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Modern Harmony: Timbre Instead of Harmonic Functions? Tracing or Building New Functionalities through the Use of the GMT Music Analysis Tools

1. Background

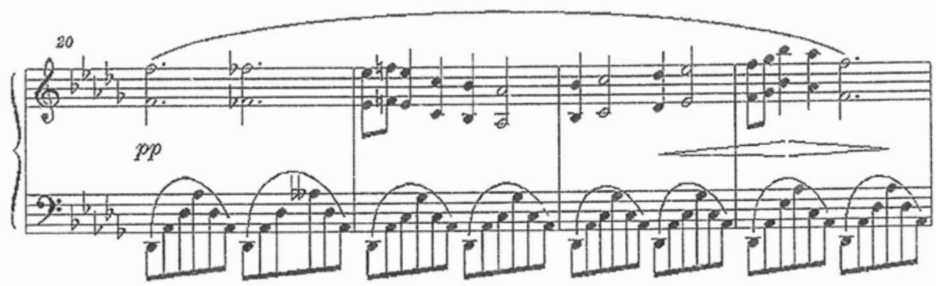
One of the main phenomena of the modern and contemporary music is the lack of the common technical basis, that, in the past, had been assured by the use of tonality. The 20th Century has developed some of its more dramatic changes in the use of harmony: chords have gradually begun to be employed for their timbre, chosen to build the required sonority, rather then for the particular harmonic function of subdominant (preparation), dominant (tension or suspension) or tonic (relaxation, conclusion or resolution), in a cadential musical logic, as it used to happen before (for example, considering a standard passage like I6–IV6–V–V7–I and so on).

Sporadic cases of such a behaviour occur also before the Romantic age: In Beethoven's Hammerklavier sonata (op. 106) we have shown how much pure pianistic timbral relations assume the main structural dynamic functions in sections where the melodic dimension is absent and/or the harmonic structure is static or poorly articulated (Guigue 1994).

However, the origin of such changes should be traced back to Romanticism: in many of Chopin's works, for example, there are sections clearly built starting from a timbre, from the particular evocative sonority that a combination of simultaneous intervals has on the piano.

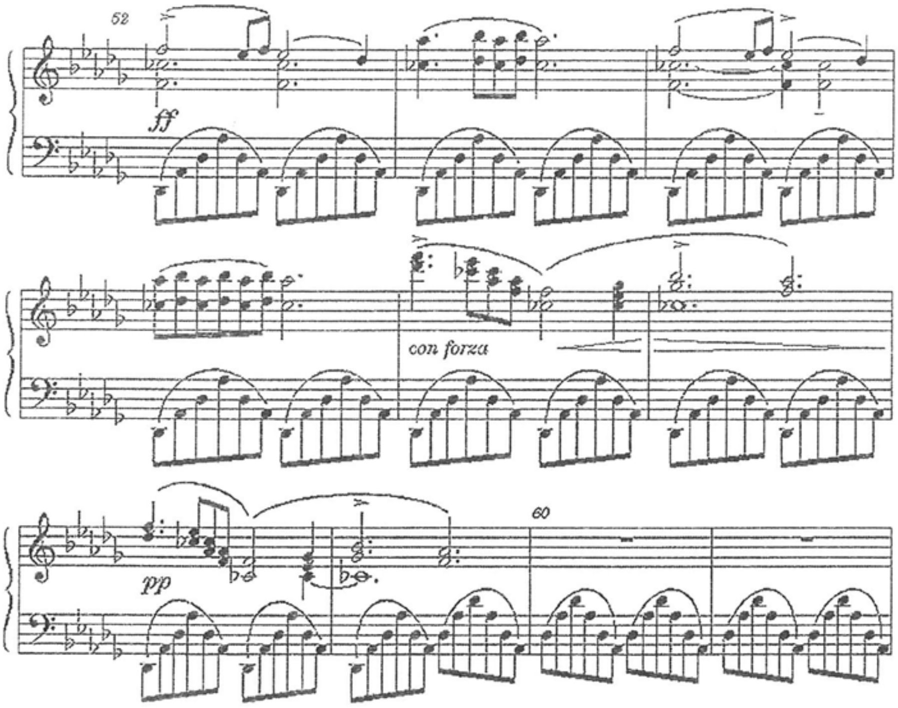
Let us make a simple example from Chopin's *Nocturne* op. 9 n. 1 (1830–1831): all the long passages from bar 20 (fig. 1) to bar 51 are based on the timbre of the *octaves* in the right hand;

Fig. 1 F. Chopin, Nocturne op. 9 n. 1, bars 20–23



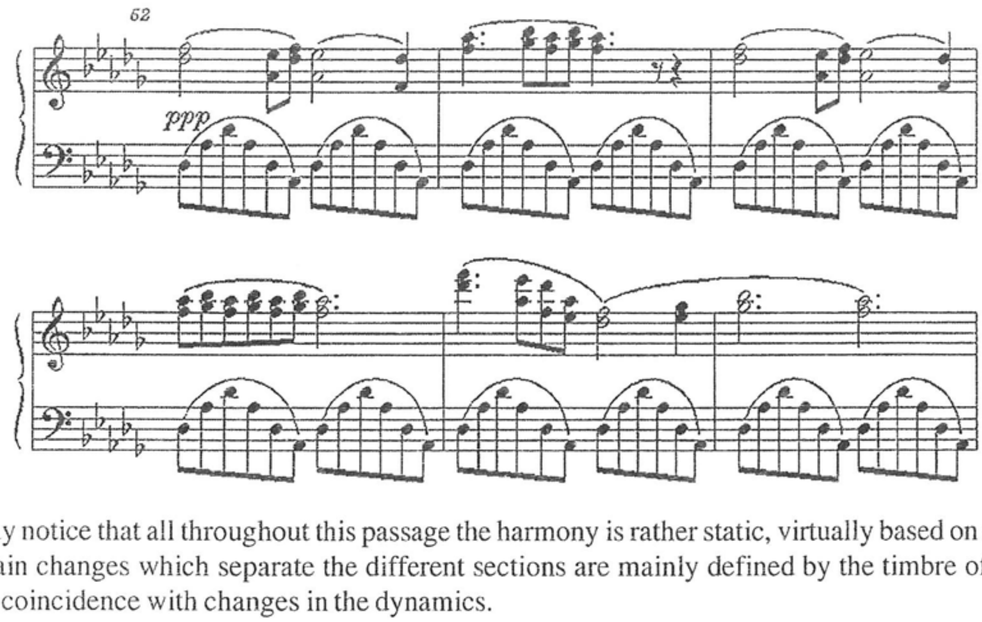
when the atmosphere changes abruptly, in coincidence with a sudden *fortissimo*, the composer prefers the use of *sixths and thirds* (b. 52); however, in the last two bars of this passage the sonority of the left hand „hollow" *fifth* (a triad with the third omitted) prevails (b. 60) and the listener's attention is attracted also by the raising of the left hand figure by one octave (fig. 2);

Fig. 2 F. Chopin „Nocturne“ op. 9 n. 1, bars 52–61



finally, after that, the *thirds and sixths* are developed into the well–known evocative „horn–like“ combination together with *fifths* and *fourths* (b. 62), exactly when the dynamics become *ppp* (fig. 3).

Fig. 3 F. Chopin, „Nocturne“ op. 9 n. 1, bars 62–67



We may notice that all throughout this passage the harmony is rather static, virtually based on one chord only: the main changes which separate the different sections are mainly defined by the timbre of different intervals, in coincidence with changes in the dynamics.

In many Romantic examples of the sonata form, besides, one can perceive that what matters is not the tensive balance among different tonalities (as was in the Classical period), but, rather, the possibility of presenting themes, as in Mendelssohn's *Scotch Symphony* (op. 56, 1842) (where in the first movement, for example, very important thematic materials are developed from the transitional bridge of the exposition and from the coda, two sections which should have been regarded as non–thematic, according to the rules of the Classical period), or the possibility of building sonorities, as in the *Symphonie Fantastique* by Berlioz, where, however, the composer's intention to build precise, peculiar timbres is evident especially if the piece is performed with the original instruments of its period – which could lead to reflect upon the interactions between music styles and the available technologies of a given period.

In the late Romanticism, the tendency to use harmony to build timbres is even more accentuated, and passages are frequent in which a composer (such as Grieg, for instance), insists on the sonority of a certain chord, that, according to the traditional logic, shouldn't have a particular importance within the harmonic cadence in which appears. In such cases, it becomes evident that the composer is not interested in the cadence itself, but mainly in the sonority of a chord, in its timbre. We see an example of this in fig. 4 from Grieg's *Folkelivsbilleder* (Scenes of Country Life) op. 19 (n. 2, *The Bridal Procession Passes*), but in his works there are many other examples of the same kind (see, for instance, the Springdans op. 38 n. 5), as there are many in the works of other different composers of the same period (see, for example, E. Satie's *Sarabandes*).

Fig. 4 E. Grieg, „Brudefølget drar forbi", op. 19 n. 2, bars 48–54
The added low staff suggests a way to analyze the passage.

This change has been detected and denounced harshly by the conservative academic teachers of the period, with alarmed words. Let's quote, for example what Théodore Dubois (1837–1924), academic harmony teacher at the Conservatory in Paris (1871–96), of which has also been the director (1896–1905), has written on his *Harmony Treatise* (Chapter II, paragraph 92) (Dubois 1891): „*The chord of major ninth, in the root position, has a particularly seducing colour. If it lasts long, it gains a grandiose, splendid, magnificent character. Some composers are often tempted to abuse of it, forgetting that in this way its effect and its efficacy are diminished.*"

What Dubois was condemning was exactly the use of this chord as a timbre, which automatically diminished its role („*its efficacy*") within a traditional cadential logic (usually as a dominant, in this case), but he did not realize that this was probably happening exactly because the traditional cadential logic itself was beginning to lose importance, and to yield to a new logic based on timbres.

It is a well–known fact that new sound aggregates began to appear in the late Romanticism music, in which unresolved appoggiaturas, ninths, and altered notes are conceived to create the required timbre, and, often, to go beyond the traditional triadic and tertian construction, based on the superimposition of thirds. To make examples about this is beyond the purpose of this article.

What we are interested in is to try to reflect on what, each time, has attracted the composers towards these new chordal combinations; perhaps, also the intuition that there is no substantial difference, as we know, between a chord and a timbre, and the intuition that a chord, with its sonority, can in a way be expressive in itself, through the careful use of its timbre, and that contrasts of timbre can be use effectively to build the formal structure of a composition.

It is however with Debussy that, in a definitive way, this new idea of aesthetics takes life. From this Author on, the 20th Century music can often be viewed and analyzed taking into account the idea of harmony as timbre (and the idea of sonic object, later explained).

The idea of harmony as timbre has appeared important to some authors, who have dedicated part of their studies to the the features of harmony in the 20th Century music.

We could read what the American composer Vincent Persichetti wrote in his essay *Twentieth Century Harmony* (1965) (a sentence here translated from the Italian version), speaking of the chords made by superimposing different kinds of intervals (not only thirds, or other exclusive categories of intervals) in the same chord (which he calls compound chords): *„The compound chords do not submit in a short time to the rules of the movements of the roots, or to tonality generally speaking. The compound chords have a little meaning if related to a root and are normally used as sonic masses (. . .) in an interrelationship with the distribution of tensions in the neighbouring chords. . .* " (Persichetti 1965). It's easy to notice that his approach, if compared to that of Dubois, is quite the opposite, with regard to the traditional tonality functionalities (root movements in the subdominant, dominant or tonic regions), but that he admits the possibility of building new functionalities starting from the observations on the timbre of each chords. This is exactly what we mean.

2. The gmt software development project

The GMT software development project provides tools for 20th Century musical analysis based on the concept of sonic object. A sonic object may be defined as the combination and interaction of the so–called secundary or statistical musical parameters (Meyer 1989), i. e. dynamics, densities, and, generally speaking, space (achronic) and time (diachronic) filling up. It is a medium–level structure, between the lower level (pitch classes), and the upper level (macro–structure). In the background of this software project is the Object–Oriented Analysis (OOA) methodology, which is thoroughly described in (Guigue 1996, Guigue 1997a, 1997b).

In this methodology, actually, the basic components of the musical language become what we call the „sonic objects", defined as the elementary structures out of which a form can be composed, generated through the combination and the interaction of all the different elements (register, timbre, phrasing, dynamics and so on) in which a passage is articulated.

Very shortly speaking, our general analysis method consists in three phases, that we could here name segmentation, analysis of the objects, analysis of the relationship among the objects.

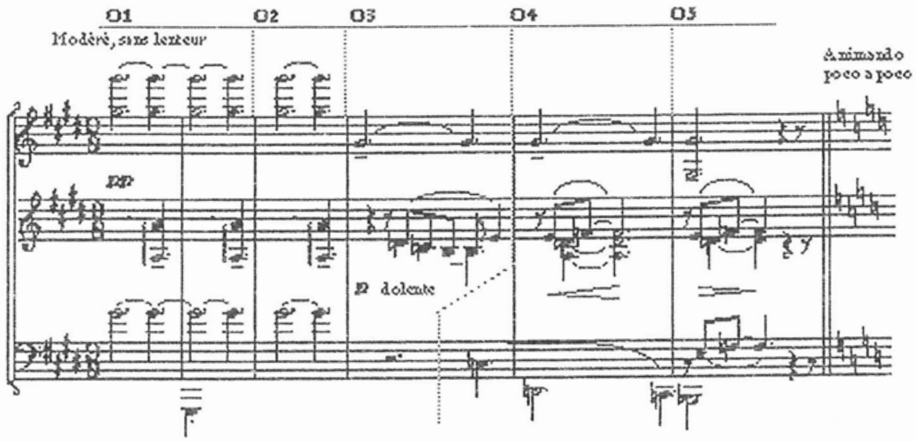
2. 1 Segmentation

It consists of segmenting the whole musical piece in a sequence of sonic objects (the method admits a „polyphony of objects", i. e. multi–layered sequences). By the meantime this segmentation is manually done, applying the OOA rules to the written score of the music. At the moment, a software that performs this task automatically is under development, and we shall consider the complex problems that must be dealt with to develop it (Trajano *et al.* 2000). This software uses concepts originated in the Artificial Intelligence research field – namely, the concept of intelligent agent – in order to segment a whole musical piece into a number of units – the sonic objects.

We assume that a gap in the structural continuity of at least one component may imply, in theory, a break in the underlying sonic continuity and, consequently, may identify a new structural/logical unit (a new sonic object). For instance, gaps may appear as: silences, fermatas, . . . ; change of the basic pulsation, global tempo or meter; global sonic changes (i. e. , instrumental group in orchestral music; pedal change in piano music, etc.); interruptions in phrasing and articulation; breaks in the homogeneity of some relevant components such as intensities, registers, densities, etc.

A first example of segmentation of a passage into sonic objects is given in fig. 5.

Fig. 5 C. Debussy „Etude pour les Sonorités Opposées"
A first example of segmentation into sonic objects.



Another example of segmentation is given in fig. 6, together with a scheme of all the possible ways of segmenting the passage, according to different segmentation rules.

Fig. 6 C. Debussy „Preludes", Les Collines d'Anacapri
A passage and some different ways to segment it.

2. 2 Analysis of the objects

The analysis of the objects implies to describe the structure of each object according to a selection of relevant statistical parameters, like Ambitus, Register, Linearity, Density, Dissonance level, Timbre Richness, Prevalent perceived intervals and so on. You will see soon hereafter some examples of such analyses.

2. 3 Analysis of the relationship among objects

Analyzing the relationship among objects means quantifying the gap of sonic continuity between consecutive objects, and also for each parameter, or homogeneous groups of parameters. This quantification configures a crucial aspect of the piece's formal kynesis and allows the form to be inferred from the succession of more or less contrasted sonic objects. The sonic objects resulting from the segmentation process are, therefore, analyzed in two ways: achronically and diachronically. The achronic analysis is the analysis of the content of each individual object independently from its temporal organization. The analysis considers all the object's pitches at point 0 on the time vector as well as the available information on dynamics and other data, like pedals. Some of the parameters analysed are: ambitus, register, space density, space linearity, among others. The diachronic analysis is the analysis of the time–related parameters. Some aspects that are analysed are: time density, time linearity, pitch direction and span, among others. You will see soon hereafter some examples of such analyses.

3. The software tools and the analysis of each parameter

All our analyses are performed using the NonTonalAnalysis (NTA) software (now developed on Max, the programming environment for the Macintosh by Miller Puckette and David Zicarelli) (Zicarelli *et al.* 1990) and the Sonic Object Analysis Library (SOAL) software (developed on the Patchwork/OpenMusic environments) (Laurson 1996). We had already presented a previous version of NTA, developed with a different programming language (Grosskopf 1998, Grosskopf 1999a) in the edition 1999 of this conference. Now, we will shortly present its new interface and features, together with the parallel SOAL software tool. The present stage of the NTA project involves the development on Max (for the Macintosh) of a software capable to integrate as many as possible of the functions of our previous works in a unique environment, providing also an intuitive and friendly user interface (fig. 7).

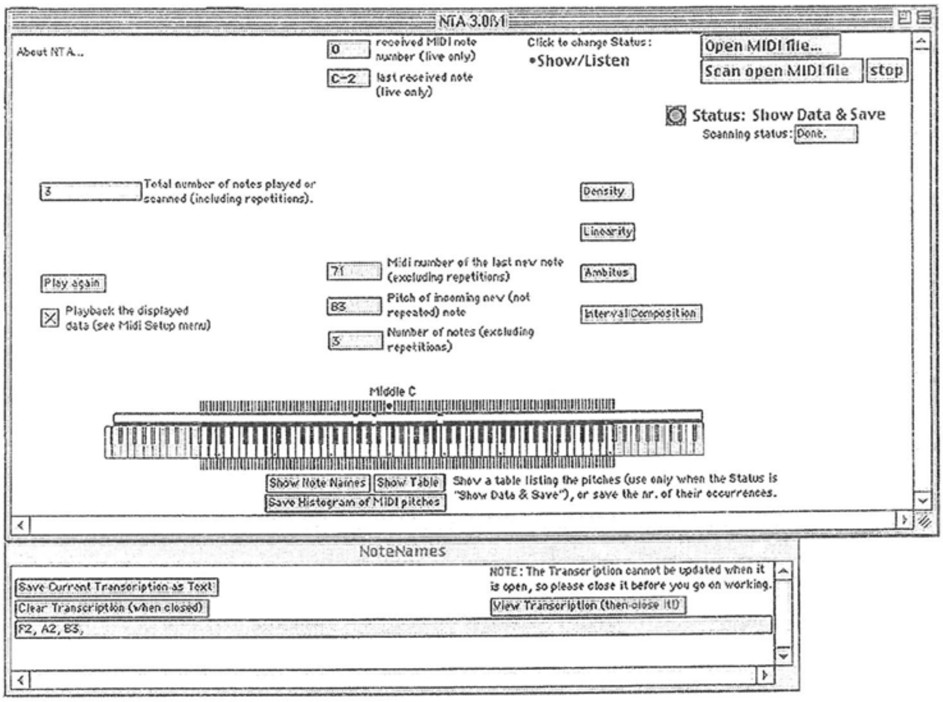
Basically, this software shall first procede to segment a musical structure into its elementary units, the sonic objects (or load a structure already segmented by another software or by the analyst), using a precise and effective method to obtain an intelligent segmentation. Then, it will have to analyze in a completely automated way the pertinent parameters, saving the data in a standard format (formatted text, midi) which will form the analysis report. The expression „completely automated" analysis refers only to the capability of the software to acquire the data automatically and to perform easily, quickly, correctly and smoothly the analysis algorithms even if they are complex, but it's of capital importance to maintain in the software the indispensable flexibility, that is the capability to be reconfigured, guided and piloted by the user's experience in each single case, and to „learn" from it, either in the segmentation phase and in the sonic objects analysis phase. Future developments may include the portability of the same software to the Windows or Unix platforms, and even an integration between midi data analysis and digital audio analysis.

The current version of NTA may acquire the data by opening and scanning a standard midi file (representing the sonic object to be analyzed), or by playing the desired notes on a connected midi instrument. The algorithms already implemented can perform the following tasks:

- count notes and show which notes are present in a played music object or in a midi file
- show how many occurences of each note are there, in the form of a Histogram
- evaluate the Density of the object
- evaluate the Linearity of the object
- evaluate the Ambitus of the object
- evaluate its Interval composition

Besides, some additional tasks are possible with the use of the previous version of the software and of a specially conceived spreadsheet. They are the analysis of Interval Perception, Interval Family Perception and Richness (timbre complexity).

Fig. 7 – The interface of NonTonalAnalysis



The Sonic Object Analysis Library performs analyses of Density, Linearity, Ambitus, Sonance (dissonance level) and many other parameters.

Some parameters (Density, Linearity, Ambitus, Interval composition, Interval Perception, Richness, Sonance) deserve some further clarification. All what follows will be illustrated taking into account that the development of NTA is presently carried on using the programming environment Max for the Macintosh.

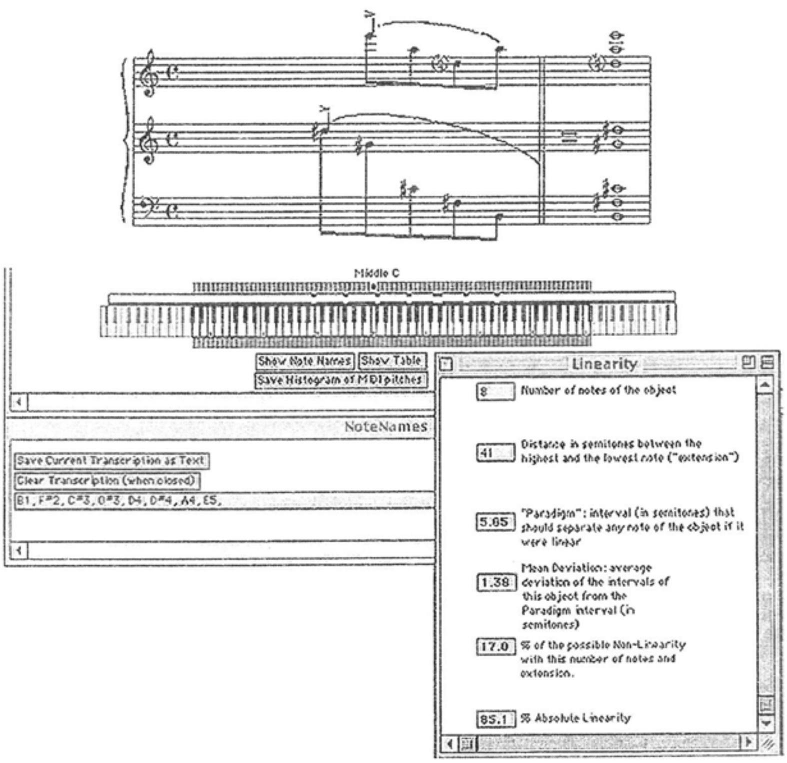
3. 1 Density

Density is a measure of the ratio between the number of notes of the object and the maximum number of notes that could be comprised between its extreme pitches in a given musical system (here, the chromatic tempered scale). For instance, a chromatic cluster will have the maximum Density value. A harmonic interval (a dyad), which has only its extreme pitches, while the space between them is empty, will receive the minimum value.

3. 2 Linearity

Linearity (fig. 8) measures how far is the object from being composed all of equal intervals. This measure must take into account that the possible degrees and variations of linearity depend not only on the extension of the object (the distance between its lowest and its highest note), but also on the number of notes that are contained in its extension. This leads to use two different measures of linearity: an absolute one and a relative one. The Relative Linearity indicates how far this chord is from being as non–linear as possible with that number of notes and with that extension. Absolute Linearity indicates how close this object is to being completely linear, not depending on other considerations.

Fig. 8 An example of analysis of Linearity in NTA.
(György Ligeti, Études pour piano, premier livre, Étude 2, bar 5)

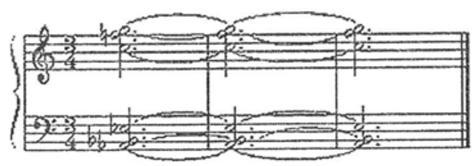


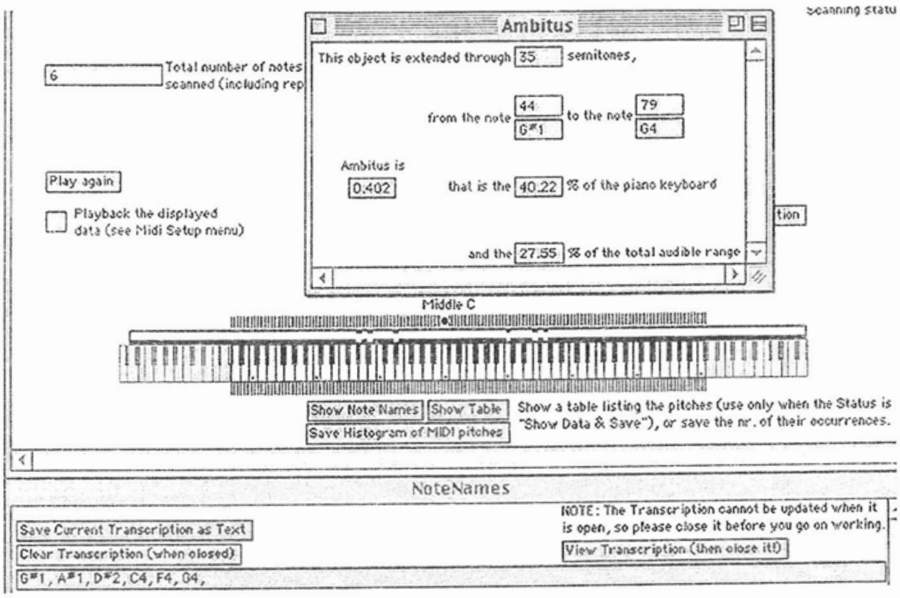
To perform Linearity, first NTA calculates the "Paradigm", the ideal interval (in semitones) that should separate any note of the object if it were linear. It is obtained simply by dividing the extension of the object (the distance between its highest and lowest notes) by the number of consecutive intervals in the object.

The „relative" Linearity measure is then defined as the ratio between the Standard Deviation of the intervals of this object from the Paradigm interval (in semitones), and the Standard Deviation, from the Paradigm, of the intervals of an object with the same number of notes, corresponding to the case of the highest possible non–linearity (all the intervals but one = 1 semitone, and the remaining one = the largest possible interval).

The „absolute" Linearity measure is the same, but takes into account the number of vacant places (the chromatic steps not occupied by notes) actually present in the object, compared to the number of vacant places that would be the maximum possible if this object had only 3–notes (in the case of triads, the two measures, absolute and relative, are one the complement of the other).

Fig. 9 An analysis example of Ambitus in NTA.
(Niccolò Castiglioni, Come io passo l'estate, piano suite, end of the first movement)

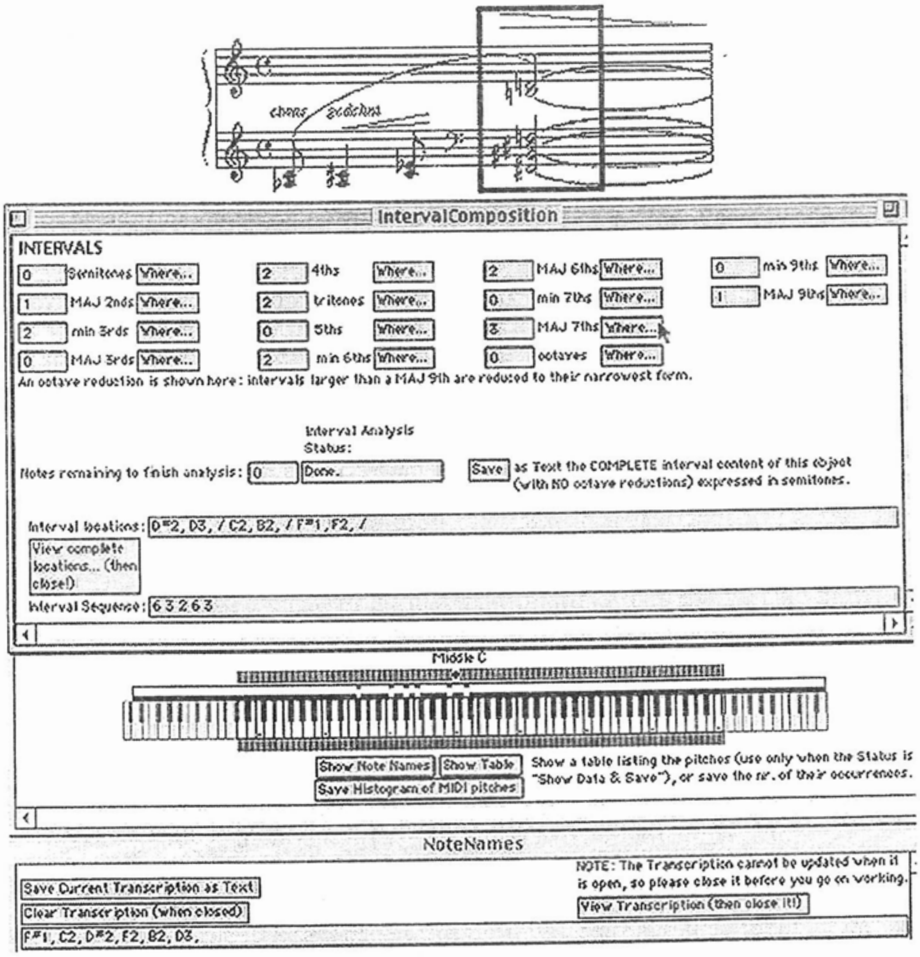




3.3 Ambitus

Ambitus (fig. 9) evaluates the extension of the object (the distance between its lowest and its highest pitch), and compares the result with some common standards of comparison, like the extension of a piano keyboard (88 notes, that is 87 semitones) or the average audible range (the latter has been approximated to the total range of the MIDI notes, 127 semitones). Other comparison standards could be added.

Fig. 10 An analysis example of the Interval Composition in NTA.
(Arnold Schönberg, op. 19 n. 2, bar 6)



3.4 Interval composition

The goals of the Interval Composition algorithm (fig. 10) are:

- to list all the existing intervals formed by any couple of pitches in the object
- to find how many occurrences of each existing interval are in the object
- to list which pitches form them
- to list their position within the object (e. g. if they are the lowest note, or the second one, or another inner note, or the highest one).

NTA is capable to measure the intervals in three ways:

- Without any octave reduction, having the semitone as the measure unit.
- With a reduction within the compass of one octave, using the usual standard names for the intervals.
- With a reduction within the compass of one major ninth, using the usual standard names for the intervals. This method has been implemented to support the Interval Perception algorithms (see below).

Besides detecting all the intervals, NTA will detect also some combinations of three notes, the sonority of which is not merely the result of the sum of the sonorities of the intervals composing them, but has a recognizable timbre in itself, and can have a large influence on the sonority of the whole object which contains them. To detect these three–notes combinations will be particularly useful for the Interval Perception algorithms (see later). The combinations to be detected are the following:

- major triads, in any position or inversion
- minor triads, in any position or inversion
- augmented triads (like C, E, G sharp), also in the open disposition (E, C, G sharp)
- the so called „conflicts of thirds", that are all the situations occurring when a major third (or minor sixth) and a minor third (or major sixth) are both present and share a common note, but do not form a triad, rather suggesting, from the point of view of traditional tonality, a minor and a major triad with the same root tone. For instance, C, E flat, E natural (that could suggest a conflict between C major and C minor) or C, E flat, C flat (that could suggest a conflict between Ab major and Ab minor: here the root tone itself is not included in the note combination).
- in some cases, the combinations traditionally analyzed as uncomplete chords of dominant seventh (like F, G, B).

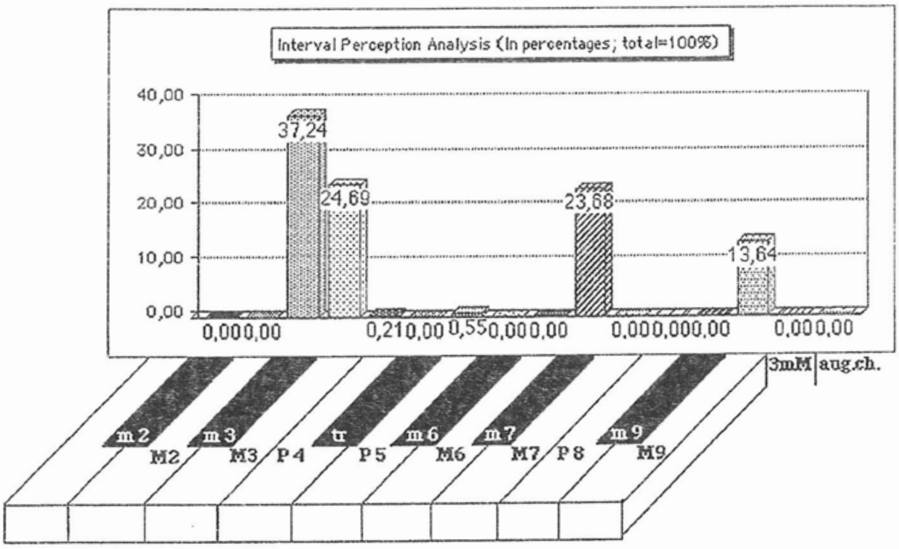
3.5 Interval perception

In the near future some Interval Perception algorithms will be added to NTA (they are already available in part by using the previous version of the software, and in part by using a special spreadsheet created for this purpose), which allow to detect which ones of the intervals (or three–notes combinations, like the conflict of thirds or the augmented triad) composing an object are perceived more clearly and have the greatest influence on its overall sonority, depending on their nature and on their position in the object. This allows to classify the objects, according to their sonority and to the „composition" of their sonority, providing a sort of „Interval Spectrum" of a harmonic object, which lists all the intervals (or three–notes combinations) contained in the object in hierarchical order, according to their importance in contributing to the global sonority of the object itself (fig. 11). It is necessary to stress that this order does not necessarily reflect the mere quantity of intervals (already analyzed in the Interval Composition section). Some strong consonances (like thirds) and strong dissonances (like seconds) are perceived better than, for instance, a major sixth or a perfect fourth, and the intervals placed in the lowest positions of a chord are also perceived better than those formed by the upper notes. Thus, some intervals can be perceived in a worse manner than others even if they are present in a larger quantity. The Interval Spectrum reflects this phenomenon.

In fig. 11 The keyboard does not represent actual notes, but rather the perceived sensation levels due to the various intervals, in this picture all conventionally transposed so that they start from the note C. The sensation levels due to intervals of the same kind are summed in the same column. A verbal descrpition of this figure could be: „the global sensation of the timbre of this chord is due for the 37,24 percent to the minor thirds F#–A and C#–E, for the 24,69 percent to the Major third A–C#, for the 23,68 percent to the minor sevenths B–A and F#–E, for the 13,64 percent to the Major ninth B–C#, for the 0,55 percent to the Perfect fifths B–F#, F#–C# and A–E, and for the 0,21 to the Perfect fourth B–E".

This kind of analysis allows also to detect the similarities or dissimilarities in the sonority of different objects, and also to measure timbre complexity or richness, and is particularly useful in the field of computer–assisted composition. The Richness analysis, or timbre complexity, is performed by a complex algorithm that we will not describe here, and is directly related to the number of different intervals which give a major contribute to the overall sonority: practically, the Richness or timbre complexity is maximum when all the columns of an Interval Spectrum (fig. 11) are of the same height.

Fig. 11 E. Grieg, „Brudefølget drar forbi„, op. 19 n. 2, bars 48–54



Richness is 52,69%.

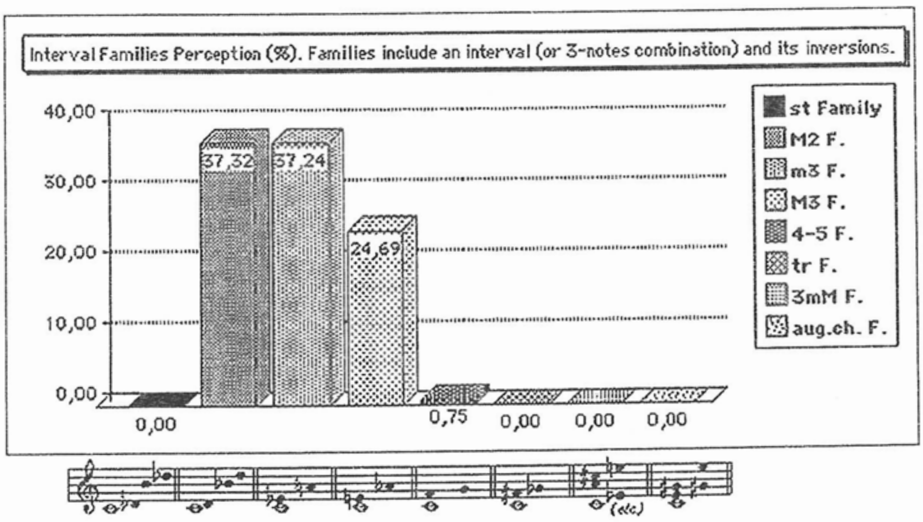
An Interval Perception Analysis (IPA) of the first chord from the same example of fig. 4, together with the related measure of Richness (expressed as Perceived Richness – see par. 4. 3).

This representation forms a sort of „Interval Spectrum". The measure of Richness, or timbre complexity, is directly related to the number of different intervals which give a major contribute to the overall sonority: practically, the Richness or timbre complexity is maximum when all the columns of an Interval Spectrum are of the same height. 3mM and aug. ch. stand respectively for the „conflict of thirds" 3–notes combinations and for the augmented triads.

At the bottom right corner the analyzed chord.

Another kind of analysis is possible by unifying the results of each interval (or three–notes combination) and its inversions in one column, thus forming the Interval Families (and an Interval Families Spectrum) (fig. 12).

Fig. 12 E. Grieg, Brudefølget drar forbi, op. 19 n. 2, bars 48–54



Richness is 52,69%.

An Interval Families Perception Analysis (IFPA) of the first chord from the same example of fig. 4 and fig. 11, together with the related measure of Richness (expressed as Perceived Richness – see par. 4. 3). Families combine the IPA results of each interval (or 3–notes combination) and its inversions. We could call this representation an Interval Families Spectrum. The measure of Richness, or timbre complexity, is directly related to the number of different intervals which give a major contribute to the overall sonority: practically, the Richness or timbre complexity is maximum when all the columns of an Interval Spectrum (fig. 11) are of the same height.

3.6 Dissonance level (sonance)

Another important development will be the implementation of several algorithms (according to different approaches) to measure the dissonance level of an object. We usually use the term Sonance to define the dissonance level, as a variable parameter (vector) from consonance to dissonance. We have listed many methods for the measure of dissonance, and it's our purpose to implement the largest possible number of them in our software, in order to provide a comparison among them when they are applied to the analysis of the same object.

For instance, in SOAL the Sonance is measured according to three methods, the Critical Bandwidth Test, the Cognitive Dissonance Rate and the Sonance Rate.

3.6.1 The critical bandwidth test

Among other phenomenons, the psychological sensation of dissonance between two simultaneous sounds is a function of the distance between them. It has been calculated (Fletcher, Zwicker, Terhardt, Plomp and Levelt, *et al.*) (Plomp and Levelt 1965) that this sensation occurs inside a critical bandwidth which is a function of the pitch of the lower tone of the dyad and the distance of the upper tone. SOAL measures the critical bandwidth between all contiguous dyads of a chord, and returns three „test" values: (0) – the dyad is out of the critical bandwidth (no dissonance sensation); (0. 5) – the dyad is inside the critical bandwidth; (1) – the dyad is inside one quarter of the critical bandwidth value, which means the strongest psychological sensation of dissonance. Then, SOAL obtains an average rate of the whole chord's sensorial dissonance. Beyond analytic purposes, this SOAL algorithm can be a composer's evaluation tool for testing the psychological sensation of dissonance of vertical structures.

3.6.2 Cognitive dissonance rate

With this algorithm, the contiguous dyads of a chord are evaluated from the cognitive (cultural) point of view of dissonance, where simple intervals, from minor second to octave, are considered more or less dissonant; in addition to this, the dissonance fades out proportionally to the real distance between the two tones, taking into account their real actual register and octave. The data are borrowed from a comprehensive study of the 19th and 20th literature in acoustics, psycho–acoustics and composition. The dissonance rate of the 12 prime intervals linearly increases by the following steps: octave (0% dissonance rate) – fifth – fourth – major third – major sixth – minor sixth – minor third – augmented fourth – minor seventh – major second – major seventh – minor second (100% dissonance rate). These first dissonance evaluations are then faded out as the actual octave distance between the lower and upper notes increases. The rate reaches 0% when the upper note becomes a prime harmonic of the lower one. The user may modify the order of intervals and the values according to his preferences or other criteria.

3.6.3 Sonance rate

„Sonance Rate" dynamically blends both the psycho–acoustical (critical bandwidth) and the cognitive evaluations of dissonance, as made by the two previous algorithms. More specifically, in this SOAL algorithm each contiguous dyad of the chord is first analysed by the critical bandwidth algorithm. If the test returns (1), this value is directly routed to the output collector, as it is assumed that the dyad is 100% dissonant, independently of the nature of the interval. If the test returns (0. 5), this value is weighted (partially modified) by the „Cognitive Dissonance Rate" algorithm. If the test returns (0), the full Cognitive Dissonance Rate is retained. An average gives then the global „sonance rate" of the chord.

3.6.4 D–index

The D–index, short for "Dissonance index", is a way of measuring dissonance (Sonance) in NTA 2. 0. 1, to be implemented soon in NTA 3. 0, based on the results of the Interval Perception Analysis. It is, of course, a number which increases if the chord is more dissonant and decreases if it is more consonant. It is calculated by a default formula that we cannot describe here, based on emphasizing the Interval Perception values of the dissonant Interval Families by multiplying them by great numbers and de–emphasizing the Interval Perception values of the consonant Interval Families by multiplying them by small numbers, and then calculating the overall sum (actually it is slightly more complicated than this, but this gives a good idea).

3.6.5 Color

The Color algorithm of NTA 2. 0. 1, to be implemented soon in NTA 3. 0, is based on the Interval Perception Analysis, and indicates the more or less evident presence of thirds and sixths, intervals that are very important in our musical culture, as everybody knows, and indicates also their nature. Four Colors are possible: Major (Major thirds or minor sixths prevailing), minor (minor thirds or Major sixths prevailing), neutral (no thirds nor sixths in important positions, or 3mM (this is the special dissonant case called "conflict of thirds", like in the chord C,Eb,E). The user may assume that this is is also a kind of rough dissonance scale, that is that Major is the most consonant Color and 3mM the most dissonant one. This method can be used also as another approximate way of measuring the dissonance of an object in NTA.

3.6.6 Harmonicity

An evaluation of harmonicity is now under development. This algorithm will detect how many coincidences an object has with the harmonic series and at what point; that is, if the coincidences occur at lower or at higher harmonics, and if the various notes of the object have simple frequency ratios or not. Harmonicity can be measured in several ways: we are now collecting different formulas to do it, in order to present at the same time many ways of measuring it. Though distinct from it, a harmonicity measure is also related to the measure of dissonance (which many associate to the presence of some simple frequency ratios). Besides, the harmonicity algorithm should also measure the amount of exact superimpositions among the harmonics of each note (when a harmonic of a note has exactly the same frequency of a harmonic of the other note). According to one of the existing theories of dissonance, this is an important factor to create consonance: namely, more superimpositions mean more consonance, so also this additional measure could be interesting.

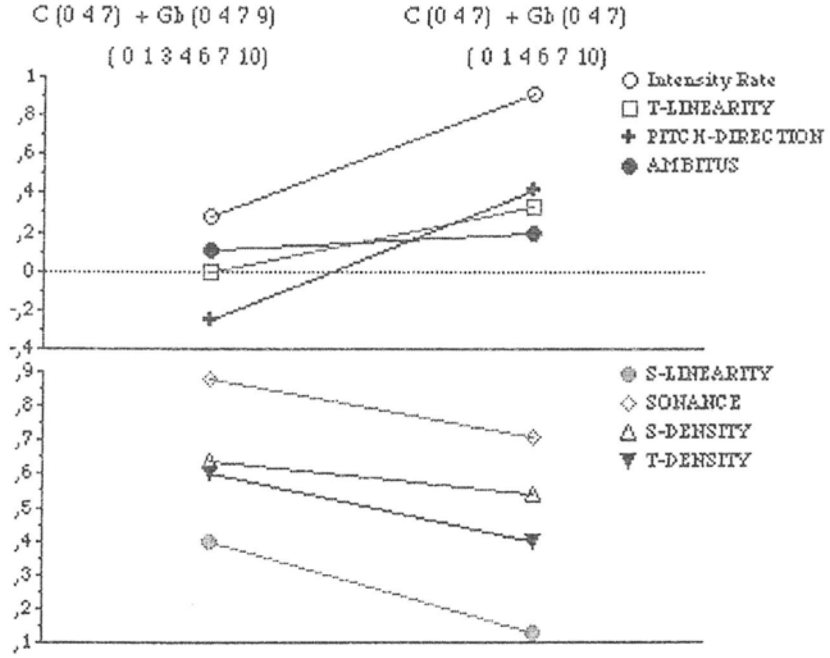
4. Analysis examples

We will show some musical examples as analysed by both softwares, and show some analytical discoveries and considerations which we can infer from these analyses, and also some examples of an effective use in composition of the same approach followed through the use of our analysis method. All these analysis and composition examples are summarized hereafter.

4.1 An example of object oriented analysis of debussy

One can, for instance, view the formal structure of a passage by Debussy as built of basic elements (the sonic objects) of various complexity; we can try to quantize the degree of complexity of each element (for instance, by measuring the Density and the Linearity of each sonic object or its dissonance degree – the Sonance – or other parameters, and combining the results of analysis in a structure), and show that the changes in complexity are of basic importance in building the form of that passage. If we do it, we will obtain results similar to those represented in fig. 13.

Fig. 13 C. Debussy, Preludes, Brouillards



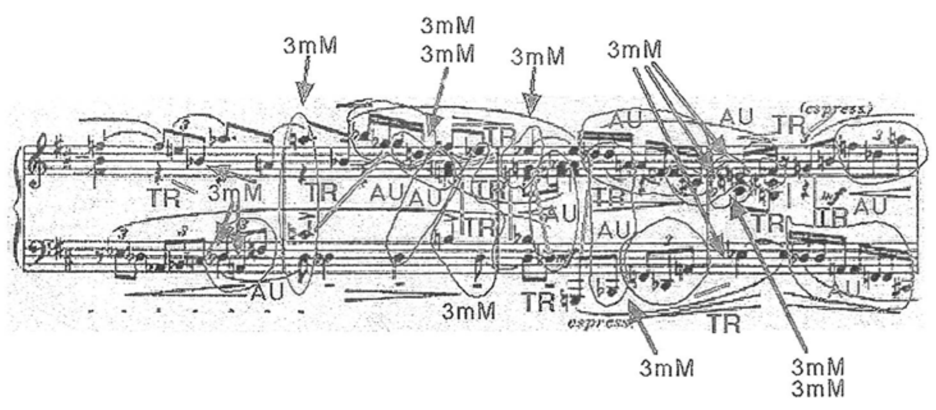
An example of analysis by comparing two sonic objects. Intensity Rate = dynamics; S– and T– indicate, respectively, the measure of the parameter with regard to the vertical distribution of the pitches considered simultaneously, or with regard to the horizontal distribution of pitches during time.

Here, the almost identical pitch–class content would be incapable of explaining the powerful contrast in the sound of these two objects, which is obtained through the augmentation of certain parameters (higher graphic) and the diminution of others (lower graphic). Our object–oriented analysis allows to show this very clearly. This example, of course, is limited to the comparison of two objects only, but the method can be extended to an entire composition.

4.2 On the similarity of three structures

Another interesting discovery is the peculiar role that some particular interval configurations, the augmented triad and the so–called „conflict of thirds" (a structure like C, A, C sharp), have in our way of perceiving the timbre of a chord. We have observed many times that, together with the tritone, they are often used together by many composers (especially those influenced by the expressionist aesthetics in various ways, like Schoenberg, Berg, or, differently, Scriabin), as shown in fig. 14 (Berg), and we may wonder why.

Fig. 14 A. Berg, Sonata op. 1



Many composers use tritones, augmented triads and conflicts of thirds at the same time, combined together, and we may wonder why. TR=tritones; AU=augmented triads; 3mM=conflicts of thirds.

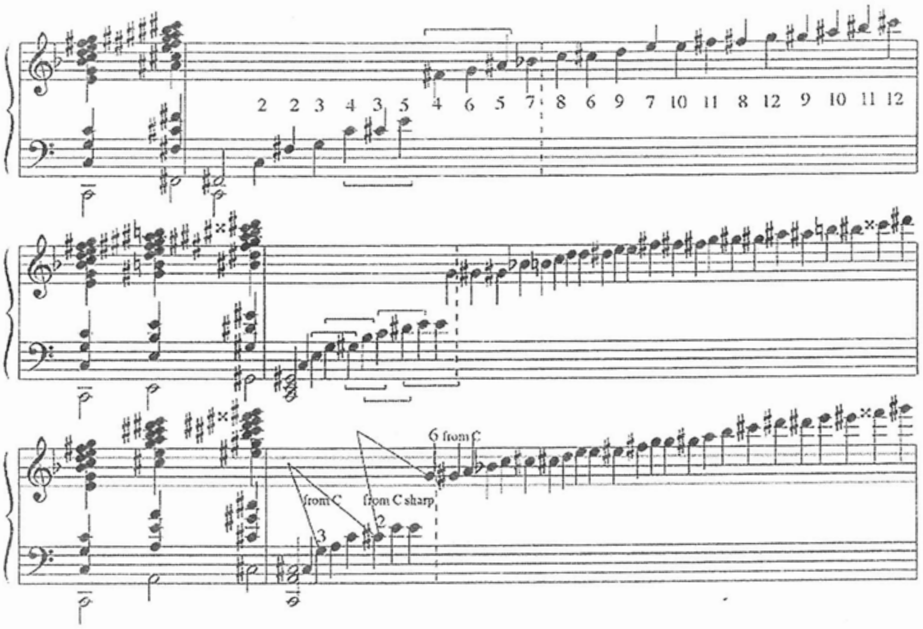
We may begin to answer with some simple observations:

– the use of the augmented triad may lead to think of using the hexatonic scale, and so tritones

– all the three of these combinations contain intervals (diminished fifth, augmented fifth, augmented octave, and, in a way, also the "clash" major/minor third) which are perfect consonances altered by one semitone.

– some patterns formed by the combination of various harmonics form, in each case, one of the other two structures, as illustrated in fig. 15 In detail: if we consider only the harmonics up to the point where all of them become closer than the critical bandwidth (that is, up to the vertical dotted lines, in the figure), we find that the lower harmonics of the tritone and especially of the augmented triad form conflicts of thirds, while the lower harmonics of a conflict–of–thirds combination form also tritones.

Fig. 15



Some patterns formed by the combination of the harmonics form, in each case, one of the other two structures. If we consider only the harmonics up to the point where all of them become closer than the critical bandwidth (that is, up to the vertical dotted lines, in the figure), we find that the lower harmonics of the tritone and especially of the augmented triad form conflicts of thirds, while the lower harmonics of a conflict–of–thirds combination form also tritones.

Now, we can go beyond these observations. If we analyze some features of their sound with NTA and SOAL, we may discover that, despite their different appearance, the augmented triad, the conflict of thirds and the tritone (at least two by two) share a similar degree of dissonance, a similar degree of harmonicity, and a similar degree of timbre richness (or timbre complexity) – what we can call the Richness. Fig. 16 summarizes all the data. We will not explain them here in detail, but, anyway, they show how our analysis methods may detect the similarities among these objects also through precise measures of well–defined parameters (which have been already described in this text).

Fig. 16 The same three structures of Fig. 15 analyzed with NTA and SOAL.
(The Richness is expressed as Average Intervallic Complexity – see par. 4. 3).

Structure	Sonance	Cognitive dissonance	D-Index	Harmonicity	Richness
AUGMENTED TRIAD	0,67	0,33		0,25	175,49
CONFLICT OF THIRDS (C,A,C#)		0,38	79,64	0,24	174,54
TRITONE	0,68		75,48	0,28	

4.3 Richness and composers

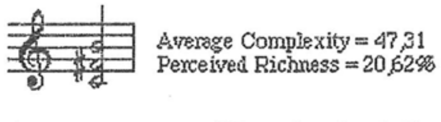
The parameter „Richness“ can be defined as a measure of the perceived complexity of a timbre of an object (such as a chord). It is completely independent from its consonance or dissonance degree. For example, if in a chord the human ear perceives only one or a few prevailing intervals, its sound will be perceived as

„poor" (low Richness); on the contrary, if the ear perceives clearly that many intervals contribute more or less in the same way to its overall sound, the result will be a „rich" or „complex" sonority (high Richness). As already stated above, Richness is directly related to the number of different intervals which give a major contribute to the overall sonority: practically, the Richness, or timbre complexity, is maximum when all the columns of an Interval Spectrum (fig. 11, see paragraph 3. 5) are of the same height.

Richness can be measured in at least two different ways: a first way, that we call Average Intervallic Complexity, gives absolute values (i. e. from 0 to an unpredictable maximum), and a second way, that we call Perceived Richness and is calculated independently from the first, gives a result in percentage.

It is interesting to investigate the behaviour of different composers with regard to this aspect of sound, in their compositional choices. For instance, it can be seen that Webern's preferences (apart from his first works) are usually for objects with a low Richness and a high dissonance: if we analyze the typical Webern chord, so much used in his works, we obtain a low Richness value (fig. 17).

Fig. 17 A Webern chord has a low Richness value.

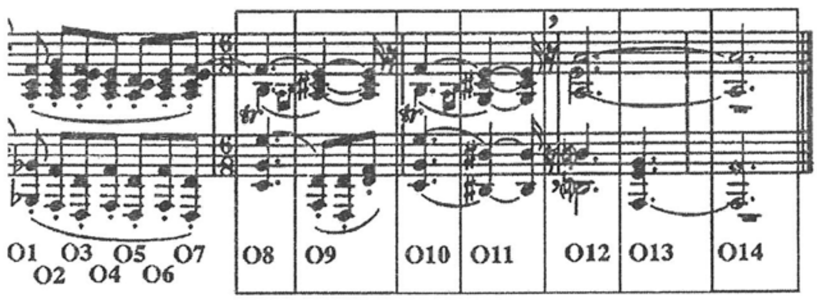


On the contrary, many modern composers of French school (from Satie to Ravel and to Messiaen) are often looking for sound aggregates with a high Richness: for example, if we try to analyze the two „magic" chords which give a very special atmoshpere to the final part of the Maurice Ravel's Forlane from Le Tombeau de Couperin, we find a very high value of Richness (fig. 18).

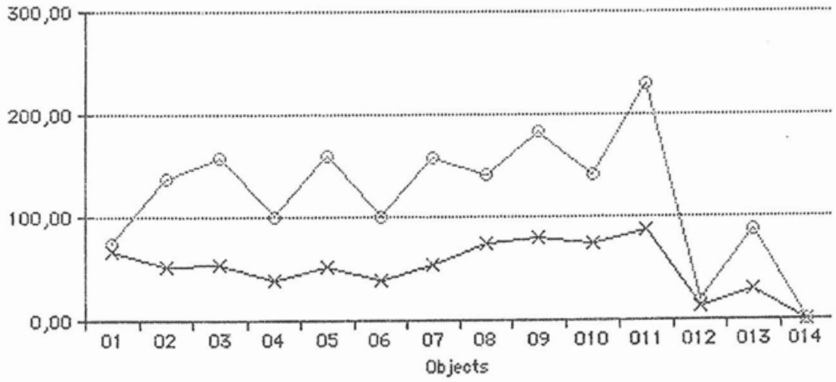
Fig. 18 Ravel's chords have often high Richness values.

Finally, we may observe a neoclassical piano composition by Stravinskij, the Hymne from his Sérénade en la, which has usually a medium–low degree of Richness with only a few exceptions which mark important moments in the form of the piece. The fig. 19 represents the sequence of chords which ends the piece, and its variations in Richness. The whole passage is to be played piano. Here Stravinskij has used medium–low Richness values, employing the only rich chord (O11) in a special position, as a signal, in order to mark with it the final event of the piece.

Fig. 19



Objects	Average Interval Complexity	Perceived Richness
01	74,24	67,32
02	137,22	52,69
03	157,68	53,59
04	100,65	38,96
05	158,79	52,69
06	100,65	38,96
07	157,68	53,59
08	140,01	73,16
09	182,59	80,43
010	140,01	73,16
011	228,73	87,08
012	18,90	13,88
013	87,75	30,30
014	0,00	0,00



Here Stravinskij has used medium–low Richness values, employing the only rich chord in a special position, as a signal, in order to mark with it the final event of the piece. Of the two different measures of Richness, Average Interval Complexity is the upper line,.and Perceived Richness (in percentages) is the lower line.

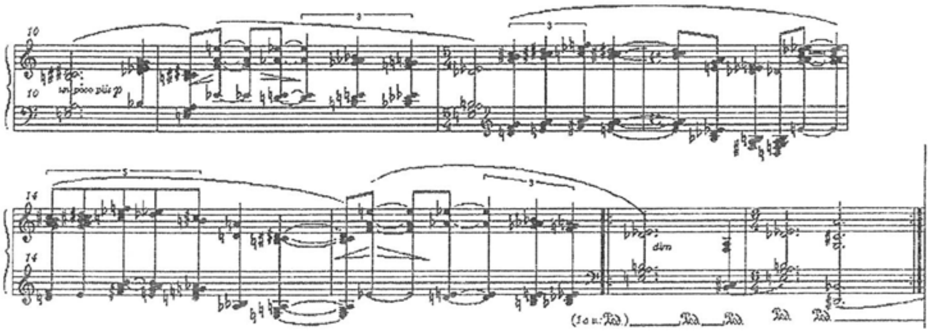
5. Assisted composition examples

A precise control on the Richness parameters (which express the complexity of a timbre) clearly corresponds to very audible modifications in the sonority (as one could infer by playing the above examples), and can be very useful in composition.

This technique, along with the others described herebelow, is often used in composing by Giovanni Grosskopf, who often uses NTA as a tool for composition. In a passage of his composition *A Midsummer Fantasy* (1998, written for and performed by the TrompetenEnsemble Linz), for trumpet ensemble, a melody is first harmonized with chords having a very high degree of Richness, then is presented again by harmonizing it with chords having a very „poor" timbre (low Richness). The contrast is evident when listening to the passage, and it is not by chance that the first harmonization may recall Messiaen, and the second Stravinskij: not because of a deliberate imitation (which was not intended at all), but rather because, by controlling the Richness parameter, one, automatically, realizes a posteriori that he gets closer to the taste of the modern French school (by increasing it) or of the neoclassical school (by decreasing it).

The first part of the same passage (the „rich" part), with a different development and transcribed for piano, has been used as the beginning of the second movement of the piano suite *Apparitions* (2001) by the same author, called *I nobili Elfi del bosco...* (The Noble Elves Of The Woods...), a passage of which you can see in fig. 20. The atmosphere of this piece owes really much to the high degree of Richness attained.

Fig. 20 G. Grosskopf, „Apparitions, I nobili Elfi del bosco„...

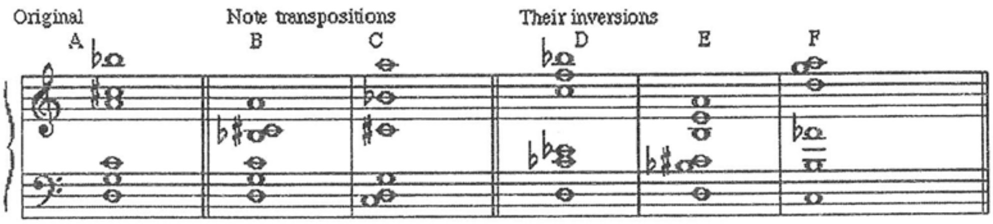


A suggestive atmosphere is created here by assembling chords with a very high Richness value (the passage is to be performed pianissimo and with pedal on each chord).

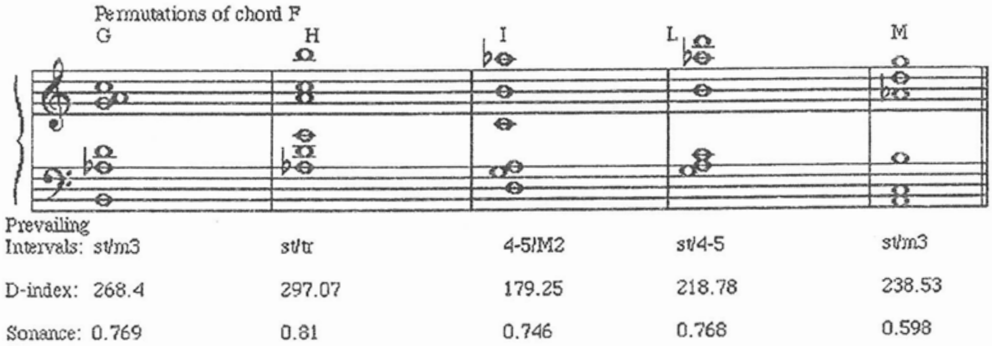
Another analysis technique which is very useful in composition is the individuation of the Interval Perception, that is the classification of the chords according to the intervals that prevail in their sonority. Sometimes many composers use mirror inversions of chords together with the original chords, or exchange in turn the position of the intervals in a chord, in order to derive many variants from an original harmony and ensure coherence with regard to the interval content of their harmonic structures, avoiding at the same time the too simple repetitions and transpositions. Others use to transpose the same pitches combining them in various ways. Nevertheless, if one pays attention to the problems stressed by the Interval Perception Analysis, one should always take into account that the strong consonances (like thirds) and the strong dissonances (like seconds) are perceived better than the other intervals (for instance, a major sixth or a perfect fourth). Besides, the intervals placed in the lowest positions of a chord are also perceived better than those formed by the upper notes. Therefore, exchanging the positions of the intervals or of the notes within the different variants of a chord and using various permutations instead of the original are not devices without consequences, with regard to the timbre and to the actual sound, which may even change greatly. By the way, also the degree of dissonance (the Sonance), of Harmonicity, Density, Linearity and timbre Richness will probably vary in such cases. One may notice, for instance, that chord I has not much in common with chord D. From this point of view, the use of chords, even apparently different in structure, but with the same intervals prevailing in their sound as perceived (i. e. in their Interval Spectrum), could probably turn out to be more consistent to attain coherence, and the opposite to obtain contrasts.

The fig. 21 illustrates some of these cases: under each chord you can read the indication of the two intervals which are prevailing in its sound, according to the Interval Perception Analysis, and their measures of Sonance and D–index (as already explained, two measures of dissonance).

Fig. 21



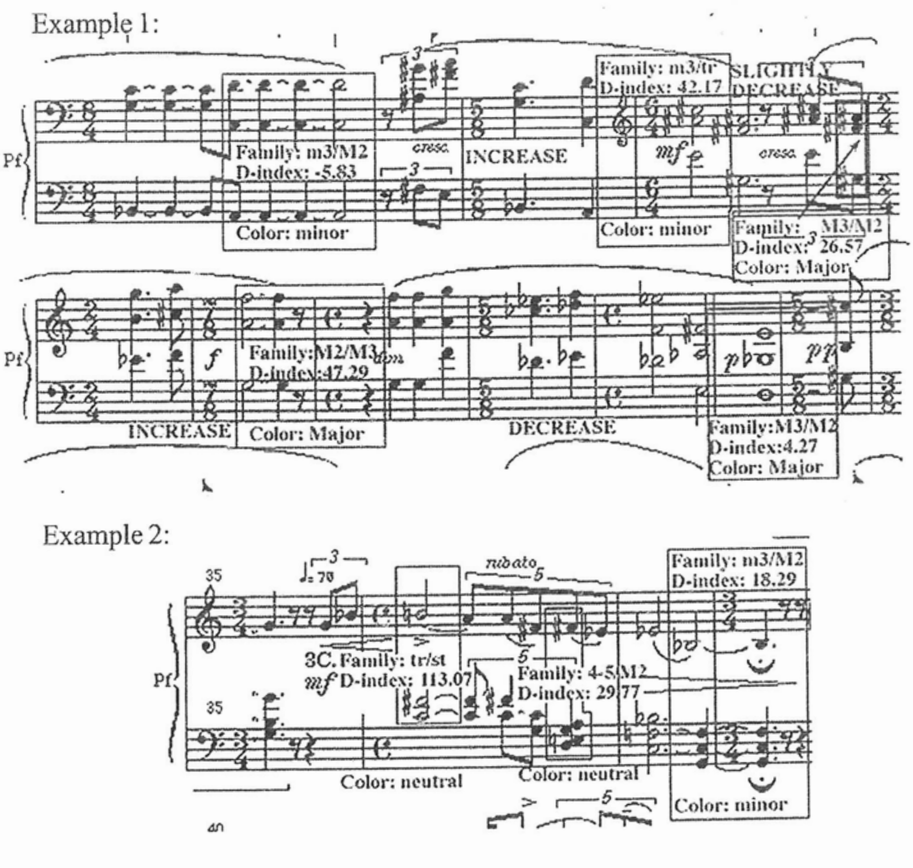
	A	B	C	D	E	F
Prevailing Intervals:	4-5/st	4-5/st	st/4-5	st/m3	st/m3	st/m3
D-index:	194.83	193.76	219.52	283.81	294.91	260.96
Sonance:	0.53	0.76	0.754	0.362	0.81	0.624



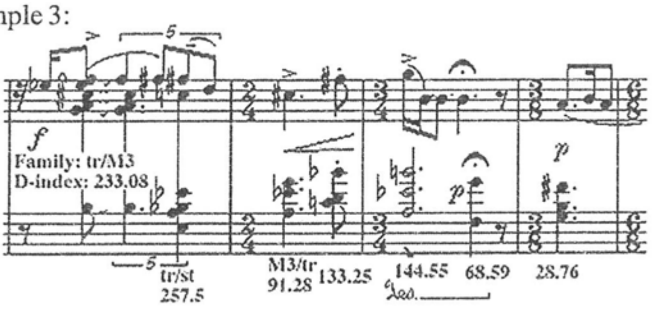
An example of analysis of the two prevailing intervals in the perceived sound of chords (together with two measures of the dissonance level). All the chords are built from the first one using various common compositional devices. Exchanging the interval or note positions and using permutations are not devices without consequences, with regard to the timbre and to the actual sound, which may even change greatly. 4–5 = Perfect fourth and/or fifth; st = minor second, Major seventh, and/or minor ninth; m3 = minor third and/or Major sixth; tr = tritone; M2 = Major second, minor seventh and/or Major ninth.

At the same time, also a precise control over the degree of dissonance or consonance (what we call the Sonance parameter) can have, of course, very useful applications in composition. There are passages in Grosskopf's music in which such control has a decisive role, and the dissonance degree (Sonance) of harmony is carefully graduated, sometimes also following the tension variations in the melodic line. For an example (see fig. 22), here is the analysis of a passage from *Tre Corali* for piano by Grosskopf, but one could also see the piece *Meditazione*, from his guitar suite *Immagini* (Grosskopf 1999b).

Fig. 22



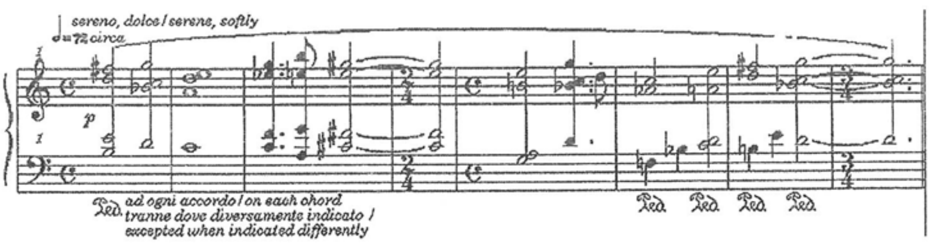
Example 3:



(G. Grosskopf, Tre Corali, for piano). The degree of dissonance (Sonance) has a decisive role and is carefully graduated, also following the tension variations in the melodic line. The word „Family" indicates the two prevailing intervals in the sound of each chord.

Anyway, by taking advantage of an Interval Perception Analysis, one could be better aware of the changes in the actual sound of the chords he is using. This is exactly what Grosskopf does in the above mentioned *Apparitions* (2001) for piano, a suite in which chords with similar timbres (checked by NTA) have been grouped together, and each group has been used in one movement of the suite, to achieve an effective contrast with the others. To realize the efficacy of the result, compare fig. 23, which represents the beginning of the fourth movement, *Il Ricordo* (The Memories), with fig. 20 (a passage from *I nobili Elfi del bosco...*, the second movement).

Fig. 23 (G. Grosskopf, Apparitions, Il Ricordo)



In this suite, chords with similar timbres (checked by NTA*) have been grouped together, and each group has been used in one movement of the suite, to achieve an effective contrast with the others. Compare with fig. 20*

Finally, we would invite to reflect on the importance of still having, in the 20th Century and today, some elements (like the aforementioned parameters Linearity, Density, Sonance, Richness, Interval Perception and so on) which can play a functional role in a music that does not rely on the traditional tonal functions, nor on tonality–based enchainments of the root notes of chords (not even in a broader idea of „expanded tonality"). It is not difficult to realize how this can be related to the question of dispersion of compositional languages: the tonality system has gradually faded away, and other compositional criteria have taken its place, but, along the 20th Century up to our days, in many of these other criteria, however very different, some common possibilities and coincidences seem to emerge in many different composers, about the definition of how harmony, conceived as timbre, can be used to build a form in music and also to give it a sense of directionality (that was previously assured by tonality) (Grosskopf 1999a), so that the study of these common possibilities can be extremely interesting and important for a musician of our age. The study of harmony as timbre, its features, and its fascinating, manifold possibilities.

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Modern Harmony: Timbre Instead of Harmonic Functions? Tracing or Building New Functionalities through the Use of the GMT Music Analysis Tools

Summary

1. Background

One of the main phenomena of the modern and contemporary music is the lack of the common technical basis, that, in the past, had been assured by the use of tonality. The 20th Century has developed some of its more dramatic changes in the use of harmony: chords have gradually begun to be employed for their timbre, chosen to build the required sonority, rather then for the particular harmonic function of subdominant, dominant or tonic, in a cadential musical logic, as it used to happen before. Sporadic cases of such a behaviour occur also before the Romantic age: In Beethoven's Hammerklavier sonata (op. 106) we have shown how much pure pianistic timbral relations assume the main structural dynamic functions in sections were melodic dimension is absent and/or harmonic structure is static or poorly articulated (Guigue 1994). However, the origin of such changes should be traced back to Romanticism: in many of Chopin's works, for example, there are chordal sections clearly built starting from a timbre, from the particular sonority that a combination of simultaneous intervals has on the piano. In many Romantic examples of the sonata form, besides, one can perceive that what matters is not the balance among different tonalities (as was in the Classical period), but, rather, the possibility to present themes, as in Mendelssohn's Scotch Symphony, and build sonorities, as in the Symphonie Fantastique by Berlioz, where, however, the composer's intention to build precise, peculiar timbres is evident especially if the piece is performed with the original instruments of its period – which would lead to reflect upon the interactions between music styles and available technologies of a certain period.

In the late Romanticism, the tendency to use harmony to build timbres is even more accentuated, and passages are frequent in which a composer (such as Grieg, for instance), insists on the sonority of a certain chord, that, according to the traditional logic, shouldn't have a particular importance within the harmonic cadence in which appears.

This change has been detected and denounced harshly by the conservative academic teachers of the period, with alarmed words.

New sound aggregates begin to appear in the late Romanticism music, in which unresolved appoggiaturas, ninths, and altered notes are conceived to create the required timbre, and, often, to go beyond the traditional triadic and tertian construction, based on the superimposition of thirds.

It is interesting to try to understand what, each time, has attracted the composers towards these new chordal combinations; perhaps, also the intuition that there is no substantial difference, as we know, between a chord and a timbre, and the intuition that a chord, with its sonority, can in a way be expressive *in itself*, through the careful use of its timbre, and that contrasts of timbre can be use effectively to build the formal structure of a composition.

It is however with Debussy that, in a definitive way, a new idea of aesthetics takes life, in which the basic components of the musical language become what we call the "sonic objects", defined as the elementary structures out of which a form can be composed, generated through the combination and the interaction of all the different elements (register, timbre, phrasing, dynamics and so on) in which a passage is articulated. From this Author on, the 20th Century music can often be viewed and analyzed taking into account the idea of sonic object.

A *sonic object* may be defined as the combination and interaction of the so-called secundary or statistical musical parameters (Meyer 1989), i.e. dynamics, densities, and, generally speaking, space (achronic) and time (diachronic) filling up. It is a medium-level structure, between the lower level (pitch classes), and the upper level (macro-structure). In the background of this software project is the *Object-Oriented Analysis* (OOA) methodology, which is thoroughly described in (Guigue 1996, Guigue 1997a, 1997b).

2. The gmt software development project

The GMT software development project provides tools for 20th Century musical analysis based on the concept of sonic object. After shortly explaining this concept, we introduce the NTA software (developed on Max) and SOAP library (developed on Patchwork/OpenMusic environments) and describe each tool.

We had presented a previous version of NTA (Grosskopf 1998, Grosskopf 1999) in the edition 1999 of this conference. Now, we will present its new interface and features, together with the parallel SOAP library software project.

We will also describe our general method.

Very shortly and roughly speaking, the method consists in

(a) segmenting the whole musical piece in a sequence of sonic objects (the method admits a "polyphony of objects", i.e. multi-layered sequences). By the meantime this segmentation is manually done, applying the OOA rules to the written score of the music. At the moment, a software that performs this task automatically is under development, and we may briefly present the complex problems that must be dealt with to develop it (Trajano et al. 2000). This software uses concepts originated in the Artificial Intelligence research field – namely, the concept of rational agent – in order to segment a whole musical piece into a number of units – the sonic objects.

(b) describing the structure of each object according to a selection of relevant statistical parameters, and

(c) quantifying the gap of sonic continuity between consecutive objects, and also for each parameter, or homogeneous groups of parameters. This quantification configures a crucial aspect of the piece's formal *kynesis* and allows the form to be inferred from the succession of more or less contrasted sonic objects.

Finally, we will show some musical examples as analysed by both softwares, and show some analytical discoveries and considerations which we can infer from these analyses, and also some examples of an effective use in composition of the same approach followed through the use of our analysis method. All these analysis and composition examples are summarized hereafter.

3. Analysis examples

One can, for instance, view the formal structure of a passage by Debussy as built of basic elements (the sonic objects) of various complexity; we can try to quantize the degree of complexity of each element (through precise methods, and by measuring the Density and the Linearity of each sonic object or its dissonance degree – the Sonance – or other parameters, and combining the results of analysis in a hierarchical structure according to precise criteria), and show that the changes in complexity are of basic importance in building the form of that passage.

Another interesting discovery is the peculiar role that some particular interval configurations, the augmented triad and the so-called "conflict of thirds" (a structure like C, A, C sharp), have in our way of perceiving the timbre of a chord. We can observe that, together with the tritone, they are often used together by many composers (especially those influenced by the expressionist aesthetics in various ways, like Schoenberg, Berg, or, differently, Scriabin), and we may wonder why. Now, if we analyze some features of their sound, we may discover that, despite their different appearance, the augmented triad, the conflict of thirds and the tritone share the same degree of dissonance and the same degree of timbre richness (or timbre complexity) – what we can call the Richness.

The parameter "Richness" can be defined as a measure of the perceived complexity of a timbre of an object (such as a chord). It is completely independent from its consonance or dissonance degree. For example, if in a chord the human ear perceives only one or a few prevailing intervals, its sound will be perceived as "poor" (low Richness); on the contrary, if the ear perceives clearly that many intervals contribute more or less in the same way to its overall sound, the result will be a "rich" or "complex" sonority (high Richness). It is interesting to investigate the behaviour of different composers with regard to this aspect of sound, in their compositional choices. For instance, it can be seen that Webern's preferences (apart from his first works) are usually for objects with a low Richness and a high dissonance; on the contrary, many modern composers of French school (from Satie to Ravel and to Messiaen) are often looking for sound aggregates with a high Richness; finally, we will show a neoclassical composition by Stravinskij which has usually a low degree of Richness, with only a few exceptions which mark important moments in the form of the piece.

4. Assisted composition examples

A precise control on the Richness parameters clearly corresponds to very audible modifications in the sonority, and can be very useful in composition. Another analysis technique which is very useful in composition is the individuation of the Interval Perception, that is the classification of the chords according to the intervals that prevail in their sonority. These techniques are often used in composing by Giovanni Grosskopf, and some passages can be shown in which effective contrasts of sonority are created in these ways.

At the same time, also a precise control over the degree of dissonance or consonance (what we call the Sonance parameter) can have, of course, very useful applications in composition. We can also show some passages in Grosskopf's music in which such control has had a decisive role, and the dissonance degree (Sonance) of harmony is carefully graduated, sometimes also following the tension variations in the melodic line.

Finally, we will try to reflect on the importance of still having, in the 20th Century and today, some elements (like the aforementioned parameters Linearity, Density, Sonance, Richness, Interval Perception and so on) which can play a functional role in a music that does not rely on the traditional tonal functions, nor on tonality-based enchainments of the root notes of chords (not even in a broader idea of "expanded tonality"), and we will try to show how this can be related to the question of dispersion of compositional languages (Grosskopf 1999): the tonality system has gradually faded away, and other compositional criteria have taken its place, but in many of these other criteria, however very different, some common possibilities and coincidences emerge about the definition of what can be used to build a form in music and also to give it a sense of directionality (that was previously assured by tonality), so that the study of these common possibilities can be extremely interesting and important for a musician of our age.