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Mc Laughlin, S (2011) Dynamical Systems, Mimesis, and Analogy in Experimental Music. Chaotic Modeling and Simulation, 1. 127 - 137. ISSN 2241-0503

Dynamical Systems, Mimesis, and Analogy in Experimental Music

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Abstract. Music and dynamical systems share aspects of patterning, repetition, and variation over time, but most music that references dynamical systems as a compositional influence are mimetic representations of the system, the music is a static 'snapshot' of the system. I propose an approach where the compositional and performative processes are analogous to the dynamical system, and the music develops in realtime through performance, acting as a model of the system in musical form. The dynamical system process is translated from the mathematical to the musical/performative, retaining its mechanisms but in a new medium. This paper will explore two examples of previous mimetic approaches, and a brief exposition on similarities between dynamical systems and musical indeterminacy (in experimental music). I will then present examples from my work *There are Neither Wholes Nor Parts* (2011), showing how feedback and hysteresis are used to create musical processes that affords non-linear and emergent sound structures.
Keywords: hysteresis, feedback, composition, music, improvisation.

1 Background and Definitions

Non-linearity and chaos are exciting ideas for composers in many ways. Music is essentially patterns of repetition and variation over time, and much of musical structure and meaning is predicated on the ambiguities of tension and release (see [6]). Non-linear systems such as strange attractors are intrinsically musical because they hover between variation and repetition, defining a structure gradually over time. Well-known examples of composers taking inspiration from dynamical systems include Ligeti's *Piano Etudes* (1985), which reference self-similarity and fractals in relation to the development of rhythm and pitch cells through the piece. Danish composer Per Nørgård also turned to fractals as the inspiration behind his "infinity series" technique, saying:

> Chaos is fascinating because you have an order behind chaos and chaos behind order. That fits very well with my feeling of life too[1].

Ligeti and Nørgård's inspiration is a version of an ancient theme in Western Art, that of "unity", a deeper order behind a seemingly chaotic surface (see [8]). These composers' works are examples of poetic inspiration, where the *idea* of dynamical systems can be applied to a composer's musical language, generating a musical idea from a non-musical source. Section 2 examines in more detail the mimetic aspect of making music from dynamical systems.

I would like at this point to make a distinction between dynamical systems used in computer music[1] and acoustic music. For this paper I will refer only to acoustic music, primarily because the use of dynamical systems in computer music is a healthy discipline with many fine examples of the realtime sonification of dynamical systems (see section 2), whereas I am proposing the application of dynamical systems to acoustic music in a manner that goes beyond the poetic, in which the dynamics of the system must be analogised in order to make it performable. I believe my research in this area represents tentative steps in a hitherto unexplored area with much potential for future work.

2 Mimesis, analogy, sonification

The generation of composers active when chaos theory was first popularised adopted it largely from a mimetic perspective, where the objects and structures of chaos theory are used to inform the composition of linear musical structures. The music is not literally mimetic, in the sense that the composers are not intending to imitate or represent what inspires them, rather the inspiration leads a musical idea, translating the physical into musical language. This translation can take the form of a highly poetic inspiration, or a more literal sonfication, I present examples of both below.

2.1 Poetic mimesis

In Tristan Murail's *Attracteurs Étranges* (1992) for solo cello, he describes his use of the strange attractor as a "poetic analogy":

> The melodic contours of the cello describe spirals that always seem to return to one of several identical points, but in fact always follow differing, warped or diverted trajectories.[7]

Murail takes a mimetic approach, translating the "warped trajectories" of the attractor into a musical language and composing a piece which is a static and linear representation of the dynamical system, like a musical photograph of the attractor, fixed and unchanging. Of course if should be noted that in live performance the piece will be "dynamic" by virtue of its unfolding in realtime, but this is still in reference to the fixed score, the dynamical system is not mapped in a manner that allows the piece to change each time it is performed.

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[1] For my argument, the terms "computer music", "electronic music", and "electroacoustic music" are essentially interchangeable, encompassing any musical situation where the computer is used for sonification of data in realtime.

2.2 Sonification

Sonification is a more rigorous approach to translation, where the equation or resulting data is mapped–directly or indirectly–onto some parameters of sound. Michael Winter defines sonification as follows:

> The parametric profiles of the changing characteristics of sound can be expressed as mathematical functions of time. By using physical scenarios and mathematical functions to determine these parameters, one can distance oneself from aesthetic opinions and attempt to relinquish intuition. This provides another way to create a new music.[13]

Outside the domain of electronic music, Iannis Xenakis is the composer most associated with the mapping of scientific and mathematical concepts onto musical parameters. His biographer Nouritza Matossian has this to say about Xenakis' sonification of such ideas:

> Xenakis never claimed that a rigorous mathematical basis is sufficient to produce a well-formed piece of music. Those who are partially informed about the mathematical theory expect the music to be a mirror of mathematical processes and equations. *Pithoprakta* is no more a translation of probability theory than an artichoke or a celery is a *translation* [Matossian's italics] of the Fibonacci series, or a flowing river is a translation of random functions. [...] Even though underlying structures are shared, particularity of musical resources ensures uniqueness in each one.[5]

Sonification is another way of interpreting non-musical information through sound in a way that allows the structures in that information to be made audible.

A brief note about musical notation. In computer music, sonification generally means bypassing the symbolic layer of notation. For example, taking realtime data from a weather satellite and mapping it to pitch/duration/etc. requires no notation other than the necessary code, which is interpreted somewhat literally (by the computer). In acoustic music, musical notation is usually a required step to interface with the performance traditions of musicians, and the interpretation of that notation is subjective; different performance traditions establish competing authoritative versions of practice. Transforming data into notation inevitably involves some scaling to appropriate ranges, but more problematically it can also involve the quantisation of data to fit musical scales and rhythmic durations. Such quantisation is only problematic from the point of view that the musical result may be less musical but more interesting without it. This is not to say that the music has to be "true" to the data, to be understood it should be translated in a manner that is idiomatic to the styles and languages of the new medium. However, much of the interest in this sort of cross-breeding of ideas is that new processes and languages can emerge, by trying too hard to fit the traditional clothing of music, this can be lost.

As an example of sonification in acoustic music, in Rolf Wallin's *Onda di Ghiaccio* (1989), "fractal equations are applied to the musical materials to describe the dynamics of a turbulent process"[12]. Wallin uses a "symmetrically coupled nonlinear system" to generate stochastic maps which control musical field parameters such as pitch center, pitch range, field duration etc., thus the dynamical system creates a fixed scaffold onto which the musical detail is composed: see also Wallin[10] for a more detailed explanation of the mapping. This is less mimetic than the Murail example but still a static representation of a dynamic process. In these examples the motion of the turbulent process is only imitated by the flow of the music, both of these applications are compositional devices that mimic their respective dynamic processes. That said, I'm sure both composers would be at pains to point out that the dynamical system here is inspiration for a musical structure, the mimesis is not intended to be literally representational of the system. As Wallin states:

> This is my first attempt to use fractal mathematics in my music. The Italian title ("Icewave") emerged in the very end of the creation of the piece, and is only one of many possible titles describing a turbulent motion captured - or frozen - in a specific moment. The notion of a wave stretched out to last 12 minutes has nothing to do with sound imitation. Instead I try to describe the dynamics of every turbulent process, be it in water, air or for that matter in our lives, where order, chaos, predictability and unpredictability give way for each other in an ever changing pattern.[11]

Both the Murail and the Wallin pieces are examples of approaches to using static snapshots of dynamical systems as a model for composing linear music. My research is not intended as a replacement for the above approaches, or to invalidate them, rather as another way of approaching dynamical systems that is less static. In the following section I will show how indeterminacy is used in experimental music to create pieces that are not static or linear, and in section 4 I will show how the tools developed by experimental music composers in can be integrated with dynamical systems as models for composition of non-linear music.

3 Experimental music, Indeterminacy and dynamical systems

For clarity, it should be explained that Experimental Music is a very broad genre, and by no means all of it conforms to my description below. There are many ways of challenging musical traditions and asking the question "what can be music?", but I wish to focus here on music that challenges received ideas of structuring, teleology, and linearity in music. Also, the music described below does not use dynamical systems as a model, but it is in many ways a more dynamical music than traditional score-based Western music, and as such I use it to demonstrate my own compositional heritage and the existence of a modern music that eschews linear construction.

The paradigm of indeterminacy, as used in Experimental Music, is demonstrably non-linear in a musical context, either as compositional process (such as Cage's "chance" procedures) or as a performance-based process (in the music of Christian Wolff, Cornelius Cardew, *et al*). The non-linear structures of strange attractors and other chaotic objects can be applied to indeterministic musical processes to move beyond the linear paradigm of static musical structures into the realm of dynamic structures and material. John Cage describes a goal of art as to "imitate nature in the manner of her operation"[4]. What I propose is analogy rather than mimesis as compositional process, where the process is translated from the mathematical to the musical/performative, retaining the mechanics but in a new medium.

In the 1960s, John Cage's popularisation of the concept of indeterminacy in music was in large part responsible for the formation of the school of experimental music, which I would describe as a schism in the composition and performance of Western music, and more importantly, a sea-change in how music is listened to. Among other things, experimental music expands on Duchamp's ideas of Art by drawing attention to the audient as an active rather than passive participant. In the case of music this is an acceptance that music is an esthesic process. The prevalent model of pre-experimental music was the narrative—in "pure" formal music as well as in programmatic music—that led the listener through a journey of the composer's design, a mainly linear experience. In much experimental music the model shifts to an experiential one, where the listener is presented with an environment that unfolds in time, a significantly less linear music.

Leonard Meyer, in his theories of meaning and emotion in music (see [6]), describes meaning in information-theoretic terms, as a function of the predictability of the musical structure based on its moment-by-moment development. In his analysis, well-composed music manipulates a sweet-spot in the human perception of musical repetition and variation, wherein the music changes just enough to be interesting but not so much that it alienates or bores the listener. In a linear piece of music this is generally controlled by the composer, working to a traditional sense of musical proportion (where the music should climax, or rest, etc.) in order to create a teleological experience and lead the listener through a narrative structure (whether explicit or implicit). In Experimental Music it is more often the case that strict linear structuring is replaced with a field-model, where musical materials are presented in time as co-existing objects without explicit relationships. Structure in Experimental Music is thus often a function of the listener's experience, rather than an explicit structure of the composer's design.

Looking at how indeterminacy is used in music, Cage's own strategy was mainly pre-compositional, in that he would employ randomisation—rolling dice, consulting the *I Ching*, or even using imperfections on the surface of the paper to decide on positions of notes on the stave—in the choice of notes and more: his concern was to distance himself to some degree from the compositional act, to make it less about ego and control, and to "let the sounds be themselves"[4]. These works are created using indeterminacy but are still largely linear in performance.

To create less linear works, many composers experimented with pieces where sections of music with fixed notation can be played in any order, locally linear but globally non-linear; for example, Stockhausen's *Klavierstück* XI from 1956[9]. However, truly non-linear music requires not just the structural sections but the the musical material itself to be indeterminate at some level. Approaching this ideal is the music of Christian Wolff, which often allows the material to be chosen by the performer, with Wolff specifying types or sometimes only specifying abstract or poetic relationships between events/materials. Wolff includes elements of feedback in his work by encouraging listening among players, and suggesting (not instructing) that they take cues from each other: the socio-political impetus behind this is give the players more choice and independence, an act of resistance against the control structures of much Western music. In works such as *Burdocks* (1970-71) and *Changing the System* (1972-73), he makes the temporal aspect of the music dependent on the interaction of the players by using cueing systems rather than the traditional grid of beats and bars.

Wolff's piece *Edges* (1968) is especially non-linear. The score lays out a series of symbols scattered arbitrarily on a page, with a corresponding legend to explain the symbols. The performers are not to play the symbols themselves, but rather use them as points to be approached. Wolff explains in the score:

> [the symbols] mark out a space or spaces, indicate points, surfaces, routes or limits. A player should play in relation to, in, and around the space thus partly marked out. He can move about in it variously (e.g. in a sequence, or jumping from one point to another), but does not always have to be moving, nor does he have to go everywhere. Insofar as the signs are limits, they can be reached but should not be exploited. The way to a limit need not be continuous, in a straight line.[14]

The piece is non-linear in its approach to time, there are no suggestions, symbolic or textual, as to how long the piece or any individual event should last. The player moves between events as they choose, in no fixed order. Yet the piece still has a structure, a set of "limits" to be approached by the players, and the interactions between these players as they influence each other, a subjective sort of feedback. The piece is also non-linear in its interpretive space. Each symbol is asymptotic in relation to its interpretation. Some are subjective, the symbol "very rapid" can be approached up to the physical limits of the player, but the limit itself is inexact. Some are more literal, "directly after a long sound" is a very clear instruction but there are an infinity of ways to play not-"directly after a long sound" and still be approaching this limit.

Experimental music has developed many notational and performative techniques for creating non-linear music. As a composer I have taken these techniques and developed them to include elements of feedback in order to take advantage of the structuring aspect of dynamical systems. In the following section I outline a recent example and the method used.

4 Hysteresis as compositional/performative process

In my compositional research, the series of pieces titled *There are Neither Wholes Nor Parts* (2011) uses feedback and hysteresis to generate musical structures in realtime through the interaction of two elements: (1) the score (a notation and set of interpretive rules) that drive the performer's pitch choices; (2) and the non-linearities of the woodwind multiphonics that make up the material of the piece: these pieces are written for woodwind instruments using only multiphonics. This section explains the choice of multiphonics as musical material, and how feedback has been used in the compositional method.

Multiphonics are used in this piece because the sound is interesting to me as a composer, but also because they have a non-linear response and produce frequencies outside the standard tempered scale of musical pitches. Arthur Benade describes multiphonic oscillation as:

> a collection of components whose frequencies are connected to one another by an elaborate set of heterodyne relationships. The ordinary tones of woodwind instruments also fit this description, but the frequency components in normal tones are limited to those belonging to a single harmonic series.[2]

Multiphonics are generally perceived as a complex sound made up of two or more notes, and the difference/combination tones resulting from the interaction of the multiple superimposed air columns. Botros *et al* cite Backus as reporting that "the heterodyne components from the interaction, [indicate] a non-linear super-position of the two notes."[3] These non-linear relationships mean that multiphonics are relatively unstable and unpredictable in performance, requiring specialist knowledge of the musician to control them and make the performance viable. In these pieces, the performer is asked to play full multiphonics, and also to isolate individual partials[2] (using breath

[2] this terminology is inaccurate but for the purpose of my argument it is sufficient to distinguish between playing the full spectrum of the multiphonic and isolat-

pressure and embouchure), as well as some in-between states: see Figure 1. Specific multiphonic fingerings can also exhibit considerable variability in pitch results across different players and instruments, so for my compositions I have avoided any references to specific fingerings, instead the performer uses whichever multiphonics work best for them as material for the performance, while the score defines the musical relationships that the performer should create with this material. This non-specificity of material is a common approach in experimental music.

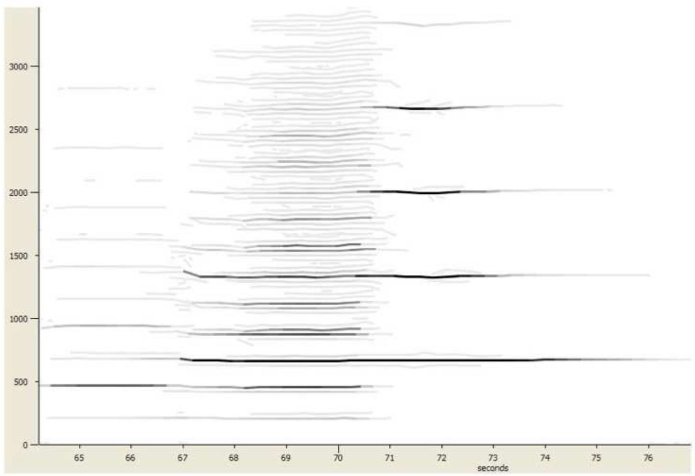

Fig. 1. Sonogram of a single multiphonic showing progression from an isolated partial to the full multiphonic and ending on a different isolated partial: like event C in Figure 3.

To explain the feedback mechanism, it is important to understand that the same perceived pitch in a multiphonic can be achieved using different fingering configurations on the instrument. However, different fingerings produce differences in harmonic spectra, and even multiphonics that sound similar in pitch have small deviations in specific frequencies of partials: see Figure 2 for comparative sonograms of two different multiphonic fingerings. These compositions rely on these small deviations because the most important instruction in the score is for the performer to try to keep the strongest perceivable pitch in the multiphonic the same from event to event. This is countered by the score also requiring the performer to constantly change fingerings, and play different phrase-shapes: such as moving from a single partial to a full multiphonic on the same fingering. For example, a certain fingering may produce

ing individual pitches from that complex spectrum. Figure 1 shows that single partials are not always isolated, sometimes a single harmonic series is isolated, but to the listener these differences are quite subtle.

the correct frequency but may not allow that frequency to be isolated as a single partial, so it may not be possible to use that fingering in certain events (see Figure 3 for some events with different phrase-shapes). The dialectic of the music is that the score pushes the performer in two contradictory directions simultaneously, the forward motion of moving through the space of available fingerings, and the reverse motion of keeping each pitch as close as possible to the previous. The musical result is a structure straining to maintain a pitch identity, with the occasional but inevitable abrupt shifts to a new pitch area when the performer finally runs out of options.

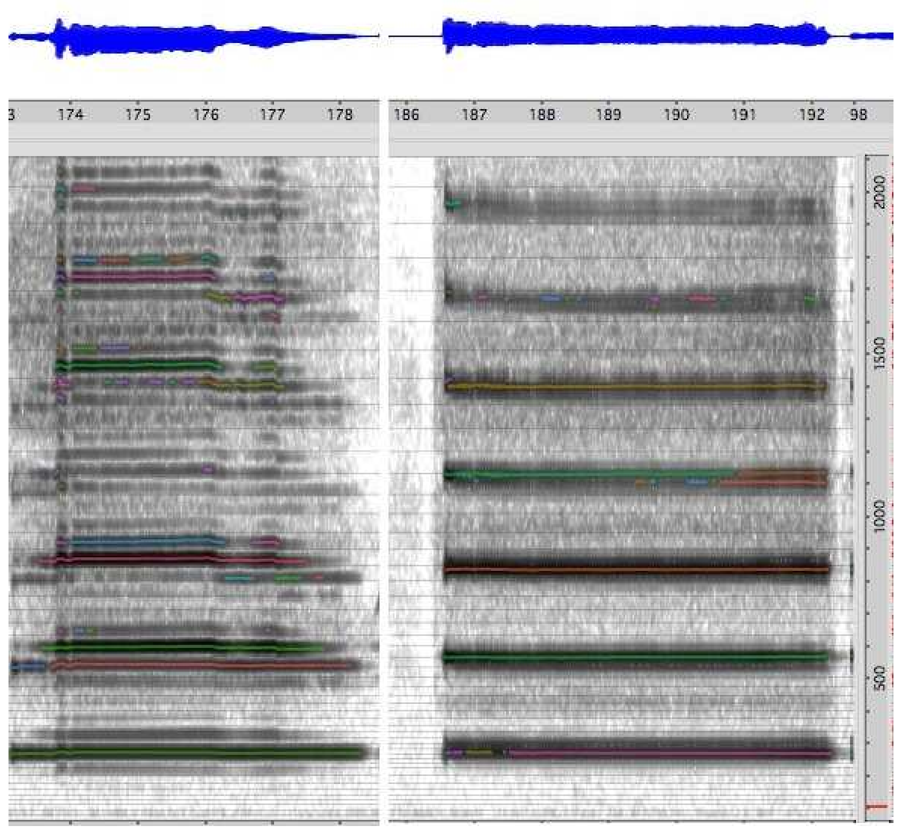

Fig. 2. Sonograms of two different multiphonic fingerings that sound similar, showing how prominent partials are similar in frequency but small deviations in overall spectra are clear.

Figure 3 shows a section of the score for *There are Neither Wholes nor Parts 2* with three different events; separated by the double vertical lines. The first event, A, is initially a single sustained partial (isolated from a

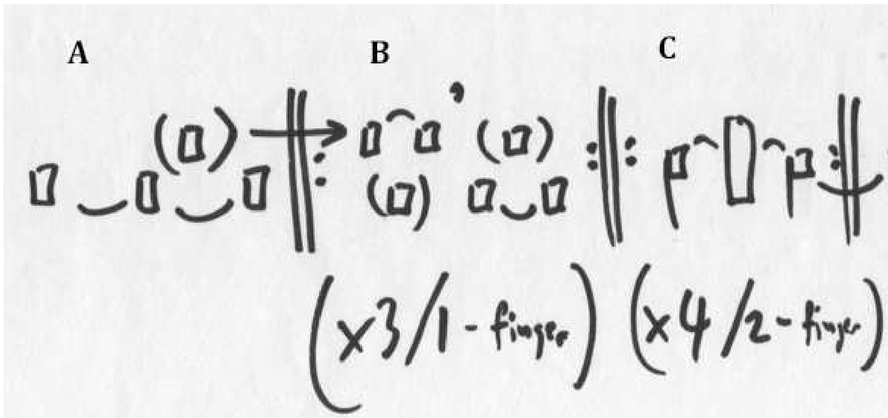

Fig. 3. Score example from *There are Neither Wholes nor Parts 2.*

multiphonic), which in the second half of the event is joined by another partial of higher frequency: shown in parentheses to indicate that this should be barely audible, a ‘halo’. For event B the frequency of this ‘halo’ partial is carried across, this time as a single partial, with another ‘halo’ partial of lower frequency. In the second half of B after the breath mark (the comma) the situation is inverted. The final event, C, begins and ends with single partials, with a complete multiphonic between them. The text below A and B is the repeat instructions for each event: B is repeated three times, one of which must be a different fingering; C is repeated four times, two of which must be different fingerings.

The non-linearity of the music is due to the many possible paths that each event can take, and that these paths are all defined by the non-linear response of the instrument to multiphonic fingerings. For example, if event A is 440Hz, there may be ten fingerings that can produce that frequency, and be able to produce a higher frequency ‘halo’ partial as well, but each of these fingerings will produce a different ‘halo’ partial at a different frequency. Assume the player chooses a fingering with a ‘halo’ partial at 500Hz, this limits B to another group of potential fingerings, ones that include partials at or around 500Hz, and are capable of playing the phrase-shape of B with its inverted envelopes. There is also the repetition of B which requires a second fingering, one that includes all the above attributes, or as close as possible.

There are Neither Wholes nor Parts 2 has a musical structure that exhibits the standard attributes of repetition and variation over time, generated through interaction of materials and the feedback mechanism. The structure is dependent on initial conditions as each event is dependent on the last; a different starting frequency on a different instrument can radically alter the course of the piece. The piece is designed so that pitch is the defining factor in the perception of structure, and pitch is the element that has the most radical potential for variation over the course of the piece.

5 Conclusions

My initial research was undertaken from readings of popular texts on Chaos Theory, this gave me sufficient insight to generate compositional ideas that have taken the research this far, but it would be interesting to take the work further by collaborating with a researcher who understands dynamical systems at a deeper mathematical level.

This set of pieces is a early attempt to introduce mechanisms of feedback and hysteresis into music as a dynamical system. The mechanism used in *There are Neither Wholes nor Parts* has been successful both compositionally and in performance. The players who have taken on the piece have all found it to be a stimulating challenge to prepare the piece, and with time it will be interesting to see if they can also approach the piece without needing to create a fixed version, but instead simply react according to the what the instrument gives them.

The next step in this research is to write a piece for two instruments. This will provide more possibilities for feedback based on two states rather than one, and to use hysteresis based on the current position (pitch) of one relative to the other.

References

1. M. Anderson, ‘The Many Patterns of Per Nørgård’, Tempo, New Series, No. 202 (Oct., 1997).
2. A. Benade, *Fundamentals of Musical Acoustics*, Oxford University Press, 1967.
3. A. Botros, J. Smith, J. Wolfe, `http://www.phys.unsw.edu.au/~abotros/thesis/Botrosetal2002.pdf`, accessed 10/06/11.
4. J. Cage, *Silence*, Wesleyan University Press 1973.
5. N. Matossian, *Xenakis* London: Kahn & Averill, 1986, 106.
6. L. Meyer, *Emotion and Meaning in Music*, University of Chicago Press, 1956.
7. T. Murail, *Attracteurs Étranges*, `http://www.tristanmurail.com/en/oeuvre-fiche.php?cotage=27526`, accessed 15/01/11
8. R. Steinitz, ‘Music, Maths & Chaos’, *The Musical Times*, 137/1837 (Mar., 1996).
9. K. Stockhausen, *Klavierstück XI*, Stockhausen-Verlag, Kürten (1956)
10. R.Wallin, ‘Fractal Music - Red Herring or Promised Land?’, `http://www.rolfwallin.org/Fractalarticle.html`, accessed 10/06/11.
11. R. Wallin, *Onda di Ghiaccio* programme note, `http://www.rolfwallin.org/onda.html`, accessed 10/06/11.
12. R. Wallin, *Onda di Ghiaccio*, `http://www.rolfwallin.org/ondaprog.html`, accessed 04/08/08.
13. M. Winter, ’On Sonification’ `http://www.mat.ucsb.edu/~mwinter/writings.html` (n.p, 2005), accessed 04/01/07.
14. C. Wolff, *Edges*, New York: Peters Edition, 1969.