FUNCTIONAL INTEGRATION OF COMPLEX INSTRUMENTAL SOUNDS IN MUSICAL WRITING.

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Abstract

This work adresses the problem of functionally integrating new instrumental techniques in musical composition.

The material consists of a data base of standardized recordings of multiphonics, produced within the woodwind instrumental family. These sound objects are first digitalized, then subjected to acoustic analysis and to a psycho-acoustical modelling which allows them to be described as discrete pitch sets. The objects are converted to a homogenous representation, then a relationship-finding module extracts subclasses out of them, and finds transition elements from one class to another. At that point graphs are constructed that express potential harmonic trajectories. Finally, formalisms are proposed for the elaboration of pitch scales coherent with the model.

This approach leads to a re-thinking of several important musical issues : discrete or non-discrete organisation of pitch space, temperament, micro-intervals, harmonic structures. It may also lead instrumentalists to situate their playing in a new sonic environment.

1. INTRODUCTION

Traditional compositional formalisms are generally limited to applications simple instrumental sounds; these sounds, due to their harmonic structure, can be reduced to the unique and easy to manipulate concept of notes.

We shall try to define a method which will provide the possibility of integrating complex acoustical objects, in musical composition, not as decorative elements but as functional ones which, with their inharmonicity and instability, contribute to the musical structure and to its aesthetics [3].

For this purpose we chose multiphonic sounds of the wood wind instruments (multiphonic sounds are best defined in this family of instruments). This choice also provides the possibility of extending our research to ensemble music, trying to transpose results from one instrument to another.

2. MULTIPHONICS : PROBLEMATICS

Multiphonics, although consistent with the producing instrument's timbre identity, cannot be integrated into the traditonal harmonic fabric owing to their complex frequential structure. Moreover the fact that they form a discontinuous space that is hard to manipulate a posteriori led us to view them as the starting point for a study focussed initially - for reasons of methodological simplicity - on the organisation of pitch space into harmonic structures.

Right from the outset, the problem arises as to the perception of these sound structures, as their identification involves both the area of timbre and that of pitch. A previous study [2] has already helped to highlight some points; multiphonic sounds are made up of components whose frequency is clearly defined, but nevertheless difficult to identify, because :

- they are very high or low in pitch , i.e. outside the area of "musical fundamentals" contained in the two staves, thus giving rise to errors of octave and omissions.
- there is no simple interrelation between them.
- they form musical intervals which do not fit into the equally tempered scale

Unstable multiphonics contain graininess due to beating between components. The perceptual effect depends here on the beat frequency since it can interfere with the components' frequencies.

Experiences have been made consisting of musical dictation of a multiphonic, with experienced musicians. The results are surprisingly far from the true pitches that are present in the sound spectrum. A possible explanation of the difficulties encountered in recognizing a multiphonic is that these sounds are related both to chords, which are compound objects whose components are perceived separately, and to spectral phenomena whose various components merge to form a single timbral entity. Furthermore, when heard as chords they are in conflict with perception habits related to equal temperament owing to their harmonic nature.

Traditional aural analysis fails in determinig the intervalic structure of the multiphonic sound. The spectral analysis (FFT) gives us better information on the frequency of the partials in a complex sound, but involves managing huge amounts of numerical data, few of which are of real interest to the composer. We have to find methods to reduce the data into a significative sub-set of values.

3. ACOUSTIC ANALYSIS OF SOUND OBJECTS

The basic tool is the fast Fourier transform algorithm (FFT). This method provides a static photograph of the spectral structure of a sound. It does not consider the temporal variations of frequencies and amplitudes, but it is sufficient for speculation on pitch space.

The first step is to calculate the FFT inside a time window in which the sound is stable enough. We experimented with Terhardt's virtual pitch pattern algorithm [5], in order to find a model which takes into account the perception of the multiphonic sounds. As the results of the full algorithm were not sufficiently satisfactory for this family of sounds, we finally used only the first steps that find the peaks in the FFT, and then eliminate those frequencies that are not perceived, due to the masking effect. At this point the multiphonic sound is described by a list of frequency-amplitude pairs , which is both significant enough and easy to manipulate by a musician.

It remains to be seen whether such a drastic data reduction preserves a sufficiently significant core of information on the chordal structure of the analysed sounds. Simulations are therefore constructed by additive synthesis on the basis of the previous results and validated by comparing them with the real sounds, auditively and visually, using sonagrams; thus there is throughout the process a continuous interaction between the data obtained from aural perception and that provided by acoustic analysis.

At this point, the multiphonics appear as an unconnected collection of pitches. An abstract construct still needs to be found to describe the phenomena studied and build new structures coherent with them.

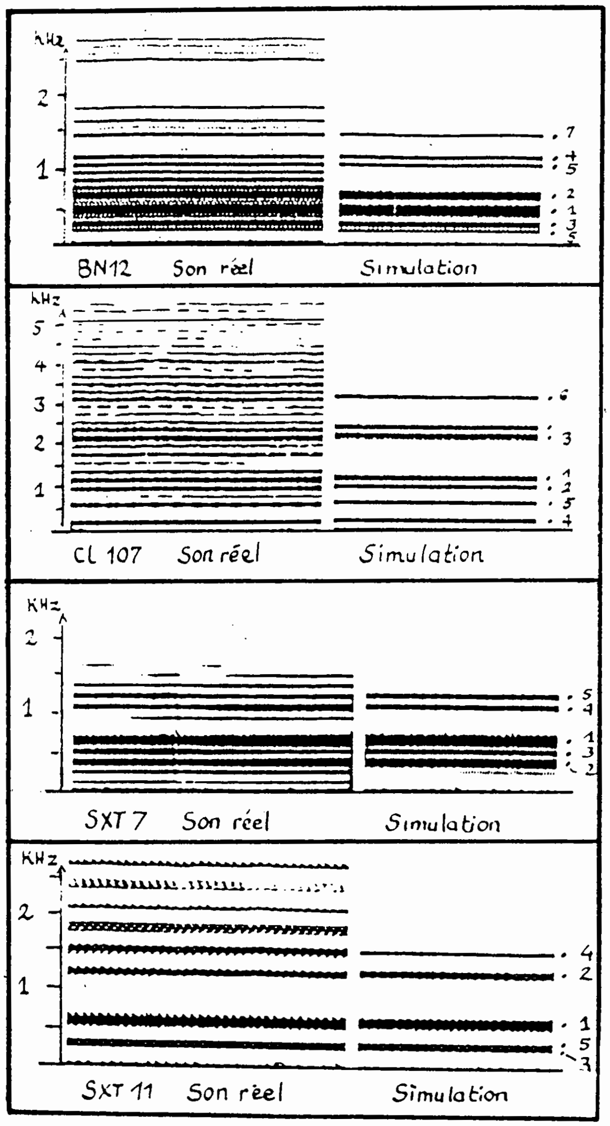


Fig. 1 comparisons of sonographic results for real and simulated sounds for bassoon, clarinet (B flat) and tenor saxophone multiphonics.

4. REPRESENTATION OF SOUND OBJECTS

The problem is now to find a reference system in order to express each object in an unique and minimal way.

We shall thus consider an object as a particular pattern of intervals, transposed at a certain pitch, rather than a frequency list. The reference system mentioned above will be the harmonic spectrum, which we may as well consider as an infinitely long pattern of intervals. Given a test object, we try to find out whether there exists a subset of increasing harmonics inside the spectrum whose pattern of intervals matches the object's pattern within a certain predefined tolerance. Our object is then completely defined by the sequence of whole numbers corresponding to the harmonic ranks, and by the pitch of the related fundamental. The frequency $f0$ of the latter is $f0 = f/h$ where f is the frequency of the lowest-pitched component in the object and h is the rank of the related harmonic. (see **fig. 2**)

There always exists a solution since it suffices to match the test object with harmonics of higher rank. The tolerance parameter is of importance since it defines the level of discretisation (1/2, 1/4, 1/8, 1/n of a tone) of the pitch space, two pitches that stand in the same micro-interval being considered as identical.

We point out that the loss of information due to the reduction of a list of frequencies to a pattern of partial numbers in a discretized pitch space is fully justified by the constraints inherent in instrumental music, the same "micro-intervalic resolution" being used for modelling the sound objects as well as for writing down the music.

We shall refer this algorithm as the "comb sorting algorithm".

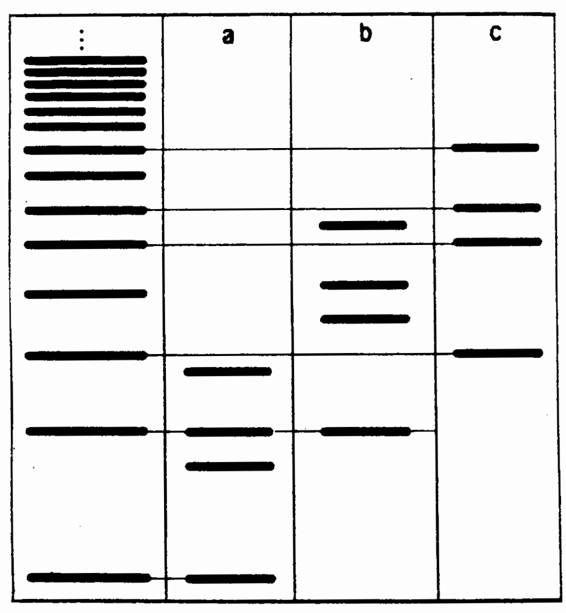


Fig. 2 "Comb" sorting algorithm *the first column on the lelft represents the Harmonic Spectrum, the vertical axis being that of the intervals. Columns a to c show a multiphonic moved along this structure until all its components coincide with those of the spectrum.*

5. INTERRELATING SOUND OBJECTS

Musical ideas develop within a set of interrelations. Therefore, a dialectical relationship has to be established between the various sound objects, each of which is considered as a pole of structuration.

We have already seen how to obtain a sequence of partials from a sound object using the comb algorithm. The latter may serve to unify several objects by expressing them if possible as partials in a harmonic spectrum with the same fundamental, as well as creating oppositions between objects modelled with different fundamentals.

In order to generalise the comb algorithm so as to treat a collection of objects, we first merge these objects in a single structure S , mixing and then re-ordering all their components in a complex "spectrum". Then we proceed as follows:
the lowest-pitched component of S is successively attached to harmonics 1, 2, 3, etc. of the reference harmonic spectrum. At each step, we examine the partial solution, i.e. the subset of components in S that match some harmonics in the spectrum. Every original object whose components are completely contained in that subset are memorized in a list as are the related sequences of whole numbers and the fundamental delivered by the comb. The algorithm ends when every object in the collection has been recognized once at least.

At this point the initial collection of sound objects has been shared among a number of subclasses, each of which is associated with a different fundamental (see **fig. 3**) Objects that belong to more than one subclass will have a different expression in numbers of partials for each. They naturally function as transition elements between the harmonic potentials associated with the classes.

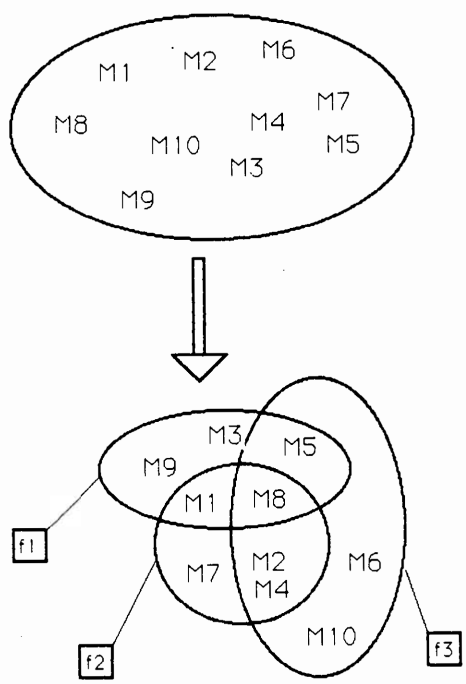


Fig. 3 Organization of a set of acoustic object into classes defined by membership to the same spectrum *Each class is defined by the fact that its elements are expressed as sequences of partials of the same fundamental. An element common to two classes thus has at least two expressions as sequence of numbers of partials.*

One can as well choose to represent this kind of structure with an "intersection graph" built as follows : each node in the graph is labelled with the elements of a particular class, and an edge joining nodes n1 and n2 is labelled with the elements in the intersection of n1 and n2 (see **fig. 4**).

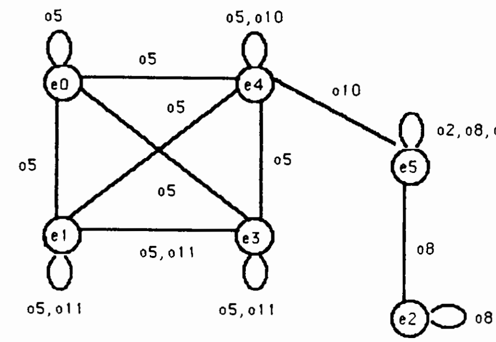


Fig. 4 Graph constructed on a sequence of 5 tenor saxophone multiphonics : *The figures labelling the transitions are the numbers of multiphonics. The encircled figures designate the classes derived from the sorting algorithm. Via multiphonics 5 and 11 one remains in class 1 or moves to 3.*

Such a graph makes up a pool of possible paths through successive states of harmonic organisation (the nodes) structured around the fundamental of the related class and its harmonic spectrum ; the objects in that class make a subgraph of harmonic poles; finally the objects on the edges make transitions possible between the different states (**fig. 5** shows a sample two-levels traversal of a graph).

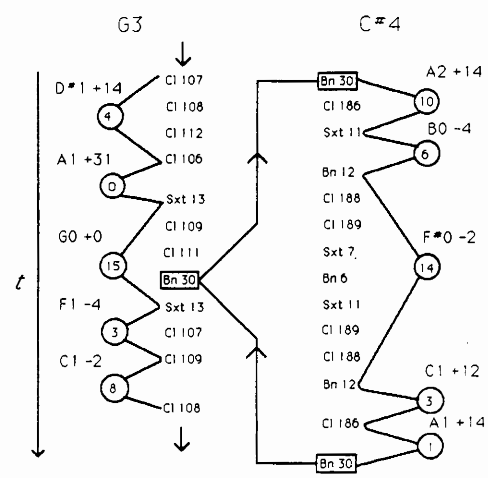


Fig. 5 Route through a graph : *This exemple which was used in the compilation of "nonsun", a piece for woodwind quintet by Claudy Malherbe, shows a possible pathway flow between two graphs interlinked by a pivot object : the point of entry is multiphonic Cl 107 in the top left hand corner. The graph should be read from top to bottom. At multiphonic Bn 30 there is a link-up with the graph on the right which is followed right through and then the flow resumes at the point of the initial derivation. The figures in circles show the graph's nodes with the associated fundamentals.*

The composer can use this pre-organisation of the acoustic material in various ways :

- common parts or differentiation
- sudden or slow state-to-state evolution
- game of redundancies and memory process
- dialectics organizing temporal development, etc.

6. SCALE CONSTRUCTION

There still remains the need for tools helping the composer to generate musical objects, such as rhythmic structures, pitch scales and pitch distribution modes, etc. in a way that is consistent with the pre-organization of the acoustic materials previously shown [1]. A formalism for scale construction is now proposed.

Let S be a sequence of numbers of partials taken from a reference harmonic spectrum.

$$P = (p_1, p_2, p_3, \cdots, p_q)$$

It may be useful to consider such a sequence as a fragment of a larger regular pattern. Now let us construct the series

$$S_i = (p_i, 2p_i, 3p_i, \cdots, np_i, \ldots)$$

for each component p_i of S. Then S_i is included in the reference spectrum and also represents one of its transpositions (for instance, if p_i=3, S_i will be a harmonic spectrum transposed to the fifth as compared to the reference spectrum).

By generalizing this principle to all the elements in the sequence and by merging the spectra obtained, the result is a scale S, extracted from the reference spectrum and containing the initial sequence P. The expression of this scale as a series of integers is called "sieve" and each one of its generators S_i is called "simple sieve" of rank p_i.

$$S = S_1 \cup S_2 \cup \cdots \cup S_q$$

example :

$$P = (3, 5, 11, 12, 15, 17, 22)$$

$$S_1 = (3, 6, 9, 12, \ldots, 3n, \ldots)$$
$$S_2 = (5, 10, 15, \ldots, 5n, \ldots)$$
$$\cdots$$
$$S_7 = (22, 44, 66, \ldots, 22n, \ldots)$$

$$S = S_1 \cup S_{2 \ldots} \cup S_7$$

$$S = (3,5,6,9,10,11,12,15,17,18,20,21,22,24,25,27,\ldots)$$

The scale made up of the combined simple sieves of rank r1, r2, rn, ... is noted :

$$[r_1 + r_2 + \cdots + r_n]$$

The scale constructed in the preceding example is noted :

$$[3 + 5 + 11 + 12 + 15 + 17 + 22]$$

which can be simplified to :

$$[3 + 5 + 11 + 17]$$

the sieve of rank 12 being contained in that of rank 3 and that of rank 22 in that of rank 11.

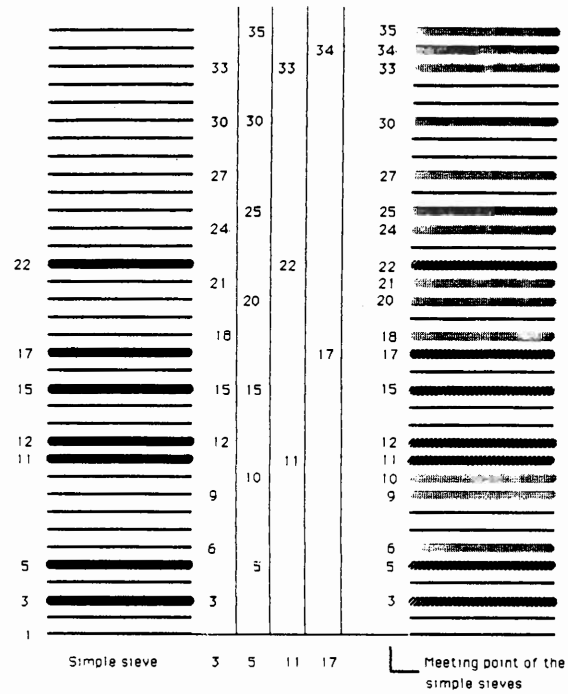
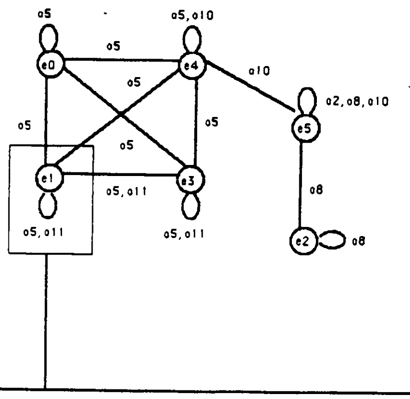


Fig. 6 Inclusion of an acoustic object reduced to a sequence of partials in a scale : *in the column on the extreme left the elements of the spectrum are shown, whilst the partials constituting the acoustic object figure in bold type. The column on the right shows the scale resulting from the union of simple sieves in grey strokes. This scale's expression is sufficient to describe the acoustic object in relation to the reference spectrum.*

The last expression is called the "largest common sieve" (LCS) for the elements of a sequence of numbers of partials, thus indicating that it is the least tight sieve, expressed in terms of combinations of simple sieves, and containing all the elements of this sequence. This is intended to imply the idea of an optimal scale to the extent that it adds only a limited number of elements to the initial sequence, thus masking as little as possible the specificity of the harmonic aggregates contained in the acoustic material; this is coherent with the basic model, as this scale is constructed on the basis of interleaving of transpositions of the harmonic spectrum.

This principle can be extended to several sequences of partials by calculating the Largest Common Sieve on their union. The result is a scale unifying a set of sound objects expressed as sequences of partials within the same harmonic spectrum. This *LCS* operator can thus be applied in an unary manner to a sequence, or in an n-ary manner to a collection of sequences.

As an experiment on this tool's capability to construct interesting pitch structures we have implemented a small expression-oriented langage as a LISP subsystem, providing the user with (among other musical structures manipulation tools) a set of operators on sieves, such as : union, intersection, difference, composition of sieves, classes of non-zero residues etc. The output of these programs is given in classical music notation so as to provide the composer with the kind of semantics he is used to.



Class 1

Harmonic Spectrum on a fundamental F1 -30 cents

Multi.	Sequence of numbers of partials	LCS
Sxt 5	[12, 14, 24, 26, 38, 50, 52, 83]	[12 + 14 + 26 + 38 + 50 + 83]
Sxt 11	[13, 15, 28, 56, 69]	[13 + 15 + 28 + 69]

LCS (Sxt 5, Sxt 11) = [12 + 13 + 14 + 15 + 38 + 69 + 50 + 83]

Fig. 7 LCS linking the two sound objects o5 and o11 inside the classe 1.

Let us now go back to the graphs in paragraph 5. We have now a means for sequencing objects that goes beyond the mere juxtaposition. We do this by constructing transition structures which in this case are scales produced by *LCS* in one of two different ways : (notation $LCS_c(O_i, O_j)$ designates the *LCS in class C* of objects O_i and O_j)

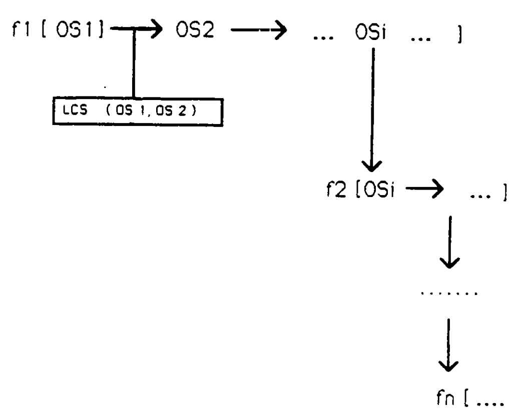


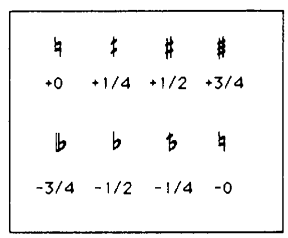
Fig. 8 Modes of transition between acoustic objects organized into classes : *the notation f_i $[OS_1 \rightarrow OS_2 \rightarrow ...]$ indicates an order of transition for the objects OS_1, OS_2, ... , in the class linked to the fundamental f_i. Class f_1 communicate with class f_2 via the common object OS_i.*

- within a class (or a node) C, transition from object O_i to object O_j can be effected through the scale $LCS_c(O_i, O_j)$
- two objects O_i and O_j belonging to two different classes (nodes) C_i and C_j can only be interrelated if there exists a transition object O_t (labelling an edge in the graph) which belongs to the intersection of C_i and C_j. The transition structures thus constructed are then : $LCS_{c_i}(O_i, O_t)$ then $LCS_{c_j}(O_t, O_j)$.

7. MUSICAL EXAMPLES

The following examples have been taken from the score "nonsun" by Claudy Malherbe; this piece for five wind instruments (piccolo, oboe, clarinet in B flat, bassoon) was written in the autumn of 1984 applying the results presented in this report.

The clarinet and the tenor saxophone are written transposed, but the examples are discussed using the pitches actually played.



Alterations used in the musical examples

Example 1 (bars 141 to 152)

*This sequence is organized on the basis of a saxophone multiphonic (***Sxt** *11).*

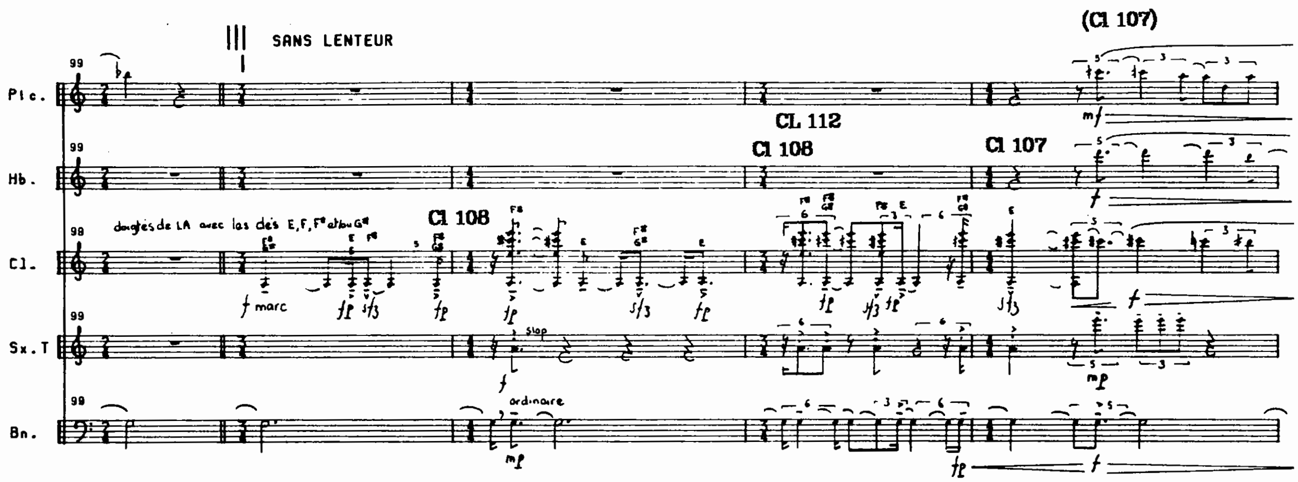
- *The multiphonic is played by the saxophone.*
- *The oboe and the clarinet use its high-pitched components.*
- *The bassoon develops a scale (LCS) constructed on a spectrum containing* **Sxt** 11. *Its point of departure (***C sharp** 4, *bar 146) is a note of the multiphonic; its point of arrival (***A** 2, *bar 150) is a doubling note of this spectrum's fundamental.*

At **figure V** *(bar 152)* **Sxt** 11 *is simulated by all the instruments with the exception of the bassoon which plays the doubling note of a new fundamental (***B** 2*).*

Example 2 (bars 100 to 128)

This fragment is built up from the beginning of the graph shown in **fig.** 5 *and characterized by the pivot note* **G 3** *which is common to all the multiphonics. It finishes here as the second pivot note* **C sharp** *and the simulation of the bassoon multiphonic* **Bn 30** *comes in.*

A clarinet (**Cl 106**) *and a saxophone* (**Sxt 13**) *multiphonic are interleaved and then superimposed* (**bar 117**). *The coherency of the sequence is provided by octave doubling the fundamental of a spectrum unifying the two multiphonics* (**A 2 + 1/4** *tone, played as a bassoon pedal note); in both multiphonics one of the components is held as a sustained note* (**G 3** *on the clarinet and* **B flat 4 + 1/4** *tone on the saxophone). The piccolo plays a shrill note of* **Cl 106** *and of* **Sxt 13** *alternately. At* **figure III** *(bar 119) a new fundamental* (**G 2**), *also is played by the bassoon. The other instruments run over the notes of the multiphonic.*




Pic.
Hb.
Cl.
Sx.T
Bn.
CL 112
CL 108
Cl 107
slap
cresc.
(Cl 108)
(CL 112)
poco
UN PEU LENT
(CL 106)
sast
UN PEU VITE
Cl 106
sur doigté de LA
fondu avec le sax
Fondu avec la CL.
123 / 467
Sxt 13
simile
RALENTIR
MODERE, ACCEL.
simile, tremolo legato
Cl 109 / Cl 111
CL 111 / Cl 109

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