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Compositional Procedures in *Tensio*

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I often think of Tensio *for string quartet and real-time electronics as my most experimental work to date. Not since my early work with real-time during the 1980s, with* Jupiter *and* Pluton, *have I made such significant use of new and experimental techniques in the conception and composition of a new work. The bulk of the research was undertaken with Gilbert Nouno, who created the electronics and fine-tuned the majority of the work's new techniques, and Arshia Cont, whose recent research was a significant influence. Miller Puckette's contribution, in particular in the field of new procedures of synthesis, was also significant. In this article, I propose to provide an overview of these new synthesis tools, which are at the core of a good deal of this quartet; I will also endeavour to provide a theoretical perspective on their relationship to the instrumental writing.*

Keywords: Mixed Electronic Music; Real-Time Electronics; Score Following; Sound Synthesis; Computer Music

1. Synthesis Tools Used in *Tensio*

Three synthesis models were used in *Tensio*, ranging from the highly traditional to the highly abstract. The electronics which respond to the quartet may be near or distant, familiar or incongruous. On occasions it was necessary to create a 'virtual quartet' and even, at times, sound configurations which were totally extraneous to that of a quartet (even though they are invariably derived *from* the quartet). In order of appearance within the work (and, as it happens, also in order of perceived proximity to the acoustic sounds of the instrumentalists), the three synthesis models are as given below.

1.1 *Synful: Physical Modelling and 3F Synthesis*

Synful, a programme developed by Eric Lindemann, recreates instrumental-sounds; what sets it apart from pre-existing sampling tools (which have long been readily available) is its ability to create transitions from one sound to another. For example, one may generate a true *legato* effect with a clarinet or a desk of cellos. Having already used Synful in *Partita I*, this synthesis tool proved most useful in composing *Tensio*, in particular in the creation of a 'virtual quartet', which was later superimposed upon the instrumental quartet. I use the term *virtual quartet* to describe electronic sounds, which are indistinguishable from those created acoustically. This is a prominent feature in the opening bars of my quartet, during which one hears a dense, polyphonic texture with material distributed between the four musicians and the 'Synful quartet'. Three layers are combined: *tremolo* chords, a succession of repeated *pizzicati*, and three *crescendo* violin sounds. The totality is subsequently subject to an ascending/descending *glissando* treatment using a real-time harmoniser (Figure 1).

Here is another example in which the same material appears but in a different configuration, and with a denser texture. The *glissandi* (created with the harmoniser), the repeated *pizzicati*, *tremolos* and *crescendos* are all present within a dense polyphony (Figure 2).

In such an environment, where synthetic sound is indistinguishable from acoustic sound, there is no reason not to include it in the score in a traditionally notated fashion; this is especially the case within a determinate context (i.e. one in which the majority of sound parameters are determined in advance; an exception to this is the exact point-of-entry of some material, which is dependent upon the score-following interface, and as such, upon the performance of the first violin). This is not the case with the two other synthesis models used in the work, which, by their nature and means of operation, elude precise notation.

1.2 *Physical Modelling of a Violin String*

During work on *Partita I* (2009) for viola and electronics, it was my desire to create an environment in which the soloist exercises complete control over synthesised strings. A real-time analysis of incoming sound data was the means by which the parameters of the artificial-string synthesis were to be determined and controlled. I had my heart set on the use of synthesis by physical modelling; this was utopian (read: unrealistic) at the time. Indeed, this remains the case today, because existing methods of real-time sound analysis are still in an embryonic state of development, if one thinks in terms of their ultimate value and potential. Furthermore, at least four computers would have been necessary with systems of synthesis by physical modelling which existed at the time—one for each string! Such systems proved to be virtually unusable for composition; the modification of a single parameter was often the cause of significant instability among a whole series of other parameters, rendering the tool fundamentally chaotic and uncontrollable. How then should a complex and powerful environment be organised in order to function as an efficient compositional tool? This is a question worthy of considerable discussion. Composition, be it notated on a score or integrated within a system of synthesis, demands a 'written' simplicity (and the avoidance of abstraction) in order to allow an elaboration of sophisticated concepts. A system that necessitates interconnections among *all* variables quickly becomes unmanageable for the composer; this is one factor which distinguishes the world of composition from that of performance or improvisation.[1] Therefore, I decided to abandon this system of synthesis in favour or Eric Lindemann's more traditional, but nonetheless highly original *Synful*.

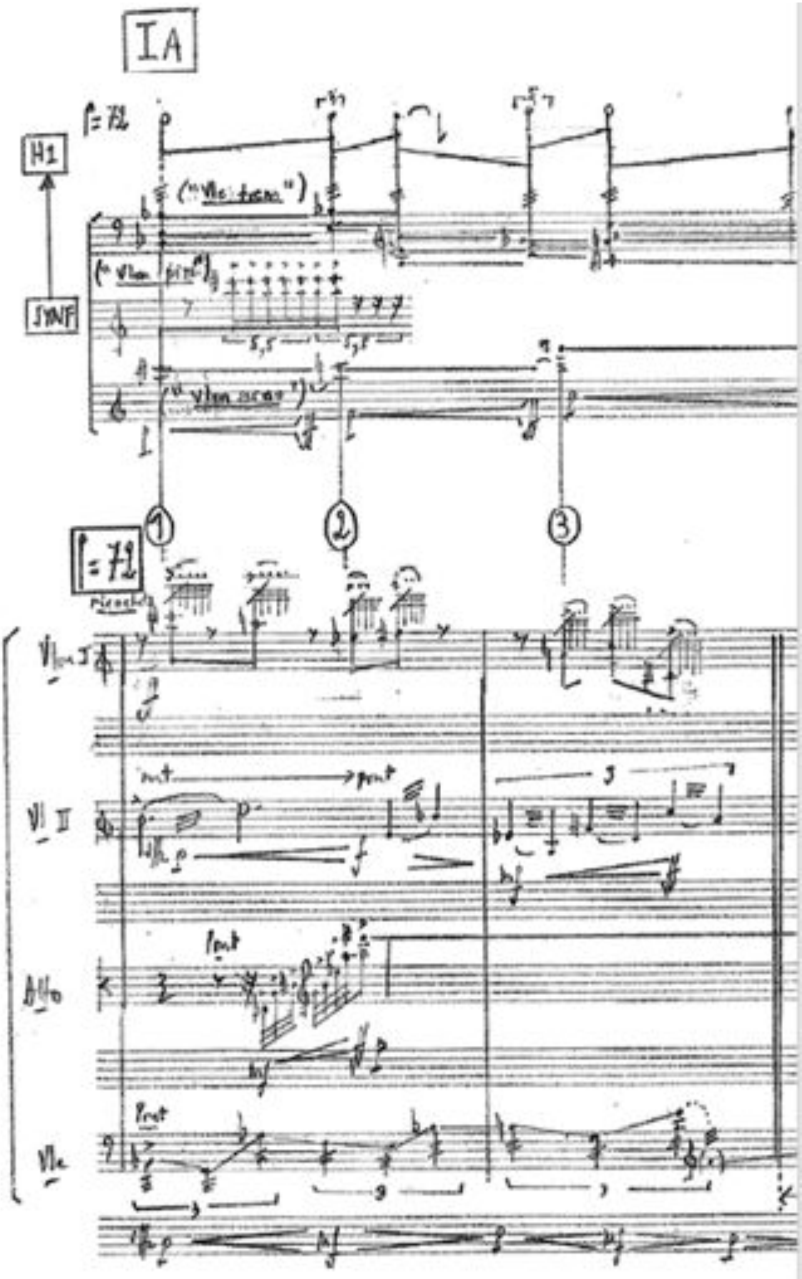

Figure 1 Synful Synthesis Example 1.

Upon completion of *Partita I*, a new system of synthesis of strings by physical modelling was brought to my attention, which Matthias Demoucron, a young French researcher, had recently developed. Although I came across this rather late,

Figure 2 Synful Synthesis Example 2.

I nonetheless decided to make use of it in *Tensio*. Synthesis by physical modelling is entirely distinct from existing forms of synthesis, in the sense that one need not provide traditional parameters such as frequency, spectra or amplitude; rather, one speaks in terms of the evolution of a gesture over time. Matthias Demoucron's system consists of a modelled violin string on a resonant body, based upon the analysis of a violin constructed in the seventeenth century. This modelled string, of which one may vary the tension (and therefore the pitch),[2] is excited by a virtual bow, which is defined by the following four parameters: force, speed, position (on the bridge, *sul tasto*, or between the two) and the pitch (i.e. the position of a musician's left-hand finger upon the fingerboard). Each of these parameters is accessible in a window in which one may manually graph temporal evolutions. The example below shows the interface with which the user may render contours representing these temporal evolutions:

- the bluish part, common to all parameters, sets a user-window which will be read in a loop according to a given tempo,
- the first window (s_force) graphs the progression of bow pressure; the example here corresponds to a *crescendo* and *diminuendo*,
- the second window (s_vel) indicates the direction of bowing, i.e. upbow/downbow,
- the third window (s_dist) graphs the progression of bow position; here, it is *ordinario* at the beginning, moving towards the bridge, then towards the fingerboard, before returning to an *ordinario* position,
- finally, the lower window (s_pitch) shows the stability of the frequency.

The sliders to the right of these windows allow the user to fine-tune these data (which may be cumbersome with the graphic data curves) (Figure 3).

Whilst experimenting with this model, one thing in particular struck me: the precision with which I was able to combine multiple parameters far exceeded that which one could expect from a performer. Moreover, combinations of movements were possible, which would run contrary to the physical nature of performance practice. To produce a soft dynamic, a violinist coordinates his or her hand/arm movements so that the bow moves slowly and with little pressure. If the instrumentalist wishes to create a *crescendo* he/she will accelerate the bow movement whilst adding pressure. Thus, a 'good sound' (this being the oft-seen term in the tomes on Western violin practice) may only be made with many rapid changes of bow stroke, using the entire length of the bow. The rapidity of these changes of bow stroke negates the effect of pressure on the bow, thus avoiding the production of a 'rough' sound. Indeed, in slowing the rate of bowing, the sound tends to become progressively more scratchier, up to the point where a 'scratch tone', in which pitch characteristics give way to noise, is produced.[3] With this in mind, let us imagine the following: what would happen if one were to apply a maximal pressure to the bow while slowing the bowing rate to the extreme? In practice, this is where the adeptness of the performer

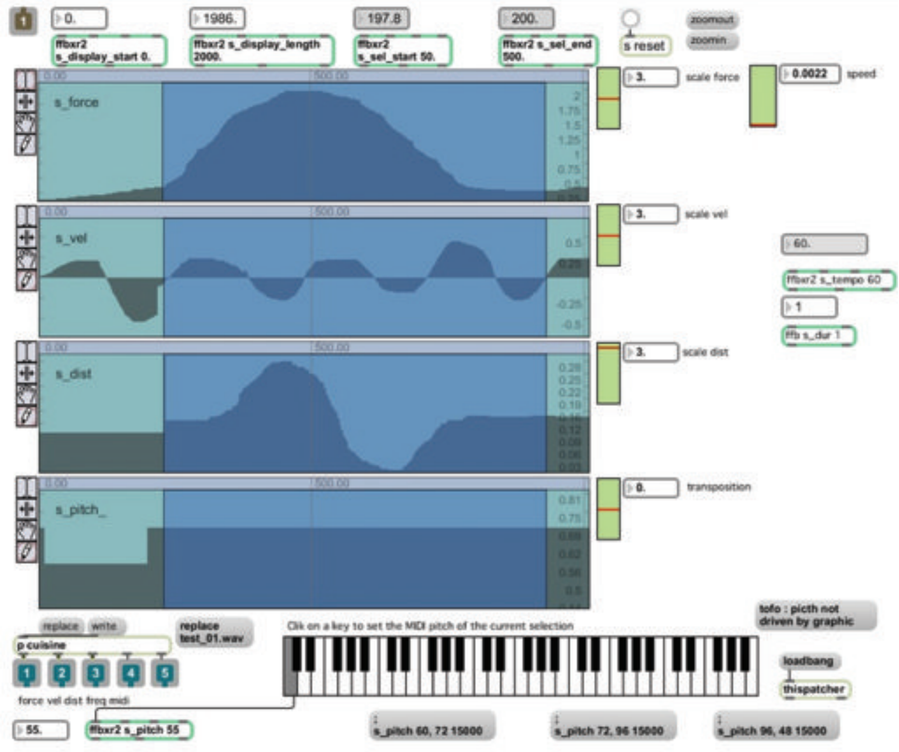

Figure 3 Interface for Physical-Modelling Synthesis of Chords.

manifests itself: the greater the vertical movement (in this case, applying pressure downwards with the arm), the less the instrumentalist is able to control horizontal movement (the speed of the bowing). In other words, more pressure placed upon the bow means more difficulty in maintaining a stable, fluid bowing speed. As we know, what is impossible for man is often simple for a machine. I was quite surprised then to discover what this unnatural gesture yielded sonically: exaggerated bow-pressure combined with an extremely slow bowing speed, contrary to what one may observe in a real-life situation, no longer gave rise to a noisier tone. On the contrary, the resulting sound might be described as little 'droplets' of high-pitched sound, or a 'perforated tone', in which the 'perforations' were highly irregular. The variable rate of these 'droplets' is determined by minor variations in pressure, which occur continuously when one plays with excessive bow pressure (as with scratch tone). In order to vary this model and move towards other, contrasting expressive registers, using a *harmoniser* I transposed the output both downwards, in order to achieve occasional low-pitched sonorities (which proved to be evocative of some mysterious wooden percussion instrument) and dynamically into a *glissando*, in order to make the sound more 'mobile'. What is most interesting with this type of synthetic model is that, although the combination of multiple movements which run contrary to natural physical movement (i.e. performance practice) produce sounds which are not immediately evocative of a violin, and although the physiognomy of such sounds is novel, or rather, atypical, one clearly still perceives a *string* which is being *excited by a bow*. This is a key principle upon which I have based part of my work: I sought to maintain a connection with the physical origin of a sound, whilst deviating considerably from its original characteristics. It was important for me to discover new sounds, but equally important to ensure that the listener was able to make a clear connection to the sonic nature of the quartet (i.e. 'tension' expressed with a vibrating string).

1.3 *'Inharmonicity' Using 3F Synthesis*

For many years, I have dreamt of being able to compose electronic music which is generated entirely in real-time, with live performance as its source. I tackled this notion in works such as *Jupiter*, *Pluton* and *En echo*, but never in such a sophisticated way as in *Tensio*. The question here is one of determinism versus indeterminism in music. To make a distinction between these categories we must first analyse the meaning of these terms within the context of musical composition and performance. In a global sense, a written score is determinate, in the sense that its constituent elements (pitches, dynamics, evolution of variables and temporality) are organised in advance by the composer, in written form. Everyone knows that scores are interpreted and that the role of the interpreter is to give a 'personal' performance at a given moment; as such, no two performances are identical. From the performer's perspective, there is always a degree of freedom within which he/she may exercise his/her creative role. Nonetheless, these choices are still anticipated, whether by the composer or the performer, even though they occur at different points in the process. The time–space of the composer is not as immediate as that of the performer: composition, if it is to demonstrate craft and intricacy, requires a time of gestation, of development of sketches (typically, the composition of a work requires much more time than the rehearsal/preparation for its performance). Although the performer is able to 'condition' his or her vision of the piece through analysis, even the most scrupulous (let us take, as an example, the pianist Maurizio Pollini) is unable to predict with absolute precision what the result will be. The determinism of composition and the indeterminism of performance are easily distinguishable: one is written and the other is not. Seen from another angle, the score conceals multiple layers of indeterminism, the most obvious of which are those concerning volume and the flow of time.[4] This fundamental separation between determinate and indeterminate elements which one finds in instrumental music, served as the model for what I call, in the realm of electronic music, the *virtual score*. I will first elucidate this term's definition: a virtual score is a representation whose constituent parameters are known in advance, but whose exact concrete manifestation is subject to variation. If such a thing is unknowable in advance, it is for the simple reason that there is some degree of dependence upon *performance* which, as we have seen, contains a degree of indeterminism. Nonetheless, it remains possible to conceive of a system which includes *both* states, determinate and indeterminate: *some* parameters necessary for the creation of synthetic sounds may be fixed in advance, whereas others will derive their values from a real-time analysis of instruments at the very moment of performance (and thus, will contain a degree of indeterminacy).

When I began work on *Tensio*, Glibert Nouno and I experimented with several synthesis models which were capable of using analyses of instrumental-sounds created in a multitude of ways, and which, thus provided spectra that varied considerably in nature. The results we obtained left me unsatisfied; invariably, it was extremely difficult to manipulate timbre accurately once a certain complexity/variability was reached. Finally, Miller Puckette, with whom I had discussed this problem, offered a solution: he conceived a system for the construction of spectra from three base frequencies, which I subsequently named as *3F Synthesis*. Here is a brief summary of the principle: three frequencies are selected (f, g and h) to which a number of operations (additions and subtractions) are applied, such as

(1) $f\ g\ h$
(2) $2f\ (2 + g\,f - g)\ (f + h)\ (f - h)\ (2g)\ (g + h)\ (g - h)\ 2h$
(3) $3f\ (2f + g)\ (2f - g)\ (2f + h)\ (2f - h)\ (f + 2g)\ (f + g + h)\ (f + g - h)\ (f + 2h)\ (f - 2h)\ (f - g + h)\ (f - g - h)\ 3g\ (2g + h)\ (2g - h)\ (g + 2h)\ (g - 2h)\ 3h$ ...

The sum of each of these operations yields an extremely dense spectrum, sometimes containing more than 100 components. Such a phenomenon gives rise to a basic problem of perception: the greater the density the less one is able to distinguish one spectrum from another. Sifting through the massive frequency-space involved is rather like trying to group clusters into distinct categories. To resolve this problem, Miller Puckette suggested that we chose, based on a precise set of criteria, sub-categories of these frequencies which would limit the number of components present. If the number of frequencies within the spectra is limited in advance, let us say to 16, we may apply a filter which would allow a frequency to pass, or not, based upon a designated system of probability. When the probability index is 1, we will obtain the first 16 frequencies (the lowest ones); as we decrease this index, more distant (read: progressively higher) frequencies begin to enter. The procedure may continue until the 'desired' 16 frequencies have been obtained. The random nature of this process is responsible for the irregular manner in which frequencies are distributed in the spectra. If the probability is set to at least 0.25, there will be a good chance that two neighbouring components (e.g. $f + g$, $f + h$, $g + h$, $2f + g + h$, $f + 2g + h$, $f + g + 2h$) are present, giving a frequency difference of either f, g or h and thus, a predominance of one of these three frequencies over the others. As such, when a low-probability-index is used, each new operation will yield a spectrum which is distinct in nature, while still being derived from the three chosen base frequencies. What is most striking is the fact that while each of these spectra is entirely unique in terms of its combination frequencies, any two are perceived as belonging to a common class;[5] the three base frequencies are always present and, in a sense, constitute the 'harmonic matrix'. Obviously, unless these three frequencies are in unison, the resulting spectrum is highly inharmonic. Inharmonic 'density' is, as one would expect, a consequence of the harmonic relationships between the chosen base frequencies. Gilbert Nouno tailored this algorithm for use with a string quartet. Each of the three frequencies is taken from the performers' sounding-pitches; a patching matrix determines, from one section to another, who among the four performers contributes to the creation of these spectra. Upon detection of a new sounding-pitch, a new spectrum is created. The effect of this 'virtual-score' is what one might call an 'inharmonisation' of instrumental-sounds. One could even describe this as an electronic 'sub-ensemble'; indeed, it is possible to recognise the totality of the instrumental part in this synthesis. In other words, everything played by the performers is present in the synthesis, with the latter broadening the musical discourse by adding spectra whose (in)harmonic characteristics depend upon the intervallic relationships between the musicians' sounding-pitches. Here is a first example in which three instruments are repeating notes; each attack is detected by the programme and triggers the creation of a new spectrum. As I have stated, the same three pitches can provide the basis for any number of contrasting spectra (albeit from the same inharmonic 'family' of spectra); therefore, the result is highly varied. The graph in the top left indicates which instruments will contribute, and how, to the generation of a new synthesis (*f*1, *f*2 and *f*3) (Figure 4).

Here is another more dynamic example in which a *pizzicato* texture forms the basis for the '3F score'; the latter's rhythmic characteristics are consistent with that of an instrumental *pizzicato* in order to achieve textural coherence (Figure 5).

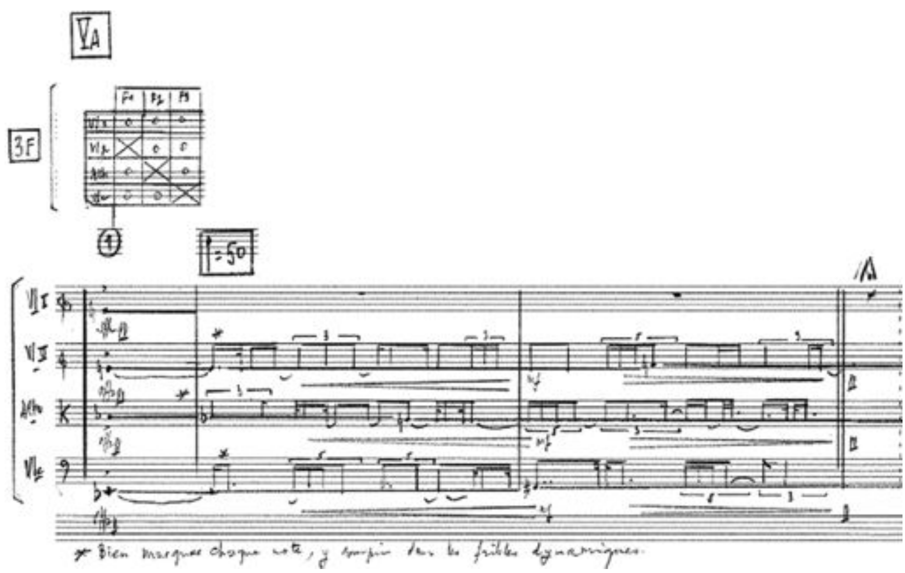

Figure 4 3F Synthesis Example 1.

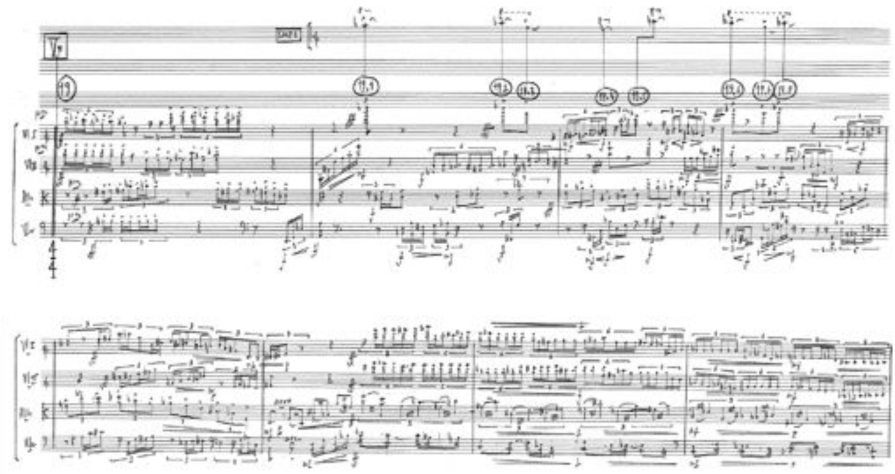

Figure 5 3F Synthesis Example 2.

I would now like to mention another principle which is pertinent to this synthesis model: *reactivity* to instrumental performance, and the use of audio descriptors. It is essential that the relationship between instrumental-sound and synthesis be as 'organic' as possible. In the realm of real-time electronics, it is desirable to be able to manipulate parameters dictating the reactivity of synthesis to acoustic sound source. Audio descriptors provide several types of analysis of instrumental-sounds in real-time: pitch, spectral-centroid, brightness, duration, etc. In *Tensio*, I limited this to the analyses of durations (a variable which determines whether the 3F system should produce a new spectrum); as such, the aforementioned model will only become active at certain moments, remaining silent if a set of pre-defined conditions are not met. As we can see from the score given later, the instruments alternate between repeated notes of moderate duration and groups of notes played extremely rapidly. By setting a threshold parameter, I may be certain that the model will only react (i.e. will perform the calculations necessary to generate a new spectrum), if the performed notes exceed a pre-defined duration. As such, the synthesis generates quite a stable output, 'ignoring' smaller figures between held-notes (Figure 6).

1.3.1 *3F example 3*

The example shown in Figure 7 is the same operation in reverse: the 3F model remains inactive when held-notes are received as input, generating output only in reaction to short, rapid notes. The result is an accompaniment to the rapid and unstable music in the instrumental score.

1.3.2 *3F example 4*

In my opinion, audio descriptors have a promising future and deserve a great deal more attention from today's researchers. In their present state, beyond providing reliable

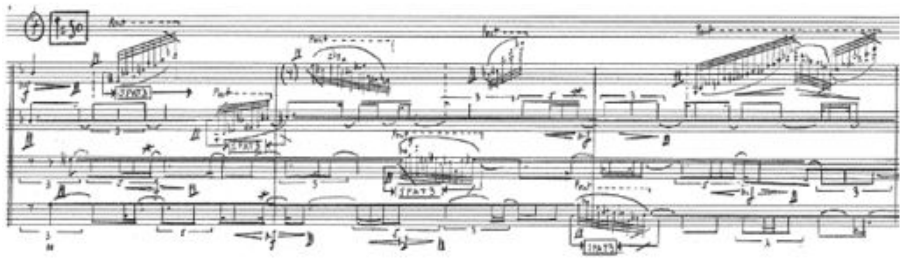

Figure 6 3F Synthesis Example 3.

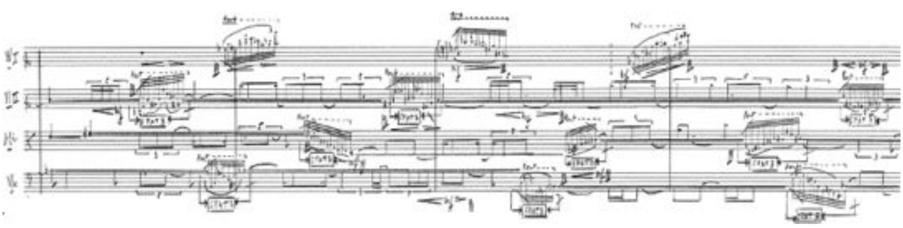

Figure 7 3F Synthesis Example 4.

analyses of pitch and duration they are not especially well adapted to the needs of composers. Nonetheless, there is a great deal of enthusiasm about the possibility of further development towards more complex analyses, such as 'spectral-characteristics'.

1.4 *Scales Derived from Spectral Structure*

3F synthesis creates irregular and variable divisions of pitch-space: irregular in the sense that the intervals separating the component frequencies can be extremely disparate, and variable because each new note played by the quartet triggers (assuming that none of the eliminatory criteria are met) the calculation of a spectrum whose constituent frequencies correspond only in very rare cases with preceding spectra. This richness and complexity pushed me to create a musical context which demanded more than the simple construction of a series of inharmonic spectra. To this end, I once again made use of a principle with which I had experimented more than 25 years ago in *Zeitlauf* (1980), my first work with electronics. The principle was to create divisions in pitch space (organised as a sort of striation) whose construction would be 'homothetic' to the internal structure of inharmonic spectra. To give a simple example, let us imagine a harmonic spectrum, composed of the superimposition of a series of intervals (octave, perfect fifth, perfect fourth, major third, minor third, etc.): one might use this intervallic structure as the basis for a scale upon which the harmonic spectrum may be 'transposed'. Now, in changing the internal composition of the spectrum we also change the scale, and as such, the collection of 'positions' in which the spectrum may occur. As such, a spectrum whose components are relatively close together

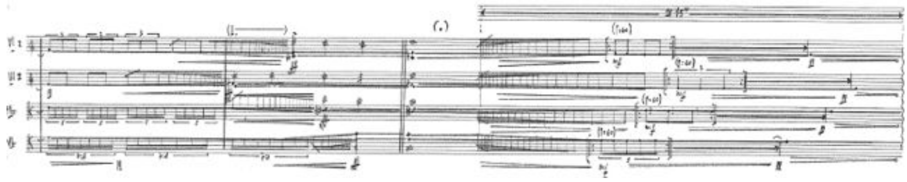

Figure 8 Markovian Control Example 1.

(as in a sort of 'cluster' formation) will evolve in a very concentrated pitch space, whereas a spectrum which is highly dilated will evolve in a much broader space. I have recreated this schematic in *Tensio* in composing scales whose intervallic organisation is derived directly from the successive evolution of spectra created using the 3F method. This occurs in the form of a sort of continuum of *pizzicati* played by *Synful*. The pitches of these *pizzicati* are determined by the newly created scales, themselves being derived from newly calculated spectra. The collective 'melodic movement' is organised according a Markov-chain algorithm, which Miller Puckette developed several years ago. According to a set of parameters (such as allowing or prohibiting continuous or discontinuous movement, taking or changing the general *ambitus* of prior melodic movement, tempo, rhythmic regularity/irregularity, etc.), the probability of a sequence of any two pitches from a given scale is calculated. For this to take place, we must first define an 'abstract' scale in which each pitch is assigned a probabilistic value, and then adapt these data to the series of frequencies generated by the 3F spectra. The example of this principle is given in Figure 8, where the four instruments begin with a unison E and move, by means of *glissandi*, to a cluster, before returning to the initial unison. So long as a unison is played, any generated 3F spectra will be harmonic, with the unison pitch as a fundamental. Scales derived from these spectrum (and therefore the resulting output, a continuum of *pizzicati*) will then, logically, be a sequence of frequencies in harmonic relationship to each other (i.e. E one octave higher, B, E, G#, B, D, etc.). During movement away from unison towards the aforementioned cluster, the intervallic relationships between pitches will provide the basis for the creation of increasingly inharmonic spectra; as such these scales will become progressively more complex. Conversely, movement back towards unison will yield a corresponding movement towards harmonicity .

In Figure 9, the 'stability' of frequencies played by the quartet produces a scale which continues to develop even once the musicians have stopped playing.

The same process occurs here, but with different pitches (and as such, different generated scales) (Figure 10).

Here is a summary of the procedure:

(1) The instrumentalists play pitches, forming a collection of intervals
(2) Three pitches (*f*1, *f*2 and *f*3), analysed from three pre-defined instruments, form the basis for the calculation of a spectrum

(3) The 3F synthesiser calculates the spectrum based upon the intervallic relationships between the three base frequencies.
(4) Scales derived from these spectra are generated by homothesis with the internal-component structure of the 3F synthesis. These scales evolve according to Markov procedures and are transformed into synthesised *pizzicati* generated by Synful.

Figure 11 further elucidates the process.

As we have seen, a series of calculations is necessary in order to derive and diffuse scales based upon instrumental-sound input; 3F synthesis is the key element connecting the two. In Figure 11, I have suppressed this intermediate step, not in terms of the overall algorithm (of which 3F synthesis plays an essential part) but terms of sound output. The quartet is playing a *pizzicato* texture accompanied by synthetic *pizzicati* (generated by Synful); scales derived from the performed material are audible (the performed pitches are also present *within* the Markovian scales), but in this case, 3F synthesis is not diffused. I also made use of such a procedure (i.e. diffusing the result of one process 'hearing' and reacting to the output of another, without the former being diffused) in *Pluton* for piano and electronics.

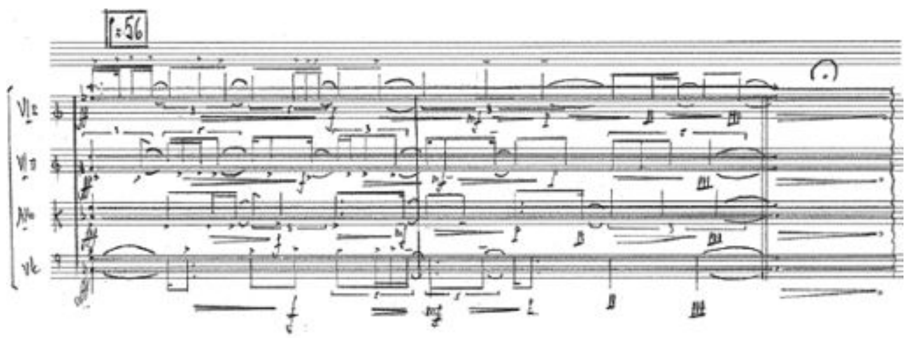

Figure 9 Markovian Control Example 2.

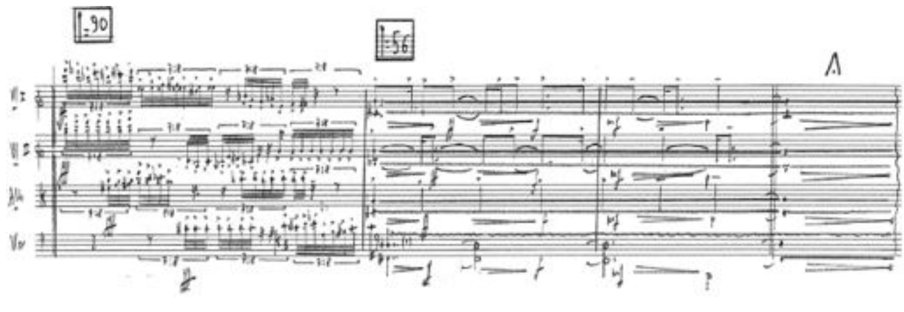

Figure 10 Markov Example 3.

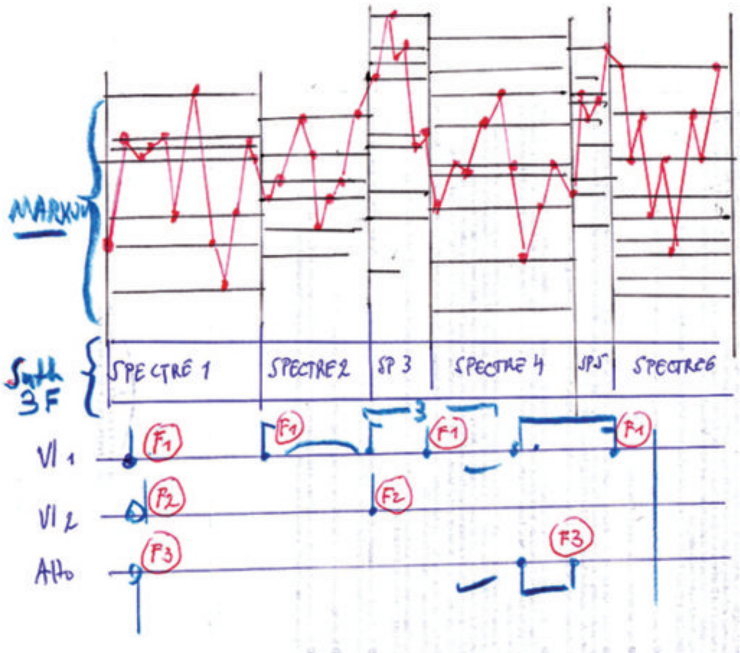

Figure 11 Markov Process Graph.

2. Harmonic Correlations in 'Sonic Spinning-Tops'

'Sonic spinning-tops' describes a process that I have used since the composition of my opera, *K*, the simulation of a sound 'rotating upon itself'. It was inspired by the famous *Leslie* speaker system (which one commonly finds on Hammond organs): two conical speakers which rotate by means of an electronic motor (Figure 12).

Figure 12 Leslie Speakers.

Serge Lemouton developed a digital simulation of this effect in MaxMSP. I invariably combine this system with harmonisers, in order to synchronise the rate of 'rotation' with relative pitch. In *Partita I*, the soloist controls the Leslie effect (as well as the transposition) interactively. During a performed *crescendo*, duration and maximum intensity are measured; this information determines the transposition factor, the duration of acceleration/deceleration and the speed which should be attained by the end of the process. I once again make use of this procedure in *Tensio*: the four instrumentalists' short bow-strokes are analysed (duration and amplitude) and used to determine the characteristics of abrupt upward-transpositions (Figure 13).

The durations of these transpositions (as well as the evolution of revolutions per second (r.p.s.) of the four 'spinning-tops') depend entirely upon the performers (i.e. are undefined in advance). Wishing to formalise this parameter, I opted for a correlation between speed (i.e. movement in r.p.s.) and transposition. To elaborate upon this procedure: first, a 'master spinning-top' is created which turns at a pre-defined rate; the four other tops will deviate from this pre-defined value either according to data obtained in real-time from the incoming signal of the performers, or by following a pre-defined process. However, with each change of transposition, the distance between the 'master' top and the others is measured in terms of *harmonicity*, i.e. a

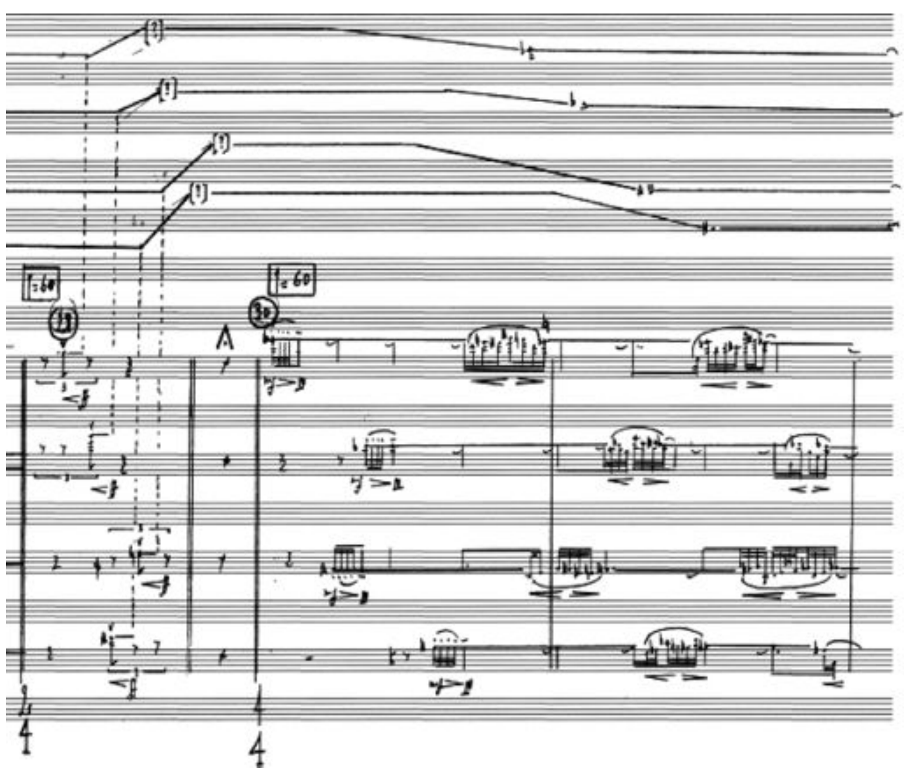

Figure 13 Sonic Spinning-Top Example 1.

top associated with a sound one octave higher than that associated with the master top will turn at twice the rate; and one associated with a sound a semitone lower will turn 1.0594631 times slower. The problem with this system is that the sounds will invariably turn faster as they are transposed upwards. To avoid this, I have implemented a number of sub-systems:

(1) a switch to 'absolute' values, whereby r.p.s. is disassociated from transposition, i.e. speed and transposition are controlled independently,
(2) a switch to 'relative' values, whereby r.p.s. is determined in terms of its relationship to the master top,
(3) a switch to 'inverse-relative' values, whereby a transposition upwards is accompanied by a reduction in the r.p.s. (whilst still respecting harmonic inter-relationships),
(4) A 'modulo' system in which all tops associated with the same pitch (regardless of register) as the master top will turn at the same rate (i.e. will be completely synchronised); in this case, with all four tops spinning at exactly the same rate, the effect abruptly becomes homogenous. The r.p.s. variable increases with an upward-transposition as far as the tritone (i.e. the 'middle' of the octave), after which it will slow down before returning to its original rate once a transposition of one octave is reached.

In Figure 14, the electronic sounds are stable, but changes in r.p.s. of each output are determined by the aforementioned processes.

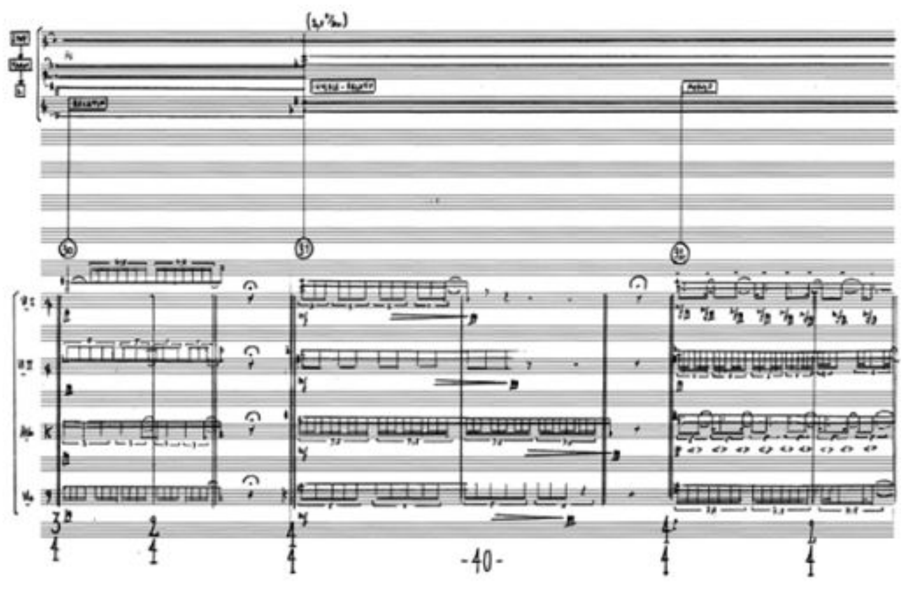

Figure 14 Sonic Spinning-Top Example 2.

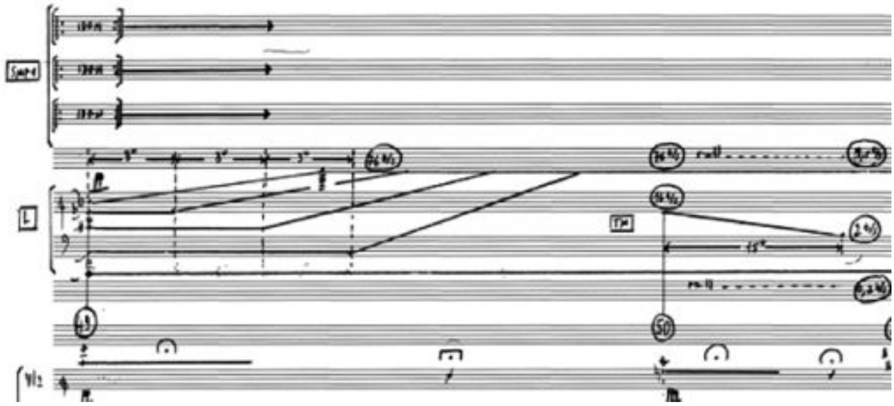

Figure 15 Sonic Spinning-Top Example from the Ending of *Tensio*.

At the conclusion of the piece, there is a gradual upward-transposition to the extreme high-register (and an accompanying acceleration of all tops to a rate of extreme rapidity—in this case, up to 72 r.p.s.). This value is determined by calculating the distance between current pitch and starting-point, i.e. the lowest pitch (Figure 15).

Another example of extreme speed may be seen in Figure 16, in which certain tops rotate at less than 2 r.p.s. whilst others reach 141 r.p.s. It goes without saying that at such a high speed, the movement is no longer perceived as a *rotation*, but rather as *modulation*; indeed, many new frequencies are created relative to the periodicity of this movement.

To conclude this section, Figure 17 shows an example of a 'fusion' of the four tops into one: as the transpositions approach an output of A-440 (the frequency of the master top) each spins at a rate which is proportionately closer to that of the master top—as if by some gravitational attraction—before ultimately melting into sonic homogeneity.

3. On Heterogeneous Time and Its Notation

The nature of musical time, its stratification and coordination, was a major preoccupation in the composition of this piece. Musical-time obeys its own distinct, autonomous laws; it may exist in a plurality of units, but these units must be coordinated, even if only in an abstract fashion. Different categories of musical-time are the basis of musical representation/notation; indeed, the latter defines the former. The absence of temporal-notation has long been a major obstacle in the composition of music using real-time tools, and one which I have sought to overcome for decades. Only recently has the situation emerged from this quagmire. Thanks to Arshia Cont's research, we are now able to intelligently create a tangible connection between the worlds of instrumental and electronic composition. His software, *Antescofo*, known primarily as a score-following tool, offers many other features that I felt immediately compelled to utilise. Before getting to examples

Figure 16 Spinning-Top with Extreme Speeds.

I would like to remind the reader that prior to the appearance of *Antescofo*, no other tool existed for the notation of time-values in millisecond precision. Nonetheless, with the advantage of extreme precision comes the inability to deal effectively with polyphony. Indeed, this solution's mechanisms for synchronisation are ill suited to precision; rather, they deal with a relative, symbolic system of logic (such as when composing with crotchets and quavers, to give an obvious example). Such symbols express only relationships, and never absolute-values; they acquire meaning only once a tempo

Figure 17 Spinning-Top Fusion by Transposition.

indication is given and then are subject to constant fluctuations. The absence of common criteria between traditional notation and 'electronic-scores' has always been a major obstacle (not only a theoretical one, but also often a perceptual one) to a fusion of these two worlds. This obstacle has now been overcome; as we will see, both temporal universes may now coexist, even in superimposed (i.e. polyphonic) form.

3.1 *Polyphonic Notation in Electronic Music*

Let us reflect upon the following: an electronic-score is subordinate to an instrumental score and only triggers events if certain conditions are met, for example, when an anticipated gesture is performed by a musician. In Figure 18, a violin triggers three successive sounds, each louder than the last.

The exact moments at which these three sounds will occur is unknown in advance; their occurrence is dependent upon the performer playing notes which have been defined as 'triggers'. However, their durations are pre-determined and are rigorously notated in the electronic-score. Now, let us add a second voice, a succession of repeated *pizzicati* which occur after a slight *ritardando* as shown in Figure 19.

A traditional system of 'computer-music notation' resolves the problem in the following manner:

Event 1: 0.5: C#, 0.7: C#, 0.9: C#, 1.1: C#, 1.3: C# 1.5: C#, 1.7: C#.

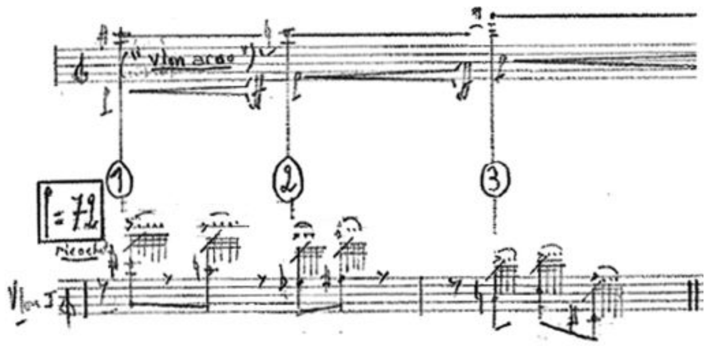

Figure 18 Electronic Event Triggering by Violin.

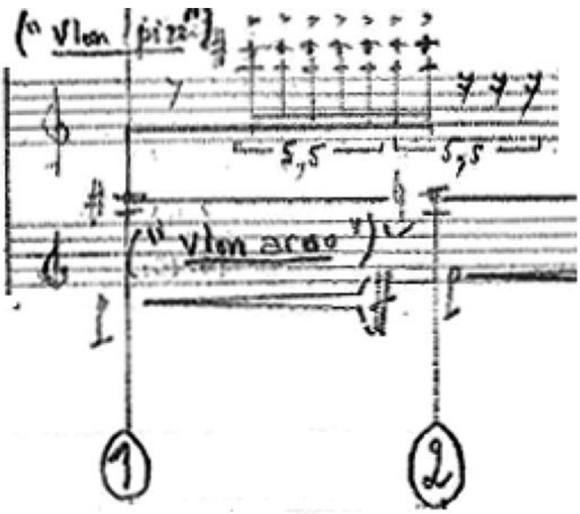

Figure 19 Inclusion of Electronic Phrasing.

If the tempo is pre-defined as crotchet = 60 (i.e. one beat per second) such an event is easily notated. However, in Figure 20, the tempo is crotchet = 72; one might imagine here that with a few calculations, the same thing would be possible without too much effort. Now, let us add a second voice: a series of chords which are subject to *glissandi* as illustrated in Figure 20.

We are now obliged to calculate two simultaneously occurring temporalities: that of the *pizzicati*, and that of the chords. How is it possible to express the beginning of each of these chords, whose timing must be differentiated from the concurrent *pizzicati* quintuplet? This would indeed be impossible if, as was the case until recently, no temporal polyphonic structure existed in the system of notation. To summarise, when only a system of absolute, homogenous temporal notation exists, it is necessary to calculate

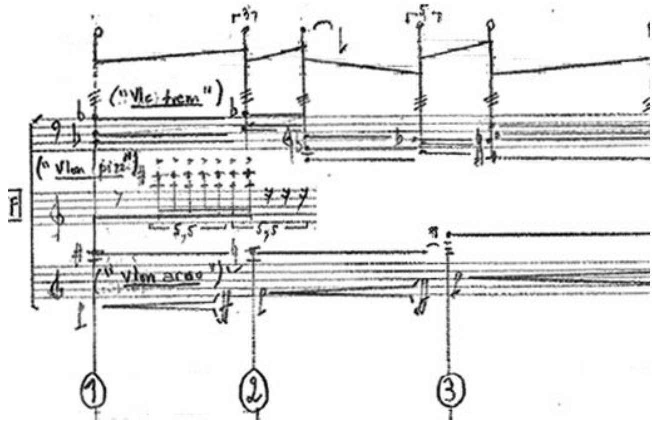

Figure 20 Electronic Action Polyphony.

the timing of each event, even when (as is the case in this example) two or more distinct layers are present, which *do not share a common temporality*. If everything is possible by human performers, a case may be made for the rejection of attempts at notating polyphony in the method which was hitherto prescribed for synthesis. *Antescofo* developed by Arshia Cont proposes a system, *Group Forward* (GFWD), whereby one instance will take charge of the *pizzicati* voice as shown in Figure 21, while another outputs the layer with chords as shown in Figure 22.

It should be noted that two forms of temporal notation are present here: the *pizzicati* section is expressed with absolute values (notes occur every 0.18 s) whereas the *arco tremolo* material is notated with relative-values, using the formula '@b2' (the event will last two beats; the tempo is given elsewhere in the score[6]). It is, therefore, possible with *Antescofo* to implement a number of temporally heterogeneous layers whose *modus operandi* is unique. Beyond facilitating notation, this opens the way for a

```
GFWD    0.5 Pizzicati
    {
                        syn_voices 3 vol 127
                        syn_voices 3     vol 127
        0.18                syn_voices 3    85 127 100
                            syn_voices 3     vol 127
        0.18                syn_voices 3    85 127 100
        0.18                syn_voices 3    85 127 100
        0.18                syn_voices 3    85 127 100
        0.18                syn_voices 3    85 127 100
        0.18                syn_voices 3    85 127 100
        0.18                syn_voices 3    85 127 100
    }
```

Figure 21 An Electronic Phrase (Group) in Antescofo.

```
GFWD        arco tremolo
    {
                    syn_voices 1    pgm 40 bnk 7    vol 127
                    syn_voices 1    56 120 @b(2)
                    syn_voices 1    50 120 @b(2)
                    syn_voices 1    46 120 @b(2)
                    h1_trans 0, 300 @bpm(2)
        2.0         syn_voices 1    53 120 @b(0.36)
                    syn_voices 1    52 120 @b(0.36)
                    syn_voices 1    58 120 @b(0.36)
                    h1_trans 0, 800 @bpm(0.46)
        0.36        syn_voices 1    69 120 @b(1.5)
                    syn_voices 1    63 120 @b(1.5)
                    syn_voices 1    59 120 @b(1.5)
                    h1_trans   0, -500 @bpm(1.5)
        1.5         syn_voices 1    66 120 @b(0.8)
                    syn_voices 1    65 120 @b(0.8)
                    syn_voices 1    62 120 @b(0.8)
                    h1_trans 0, 800 @b(0.8)
        0.8         syn_voices 1 bnk 7
                    syn_voices 1    72 120 @b(2.5)
                    syn_voices 1    69 120 @b(2.5)
                    syn_voices 1    67 120 @b(2.5)
                    syn_voices 1    61 120 @b(2.5)
                    spat1_ctl fact rev 80
                    h1_trans -500, 0 @b(2.0)

    }
```

Figure 22 Parallel Group Authoring of Electronics in Antescofo.

polyphony the likes of which was virtually impossible with the methods of representation of the past. If we accept that conception (and in a broader sense, composition in general) is to some extent dependent upon representation, this example should help to dispel more than a few archaic prejudices.

3.2 *Tempo-Tracking*

Variability in tempo is an age-old phenomenon. The distinctions (conceptual and other) between music for which time is dynamic and 'organic', and music which is rigid in its temporality are, for me, a principal stumbling block in mixed music. The first works composed using magnetic tape might be seen to represent the extreme end of this spectrum, but in all honesty, music with real-time electronics has, or had until recently, scarcely progressed in this regard. In many cases, so-called real-time electronics were simply dissected parts of a work for tape which remained rigid and inorganic. The only channel of temporal 'communication' was the ability to trigger such events freely; further adaptation to context was impossible. Another advance in this field, again in *Antescofo*, is tempo tracking, which allows a seamless transition between instrumental and electronic sound events. I have made heavy use of this tool in *Tensio*. Figure 23 shows a typical example: in this sequence, the violin plays a *tremolo* chord (in free time) followed by a small *pizzicato* septuplet figure.

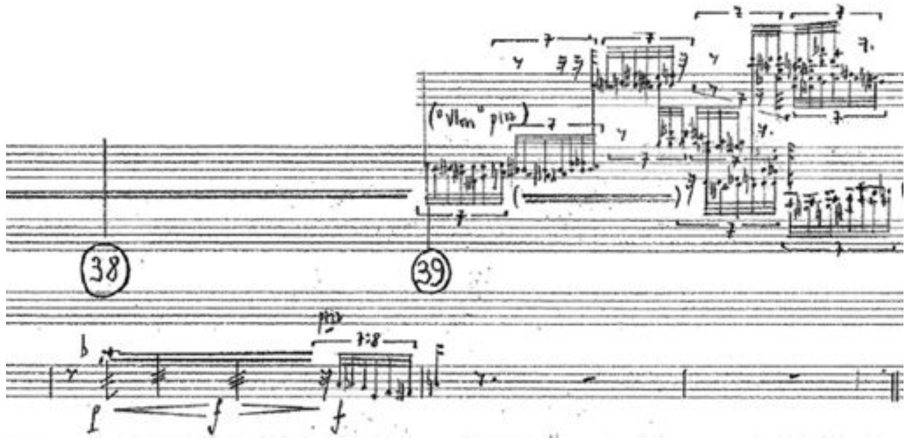

Figure 23 Example of Interaction with Live Tempo.

The electronic score dictates that the synthesis respond with its own septuplet figure following on in perfect continuity from that of the violin. The successful realisation of this sequence is dependent upon the score-following tool's ability to determine the precise current tempo: the violin's *pizzicati* are received and interpreted as septuplet hemi-demi-semi quavers, thus providing the computer with the tempo; all that remains is to use this tempo to determine the rate of the electronic *pizzicati*.

Figure 24 illustrates a 'call-and-response' exchange between the quartet and the electronics (which also generates *pizzicato* sounds); here, the computer must constantly adapt its tempo to that of the performers. In other words, the quaver triplets of the quartet must be analysed throughout the entirety of the sequence and used to determine the tempo of the 'electronic *pizzicati*'.

As one might expect, *tempi* are subject to considerable variability; the stratification of heterogeneous time in composition will be the focus of the following section in this article.

3.3 *Heterogeneous Time*

In the second section of my piece, I make use of structures which react to each other within the context of a flexible, fluid temporality. At times, the performers dictate the tempo to the electronics; at others, the opposite is true. Sometimes two distinct *tempi* coexist, sometimes there is an absence of tempo altogether. A glance of the extract shown in Figure 25 from the score illustrates this notion. Event 9, played by violin I contains a *rallentando,* which upon its completion, provides the tempo for the subsequent synthesis (indicated here: *tempo B*), a simple repeated note which will function as a metronome for the musicians. 'Tempo A' is dictated by another voice in the synthesis' polyphony (an irregular repeated quintuplet). Tempos A and B are completely independent of each other; here, the viola and cello play a sequence following the

Figure 24 Interaction with Tempo: Call-and-Response Example.

'metronome' (tempo A) whereas violin II follows tempo B. Each group is free to begin at any time.

Further on in the score, this principle is developed: the two violins play a sequence of septuplet semiquavers, thus providing the tempo for the electronics (tempo C) and superseding the previous value (tempo A). The quintuplet is replaced by a septuplet whose tempo is taken up by violin I; a second group, consisting of the viola and cello, plays a new sequence which remains in the hitherto constant tempo B (Figure 26).

Next is a new sequence in which both violins play at tempo C (i.e. that of the preceding septuplet figure) before, at event 15, all four musicians perform an *accelerando* sequence in *pizzicato*. The terminal tempo of this *accelerando* dictates the new 'metronome value', tempo D (Figure 27).

In the sequence of Figure 28, we once again find the viola and cello 'group' in synchronisation with tempo C (albeit in septuplets), while the two violins play a new sequence at tempo D.

Another similar example occurs at event 17 illustrated in Figure 29: a new tempo (E) is generated arbitrarily by the computer and articulated with a 9:8 figure, providing the basis for a sequence, which is played by all four performers.

Figure 25 Heterogeneous Time Interactions Example 1.

Finally, at event 20 (Figure 30) an *accelerando* once again 'resets the metronome'; the score calls for all four musicians to play a fast triplet figure at this new tempo.

Such modulations of tempo would have been impossible without the invaluable work of Arshia Cont in the field of temporal representation in electronic music. With *Antescofo*, two significant obstacles have been overcome: the ability to establish temporal continuity between instrumental and synthetic sound-worlds, and the ability to easily superimpose heterogeneous tempi in a form, which is comprehensible for a computer. These innovations allow a fluidity of 'dominance', between musician and computer: each may, at a given moment, listen and respond to the other.

3.4 '*Temporal-Landscapes*'

In his book *On Music Today*, Pierre Boulez defines three key categories of time in music; in hindsight one can acknowledge the remarkable insight behind these distinctions. The three categories are as follows:

(1) 'Smooth' time is that which is perceived as being free from sub-divisions into regular or irregular values;
(2) Time with 'pulsation(s)' is that which may be sub-divided into regular units (i. e. tempo); and
(3) 'Striated' time is that which may be divided into unequal units (i.e. an absence of tempo, but not of divisions).

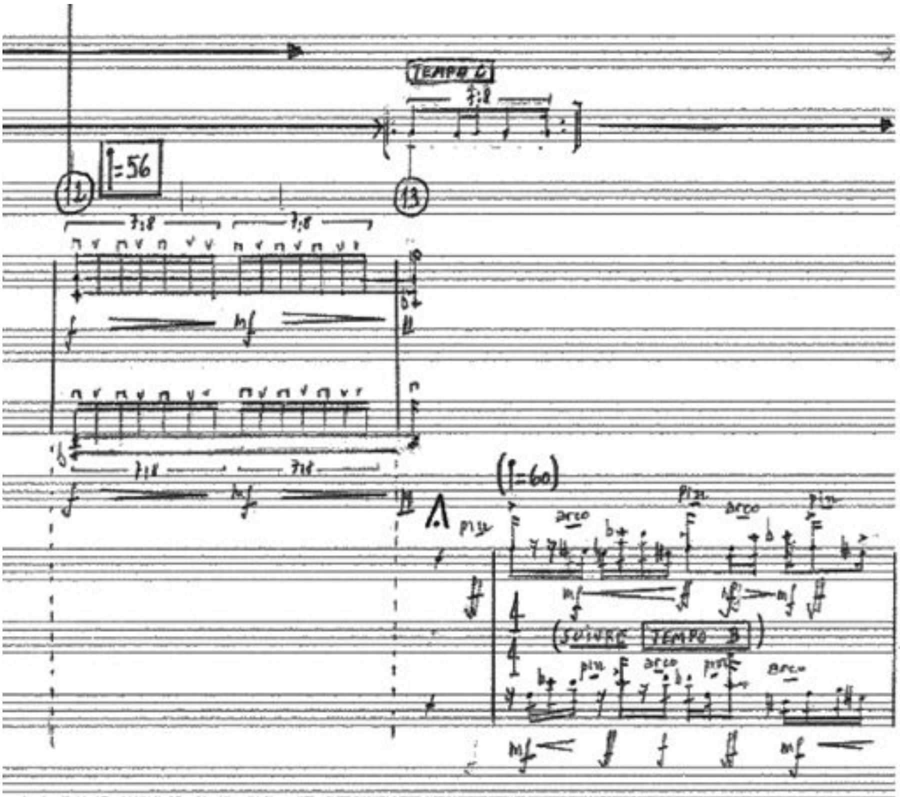

Figure 26 Heterogeneous Time Interactions Example 2.

These categories may be further refined by taking into account 'multi-pulsations' in time, as with polyphonic textures (i.e. 'multi-striation', or even 'hyper-striation'). Figure 31 shows a famous example containing multiple pulsations.

First, we have regular semiquaver pulsations superimposed upon a minim pulse (perceived as a secondary pulse, which signals the repetition of a formula). Finally, there is a slower pulsation which corresponds to each change of bar and coinciding change of harmony. These proportions may also be enlarged and applied to groups of bars. In contrast, the example in Figure 32 is striated; it is divided into units (which may themselves be sub-divided into variable parts), but is free of any clearly defined pulse.

Of course, striation may accumulate, culminating in 'hyper-striation', a process invented by Stockhausen in his first works for solo piano and subsequently developed and taken to its extreme limitations by Brian Ferneyhough (Figure 33).

In each case, an equal division is present, regardless of how superimposed it may be (5:4 of 3:2 of 7:8, etc.). When time is not divisible in this way it becomes fluid, i.e. it becomes impossible to detect speed or tempo; the performer does not work

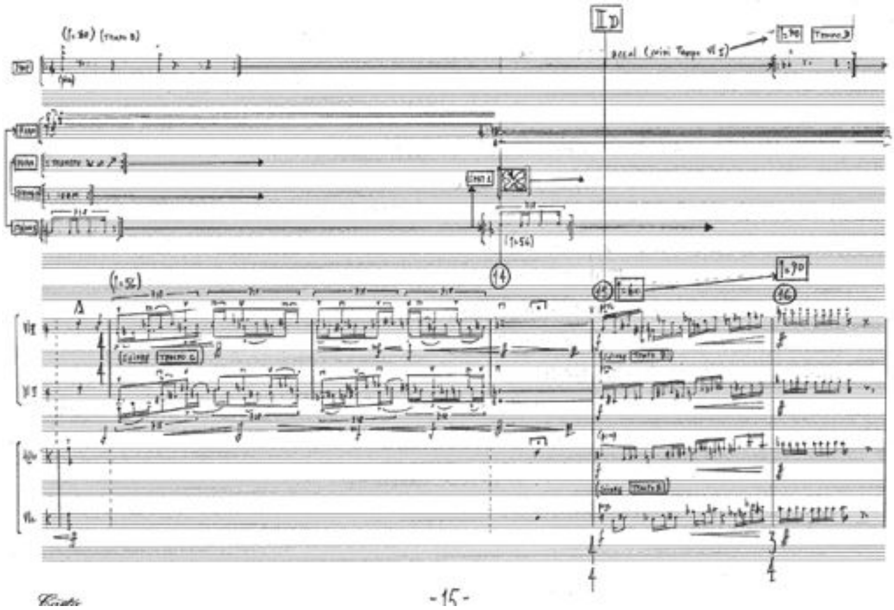

Figure 27 Heterogeneous Time Interactions Example 3.

with an internal 'counter' of multiplications/divisions of temporal values. Such music may be said to operate in the absence of temporal reference-points (Figure 34).

One should note that these categories rapidly become purely theoretical and are ambiguous in terms of perception; it is possible to perceive 'hyper-striation' as temporal fluidity, for example. Indeed, it would be possible to notate the preceding example in an extremely complex manner, but this would not change the way in which it is perceived by the listener. I took great care in this regard in composing *Tensio*, in particular in the third and fourth sections. My goal was to create

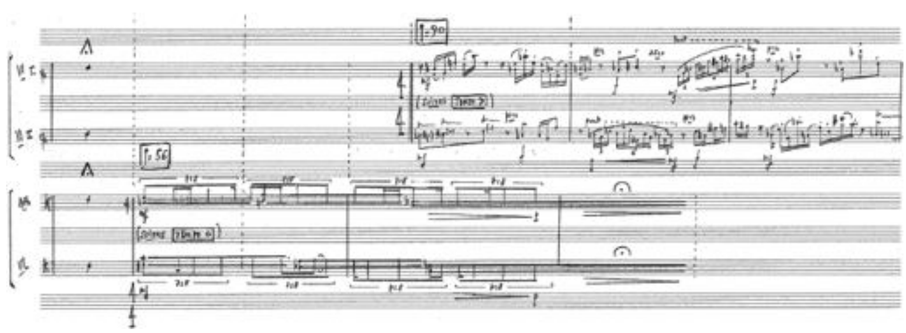

Figure 28 Heterogeneous Time Interactions Example 4.

Figure 29 Heterogeneous Time Interactions Example 5.

moments of ‘freedom and repose’ in anticipation of the high level of complexity which is to follow. I describe such sections as ‘temporal-landscapes’ because they do not impose directionality; the listener is free to shift his or her gaze freely around a landscape. In these moments, there is an absence of global direction in the musical discourse: abrupt shifts and synchronisation between contrasting superimposed layers are absent. I had in mind the famous study written by film critic André Bazin, regarding the role of depth-of-field in the work of Orson Welles. This essay hypothesises that the lack of a sharp depth-of-field allows the audience member to freely choose the trajectory of his/her sequential viewing of the image. When two characters are conversing the viewer may shift his/her attention from one to the other (a close-up, in contrast, imposes a vision which may be of either the party whom is speaking or listening). A comparable procedure was used in the third section of *Tensio*. Solo instruments are juxtaposed with electronic sounds; the number of layers may be multiplied, creating a highly polyphonic texture and thus allowing the listener several possibilities in choosing where to direct his/her attention. The audience member is not coerced into shifting his/her focus from one place to another. The result is a contemplative atmosphere that negates anticipation. The texture is composed of string-harmonic figures and *glissandi*; each instrumentalist finds him/herself before an ‘open door’, with several possibilities about where to begin and end the written material (Figure 35).

The duration of these ‘landscapes’ is at the discretion of the performers. The electronics, here, consist of transpositions and delays of the strings’ *glissandi* harmonics.

Figure 30 Heterogeneous Time Interactions Example 6.

4. Generative-Grammars

Since composing *Partita I* for viola and electronics I have made use of a method of composition that continues to evolve with each new work. I describe this method as 'generative-grammar'; this nomenclature is not intended to evoke Noam Chomsky,

Figure 31 Multiple Pulsation in J.S. Bach's Prelude.

Figure 32 Striated Time Example from Manoury's *Jupiter* for Flute and Live Electronics (1987/1992).

Figure 33 Hyper-Striation Example from Brian Ferneyhough's *Cassandra's Dream Song* for flute (1970).

because it is not a tool for the analysis of something pre-existent (such as a language); rather, it is an attempt to elaborate upon temporal forms, which are based on the presence of clearly defined morphological building-blocks. In one sense, it is reminiscent of *L-systems*, invented by Hungarian biologist, Aristid Lindenmayer; by using certain

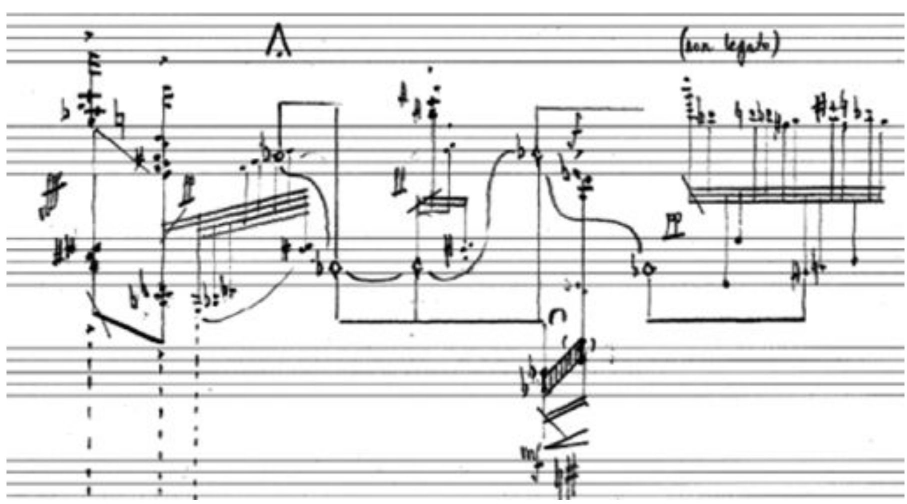

Figure 34 Striated Time with Absence of Reference Points. Excerpt from Manoury's *Veränderungen*, 2nd Piano Sonata (2008).

Figure 35 Contemplative Temporal Landscape from *Tensio*.

algorithms, it provides an elaboration of a sequence of events based upon a starting point. By applying a series of formal operations, one may transform a collection of units into something new. Formal operations may include the addition, removal, substitution, displacement, superimposition, exchange, grouping, inversion, creation of symmetry, creation of density, etc., of one or more values. Each of these operations is undertaken in accordance with a set of strict rules. For example, the removal of a

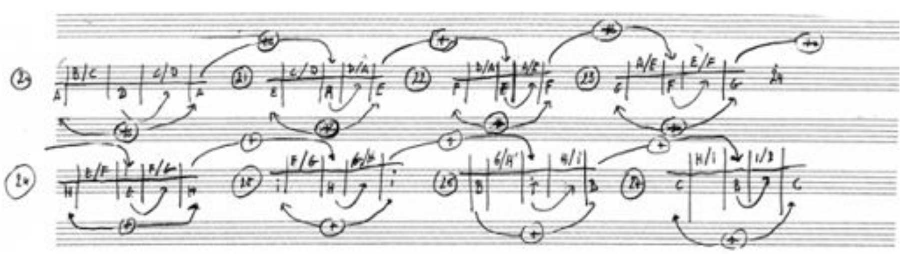

Figure 36 Grammar Example with Symmetries, Substitutions and Groupins.

value may occur as the result of a process of filtration; movement may be the result of a process of permutation, and so on. For the most part, one may describe these procedures are 'rules of *re*-composition'. Figure 36 shows an exemplary sequence in which it is possible to identify symmetries, substitutions and groupings.

In the first part of *Tensio*, I elaborated upon a simple grammatical notion: variations in motivic density, i.e. the number of times a motive (or 'unit') appears within a given sequence. Figure 37 shows a sketch of the opening section of the work.

Figure 37 Sketch of the Grammatical Structure for the Opening of *Tensio*.

Figure 38 Final form of the Grammatical Structure in Figure 37.

Eight motivic units are used here:

(1) a sound increasing in volume,
(2) a trill or 'roll',
(3) a rapid group of notes moving upwards in pitch,
(4) a *tremolo*,
(5) a group of five repeated notes,
(6) the sound of a high-pitched bell,
(7) a *glissando*,
(8) a *ricochet.*

Figure 39 Permutating Grammars in Section IC of *Tensio*.

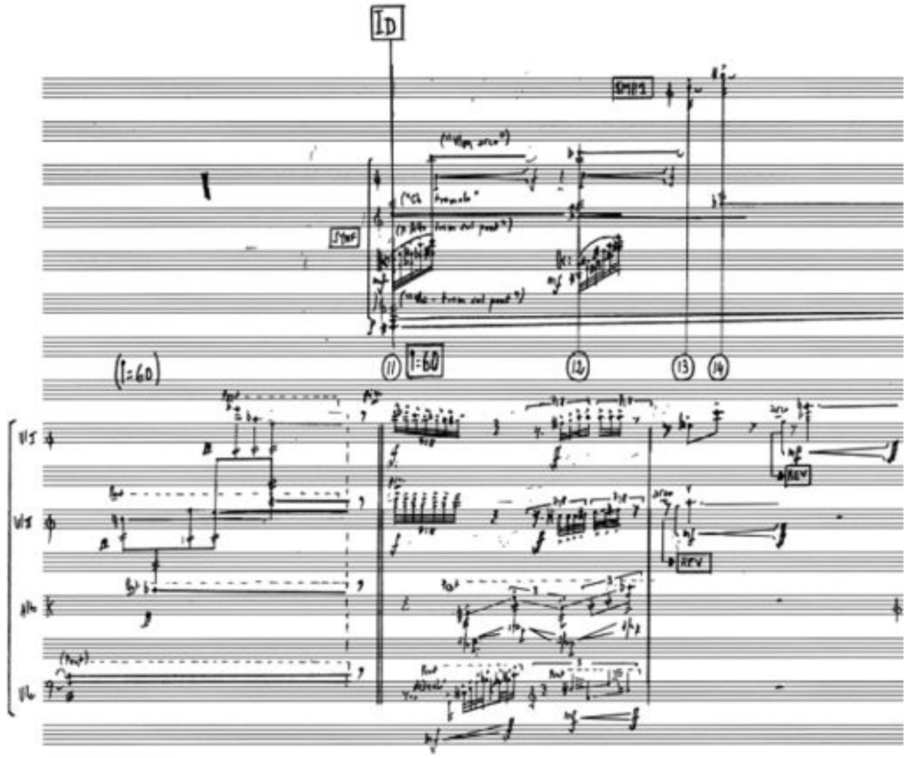

Figure 40 Completed form of Grammar in Figure 39.

Figure 38 shows the sequence in its completed form.

Each unit appears a unique number of times in this section:

$$a = 3,\ \ b = 4,\ \ c = 2,\ \ d = 6,\ \ e = 1,\ \ f = 5,\ \ g = 8 \text{ and } h = 7.$$

It is worth pointing out that this rule does not take into account the order in which units appear; rather, it applies to their prominence within the sequence. By permutating degrees of prominence, I obtained a number of contrasting 'sonic-perspectives', some of which proved more perceptible than others; as shown in Figure 39 from *Tensio*'s 'IC' section, followed by its completed form in Figure 40.

The proportions of each of these sequences were calculated according to other principles (i.e. varying temporal divisions in the form of contractions/dilations). Certain sequences are connected to others through some other freely defined parameter, which is extraneous to the intended 'grammatical structure', such as the short *tremolo* passage which introduces the 'ID' sequence shown in Figure 41.

By creating 'thematic permanence' and varying the hierarchical organisation of sequences, this procedure of 'generative-grammar' ensures a certain level of coherence

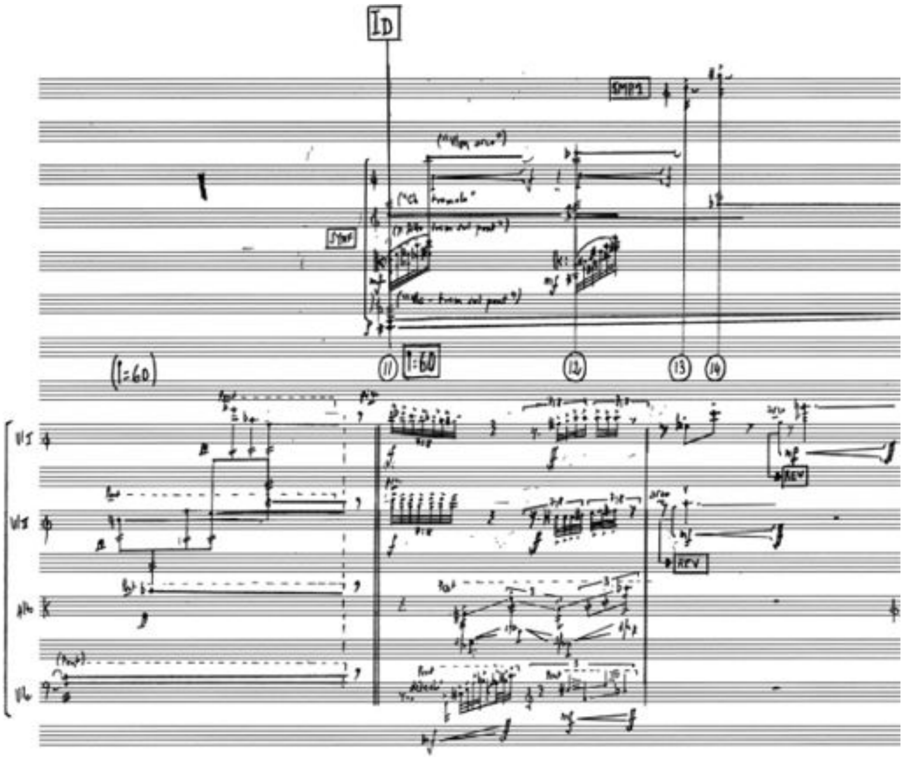

Figure 41 Free Parameters in Grammatical Structure of Passage ID in *Tensio*.

in the musical discourse (in terms of the ordering of sequences, and relationships between motivic units). The characteristics of these sequences (i.e. those variable elements which are necessary for composition) are not included in this syntax. This process is intended to provide a basis for temporal organisation, in a way which might be summarised with the following allegory: if something is important to say, it is just as important to say it at the right time.

Notes

[1] In a discussion, I once had on this subject with Don Buchla (an American researcher whose inventions and innovations in the field of synthesis justify his fame), he put the success of his machines down to the fact that they were unpredictable; to this I responded that unpredictability is the antithesis of what a composer seeks, that we desire the ability reproduce sound-expressions verbatim. Musical works establish an identity only when we are able to recognise/distinguish them distinctly from one another.

[2] This was the origin of the work's title, Tensio.

[3] Such effects are now commonplace in contemporary repertoire for sting-instruments: composers such as Helmut Lachenmann, and to a lesser extent, Gérard Grisey, have made heavy of such timbres. Noise pushed to the point of saturation is now accepted as containing a valid, expressive quality in certain aesthetics.

[4] These levels vary from one instrument to the next, because, of course, a piano is not capable of producing pitches/sequences of pitches with the same degree of precision as, say a violin. As a general rule, the greater the mechanical complexity of an instrument (such as with the system of hammers and strings on a piano), the more it is subject to limitations of musical parameters.

[5] To give a concrete analogy, I will make an example of a harmonic chord which may contain disparate intervals whilst still retaining its distinct colour and function: the G dominant seven may be ordered [G-B-D-F], [B-D-F-G], [D-F-G-B], [F-G-B-D] or [G-D-F-B], [G-F-B-D], [G-B-F-D], etc. Each note may, at a given instance, appear in any register without diminishing our capacity to identify the chord as a dominant seven.

[6] This value itself may also be determined by a real-time analysis of the performers.