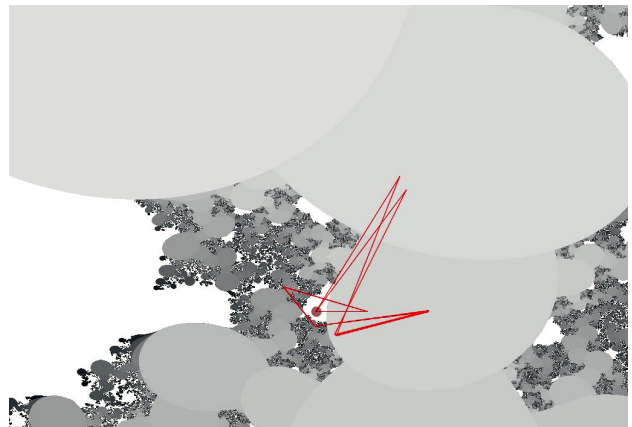

Figure 2: *Detail from an ETF generated from $z_{n+1}=exp(z_n/z_o)$ with an iteration path (downscaled).*

3.1.1. Recapturing some maths

The formulas generating ETFs can be generalized to:

$$z_{n+1} = f(z_n, z_0) \qquad (1)$$

In the case of the standard Mandelbrot set (Fig.1), this becomes

$$z_{n+1} = z_n^2 + z_0 \qquad (2)$$

Points z_0 in the complex plane for which the orbit z_n does not tend towards infinity are inside the set. If the orbit of z_{n+1} has

not transcended the escape horizon after a maximum number of iterations, the iteration is stopped, and z_0 is declared to be inside the set. An iteration path $(z_1 \ldots z_n)$ is thus generated from each point z_0. The number if iterations or length of the path are determined by the first z_n lying outside the escape horizon, or with the stop criterion.

In visual representations of the fractal the color for each graphics pixel it is determined from the properties of the resulting path [8]. In most cases, the color is taken from a color gradient and denotes the number of iterations the calculated path contains before the escape criteria are met. The choice of the color gradient is up to the person involved in the rendering of the image. Thus, the visual quanta from which the ETF-image emerges are screen pixels mapped to the plane of complex numbers: A comparable quantum for the auditory realm can be found in basic frequency components such as trigonometric functions. Just like screen pixels can display any image, according to Fourier's theory any sound can be deconstructed into or generated from sine components.
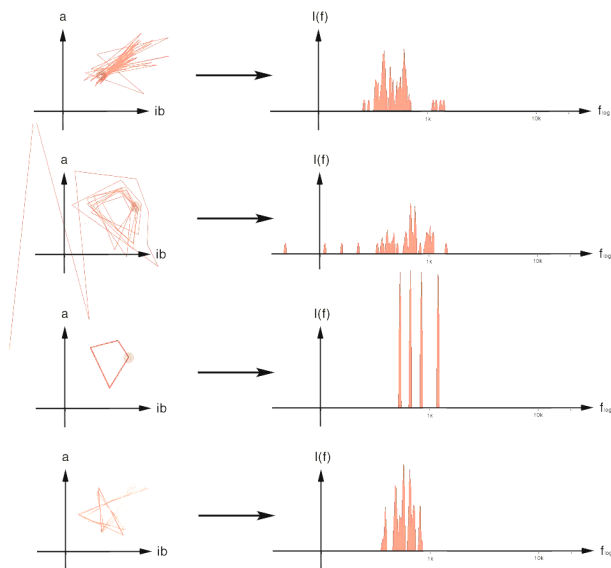

Figure 3: *Iteration paths and their corresponding spectra.*

3.1.2. *Making the iteration paths readable to the ear using additive synthesis*

There are several ways to generate sound from the iteration paths. One of them is a direct audification by creating a iterative Oscillator, another is the usage of the properties of the paths to generate parameters for granular synthesis. These strategies will be investigated in future applications. For now, we use the iteration path to create a spectrum by adding up trigonometric components. The distance between two subsequent points in the iteration path is transformed into a frequency, according to the quasi-physical equation of

$$f_n = \frac{f_0}{|z_{n+1} - z_n|}, \quad f_0 = 40Hz \quad (3)$$

The base frequency $f_{0=}$ 40 Hz is chosen from the dimension of the escape horizon: Since the lowest audible frequency is between 16 and 20 Hz, a step-length of 2 is mapped to a frequency of 20 Hz.

The possible iteration steps that lie beyond the escape horizon are disregarded. They are not calculated and their frequencies would accordingly be in the subsonic range.

Each iteration step is thus represented by a trigonometric function, together they are assembled into a spectrum. The time-function P(t) of an iteration path P would therefore be

$$P(t) = \sum_{n=0}^{n<(n_p-1)} \frac{\sin(f_n \omega t)}{a_f} \quad (3)$$

n_p is the number of steps in the path, a_f is an amplitude weighting factor. According to logarithmic processing of frequencies in the ear above 500 Hz [10], the 1/f law is applied for the volume of partials above that frequency (this is a subjective choice made during experimentation and listening)

3.1.3. *Spatialisation*

Sound localization works best with sounds that feature broad spectra or impulses. Pure sine tones are especially hard to localize and tend to recombine into a single perceived spectrum when projected onto the listener from different directions. In our application we use these recombinant spectra to envelop the visitor with sound: Each sine tone is spatialised in the direction of the represented iteration step, taking the origin of the complex plane as a reference point.
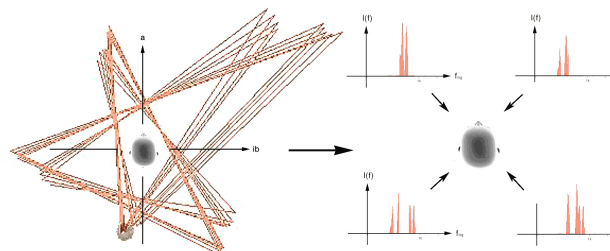

Figure 4: *Transforming a path into a spatially dispersed spectrum surrounding the listener.*

More distinct localizations appear if the path is unequally dispersed around the origin of the complex plane or certain frequency components only appear on one side. Since we are using iteration paths of 500 steps or more, resulting in broad spectra composed of 500 trigonometric components, these phenomena produce quite clear localizations.

3.1.4. *A small audio-guide to good old z^2*

In general, it can be stated that the sounds generated from the z^2 "Mandelbrot" (Fig.1) fractal fall into three main categories: Noise-like, disharmonic and chord-like. In the central kidney-shaped area of the fractal, the components form dense clusters sounding like band-filtered noise. The clusters get lower and denser toward the borders of the area. Entering the circular pockets, the noise separates into bands that narrow down into

discrete pitches: The largest pocket (to the right of the kidney) contains a diad: An octave. The two smaller pockets on top and bottom of the structure contain a triad. Going around the brim into the smaller pockets, each one splits into more pitches. The pitches are clearest in the center of the pocket, becoming more and more unstable toward the border. The sub-pockets within the pockets contain more and more complex chords. Exiting the Mandelbrot results in the addition of low frequency components. The sound disintegrates into a seemingly amorphous "disharmonic" spectrum. Approaching the set from the outside, more and more components are added to the sound as they ones present become higher and higher (comparable to a Shepard tone), but the spectrum stays chaotic and disharmonic until the set is entered, at which point the spectrum suddenly simplifies into a chord of discrete pitches.

The self-similar sub-sets in the border region of the Mandelbrot feature an individual chord sound each – all of them are different, yet their sound quality is similar. It may be said that they sound as similar and yet different as they look.

Yet – there is a lot more to discover for the ear in the border areas of the fractal.

3.2. Physical Installation

The setup chosen is a pedestal in the center of the room, which is equipped with a graphics tablet, while being used as a projection screen at the same time. This allows the visitors to gather around the visual display sharing the view and the sound experience without blocking each other.

The sounds are projected into the room through eight speakers mounted at a height of 2.2 m, surrounding the visitors in an even circle. For low frequency projection, a subwoofer was added. This setup allows a highly defined projection of a spatial sound scene in combination with unhindered access to a visual display, all of which can be shared by a small group of people gathering around the pedestal.

4.   CONCLUSIONS AND FUTURE WORK

We think that this strategy to sonify escape time fractals, opening them to an interactive exploration, is quite successful at exposing properties of these structures that are not visible, displayed much more efficiently in an auditory language. Certain questions about how these structures are shaped in the way they are can be answered intuitively by interacting with the sounds themselves. The use of additive synthesis limits the expressiveness of the sounding result, but it also enables the installation to generate a seemingly infinite amount of different spectra each of which carry discernable individual characteristics. Yet, the possibilities of letting data paint themselves onto the canvas of our auditory perception are by far not exhausted with this installation: future installations will explore the possibilities of granular synthesis and complex oscillators. Pushing the installation further along the line between an instrument for sonification and a tool for electroacoustic music, metaphors are being developed including multi-indexing (each loudspeaker being and index on the complex number plane) or the generation of algorithmic behaviors for automatic motion of an index across the complex plane (…)
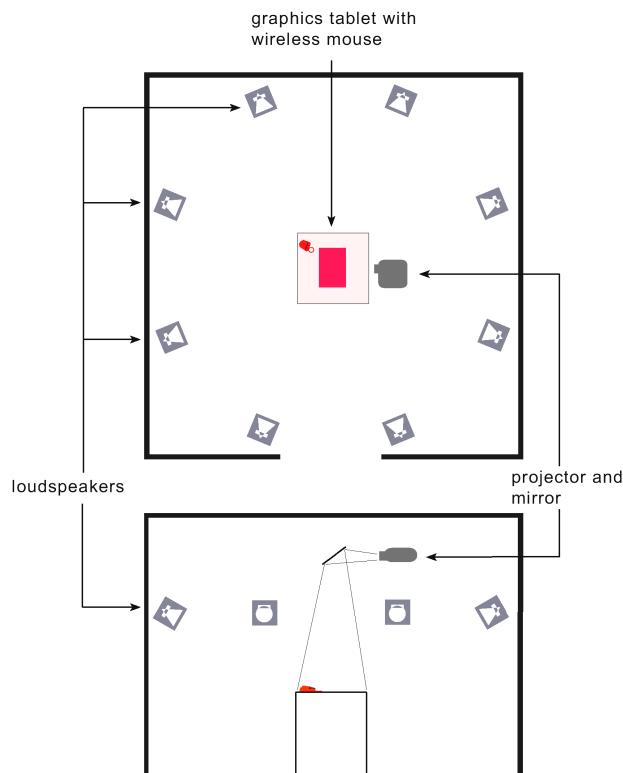

Figure 5: *Schematic of the display setup*

5.   ACKNOWLEDGEMENTS

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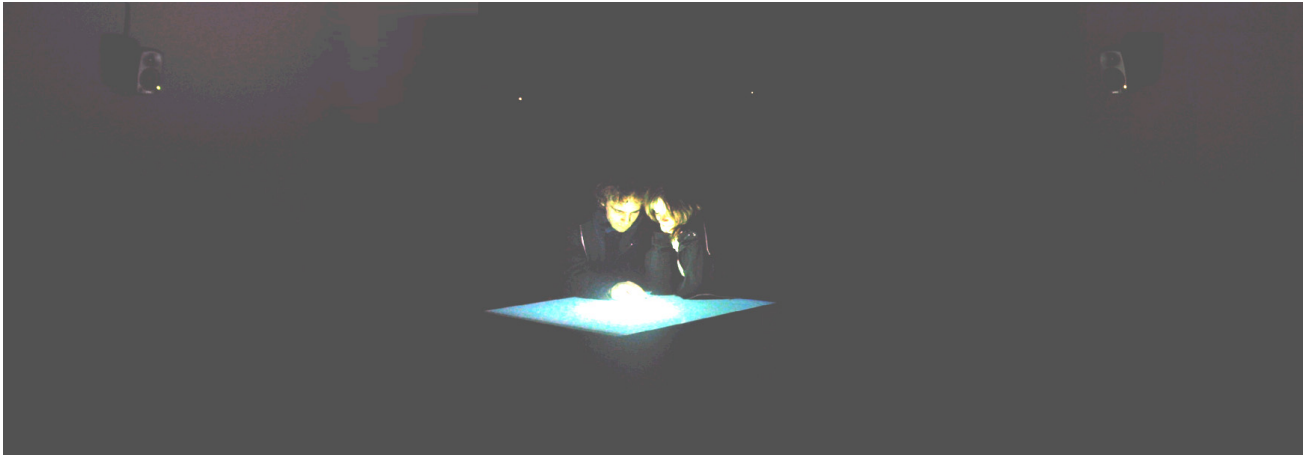
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Figure 6: *Inside the "Audio Fraktal" exhibit*