Extensions in Spectral Music

(work in progress)

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In one sense, different things have different causes and principles, but in another one [sense] – generally and by analogy – they have the same cause.

Aristotle, *Metaphysics*; book XII/4

Abstract

The research presented in this paper is based on the idea (among others supported by the well known French composer, belonging to the spectral school, Tristan Murail) that the entire new(est) music emerges from the knowledge of the rules governing the inner life of the sound. Here is the proposal – embodied both, in a piece of work and the theoretical approach – that intends a possible extension of the data furnished by the spectral search of the sound. Actually, our research makes a coherent extension, based on the transformational grammars, of the entire strategy and material used in a piece of work.

Keywords: spectra, transformational grammars, filters, live electronics, electroacoustics, Chowning's formula, musical form.

Preliminaries

In the following, we will present a compositional strategy aimed to some estimated extensions of the spectralism. This strategy is embodied in a specific project – "Concerto avec plusieurs instruments et quelques inharmoniques" by Fred Popovici – of which building has three stages, as follows:

1. Firstly, a general and abstract schedule of the three "movements" that form "Concerto ..." by Fred Popovici. Here we show the electroacoustical procedures used by the composer in order to shape the musical form.

2. Secondly, it will be shown how the above mentioned schedule is actually filled in the score with sound material generated by a selection (en ensemble) of acoustical instruments. [The methods of producing sounds, the distribution of sub-ensembles of instruments and so on]

3. Thirdly, the sound material produced by the instruments is extended through a set of live electronics techniques, in order to enlarge the potential of expressiveness and sound efficiency.

Our paper is also divided in three sections. In the first one, we will show how we extracted a possible transformational grammar from the acoustical coordinates designed in the general schedule of the score. In the second section we present the way we have chosen to associate to the previous grammar a new one, acting on the wholeness of the instrumental techniques and their interconnections inside the exigences of the score. The final section is dedicated to an original project, namely, the making of a third grammar concerning the organization of the live electronics procedures, according to the two former grammars; the aim is the extension of the sound production emerging from Fred Popovici's work.

Contents

1 Form Schedule to Grammar

1.1 Raw Material

The musical discourse of "Concerto ..." by Fred Popovici uses a specific raw material; it consists of a selection of spectra of frequencies. There are considered three kinds of spectra:

- spectra of odd harmonics
- spectra of inharmonics
- compressed/expanded spectra.

Definition 1 *The spectrum of* **m** *odd harmonics of a fundamental frequency,* **f***, is the set of frequencies*

$$\mathscr{H}(f,m) = \{f, 3f, 5f, \ldots, (2m-1)f\}$$

□

Definition 2 *The spectrum of inharmonics of* $2n+1$ *components defined, according to John Chowning's formula, symmetrically around* f *is the set of pitches:*

$$\mathscr{I}\mathscr{H}(f,n,\delta f) = \{(f-n\delta f),(f-(n-1)\delta f),\ldots,(f-\delta f),f,(f+\delta f),\ldots,(f+n\delta f)\}$$

where $\delta f < f_0$*, with* f_0 *the fundamental frequency of the spectre of od harmonics which includes* f. □

Definition 3 *The compressed/expanded spectrum of* $n+1$ *components defined for the frequency* f_1*, as follows:*

$$\mathscr{C}/\mathscr{E}(f_1,n,\alpha) = \{f_1,(1^\alpha \times f_1),(2^\alpha \times f_1),\ldots,(n^\alpha \times f_1)\}$$

where α *can be* <1 *for compressed spectrum* $\mathscr{C}$*,* >1 *for expanded spectrum,* $\mathscr{E}$.
□

1.2 Basic Acoustical Processes

The music flow results from the activation (expansion) of one or more spectra which are submitted to a dynamic filtering process. A spectrum of frequencies a *host-temps* structure (Xenakis) which set in time becomes a process. Once activated, a specter may always run affected by a filter. Thus, the following basic processes can be emphasized:

- stationary: s – the characteristics of the spectrum are stable maintained
- generation: a specter is instantaneously activated
  - h(f): activation of a canonic spectrum of m **h**armonics, $\mathscr{H}(f,m)$ of the fundamental frequency f
  - i(f): activation of a stretched "spectrum" centered on a frequency f and build according to the Chowning's formula.
  - c(f): activation of a **c**ompressed/expanded spectrum of n in-harmonics $\mathscr{C}(f,n,\delta f)$ centered on the frequency f with δf step between successive components
- filtering:
  - $g(f_{initial}, f_{final})$: a **g**liding pass-band filter with a constant passband defined by (f_m, f_M), with $f_M - f_m = p \times f_0 = const$, which glides from from $f_{initial}$ to f_{final}, where $f_{initial}$ is the initial value of f_m and f_{final} is the final value of f_m (the complexity of the resulting sound depends on the raw material submitted to the filtering process)
  - e(f): pass-band filter with a central frequency f **e**xpanding its passband (that means the complexity of the sound is continuously increasing)
  - n(f): pass-band filter with the central frequency f **n**arrowing its passband (means the complexity of the sound is continuously decreasing)

The following parameters are initially defined as global: m, n, $\delta f, f_m, f_M$.

1.3 Grammar

In the following definition, a grammar is provided, “inspired” by the musical structure represented in Figure 1 (first movement of “Concerto ... ”), is provided. The description of this first movement of the work uses a series of terms belonging to the classical analysis of music, but this time taken in an enlarged acceptance (movement, section, subsection, ...)

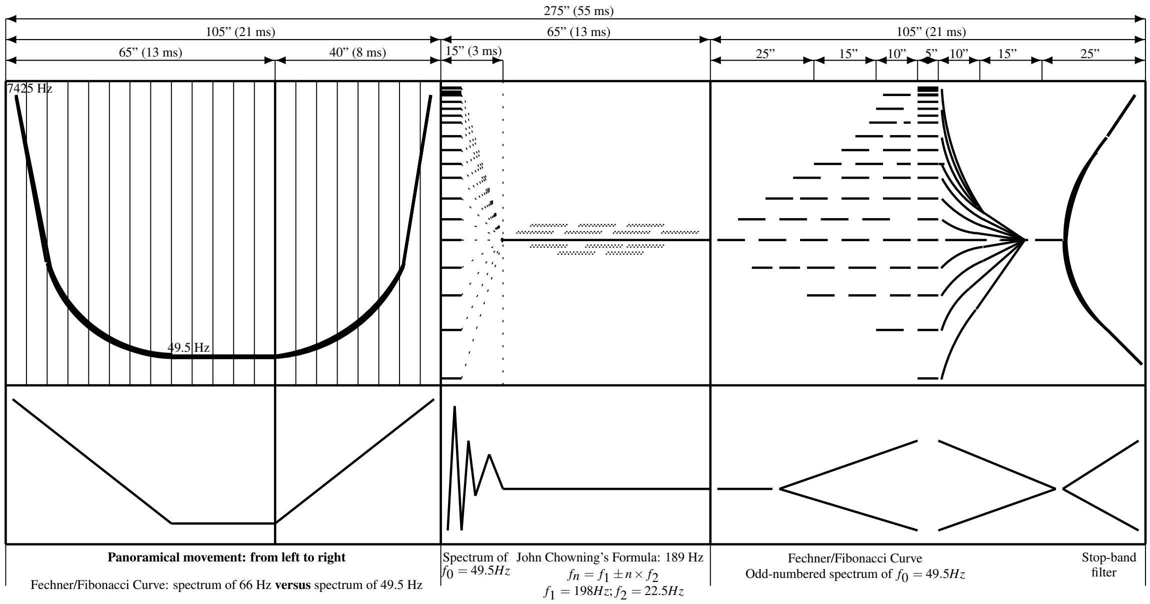

Figure 1:

This first movement has the following structure:

Section A : is shaped according to Fibonacci’s series (the unit being a measure, *ms*, of 5 seconds)

$$A = (8ms + 5ms) + 8ms = 13ms + 8ms = 21ms$$

The dynamics is ruled by the Fechner’s curve.

subsection a_1 : of 8ms, it represents a gradual passage from the highest region of the residual zone down to the fundamental of G (49.5 Hz); because the highest region is very dense in its components, automatically this passage acts as a filter (aiming to harmonics of G)

subsection a_2 : of 5ms, it represents an establishment accompanied by a defective spectrum (filter again: the upper region of the spectrum is cut-of)

subsection a'_1 : of 8ms, it is a reversed gradual passage from the low region of the spectrum up to the highest region of the residual zone

Section B : is a passage from a large spectrum of G (49.5 Hz) drastically filtered to single component around which a spectrum of in-harmonics is built according to John Chowning’s formula. The Fibonacci schedule is also there:

$$B = 3ms + 5ms + 5ms = 8ms + 5ms = 13ms$$

subsection b_1 : from a large spectrum of G (49.5 Hz), made only of odd numbered components, through a fast acting filter (in 2ms), a single central component is reached (198 Hz)

subsection b_2 : around the resulting central G (198 Hz) an in-harmonic spectrum is built according to Chowning's formula:

$$\mathscr{I}\mathscr{H}(f,n,\delta f) = \mathscr{I}\mathscr{H}(198Hz,n,22Hz)$$

Section C : is made of a gradual building of an odd numbered spectrum of G (49.5Hz) followed by a filtering process and ended by a process equivalent with a superposition of a_1 and a'_1

$$C = (5+3+2)ms + 1ms + (2+3)ms + 5ms$$

subsection c_1 : of 16ms

semi-subsection c_{11} : of (5+3+2)ms, gradual up and down addition of odd numbered components of G (198 Hz)

semi-subsection α : of 1ms, the largest spectrum of odd numbered components of G

semi-subsection c_{12} : of (2+3)ms, a gradual filtering (a reverse of c_1)

subsection c_2 : of 5ms, a process equivalent with a superposition of a_1 and a'_1

Summarising we have for the entire movement, M:

$$M = A + B + C = 21ms + 13ms + 21ms = 21ms + 34ms = 55$$

that verifies once more again the Fibonacci series.

Definition 4 *Let be the grammar:*

$$G_1 = (N, T, \mathscr{P}, S)$$

where:

- *S: is the starting symbol*
- $N = \{S, M, U, H, C, P, F\}$*: is the set of non-terminals, where:*
- $T = \{s, h(f), c(f), g(f_i, f_f), e(f), n(f), i, d, a\}$*: is the set of terminals, where:*
  - *s: stationary process*
  - $h(f)$*: instantiate harmonic spectres with fundamental* f
  - $c(f)$*: instantiate compressed spectre with central frequency* f
  - $g(f_i, f_f)$*: glides the pass-band filter from* f_i *to* f_f
  - $e(f)$*: expand the passband of the pass-band filter centered on* f
  - $n(f)$*: narrow the passband of the pass-band filter centered on* f
  - $i = f_{min}$*: the fundamental of the harmonic specter (*
  - $d = f_{med}$*: the middle frequency*
  - $a = f_{max}$*: the highest harmonics of the harmonic spectre*
- $\mathscr{P}$ *is the set of production rules:*
  - `S -> MSM | U | C | M | H`
  - `U -> HCH`
  - `M -> (h(F)c(F))P` *// instantiate in parallel two spectres and the associated process*
  - `H -> h(F)P`
  - `C -> c(F)P`
  - `P -> (PP)` *// instantiate in parallel two processes*

- `P -> PsP | g(FF) | e(F) | n(F)`
- `F -> i | d | a`

□

Example 1 . *The generic structure represented in Figure 1 can be generated, using G_1, as follows:*

```
S->
MSM->
MHCHM->
(h(F)c(F))PHCHM->
(h(F)c(F))PnPHCHM->
(h(F)c(F))g(FF)sPHCHM->
(h(F)c(F))g(FF)sg(FF)HCHM->
(h(F)c(F))g(FF)sg(FF)h(F)PCHM->
(h(F)c(F))g(FF)sg(FF)h(F)n(-F)CHM->
(h(F)c(F))g(FF)sg(FF)h(F)n(F)c(F)PHM->
(h(F)c(F))g(FF)sg(FF)h(F)n(F)c(F)PnPHM->
(h(F)c(F))g(FF)sg(FF)h(F)n(F)c(F)e(F)sPHM->
(h(F)c(F))g(FF)sg(FF)h(F)n(F)c(F)e(F)sn(F)HM->
(h(F)c(F))g(FF)sg(FF)h(F)n(F)c(F)e(F)sn(F)h(F)PM->
(h(F)c(F))g(FF)sg(FF)h(F)n(F)c(F)e(F)sn(F)h(F)PnPM->
(h(F)c(F))g(FF)sg(FF)h(F)n(F)c(F)e(F)sn(F)h(F)e(F)sPM->
(h(F)c(F))g(FF)sg(FF)h(F)n(F)c(F)e(F)sn(F)h(F)e(F)sn(F)M->
(h(F)c(F))g(FF)sg(FF)h(F)n(F)c(F)e(F)sn(F)h(F)e(F)sn(F)(h(F)c(F))P->
(h(F)c(F))g(FF)sg(FF)h(F)n(F)c(F)e(F)sn(F)h(F)e(F)sn(F)(h(F)c(F))(PP)->
(h(F)c(F))g(FF)sg(FF)h(F)n(F)c(F)e(F)sn(F)h(F)e(F)sn(F)(h(F)c(F))(g(FF)P)->
(h(F)c(F))g(FF)sg(FF)h(F)n(F)c(F)e(F)sn(F)h(F)e(F)sn(F)(h(F)c(F))(g(FF)g(FF))->
(h(i)c(F))g(FF)sg(FF)h(F)n(F)c(F)e(F)sn(F)h(F)e(F)sn(F)(h(F)c(F))(g(FF)g(FF))->
(h(i)c(a))g(FF)sg(FF)h(F)n(F)c(F)e(F)sn(F)h(F)e(F)sn(F)(h(F)c(F))(g(FF)g(FF))->
(h(i)c(a))g(aF)sg(FF)h(F)n(F)c(F)e(F)sn(F)h(F)e(F)sn(F)(h(F)c(F))(g(FF)g(FF))->
(h(i)c(a))g(ai)sg(FF)h(F)n(F)c(F)e(F)sn(F)h(F)e(F)sn(F)(h(F)c(F))(g(FF)g(FF))->
(h(i)c(a))g(ai)sg(iF)h(F)n(F)c(F)e(F)sn(F)h(F)e(F)sn(F)(h(F)c(F))(g(FF)g(FF))->
(h(i)c(a))g(ai)sg(ia)h(F)n(F)c(F)e(F)sn(F)h(F)e(F)sn(F)(h(F)c(F))(g(FF)g(FF))->
(h(i)c(a))g(ai)sg(ia)h(i)n(F)c(F)e(F)sn(F)h(F)e(F)sn(F)(h(F)c(F))(g(FF)g(FF))->
...
(h(i)c(a))g(ai)sg(ia)h(i)n(d)c(d)e(d)sn(d)h(i)e(d)sn(d)(h(i)c(a))(g(da)g(dF))->
(h(i)c(a))        //generate a mixed spectre; compressed on fmax, harmonic on fmin
g(ai)             //pass-band filter glides from fmax to fmin
s                 //pass-band filter is stationary
g(ia)             //pass-band filter glides from fmin to fmax
h(i)              //generate harmonic spectre on fmin
n(d)              //narrowing band-pass filter centered on fmed
c(d)              //generate compressed spectre centered on fmed
e(d)              //expanding pass-band filter centered on fmed
s                 //pass-band filter is stationary
n(d)              //narrowing band-pass filter centered on fmed
h(i)              //generate harmonic spectre on fmin
e(d)              //expanding pass-band filter centered on fmed
s                 //pass-band filter is stationary
n(d)              //narrowing band-pass filter centered on fmed
(h(i)c(a))        //generate a mixed spectre; compressed on fmax, harmonic on fmin
(g(da)g(di))      //two pass-band filter glide from fmed, one to fmin, one to fmax
```

The following parameters work as global and are defined initially: `i, d, a`. *The our example they are:* $i = 49.5Hz$, $d = 8i = 396Hz$, $a = 151i = 7474.5Hz$. ⋄

1.4 From the Generic Form to the Actual Form

1.4.1 Field of Pitches

The sets of pitches are organized as several different spectra:

- spectrum of odd numbered components:

$$f_i = (2i-1) \times f_1 = (2i-1) \times 49.5Hz$$

  for $i = 1, 2, \ldots, 128$.

- inharmonic spectrum based on John Chowning's formula:

$$\mathscr{I}\mathscr{H}(f, n, \delta f) = \mathscr{I}\mathscr{H}(198Hz, 7, 22Hz)$$

- compressed spectrum of harmonics:

$$\mathscr{C}(f_1, n, \alpha) = \mathscr{C}(49.5Hz, 128, 0.75)$$

  and an expanded spectrum of harmonics:

$$\mathscr{E}(f_1, n, \alpha) = \mathscr{C}(49.5Hz, 128, 1.25)$$

1.4.2 Field of Durations

In order to build the set of durations we will take into account a similar procedure: the durations correspond to the frequencies of the fundamental sound multiplied with the inverses of each odd numbers from 1 to n.

- spectrum of odd numbered components:

$$t_i = 1/((2i-1) \times f_1) = 1/((2i-1) \times 49.5Hz$$

  for $i = 3, 4, \ldots$.

- inharmonic spectrum of odd numbered components:

$$\mathscr{T}(f, n, \delta f) = 1/\mathscr{I}\mathscr{H}(f, n, \delta f) = \mathscr{I}\mathscr{H}(6.2Hz, 7, \delta 22Hz)$$

- compressed spectrum of odd numbered components: the correspondent of fundamental of pithes (49.5Hz) is $1/(49.5Hz/256) = 5sec$

  $\delta t << t_{med}$. Ex. $\delta t = 0.11sec$. The spectrum contains 6 symmetrically distributed values around t_{med}. The results is: $(0.64-5\times0.11), (0.64-3\times0.11), (0.64-1\times0.11), 0.64, (\times0.11+0.64-1\times0.11), 0.64, (1\times0.11+0.64), (3\times0.11+0.64), (5\times0.11+0.64) = (0.09, 0.31, 0.53, 0.64, 0.75, 0.97, 1.19)$

- the set of durations is the "inverse" of the set of pitches, starting from the first division of f_{min} that could be considered the inverse of a duration. (Ex.: $f_{MAX} = 49.5/4 = 12.5Hz$ which corresponds to $t_{min} = 0.08sec$). The longest duration is $t_{max} = 151 \times t_{min} = 12sec$, similar to the scale of frequencies. The result is the spectrum of durations:

$$t_{min}, 3 \times t_{min}, 5 \times t_{min}, \ldots, t_{max}$$

- t_{med} corresponding to the f_{med} is $t_{med} = 8 \times t_{min} = 0.64sec$

- the compressed spectrum of durations is built using a $\delta t << t_{med}$. Ex. $\delta t = 0.11sec$. The spectrum contains 6 symmetrically distributed values around t_{med}. The results is: $(0.64-5\times0.11), (0.64-3\times0.11), (0.64-1\times0.11), 0.64, (\times0.11+0.64-1\times0.11), 0.64, (1\times0.11+0.64), (3\times0.11+0.64), (5\times0.11+0.64) = (0.09, 0.31, 0.53, 0.64, 0.75, 0.97, 1.19)$

- the compressed spectrum of durations is built using a $\delta t << t_{min}$. Ex. $\delta t = 0.33sec$. The spectrum contains 6 symmetrically distributed values around t_{min}. The results in frequency is (approximatively):

$$3, 6, 9, 12.5, 15, 18, 21$$

  which in seconds are:

$$0.33, 0.166, 0.11, 0.08, 0.066, (0.055), (0.047)$$

- the pass band filter has the range from $f_{MAX}/4$ to $F_{MAX} \times 4$. Thus: $\Delta f = 47Hz$

1.4.3 Defining the Actual Field of Dynamics

- we decided the dynamic spectrum is made of: `fff, ff, f, mf, mp, p, pp, ppp`. Roughly speaking it corresponds to a logarithmic scale. It implies that between a frequency and its octave all the harmonics included in this interval are submitted to a single dynamic level. The idea is the lowest fundamental frequency, 50 Hz, is the loudest, fff. Accordingly, the scale of dynamics decreases from this fff to ppp assigned the highest frequency, 6400 Hz.

- the spectrum of inharmonics following the Chowning's formula, where the basic frequency is 198 Hz (in fact 200 Hz), corresponds to the interval between f and fm. A continuous variation in this interval (a very little below f, a very little above mf) corresponds to a conventionally named level *quasiforte*, qf. It is clear that this procedure could be considered a dynamic equivalent of the inharmonics spectra of the actual frequencies, based on Chowning's formula. of dynamics is centered on $f_{med} = 396$ and is extended on $f_{med} + / - 10 times 17 = (227Hz - 566Hz)$

- the compressed spectrum of dynamics means that starting from the loudest nuance (fff) up to the softest (ppp) the intermediary nuances decrease according to the value of $\alpha < 1$. The expanded spectrum of dynamics is the reversal scale of the previous one, but now starting from the softest nuance up to the loudest. Now $\alpha > 1$.

1.4.4 Defining the Actual Field of Timbres

According to recent researches concerning to this dimension of the sound we know that the production of the sound is made of three phases:

- the attack transients: could be assimilated to a increasing pink noise (as concerns the ambitus)

- the permanent regime: corresponds to the discrete series of harmonics (from which a limited set makes the so could formants)

- the extinction transients: could be assimilated to a decreasing pink noise

The attack transients is a phase that could be appropriately made by applying several times the Chowning's on several components of the spectrum of harmonics. The same could be applied to the extinctions transient but in the reverse order.

The formants are introduced using $\alpha > 1$ and $\alpha < 1$.

1.5 Defining the Actual Field of Spatial Relations

IN our case we take into consideration a two-dimensional net of spatial relation, given by the view from above of the concert stage. The instruments will be considered as points in this space.

It easy to notice that the percussion-like sounds production (including here those made under spacial circumstances by string and wind instruments) could, by their simple and homogenous production, coherently organize a spatial net. Therefore, they could assume a kind of similarity with the idea of a spectrum made of sinusoidal components. The kind of wave form characteristic to percussion, i.e., noise-like production (a strong and short attack followed by a rapid decay) allows a very simple, non-ambiguous, spatial positioning. Syntactically speaking a noise-like production could be assimilate to a invariant.

1.5.1 Spectrum of spatial "harmonics"

The formal expression of a spatial net (equivalent to a basis or to a frame, eventually to a fundamental) defined this noise-like mechanism is a vector of pairs of coordinates. For example, a space of fundamentals has the following expression:

$$FS = < (x_1, y_1), (x_2, y_2), \ldots (x_n, y_n) >$$

represents a space delimited by n points.

The next step is to try to define an equivalent to the construction of a spectrum. We propose the enriched parameterized expression of form:

$$FS = <(x_1, y_1, <p_1, \ldots>), (x_2, y_2, <p_1, \ldots>), \ldots (x_n, y_n), <p_1, \ldots>>$$

where $< p_1, \ldots >$ is the vector of specific parameters used to define a series of spatial spectral components. For example:

- $< 1 >$ or $< 0 >$ means the associated instrument (example: maracas) is active or inactive
- $< i >$ for $i = 0, 1, \ldots$ is associated to in instrument which does soft or strong with different degrees (example: grancassa)
- $< i, p, t >$ is associated to an instrument having three possibilities: dynamics, pitch and timber (example: timpani)

We suggest that because each instrument has only one occurrence, this could be paralleled to the idea of odd numbered spectrum (where each component has equally only one occurrence).

1.5.2 Spectrum of spatial "inharmonics"

We recall that a spectrum of inharmonics consists of a basic big frequency accompanied by series of small variations, above and below, of this frequency.

Accordingly, a basic percussion-like signal made by an instrument is accompanied by a series of small echoes around this signal. The appearance of this multitude of echoes makes in a way a same effect as the frequency modulation in respect with Chowning's formula. Eventually, the result is a kind of ambiguity concerning the initial precise spatial frame.

1.5.3 Spectrum of spatial compressed/expanded "harmonics"

In order to better clarify the idea of compressed/expanded spatial spectra we will now introduce the other two main families of the orchestra, namely the strings and the winds/brass instruments.

Roughly speaking, both these families could be put to make two kinds of sounds: (1) percussion-like sounds (pizz, legno butt – for strings; slap, "pitz" – for winds/brass) and (2) sustained sounds (without taking into account the length of these sounds).

The continuous multiplication of percussion-like sounds – in all directions – generates a continuous expansion of the space.

The continuous multiplication of sustained sounds – in a precisely defined ambitus – generates a continuous compression of the space.

2 How to Use Grammars

There are three main processes:

- producing a grammar G
- producing a sequence σ in the language L(G)
- producing modifications in σ

The to control the complexity of an sound organism there are two main mechanisms:

- selecting the size of the spectra
- modifying the bandwidth of the filters

The organism and its modified forms are used to generate a linear sequence of organisms.

In the moment of reaching its maximum complexity an organism could generate a new parallel linear sequence of organism.

The growth of a sound form is governed by three rules:

- serial concatenation
- parallel generation
- stop

3 Sound Organism

The concept of sound organism will replace the classical concept of form and/or macro-form. Instead of presenting the final result of a process hidden to our perception and understanding (this is the case o classical form), we propose the entire process of birth, development and extinction which could be done by working on the five parameters of the sound. In other words, we could state that in our conception a sound form is actually a process inspired by the vital processes. To be more precise we advance the idea of a genesis which flows into a process (with all the accidents implied in such as evolution).

Complexity means the size of the three types of specters involved in a sound organism.

From a sound organism to the next we change mainly the sizes of the specters involve, and the sequence of rules is slightly modified..

The emergence of a new sound organism (a child) is ruled by:

- the spectrum is for instance only a uniformly distributed half from the specter of its genitor
- the sequence of rule is only slightly modified
- the child is born when the genitor is maximally expanded
- the number of children increases with the maturity of genitor, and decreases when the genitor gets old

Definition 5 *A* **sequence** *is the result of an action according to a grammar extended to all the five sound parameters. The evolution of the sequence is ruled by the increasing and then decreasing of its complexity.*

Definition 6 *The* **complexity** *of a sequence is given by the size of its description in the given grammar.*

Definition 7 *A* **segment** *is linear succession of sequences. The evolution of the segment is ruled by the increasing and then decreasing of its complexity.*

Definition 8 *The growing rules:*

- *serial growth:*
- *parallel growth:*
- *stop:*

Definition 9 *The* **sound organism** *is a set of parallel evolving sequences. Its complexity is given by the number of sequences running simultaneously. The evolution of a sound organism is ruled by the increasing and then decreasing of its complexity.*

Figure 2: Growing rules for a sound organism made of sequences. **a.** Serial growth. **b.** Parallel growth. **c.** Stop.

Figure 3: Example of generating a sound organism by applying the growing rules.

4 From Grammar to Instrumental Score

5 From Grammar to Live Electronics Procedures

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