

FracWave: Non-linear Dynamics as Timbral Constructs

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Abstract

FracWave produces sounds with dynamic characteristics by means of a parametric control of simple non-linear maps. It is a compositional tool which allows a composer to generate new sounds and to build up sonic structures from an atomic level. This paper discusses the basic concepts about FracWave, it elucidates how the model was derived from recent research on non-linear dynamics, it presents a compositional approach based on parametric scores, and it illustrates the musical results presenting graphics and sound examples taken from compositions created by the author using FracWave.

Introduction

The use of Non-linear Dynamics (NLD) in music is in line with the recent development of scientific models led by the Theory of Chaos (Gleick, 1987). Methods derived from NLD have been applied to Acoustics - a basic reference is found in (Lauterborn & Parlitz, 1988), and a method of Analysis of Musical Signal is presented in (Bernardi, Bugna & De Poli 1992). In Algorithmic Composition, there has been research on applications of Iterative Maps to describe compositional systems (Bidlack, 1992). In parallel, the use of NLD have revitalised Timbral Design (Truax, 1990; Scipio, 1990), in these methods non-linear maps are used to organize musical structures from an atomic level.

FracWave is in line with the third perspective above. It aims to develop micro-structural constructs to produce new types of sonic behaviour and to create sounds with complex and dynamic characteristics. Numerical material generated by non-linear maps shapes waveforms i.e. the method is an application of mathematical iterative processes. Therefore FracWave is a synthetic and heuristic approach. Using Smith's definition (Smith, 1992) it could be described as an Abstract Algorithm for Sound Synthesis. It produces sounds with rich spectra and it does not intend to simulate either an acoustic instrument or a classical acoustic model.

This paper is in line with previous publications in which the author introduced FracWave as a sound generator, discussed its possible musical applications and presented an extensive documentation of the method (Manzolini, 1992,1993). The report here concentrates on compositional issues. Nevertheless it recapitulates FracWave basic ideas, it summarizes the relations between NLD and FracWave, and it presents a mathematical formulation of the algorithm. After that, sonic and compositional issues are discussed and followed by graphics and sound examples.

FracWave Basic Ideas

The basic concept behind FracWave is: the model was developed in contradistinction to digital techniques which use wavetables as invariant sound synthesis units. FracWave produces sounds using numerical buffers controlled by simple non-linear dynamical systems. These buffers are coined *Dynamic Wavetables* and they replace the traditional digital oscillators. The idea is to use algorithmic manipulation to generate complex types of sonic behaviour. There are models similar to FracWave concerned with this manipulation of data which then produces *abstract waveforms*. Berg (1979) developed a sound synthesis language called PILE. His method was described by him as *one single sound, the perception of which is represented as a function of amplitude distribution in time*. Another approach was presented recently by Serra (1992), *a new achievement in Xenaki's stochastic work*. This method is based on stochastic control of waveforms defined by polygonized lines.

The FracWave algorithm is divided into two kinds of processors: a) *non-linear processors which are a set of eight simple non-linear maps and b) linear processors which are the Dynamic Wavetables*. The basic principle is to work with a sound generator unit which produces a time-varying waveform based on two iterations in parallel: the non-linear map's iteration and the Dynamic Wavetable iteration. Finally, the basic elements of the method presented here are: a) *non-linear maps - source of waveforms, b) Dynamic Wavetables - micro-structural constructs and c) Structural Links (Sound Cells and Sound Streams) - tools to link the micro with the macro level of composition*.

Phase Space Analysis

Feedback applied to simple mathematical models could generate chaos. In Chaos methodology it is visualised in a space called phase-space or state-space in which the coordinates are the degrees of freedom of the system. Each point in the phase-space represents the entire state of a dynamical system in a certain moment of time. A non-linear map generates single points, limit cycles, simple or chaotic oscillators in the phase-space. These graphics are named attractors or strange attractors (i.e. in a chaotic case) which are asymptotic limits of the system's solution as time approaches infinity.

Based on these concepts the author developed a software tool to analyse the phase-space graphics. The FracWave's thesis were derived from this analysis as follows: a) a non-linear map produces periodic, quasi-periodic or chaotic motion by changing its initial conditions (X0, Y0) or its parameters (A, B, C) (see Table 1), b) this behaviour in the phase-space is visualised by an attractor (see Figure 2) and c) the numerical behaviour of the map in the phase-space mirrors the sonic behaviour of a waveform.

Non-linear Maps

The author created a set of eight simple non-linear maps to use in research. This text does not include the complete set, see (Manzoli, 1993) for more information. Three non-linear maps used in FracWave are presented below:

$$\begin{cases} X_{k+1} = Y_k - \text{sign}(B - Y_k) \sin(C\pi k) \\ Y_{k+1} = A - X_k \end{cases}$$

$$\begin{cases} X_{k+1} = Y_k - \text{sign}(X_k) \sqrt{|BX_k - C|} \\ Y_{k+1} = A - X_k \end{cases}$$

$$\begin{cases} X_{k+1} = Y_k - \text{sign}(X_k) + \sqrt{|BX_k - C|} \\ Y_{k+1} = A - X_k \end{cases}$$

The sequence (X_k) produced by the maps is mapped into the interval [-1,-1] to be used as waveform. Additionally, linear interpolation and oversampling are applied to smooth the resultant curve.

Implementation and Mathematical Formulation

The computational implementation of the FracWave's sonic construct i.e. Dynamic Wavetable (DW), is based on a numerical buffer which is read using one increment (I_n) while it is simultaneously refilled with new values from a non-linear map using another increment (J_n). A DW is a delay line (Figure 1 illustrates FracWave implementation) and it is also used as an Average Filter. This procedure could be related to the LAsy Technique (Chareyron, 1990) and Physical Models (Smith, 1992). The average process used in FracWave slows down the energy of the generated sound working as a dumping factor. It is a digital filter which concentrates the spectrum's energy on an average partial. The implementation is described by two equation as follows:

$$Y_n = W[I_n]$$

$$W[J_n] = \alpha X_n + \frac{1-\alpha}{p+1} \sum_{m=0}^p A_m Y_{n-m}$$

where Y_n is the output sequence, W[.] is a DW, X_n is the non-linear map sequence, 0 ≤ α ≤ 1 is a combination factor and (A_m)_{p=0...m} is the coefficients of the average filter.

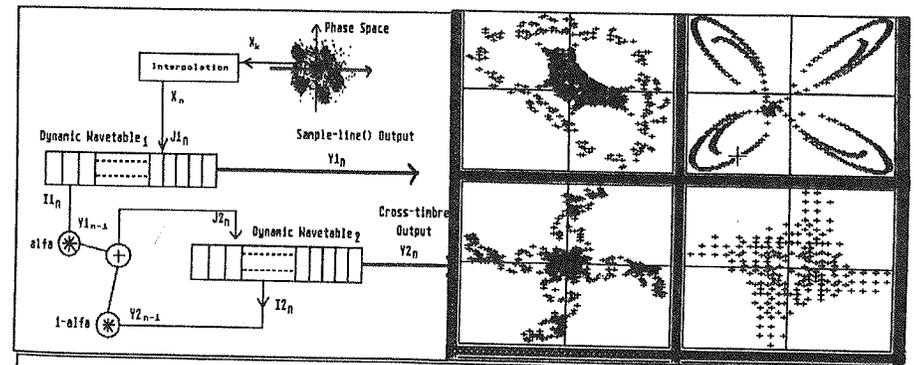
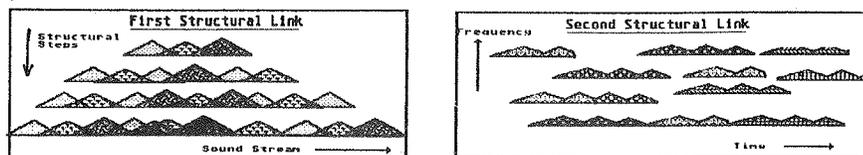


Figure 1, on the left, is a diagram of the FracWave Algorithm. Figure 2, on the right, is a sequence of four attractors in the phase-space.

Structural Links

The structural manipulation described here was inspired by Granular Synthesis (Roads 1985). The author developed two tools to build sonic structures: a) *Sound Cell* - the parameters which controls FracWave (see Table 1) and b) *Sound Stream* - parametric score produced by Sound Cells. Starting from the micro level, two structural link build up macro structures: a) *First structural link* - Sound Cells which control sound segments (50-100 ms), form Sound Stream and b) *Second Structural Link* - Sound Segments (500-1000 ms) generated by Sound Stream are transposed and superimposed to build macro sound events.

A sequence of Structural Steps constructs Sound Stream in the First Structural. Starting from an initial set of Sound Cell, operations such as permutation and sequencing are used to produce a Sound Stream. This new Sound Stream is used as a unitary Sound Cell in the next Structural Step. This iterative process produces a growth through levels of scale which forms the Sound Streams. These parametric scores generate a *Sound Palette* which is used in the next structural link. In the Second Structural Link concatenation of the sounds of Sound Palette is produced by means of permutation in the horizontal axis (time axis), and superimposition and frequency transposition in the vertical axis (frequency axis). In parallel, a Triangular Window is used to splice these sounds for it smooths gaps between two waveforms avoiding glitches in the resultant sound.



Mutations of Sound Cells

To create a Sound Stream a composer needs to input a great deal of data from the computer keyboard. Thus a computational tool was developed in research to generate a Sound Stream as a sequence of parametric mutations of an original Sound Cell. A composer has therefore to input less data as follows: a) an original Sound Cell, b) a set of three parameters to control the percentage of change in the Sound Cell and c) a set of three parameters to determinate the parameters involved in change. After that, the computer generates a Sound Stream using these three parameter sets to control an iterative random process. Notice that, the Mutation Operations is used as First Structural Link. Finally, the Iterative Random Equation is presented as follows:

$$P_{k+1} = P_k + ((\text{Rnd}() - 0,5) * C) / 100$$

where P_k is a Sound Cell parameter, $(C)_{i=1...3}$ are the percentual of changing, and K is determined by a random choice in $(K)_{i=1...3}$.

| duration | non-linear map | | | | | dynamic wavetable | | | average filter |
|--------------|----------------|---|---|----------------|----------------|-------------------|------------------|---|---------------------|
| | A | B | C | X ₀ | Y ₀ | F _{osc} | F _{ref} | α | |
| milliseconds | | | | | | | | | $\{A_m\}_{m=0...P}$ |

Table 1 presents the parameters of a Sound Cell. Notice that F_{ref} and F_{osc} are related to J_n and I_n by the the same equation $J_n = \text{ROUND}(n * F_{ref} / F_s) \text{ MOD } L$ with F_s = sampling frequency and L is the number of points in the DW.

Composing Soundscapes

The sonic aim of FracWave was inspired by the complexity of sounds found in nature. The research focused on generating sounds which evoke forces of nature recalling phenomena such as turbulences, wave-breaks, explosions etc; a timbral palette distincts from more typical electronic ones. The spectral typology of the sounds produced by FracWave can be related to the description of Smalley (1986) in *Spectro-morphology and Structuring Processes*. Most of these sounds are allocated to the *pitch-effluvium continuum*, as defined by Smalley, between *nodal spectrum* and *noise*. These sounds have complex internal morphologies. Therefore the composer has to confront the compositional challenge: how to organize them in a convincing musical way? Wishart (1985) presents a classification of sounds with complex morphology which is useful here. In his words: a *number of archetypes which allow us to classify these complex sounds perceptually, such as Turbulence, Wave-break, Open/Close, Siren/Wind, Creak/Crack, Unstable/Settling, Shatter, Explosion, Bubble*.

From one point of view the sounds produced by FracWave have complex internal morphologies, from the other these morphologies are very characteristic (such as Turbulence, Wave-break). Thus it is possible to operate with these peculiar features to produce sound-images. The compositional tool for organizing complex sounds could be to manipulate them in a symbolic context, and to associate the musical meaning with the sonic behaviour of these complex constructs.

Let us to exemplify the compositional approach presented here with ideas from Berio's vocal work *A-Ronne* (1974). This piece was based on a poem by Sanguineti in which he arranges quotations from different languages in segments and agglutinates them in hybrid sentences. There is an example of the poem *A-Ronne* as follows:

a:ah:ha:hamm:anfäng
in:in principio: nel mio
principio:
am anfäng: in my beginning

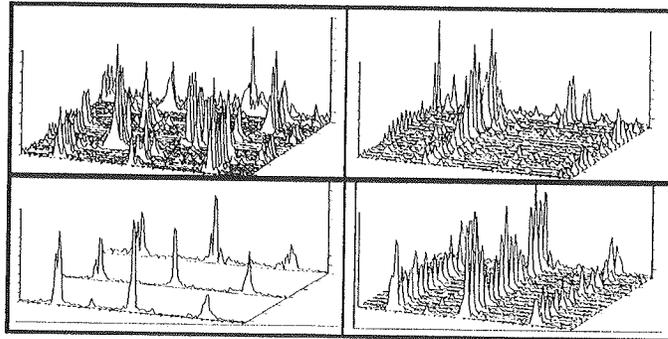
The structural manipulation used by Sanguineti was to re-create expressions from different languages copying words and linking them according to similarities of meaning. The aesthetic view of *A-Ronne* was described by Berio (1976) as *changes in expression imply and document changes in meaning*. In the same way the poem *A-Ronne* was constructed using words, a electroacoustic suite called *Turbulências* was composed using sounds. The compositional approach was an agglutinative technique in which sounds (i.e. equivalent to words) were combined to form sound-images (i.e. equivalent to sentences) - similarities between sounds were related to the similarities between sonic archetypes (see Wishart above).

For instance, the name of the first piece in *Turbulências* give us a cue to understand the aesthetic of the piece. *Agglomerados* is Portuguese for agglomerates, which are fragments of rock fused together in a mass. An agglomerate material is a structure which grows into a mass, for example a growing crystal. Within this metaphorical context, it is possible to say that sounds could be compacted to form a soundscape of musical crystals. This idea is related to two different sonic structures in *Agglomerados: Monoliths and Creatures*. The first one resembles massive and dense structures such as compacted stones, diamonds. The second one resembles granular sound structures, like graphite.

The micro structure of these two sonic entities is controlled by Sound Cells and Sound Streams as described above. They differ from each other by the way they are built at the First Structural Link. Monoliths are compact structures with an implied amalgamation of atomic sound/waveforms. This is created by using Sound Cells with durations between 50-100 milli-seconds and Sound Streams with the number of Sound Cells between 10-15. Creatures are rhythmic structures, an implied increase of distinction between the components micro sounds. This is produced by using Sound Cells with durations between 30-70 milli-seconds and Sound Streams with the number of Sound Cells between 5-10.

Graphic Examples

The examples below illustrate Sound Transformations produced by FracWave. The first example (from left to right) describe a spectral shift which concentrates the spectrum's energy on an average partial produced by the Average Filter. The second example shows a spectral development derived from an initial Sound Cell and a subsequent Sound Stream.



In the graphics above the horizontal axis is frequency, the vertical axis is amplitude and the third axis describes the time evolution from the background to the foreground.

Discussion and Conclusion

The application of non-linear maps as sonic constructs confronts the musician with a compositional challenge: to organize chaotic sounds in a meaningful and coherent musical structure. On one hand, this can be approached by agglutinative techniques and by the symbolic development of chaotic soundscapes. On the other hand, this complex sound material produces a sonic paradox - while it is the musical construct it may cause sonic opacity, which will serve rather to de-construct the music. The composer needs therefore to handle this material with studio techniques developed to avoid losses in structural clarity.

The next step on this investigation is to use FracWave to transform environmental sounds. These sounds could be rich sounds such as the material found in the Brazilian Soundscape. In this implementation, a DW filled by these samples could be combined with the waveforms generated by FracWave. Another possibility, could be to apply the average filter as a dumping factor creating spectral changes in the original sound. It is possible to project other transformations, but the main compositional issue is to integrate FracWave's synthetic sounds which resemble natural phenomena with similar sounds found in nature. This could produce new sonic textures which either FracWave or the natural sounds generates by itself.

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