GENDYN, NOISE AND THE VIRTUAL: SMOOTH SPACE-TIME AND ENTROPY IN THE STOCHASTIC SYNTHESIS OF XENAKIS

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In Makis Solomos, (ed.), Proceedings of the international Symposium Xenakis. La musique électroacoustique / Xenakis. The electroacoustic music (université Paris 8, May 2012).

ABSTRACT

Iannis Xenakis's dynamic stochastic synthesis program, GENDYN, and its parameter settings, PARAG, are discussed in terms of their appropriateness to various models proposed by Trevor Wishart, Karlheinz Stockhausen and Pierre Boulez, from striated to smooth time-space. The latter is argued to be the most suitable through expanding on GENDYN and PARAG's emergent characteristics as highlighted by Agostino Di Scipio and Peter Hoffmann. The relevance of smooth time-space to Gilles Deleuze and Félix Guattari's concept of the virtual as explained by Manuel DeLanda is then explored, as is its affinity to noise. In conclusion, how 'noisy' GENDYN and PARAG are is evaluated using Warren Weaver's extension of Claude Shannon's definition of entropy in information theory, in addition to suggesting possible developments which Xenakis may have approved of himself that are in keeping with considering GENDYN and PARAG as a virtuality.

1. INTRODUCTION

The use of stochastics provided Iannis Xenakis with considerable invention in terms of form through the organisation of notes and their movements in his instrumental works. It also allowed him to create material by the direct production of timbre through dynamical stochastic synthesis in his program, GENDYN. This was controlled by PARAG which included a limited but further use of stochastics. The two programs were used together to produce his two late electroacoustic works, *Gendy3* (1991) and *S.709* (1994). This article presents possible frameworks for GENDYN and PARAG which are also applicable to current trends in electronic music such as noise, the use of digital technology and generative music.

2. SMOOTHNESS WITHIN EACH TIME SCALE

2.1. Lattice

Trevor Wishart's book On Sonic Art is a response to what he calls lattice-oriented thinking evident in Pierre Boulez's Boulez on Music Today (Wishart, 1996, p. 6; Boulez, 1971). A lattice is finite and discrete: it does not extend beyond its outer limits, and values in between are not easily permitted. For Wishart, the piano is the instrument that most characterises this model and the analogy is certainly apt in this case. A lattice is also two-dimensional: the axes being pitch and rhythm which are the parameters most easily controlled and explored on the piano and in much of classical Western music (Wishart, 1996, p. 23).[1]

2.2. Striated space

[1] Acousmatic or electroacoustic music as a whole could be viewed as an escape from the rigid lattice-based theory of the acoustic instrumental notated tradition (although this is a huge generalisation and there are many exceptions including those by Xenakis).

A lattice fits properties of striated space as given by Gilles Deleuze and Félix Guattari: '... the striated is that which intertwines fixed and variable elements, produces an order and succession of distinct forms, and organises horizontal melodic lines and vertical harmonic planes. The smooth is the continuous variation, continuous development of form; it is the fusion of harmony and melody in favour of the production of properly rhythmic values, the pure act of the drawing of a diagonal across the vertical and the horizontal' (Deleuze and Guattari, 1987, p. 478).

In the example of the technological model of a fabric, there are two perpendicular elements, the vertical and the horizontal, that intertwine (Deleuze and Guattari, 1987, p. 475) as with the two dimensions of pitch and rhythm in Wishart's lattice; the elements have different functions, one mobile and one fixed (Deleuze and Guattari, 1987, p. 475) relating again to pitch and rhythm respectively; it is delimited, meaning that the width is fixed and the length can be expanded (Deleuze and Guattari, 1987, p. 475) – again pitch and rhythm, or the dimension of time that can in theory be prolonged.

2.3. Types of striation

Wishart's analogy of the lattice for Boulez's conception of different musical organisations is valid in some respects as Boulez describes pitch and rhythm as being primary, and timbre and amplitude as being secondary. But Boulez proposes extensions in numerous ways to the lattice model/striated space, such as through curved spaces produced by altering the module – a proportion such as 2:1 for an octave (Boulez, 1971, p. 83) – and varying the partitions either regularly or irregularly. In other words, the lattice grids are not necessarily equidistant, and the variation of their spacings themselves can be uniform or otherwise.

These forms of striation are certainly more appropriate for modelling GENDYN than Wishart's lattice, or Boulez's regular straight striation. Xenakis's stochastic synthesis begins with a waveform consisting of a number of breakpoints. Through applying a process of a random walk occurring within mirror boundaries on the *x*- and *y*- values of the breakpoints corresponding to time and amplitude displacements, the waveform is altered continuously. The *x*- and *y*-coordinates are reflected more in the distribution rather than as a lattice in a two-dimensional space. The number of breakpoints and the stochastic distributions were fixed for the duration of each section in *Gendy3*, but were altered across different sections and so the time-space could be described as curved over the duration of the entire work.

2.3. Smooth space

Conceptually, GENDYN is closer to what Boulez and Deleuze propose as smooth time-space, devoid of the lattice contrary to striated space. It corrsponds to GENDYN in two ways: through high fidelity discreteness leading to what is effectively a continuum (Boulez, 1971, p. 85), and where instead of partitions, a more appropriate measure would be a statistical distribution (Boulez, 1971, p. 92). The former is achieved through Xenakis's idiomatic use of the digital medium through the direct manipulation of sample values (Hoffmann, 2009, p. 59-63) where the lattice reaches a level of detail where the discrete effectively becomes continuous. The latter is of course reflected in the use of probability distributions for the movement of breakpoints of a waveform at the sample level.

GENDYN also represents a further movement from striated to smooth space in relation to his instrumental works that use stochastics for the formation of clouds of sounds – where the shortest unit of sound was still a 'note', and with

granular synthesis – where its base unit was a grain being approximately 20 ms in duration. Xenakis actually wanted an even higher sampling rate of 1,000,000 in order to obtain less distortion from digital audio and hence more detail, and also for fractal possibilities in sonic organisation (Xenakis, 1989, p. 91).

3. SMOOTHNESS BEYOND EACH TIME SPHERE

3.1. Overlapping between the time spheres

Whereas Boulez clearly differentiates between the time-scales (in his theoretical writings and in practice),[2] Karlheinz Stockhausen demonstrated the continuity of these supposedly different dimensions. Or more accurately, he highlighted the possibility of an alternative to the two- or even three-dimensional model of musical time-scales or time-space, this being 'a continuous overlapping between the time sphere of "frequencies" ("sounds" and their "colours") and the sphere of "rhythms" (individually audible pulses within given time intervals)' as demonstrated in a passage from Kontakte (Stockhausen, 1962, p. 44).

3.2. Phase transitions

Stockhausen's experiments could be viewed as a way of expanding the outer limits of each dimension of the lattice, so that the boundaries of the dimensions are now interconnected. The process by which one time sphere becomes transformed to another could be described as a phase transition, of which there are many instances in disparate fields of study. Manuel DeLanda gives the example of water: when its 'control parameter' of temperature reaches critical thresholds of 0 ºC or 100 ºC (DeLanda, 2002, p. 19), 'its extensive properties suffering a radical change in nature' (DeLanda, 2002, p. 70).[3]

One could describe the passage from Kontakte as demonstrating the existence of phase transitions, the control parameter being frequency, and the transition points between time spheres being their 'critical values' (DeLanda, 2002, p. 19).

3.3. Magnitude/Distance

Stockhausen's demonstration appears to reduce the different properties of sound to one dimension to that of frequency. However, this is merely one possible reduction, which becomes clear through considering the nature of these different time spheres. Based on terms derived from Meinong and Russell, for Deleuze, frequency is a magnitude whereas timbre is a distance (Deleuze and Guattari, 1987, p. 483), or intensive and extensive physical properties for DeLanda (DeLanda, 2002, p. 26). The former include metric properties such as length, area and volume, which are intrinsically divisible. The latter include (non-metric) properties such as temperature and pressure and cannot be divided. The difference is also noted by Boulez.

3.4. Cardinal/Ordinal

[2] He does, however, acknowledge their interconnection somewhat: as timbre being a complex function of pitch, duration and amplitude, a continuum of timbre entails that of the complex function itself (Boulez, 1971, p. 95).

[3] Other examples include the different forms of movement of a horse of gallop, trot or walk, depending on its speed (Deleuze and Guattari, 1987, p. 504) and the nature of hydrodynamic flow patterns being steady-state, cyclic or turbulent (DeLanda, 2002, p. 20).

Furthermore, rhythm and pitch could be described as cardinal – a quantity – whereas timbre could be described as ordinal – an 'ordering' rather than a fully developed numerical quantity (DeLanda, 2002, p. 73) – equating the former with metric space and the latter with topological or nonmetric space.

3.5. Topological space

Xenakis goes further, stating the possibility of a topological space: 'The definition of an ordered structure is as follows. Given three elements of a set, they can be ordered in just one way by saying that one of the three is between the other two. ... We can say this about pitches, ... dynamics ... but we cannot say this about timbre' (Xenakis, 1996, p. 144). Thus it is probable he would have felt that the criticism of UPIC reducing timbre to just one parameter represented by the y-axis (Di Scipio, 1998, p. 222) was justified.

4. EMERGENCE

4.1. Pitch

In GENDYN, a waveform with m breakpoints produces m+1 possible pitches (Hoffmann, 2004, p. 141) indicating a form of striation. With 10 breakpoints yielding 11 pitches being typical values, as a lattice, it would be very limited. But the pitches themselves are determined by the lower and upper mirror boundaries which can be altered as at each new section in *Gendy3*. These boundaries as well as the number of breakpoints determine the 'partitions'. As such, they would be the 'module', as the equivalent of a ratio such as 2:1 for an octave. As they are controlled externally through PARAG, it is an irregularly varying module and hence a curved space (Boulez, 1971, p. 86).[4]

Due to the presence of these two mirror boundaries, values tend towards these bounds (Hoffmann, 2004, p. 140), and the pitches occur at these points and are most prominent. But notes in between are possible, when the distance between the breakpoints take on values other than the minimum and maximum possible. Hence this is closer to a smooth space made directional by a statistical distribution (Boulez, 1971, p. 92).

Hoffmann notes how Xenakis bypassed the random walks and specified the length of waveform segments (the distance between breakpoints) in order to obtain fixed pitches in Gendy3. This could be described as a special case where the space becomes striated and curved. However, the same result could have been achieved with pitches which differ only slightly by reducing the random walk space to zero (Hoffmann, 2004, p. 142).

4.2. Sonological Emergence

Agostino Di Scipio and Hoffmann state that 'timbral characteristics and pitch movement come about as an emergent by-product of accumulating random wave form fluctuations' (Hoffmann, 2004, p. 140). In recent times, the term, emergence, has become popular amongst many different fields of study and has been used to describe a range of disparate phenomena from crystal formations, consciousness, Bénard (convection) cells and pricing fluctuations (Corning 2002: 19). James Crutchfield's provisional description is as follows: 'Emergence is generally understood to be a process that leads to the appearance of structure not directly described by the defining constraints and instantaneous

[4] Boulez describes composers such as Webern as tracing a new diagonal (Deleuze and Guattari, 1994, p. 296), that escapes the rigid striation imposed by the Western tempered scale. This is curious, considering that previously, his Op.24 had been criticised by Adorno for example as having less possibilities, not more, than previous music based on dodecaphony or the chromatic scale (Scherzinger, 2010. p. 114). This description of a diagonal appears to be more appropriate for GENDYN.

forces that control a system. Over time "something new" appears at scales not directly specified by the equations of motion. An emergent feature also cannot be explicitly represented in the initial and boundary conditions (Crutchfield, 1994, p. 2).[5]

4.3. Pre-biotic soup

A good example which would serve as an appropriate metaphor for GENDYN is that of the pre-biotic soup becoming a fully fledged and fleshed organism: 'the fertilized egg, defined mostly by chemical gradients and polarities, as well as the early embryo defined by neighbourhoods with fuzzy borders and ill-defined qualities, may indeed be viewed as a topological space' (DeLanda, 2002, p. 52), equating to the thus-far smooth space of samples where initially, no predefined musical time scale such as a note exists. It would then '[acquire] a rigidly metric anatomical structure as tissues, organs and organ systems become progressively better defined and relatively fixed in form' (DeLanda, 2002, p. 52), which correspond to striation of timbre, pitch, rhythm etc. DeLanda's description of 'the aggregation of individual cells into different neighbourhoods or collectives' (DeLanda, 2002, p. 52), seems equally applicable to GENDYN's stochastic manipulation of samples: a lack of a well-defined metric structure, the importance of a sufficiently large enough group with a shared history rather than the exact location of one cell, and interactions between cells being non-linear and statistical. Furthermore, cellular migrations that move entire collectives into new places and cellular folding and invagination that create larger-scale structures are determined by 'intensive relations': phase transitions between different states mediated by non-linear relations (DeLanda, 2002, p. 52-3).

4.4. UPIC

The production of higher-order time structures such as pitch and timbre as emergent phenomena through sample-level composition is in contrast to UPIC where the use of wavetable lookup synthesis limited the dynamic potential of 'microcomposition' (Di Scipio, 1998, p. 222).[6] Although the number of breakpoints in a waveform is fixed for each section with GENDYN, the length and the content of the waveform are developed dynamically.[7]

4.5. Type and order of emergence

Various categories of emergence have been proposed in recent years. Luc Steels describes the first type of first-order emergence as occurring as a side effect when behaviour systems are made to operate together in a particular environment (Steels, 1993, p. 90-1). GENDYN and PARAG correspond to such a framework in the following manner:

- component behaviour systems and environment would equate to the movement of the breakpoints according to the chosen probability distribution and mirror boundaries;
- emergent behaviour that is the side-effect is the production of timbre, rhythm pitches etc;
- emergent functionality is production of audio .

If Xenakis had been able to use stochastics or other emergent systems for PARAG more extensively e.g. in the location of mirror boundaries or the probability distribution used, then the second type of first-order emergence based on

[5] Although this description is given by Crutchfield to highlight the necessity for a more concrete definition, it suffices for our present purpose.

[6] That is unless one were able to magnify the scale of the interface to the sample level with UPIC.

[7] Furthermore, although the parameters can be separated into those affecting pitch and those affecting timbre (Serres, 1993, p. 247), due to the nonstandard nature of synthesis the relationship between them and perceptual attributes are not linear and do not necessarily correlate.

temporary spatiotemporal structures that emerge as a side effect of interactions between certain actions of the agent and the environment (Steels, 1993, p. 92) may have been possible. In such a framework:

- behaviour systems and environment are the movements of mirror boundaries and distributions;
- the temporary structure that is the side-effect consists of the values for the mirror boundaries and the probability distribution for each section;
- this temporary structure would then be used by component behaviour systems and environment that equate to the movement of the breakpoints according to the chosen probability distribution and mirror boundaries;
- emergent behaviour that is the side-effect is the production of timbre, rhythm, pitches etc.

However, it does not amount to second-order emergence, where new behaviour systems are formed (Steels, 1993, p. 96), with the ability to process information or to evolve its capacity to evolve (Hayles, 1999, p. 243).

5. NESTED TIME CYCLES / LIVED PRESENT

5.1. Pitch to noise

A description in terms of pitches becomes almost irrelevant in many sections of the GENDY compositions, where broad-band noise is more prominent than any identifiable regular oscillations. As Hoffmann notes, this is produced by GENDY through the acceleration of pitch movement to reach the audio domain i.e. to rates comparable to 20 Hz and above. To an extent, such phenomena again demonstrate Stockhausen's conception of a continuum of the different time spheres, and a possible reduction of the domains to just one dimension of frequency, whereby the two- or three-dimensional lattice with axes for pitch, rhythm and possibly timbre become just one axis representing one parameter.

5.2. Shepard tone analogy

Additionally, the above appears to imply a circular continuum, whereby pitches (already composed of accelerated rhythms or impulses) would be transformed to further rhythm and then timbre/pitch through a further acceleration. This is achieved through the complex and multi-layered inner structure (in terms of time scales) produced by GENDYN, and is perhaps analogous to the Shepard tone.

5.3. Perception on all levels

A fundamental difference with the famous passage from Kontakte is that whereas Stockhausen demonstrated the continuity of the different time spheres of timbre, pitch, rhythm, meter and form (Stockhausen, 1962, p.42-4) in succession or in series, GENDYN can potentially produce all of these levels simultaneously or in parallel i.e. these time spheres coexist. Although not fully achieved in combination with PARAG, this was at least his intention: 'The result of these deformations is perceptible on all levels, microstructure (= timbre), ministructure (= note), mesostructure (= polyrhythm, melodic scales of intensities), macrostructure (= global evolution on the order of some tens of minutes)' (Xenakis, 1989, p. 91).

He believed that in general, computer and electroacoustic music was in its infancy in terms of its formal development in comparison to traditional classical music, the latter being more complex and going beyond the multidimensionality of the former: 'In [classical] music we have several layers which can be described' (Xenakis, 1996, p. 146). These levels and complexes are:

- Form (a movement)
- Phrases, Chords
- Pitch, Intensity, Timbre

He continues that: 'One has to listen to pitches, time instants and durations, dynamics, phrases, themes, structures of movements and so on simultaneously, even if one is not entirely conscious of it ... Music is like a multiple sandwich, but a transparent one. Whilst in the middle of it, one can see at the same time lower or higher layers everywhere' (Xenakis 1996: 146).[8] One can probably assume that Xenakis was intending to emulate these complexities in his electronic output.

5.4. Nested time cycles

Xenakis's multiple sandwich is comparable to Arthur Iberall's concept of nested time cycles of different time scales of atoms, organisms and cosmic bodies, where each would be governed by its own independent temporal scale or oscillation which consist of smaller scales and forms a constituent part of larger scales (DeLanda, 2002, p. 86-7). According to Iberall, 'Time is not a universal unity for all levels of organisation. Yet levels are nested within one another and, within limits, are referable to each other' (Iberall in DeLanda, 2002, p. 87). Additionally, DeLanda states that '... rather than assuming that time exists as an already quantised flow ... we should account for this metric structure using the embedded set of differently scaled oscillations. In a sense, each oscillation would 'synthesise' a pulse of metric time, many nested sequences of these pulses yielding the familiar form of time which we humans can measure using a variety of chronometers' (DeLanda, 2002, p. 87-8).[9]

5.5. Lived present

DeLanda uses the model of Iberall's nested time cycles to illustrate the concept of time proposed by Deleuze. For him, each temporal dimensions would constitute a synthesis of 'present time' (the 'lived present' of atomic, biological and cosmic oscillators)' where a lived present or a vast present is different for each scale. 'Chronos', or 'metric, extensive time' would then be fundamentally cyclical and 'composed only of interlocking presents' (DeLanda, 2002, p. 88). [10]

6. VIRTUALITY

The characteristics described above correspond to the Deleuzian concept of the virtual as developed by DeLanda as a model for dynamical systems that include the following formulations.

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[8] This would appear to be more than mere 'auditory scene analysis' as suggested by Di Scipio (Di Scipio, 1994, p. 206).

[9] Perhaps this is a better analogy to audio than the development of pre-biotic soup, and not just for the obvious reason of having a more relevant temporal correspondence. Although in the earlier example, one part of a higher-order structure such as a muscle would consist of lower-level elements such as tissues, which would in turn consist of cells etc, and be all of those constituent parts simultaneously, the location of smaller parts would generally be constricted by the exterior of the larger part to which it belongs. E.g. one cell could not be part of two separate tissues simultaneously without becoming split. No such quantisation issues arise with the model of nested time cycles, which can accommodate for 'overlaps between the multiplicities of time scales (DeLanda, 2002, p.86), in a similar manner to how 'the transitions and overlappings between all the time spheres are quite flexible' (Stockhausen, 1962, p. 43).

[10] E.g. for a particular organism, its immediate past and future (of say, a few seconds, or minutes or hours) would still be part of the lived present of an entity operating at a larger time scale such as that of a planet or a star; in turn, the lived present of an organism (of say, in the order of tens of milliseconds) would already consist of many instances of the past and the future for entities operating at smaller time scales such as atomic and sub-atomic particles. However, as DeLanda highlights, this sense of the lived present in no way indicates a subjective sense of the passing of time. As with Einstein's formulation of time, neither is it relational.

6.1. Manifolds

According to DeLanda, 'manifolds are connected to material reality by their use as models of physical processes', a 'space' with any number of dimensions and 'the absence of a supplementary (higher) dimension imposing an extrinsic coordinatisation' (DeLanda, 2002, p. 12-13) e.g. the surface of a sphere would be a two-dimensional, non-Euclidean manifold if it is not considered in a three-dimensional space (DeLanda, 2002, p. 181).[11] The idea originates from Riemann metric and geometry, and is often nonmetric and topological with no predetermined scale.

6.2. Dimensions, trajectories

The parameters of GENDYN set by PARAG could be considered as the dimensions of such a manifold.[12] Trajectories through a manifold describe their 'change of state' (DeLanda, 2002, p. 14), which in this case would be eleven different points corresponding to each section of Gendy3. However, the location in this manifold – which correspond to the parameter settings for each section – is insufficient in describing the audio output as the parameters do not necessarily correspond to perceptual audio attributes. Hence the term 'non-standard' is used in describing such synthesis methods.

In contrast, if a similar model is used for standard forms of synthesis such as frequency modulation, with the dimensions of its manifold corresponding to its parameters – i.e. modulator frequency, its amplitude, modulation index and carrier frequency –a set of coordinates would suffice in predicting the perceptual attributes of the sound output with the additional information of phase.[13]

6.3. Singularities, basins of attraction, phase transitions

For a more accurate characterisation of GENDYN, the horizontal and the vertical components of the displacements for each breakpoint would correspond to the dimensions of this manifold. Thus if there are 10 breakpoints, then the manifold would be 20-dimensional. The position of trajectories through this manifold would be altered at every cycle of the waveform. The mirror boundaries would form singularities that affect the trajectories through the manifold by acting as attractors. In addition, its combined effect with the probability distribution would determine the locations of basins of attraction which indicate which attractor a trajectory might converge on if at all (DeLanda, 2002, p. 15). These convergences or divergences would correspond to phase transitions e.g. convergence on a periodic attractor would result in oscillations and pitch, whereas divergence and chaotic movement would result in noise.

6.4. Vector field

The presence and the effects of attractors and their basins of attraction can be represented in a vector field, usually displayed as a grid of arrows referring to the direction and magnitude of the rate of change at those particular points. In other words, the vector field is determined by the settings of PARAG. The presence of a vector field ensures the dynamic nature of any trajectory through it: only at particular locations of the singularities will movement cease. Furthermore, the movement through the manifold and hence alterations in the sound are due to the properties of the

[11] Colour would also be a manifold consisting of three dimensions representing the three primary colours. In general a phenomenon can be expressed in a manifold with the number of dimensions corresponding to the number of 'variables or coordinates upon which [it] depends' (Deleuze, 1994, p. 182).

[12] There would be 11 dimensions corresponding to: the number of segments in the waveform I, the stochastic distribution fx, the mirror boundaries (fxmin, fxmax) and (Nmin, Nmax), the stochastic distribution fy, the mirror boundaries (fymin, fymax) and (Ymin, Ymax) (Serra, 1993, p. 247).

[13] It is only through the addition of feedback – e.g. in FM – that the signal may become significantly more unpredictable.

vector field itself.[14] Additionally, the non-linear effects of the vector field on the manifold indicate how there is no simple way of predicting its audio output with anything short of allowing the algorithm to run its course. In contrast, with the previous example of FM where an analogous vector field is absent, any movement through the space of parameter settings and hence the sound produced would have to be imposed externally. As the properties of the attractors and their basins of attraction are determined by the laws of the system – i.e. the GENDYN parameters – these can also serve as a comprehensive description of the manifold for each section of Gendy3.

6.5. Multiplicity, virtuality, actuality

The possible vector fields of a manifold, along with the singularities and differential relations they illustrate, constitute a multiplicity (DeLanda, 2002, p. 32). Thus the multiplicity is constituted by PARAG – i.e. GENDYN parameters – and the method of conversion into audio. The status of a multiplicity is 'virtual', and thus GENDYN with PARAG is a virtuality; Gendy3 and S.709 as two instances of trajectories of the virtuality, are actualisations.

The concept of the virtual allows for:

- starting with a smooth rather than a striated time-space (Boulez/Deleuze), a nonmetric/topological rather than metric space (Deleuze/DeLanda) or a continuum rather than a lattice (Wishart);
- the continuous overlapping between time spheres (Stockhausen) or phase transitions at critical thresholds (DeLanda);
- sonological emergence (Di Scipio/Hoffmann) or a pre-biotic soup-model (Deleuze/DeLanda);
- nested time cycles (Iberall/DeLanda), lived present (Deleuze/DeLanda) or perception on all levels of structure (Xenakis).
- production of difference and the cosmic (Higgins/Deleuze) described below.

6.6. Cosmic

DeLanda's interpretation of the virtual is aligned to the Cosmic as described by Deleuze and Guattari which has resonances with the integration of microcomposition (sound design) and macrocomposition (score design) (Hoffmann, 2004, p.138) and the blurring of the distinction between algorithmic composition and timbral design (Di Scipio, 1994, p. 202).[15]

According to Deleuze and Guattari, the modern age is cosmic, the term being a reflection of their transdisciplinary approach and view, where a direct relation of material-forces comes into play: 'There is no longer a matter that finds its corresponding principle of intelligibility in form. ... [It is] no longer forms and matters, or themes, but forces, densities, intensities. ... It is now a problem of consistency or consolidation: how to consolidate the material, make it consistent, so that it can harness unthinkable, invisible, nonsonorous forces' (Deleuze and Guattari, 1987, p. 342-3).

Such a description may appear to be relevant to any music organised through extramusical material. But for this Modernist purpose, Deleuze and Guattari state that 'the material must be sufficiently deterritorialized to be molecularized and open onto something cosmic' (Deleuze and Guattari, 1987, p. 343). The virtuality of GENDYN fulfils this role by the sample level being the smallest deviation or the minimum excess in the differential form of the

[14] This constitutes what Hoffmann desribes as rigorous algorithmic composition (Hoffmann, 2004, p. 138).

[15] This is in contrast to UPIC which reinstated 'the distinction between "musical structure" and "sound structure"' i.e. there was one distinct time-scale of the waveform used for the table look-up synthesis, and another for the control through the graphical tablet (Di Scipio, 1998, p. 222).

'clinamen', the nearest conceivable scale to infinitesimal proximity or limiting to zero that is smooth space-time responsible for sounds or even colours (i.e. timbres), as opposed to visual Euclidean space (Deleuze and Guattari, 1987, p. 371).

GENDYN and PARAG's manner of producing striation can be aptly described as thus: 'individual atoms can enter into probabilistic or statistical accumulations that tend to efface their individuality; this already happens on the level of the molecule, and then again in the molar aggregate. But they can become complicated in interactions and retain their individuality inside the molecule, then in the macromolecule, etc., setting up direct communications between individuals of different orders' (Deleuze and Guattari, 1987, p. 334-5).

Furthermore, instead of matter and form (or sound and score) relating to content and expression respectively, they are both encompassed by content and expression whose connection is evident. Singularities of the space-time – i.e. the probability distributions and mirror boundaries – constitute a form of content. Expression is no longer formal, but inseparable from the vector field which constitutes a matter of expression (Deleuze and Guattari, 1987, p. 369).

7. ENTROPY

7.1. The three levels of communication

Warren Weaver in his interpretation of Claude Shannon's concept of entropy in information technology describes three levels of communication: technical, semantic and effectiveness (Shannon and Weaver, 1949, p 4).[16] The technical level concerns Shannon's definition, which has also been applied to the scale of individual notes in standard Western music notation; it would also be applicable to GENDYN's sample-level manipulation. The semantic level relates to longer time scales and to its 'meaning'. The effectiveness level involves aesthetic considerations, as affect and its qualification. How 'noisy' GENDYN is will be considered at the first two levels.

7.2. Technical level

At the technical/note level, research has shown that classical music through the ages has steadily increased in average entropy, from Mozart to Beethoven to Berg to Hindemith (Hiller and Bean, 1966). It appears likely that with electronic and noise music and experimentation with timbre and structure, this trend is continuing. However, previous work on entropy in music mostly concerns music with clear delineated features of rhythm and pitch (see for example Pearce, Müllensiefen and Wiggins, 2008). Therefore comparing the entropy of a work by Merzbow with one by Mozart remains problematic.

What is required is the equivalent of a note as a unit for the purposes of analysis. Although pitches do appear and are made to do so deliberately as shown by Hoffmann, Xenakis's main objective through the use of stochastics concerned density which was more relevant to perception in his view: its application was for the purposes of producing pure timbre as he put it, and controlling 'the colours and the shapes inside' (Robindoré, 1996, p. 13). It would be arduous ascertaining adequate units for these phenomena that is relevant to how one hears them. Furthermore, in the model of the smooth, virtual space proposed, a fixed 'unit' is impractical as it would amount to an imposition of striation.

[16] Weaver notes that this is a theory so general that one does not need to say what kinds of symbols are being considered - whether written letters or words, or musical notes, or spoken words, or symphonic music, or pictures. The theory is deep enough so that the relationships it reveals indiscriminately apply to all these and to other forms of communication such as music or art (Shannon and Weaver, 1949, p. 25).

Entropy at the sample level is the most straightforward to calculate but this unit is obviously far too short to be perceptually relevant. These would consist of what Di Scipio describes as relations on a presyntactic or subsymbolic level (Di Scipio, 1998, p. 237). The same also applies to the unit of one waveform at the lengths used by GENDYN. Nevertheless, at the unit of individual samples, one could speculate _ from its modelling as a manifold, its lack of reducibility and moving trajectory _ that the entropy of GENDYN is relatively high in comparison to the example of FM. At the sample level, GENDYN is certainly noisy.

7.3. Semantic level

Weaver represents Shannon's model of communication as the following (Shannon and Weaver, 1949, p. 7):

- an information source produces a message which a transmitter codes into signal;
- noise may be introduced into the signal at this point;
- this signal is received by the receiver and decoded back into the message for the destination.

At the semantic level, Weaver proposes the addition of a 'semantic receiver', corresponding to the original engineering (or technical level) receiver in Shannon's model just prior to the destination. This second decoding entails a matching of the statistical semantic characteristics of the message to the statistical semantic capacities of the audience. He also proposes the insertion of 'semantic noise' in addition to the original 'engineering noise' at Shannon's technical level where unintentional perturbations or distortions of meaning affect the signal.

The simple summary outlined is sufficient in highlighting the simplistic and inadequate nature of the model for aesthetic purposes, or perhaps Weaver's understanding of art. Nevertheless, a pseudo-objective description of noise can be arrived at i.e. the semantic characteristic of the audio that does not correspond to the semantic capacities of the audience in constituting a message. This is a slightly more rigorous version of the usual subjective definitions such as those indicated by how one person's noise is another's music etc (see for example Hegarty, 2007).

7.4. Semantic Noise

The opposition of music to this notion of noise corresponds to that of thought and counterthought in Deleuze: the former as the recognition of a predefined, transcendental and idealised model of the same, the latter as the attempt to synthesise a sensibility by confronting the empirical, the unrecognisable, or difference, that moves memory to attempt to remember what it cannot (Higgins, 2010, p. 60-3).[17] Music as an image of thought covers all of thought as interior concept in order to function as a means of control. Noise as counterthought is thought as a proceeding and a process that is not merely another image in opposition to the image but destroys every possibility of thought's subordination to a preconceived model assumed to be common sense and instead awaits its meaning from a new external force (Deleuze and Guattari, 1987, p. 375-8).

Additionally, Weaver warns against overloading the capacity of the communication channel with information, 'that you do not, so to speak, fill the audience up and then waste only the remainder by spilling. More likely, and again by direct

[17] For Higgins, musique concrète is noise par excellence because of its potential for highlighting the medium (Higgins, 2010, p. 71). This McLuhanian critique on the importance of materiality is equally applicable to GENDYN through its idiomatic use of the digital medium through its sample manipulation (Hoffmann, 2009, p.59-63).

analogy, if you overcrowd the capacity of the audience you force a general and inescapable error and confusion' (Shannon and Weaver, 1949, p. 26-7). This excess of information/uncertainty equated with entropy in Shannon's theory of communication is noise as audio.

7.5. At the level of entire works

Related to the issue of whether noise can remain noise upon repeated listenings, Xenakis was well aware that even a compositional structure modelled on the laws of chance and probability of exceptional events would lose its surprise, or noise effect, when heard several times: 'during successive rehearings the relations between the events of the sample ordained by "chance" will form a network, which will take on a definite meaning in the mind of the listener, and will initiate a special "logic", a new cohesion capable of satisfying his intellect as well as his aesthetic sense' (Xenakis, 1992, p. 37). Whilst the repetition of musical cells, motifs and sections that are fundamental in traditional music is avoided to an extent in noise and stochastic music, its appearance at the level of a whole work cannot be avoided through successive performances; the difference is merely that of scale.

He proposed a possible solution in 1956-57 which could be interpreted as a form of generative music still being explored today: 'If, on the other hand, we wish the sample to be unforeseeable at all times, it is possible to conceive that at each repetition certain data might be transformed in such a way that their deviations from theoretical frequencies would not be significant. ... Perhaps a programming useful for a first, second, third, etc., performance will give aleatory samples that are not identical in an absolute sense, whose deviations will also be distributed by chance. ... a system with electronic computers might permit ... a music which can be distorted in the course of time, giving the same observer n results apparently due to chance for n performances' (Xenakis, 1992, p. 37).

With a rigorous algorithmic composition such as GENDYN, the possibility of producing different versions of the same piece does not seem far off. The fact that this was not pursued could confirm the view that he was advocating the generation of new aesthetics and significations through repeated listenings. However, it is likely that he was unable to produce a program capable of creating results which he was happy with aesthetically. As Xenakis explained himself, he was unable to write a completely algorithmic composition: 'I am always trying to develop a program that can create the continuity of an entire piece. This is a struggle, because there are always parts that you prefer over others. So you have to change them, to stop the process, start some other one, and then put these two different ones together' (Robindoré, 1996, p. 13).

In the case of GENDYN and more specifically PARAG, it is perhaps fair to deduce that ideally, Xenakis would have controlled all parameters by stochastics or some other system of organisation, in a 'continuous variation of variables' (Deleuze and Guattari, 1987, p. 372); in practice, only the start and end times of each of the 16 'voices' are controlled stochastically, the rest being left to his intuition and hard-coded. As Xenkais was not capable of extending his control through stochastics to the macrolevel (e.g. as in Achorripsis), it would seem correct to assume that he did not possess the technical means for tackling generative compositions.

His suggestion of generative works, statistically varied, by the same stochastic process found within the work, would have produced a value of entropy at the level of entire works comparable to that found within the work. In contrast, the

definitive works produced effectively have a theoretical entropy of 0 at the level or unit of whole works from the second performance.[18]

7.6. Meaning

Jacques Attali describes the possibility of the formation of new meanings or sense in noise as an important attribute: 'Noise does ... create a meaning: ... the very absence of meaning in pure noise ... by unchannelling auditory sensations, frees the listener's imagination. The absence of meaning is in this case the presence of all meanings ... a construction outside meaning. ... It makes possible the creation of a new order on another level of organisation, of a new code in another network' (Attali, 1986, p. 33). Likewise, Xenakis states: 'For me it is always important to go to the limits, to push them, as it were, and to explore these domains which, in a sense, are beyond the aesthetical concerns of art' (Xenakis, 1996, p. 149). GENDYN can be qualified as noise in terms of entropy, as the statistical semantic characteristics of the message do not match the statistical semantic capacities of the totality of the receiver – the audience – and the amount of information overloads their capacity for receiving information.

7.7. Discernment

Deleuze and Guattari state that the modernist project involves 'rendering visible, instead of reproducing the visible' for painting and 'rendering sonorous, instead of reproducing the sonorous' in music – which again, is an evocation of the cosmic.[19] They continute that these are 'reflected in relations between matter and form' (Deleuze and Guattari, 1987, p. 346-7), as with Xenakis's preoccupation with composition at both micro and macro levels. It is also 'a question of thresholds of perception, or thresholds of discernibility' (Deleuze and Guattari, 1987, p. 346-7).[20] GENDYN produces analogous conditions necessary through molecular or sample-level composition, rendering sonorous emergent higher-order audio phenomena and allowing for the furthering of boundaries of thresholds of perception or discernibility which for Xenakis is the primary factor in composition (Robindoré, 1996, p. 12).[21]

7.8. Fractals

In Deleuze's concept of smooth spaces, the most appropriate general mathematical definition is that of a fractal as popularised by Mandelbrot. E.g. a Koch curve is constructed by substituting the middle third of a straight line with two sides of an equilateral triangle of which the removed section would form the remaining side, and then continuing the operation ad infinitum on each straight line segment at each iteration (Deleuze and Guattari, 1987, p. 486). Similar

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[18] In practice, due to the improbability of being able to recall or memorise an entire work produced by GENDYN, the entropy would decrease upon repeated listenings without ever quite reaching 0. The entropy of generative works would also decrease upon repeated listenings as one becomes familiar with the boundaries or limitations of the what is generative. This is also an issue in analysing the entropy of traditional note-based music that has only begun to be addressed in recent times (Conklin, 1990; Pearce and Wiggins, 2004).

[19] This is already present through a 'freeing of the molecular' in 'classical matters of content, operating by destratification, and in romantic matters of expression, operating by decoding' (Deleuze and Guattari, 1987, p. 347).

[20] Deleuze is critical of 'concerts of noise', which he gives as an example along with 'the modern valorisation of children's drawings' and 'texts by the mad', where instead of 'rendering sonorous', 'a scramble effacing all sounds' is produced'. For him, it is impossible 'to distinguish the disparate elements constituting that aggregate' i.e. a lack of "discernibility'. He prefers instead '[a] very pure and simple sound, an emission or wave without harmonics' such as La Monte Young (Deleuze and Guattari, 1987, p. 343-4). But it is precisely on this point concerning 'discernibility' that he reveals his taste for experimental music (and other art) as being naive and conservative.

21 However, Xenakis is concerned with human and perhaps phenomenological perception which is not the case for Deleuze. Also, the level of discernibility is also an emergent phenomena and a qualitative amount instead of a reductionist binary opposition between the hearable and the unhearable, or the chance-like pure sensual experience for the uninitiated and the total serialism for the contemporary music connoisseur (Scherzinger, 2010, p. 126-7) curiously advocated by certain Deleuzians in describing new music.

processes have been carried out in the audio domain by Shahrokh David Yadegari (Yadegari, 1991) and by Gordon Monro through fractal waveform interpolation (Monro, 1995). Interestingly, when the rate of playback is altered for some waveforms, the inverse phenomenon to the Shepard tone occurs whereby the pitch appears to cycle in one octave rather than continuously decreasing (Monro, 1995, p. 90). Although GENDYN is not strictly-speaking self-similar to the same extent, an analogous effect of a circular continuum or topological space of rhythm and pitch/timbre has been noted, as has Xenakis's speculation on higher sampling rates providing more fractal possibilities. One can probably assume that he would have taken microcomposition to an even smoother space-time had he had the means to do so.

8. CONCLUSIONS

There are several shortcomings of GENDYN (and PARAG) mentioned above that Xenakis might have perhaps accepted:

- no incorporation of the possibility of obtaining fixed pitches using the same algorithm by reducing the mirror boundaries to zero;
- lack of dynamic control of parameters within sections that would have resulted in the second type of first-order emergence;
- lack of an algorithmic macrolevel structure;
- not generative i.e. lack of stochastic variation at the level of entire works.

These extensions are all within the various models proposed, and can all be categorised as a movement towards a smoother, less striated space-time i.e. the virtual.

In addition, Weaver states that 'the interrelation of the three levels is so considerable that one's final conclusion may be that the separation into the three levels is really artificial and undesirable' (Shannon and Weaver, 1949, p. 25). GENDYN could perhaps also be a starting point for an interconnected or fractal formation of levels of meaning.

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