Analysis of Ligeti's Supersaturated Canon in Atmosphères by Means of Computational and Symbolic Resources

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Abstract:

We propose applying music structure detection techniques for exploring the acoustic dimension of *Atmosphères* and compare the results with the analysis of its music score. From the symbolic perspective, we focus mainly in music pitch range, texture, rhythmic profile and timbre disparities in specific instrumental grouping, e.g., string instruments. The computational method considered was centered on Mean Shift algorithm whose acoustic features were extracted by Librosa library. Among the three possible relationships between acoustic events (repetition, novelty and homogeneity) we focus on homogeneity exclusively arising from the timbre dimension.

Keywords: music analysis. computer music analysis. ligeti. micropolyphony. music information retrieval

1. Introduction

Following Cambouropoulos and Tsougras (2009) one of the aims of Musical Analysis is focused, primarily, on aspects of compositional design, mathematical/formal relations between musical materials or on musical theoretic forms and functions. Accordingly, the specific music study field grips with musical pieces consistent with the particular outlook. There are a large number of musical analytical methods and they focus on to chop a piece of music into a series of, *more-or-less* independent sections (COOK, 1987, pp.02). Needless to say, when studying a particular musical work under the perspective of musical analysis, the current object is not the same one that was at the first sight and, of course, it is not perceived as it before.

According to Ferraz (2002), music analysis apparatus might be able to be dissevered in those in which is focused on the music objects from the symbolic music analysis and on the sound acoustic object via computer music analysis. This detachment allowed the analyst both to fragment melody patterns, harmonic developments, rhythmic structures or to retrieve acoustic features, analyze spectral content from a digital audio signal indeed.

Computer environment is a medium of simulation (BROWN, 1999, pp.

03). One of the pivotal aspects for using computer devices on music analysis is its ability to model. Data entry usually at a more abstract level such as alpha-numeric strings, visual blocks representation or even statistically image inferences. Starting from the perspective of a global music analysis schema intertwining both symbolic music analysis and multi objective computational resources the complementary devices combines musicology with computer science and perception multidisciplinarly.

The early modern acoustic music composition, especially in the first half of the Twentieth Century, was capable to underpin a pivotal outlook between up-to-date electronic music resources and acoustic music instruments. In doing so, there is a potential coherence in that intertwining according to a myriad of composers whose compositional projects rely on the aforementioned displayed. It is undoubtedly prominent to expound Edgard Varèse's instance in his Liberation of Sound (VARÈSE; WEN-CHUNG, 1966), the mixture between acoustic instruments and sound synthesis techniques in Karlheinz Stockhausen (HOLMES, 2012), the conceptual and metaphorical applications of electronic music resources on music composition for purely acoustic instruments on György Ligeti's works in the 1960s (LIGETI; VÁRNAI, 1983) and the computer and music analysis advances in *French Spectral Music* (FINEBERG, 2000). Some of these compositions incorporates a whole new set of sound materials, as in the case of Stockhausen's music synthesis; and some adapts previous resources to a new music reality, as in the case of György Ligeti whose conventional symbolic writing such as in musical pitch, dynamics, rhythmic assemblies are adapted in order to represent new sonic metaphors.

From the music symbolic analysis on György Ligeti outputs some researches focus on pitch and harmony content of the composerś planning (VITALE, 2016; COREY, 2011; YU, 2013; BERNARD, 1987); spatial function of voice leading on his composition (BERNARD, 1994); structural procedures and formal processes (ROIG-FRANCOLI, 1995; CONT, 2005; SHIMABUCO et al., 2005); rhythmic aspects, temporal and metric organizations (BAIK, 2009; TAYLOR, 2003); music texture (CHEMILLIER, 2001; VITALE,). Exhaustively, computer music analysis resources are used on the study of Ligeti's works aim on subjects such as music textures (MONTEIRO; MANZOLLI, 2015); pitch-time representations (CHEMILLIER, 1995; MANZOLLI; LUVIZOTTO, 2015); algorithmic model under compositional processes (SANTANA; FREITAS; MANZOLLI, 2018), global features combining overall and local characteristics (LALITTE, 2015); and auditory perception (DOUGLAS; NOBLE; MCADAMS, 2016; CAMBOUROPOULOS; TSOUGRAS, 2009).

We propose a method from Computational Music Structure Analysis for exploring one excerpt from *Atmosphères* in which the composer applies micropolyphony and compare the results with the analysis of its music score (c. 44-53) (LIGETI, 1961). The exerted audio recording was performed by New York Philharmonic and was conducted by Leonard Bernstein in 1999 (Music of Our Time. Sony Classical SMK 61845[1]).

In order to retrieve the elements that compose the current excerpt we assume frequency spectrum slices separated in independent groups by similarity, and the discontinuities between these groups as their boundaries. We also assume small groups as containing more informative acoustic content, and a hierarchy among the elements according to their novelty level.

2. György Ligeti

György Ligeti (1923-2006) based most of his music compositions on very complex techniques inspired both in technological input from electronic music studio and ancient music such as Palestrina and Ockeghem (KIEVMAN, 2003). In *Atmosphères* 1961, Ligeti focus on timbre and textures in sense of the aforementioned content with little to no concern for traditional compositional rules such as melody, harmony or rhythm. These elements are not the centre of its composition however they do play a crucial role in producing dense sounds.

There are two main compositional instances in which Ligeti creates his dense and chromatic sound clouds. The sonorities are produced when each member of the orchestra is playing a single note or specific interval. Accordingly, Ligeti was interested in creating sound masses by layering sound waves that were resonating at various frequencies via acoustic instruments from the orchestral settings (IVERSON, 2009b). Another perspective in which Ligeti creates his dense sonorities is through a technique he called 'micropolyphony'. This technique is a variation of a renaissance canon: each voice is playing the same set of ordered pitches or nearby, yet to a separate rhythmic pattern with micro interval duration span. The sound *saturation* provided by the micropolyphony technique makes it impossible to discern individual music elements for the sake of the global sound resultant (VITALE, 2016, pp. 09). In doing so, there is actually no juncture apogee or climax such as a tonal reference center, individual pitch or harmonic progression. Therefore, once pitch notes lose the dissonant and consonant discrimination, it would follow that they be freed from any definition (MAYVILLE, 2014). Despite the fact that micropolyphony technique produces a more rhythmically active cluster, all the played notes, dynamics and articulations will result in a chromatic, impenetrable, interwoven mass of sound (DROTT, 2011). Micropolyphony's technique was partly inspired also by layering used in electronic music, mainly in music production studios in Cologne in the 1960s.

[1]More details on goo.gl/Jx19ph

According to Floros (2014), micropolyphonic structures can be traced by three main compositional features in which they reveal some peculiarities that clarify their differences from tonal composition practices: *1) the basis of micropolyphony is the canonic manner of composing*; *2) rhythmic relations are altered in such a way that no voice is like any other in rhythmic respect* and; *3) musical textures in micropolyphony favor an extreme number of voices*. The micropolyphony technique conceived by Ligeti as aforementioned was inspired by the renaissance canons, polyphony and electronique music. In the following, it will be discussed the implementation of the technique called 'supersaturated canon' on Ligeti's compositional procedures.

3. Supersaturated canon

From a global perspective, the *supersaturated canon* is a mid-level music construction based on ancient canon structures for the micropolyphony improvements in Ligeti's compositional planning, primarily in *Atmosphères* excerpt from measures 44-53. Following Vitale (2016), the *supersaturated canon* is a musical symbolic approach which it is assembled by multiple individual melodic layers primed in overlapping manner. On the canon in a Ligeti-like compositional manner, notably in *Atmosphères*, a myriad of instrumental voices pipe up pitch sequences in a definite range interchanging half-tones and whole-tones intervals. It results in a wide moving chromatic clusters with which the harmonic saturation provides the non-melodies recognition of melodies but continuously floating sound textures iridescences (VITALE, 2016, pp. 11).

4. *Atmosphères*

Conceptually inspired by an earlier electronic work named as *Pièce électronique Nº 3* (1957-58), *Atmosphères* in which the focus was in creating sound masses by layering sound waves that were displayed at a myriad of sound frequencies. The electronique piece is composed based on additive synthesis (IVERSON, 2009a, pp. 29). Afterwards, Ligeti derelicted the electronic composition in favor to 'create a sustained texture' consistently 'within which composite sounds would emerge and recede like shadows' (MAYVILLE, 2014, pp.33). The complex instrumental cluster on *Atmosphères* is equivalent of *Pièce électronique*'s additive synthesis techniques.

As aforementioned above *Atmosphères* for orchestra without percussion (1961) in which there is no longer any attempt to deal with units of pitch, duration, loudness, and timbre in a serial manner, or indeed any other, sealed Ligeti as the most representative figure on 'sound masses' and 'tone-color' composition. For Bauer (2001), *Atmosphères* represented 'polyphony' of tone color, severing timbre from any identifiable harmonic context and creating a laboratory in which 'the tone colors were the musical elements pre-eminent in determining the form'.

On the work, the rhythmic movement is eliminated by staggering instrumental entries emphasizing sustained sounds and avoiding all sense of pulse. The harmony is held in suspension by the use of clusters as discussed on Section 3. *Atmosphères* discovered a unique region of sound between tone and noise (FLOROS, 2014, pp. 65). The whole effect of continuity stir up a sound experience as sound texture whose timbral resultant is peculiarly permeable) (GRIFFITHS, 2010, pp. 147).

On the discussed excerpt, a mirror canon over five octaves gradually pulls inward to a minor third. Although the canon decreases its range, it remains densely chromatic, with no recognizable melodic profile (BAUER, 2001). Moreover, the pitch motion present on the canon is revealed by timbral dynamic profiles with unique string techniques and color articulations such as *sul tasto* and *sul ponticello*, followed by a higher range in music dynamic amplitudes between *pppp* and *ffff*. Thus the canon as a device develops the opening cluster by varying its density, articulation and volume, and implies that the "formless" *Atmosphères* may actually represent a series of variations on a theme (BAUER, 2001, pp. 46).

5. Computational Music Structure

From an empirical perspective, the idea of musical structure assumes one musical piece as a group of acoustic events organized in time. Each of these events (note, group of notes, chords, sonority, or even a rest) is related to the previous and the following ones, as a simple matter of continuity; but can also be associated to any other event in the sequence, for example, in the case when a motive is repeated in a different part of the piece.

These events can present some direct reference to the music score, for example, in the case of a monophonic recording of a melody played in *staccato*, when each note can be heard separately from its neighbors, and can be distinguished as an unit. However, when it happens that a recording of a cluster of notes is being analyzed, then the acoustic unit may not correspond directly to any discrete element in the score. The cluster itself may be perceived as a single event even being associated to a group of notes in the score.

The aim of Computational Music Structure Analysis area is to help analysts in finding the acoustic elements that compose one musical piece through the information extracted from its recording. This process is usually separated in two consecutive parts: first, the boundaries of each element are detected in time (local); and then they are compared with every other one in the sequence for finding useful relationships among them (global) (KLAPURI; PAULUS; MÜLLER, 2010). The boundaries detected for these elements can arise from melodic, harmonic or timbre discontinuities, and the relationships between them can be associated to (i) repetition, (ii) novelty or (iii) homogeneity.

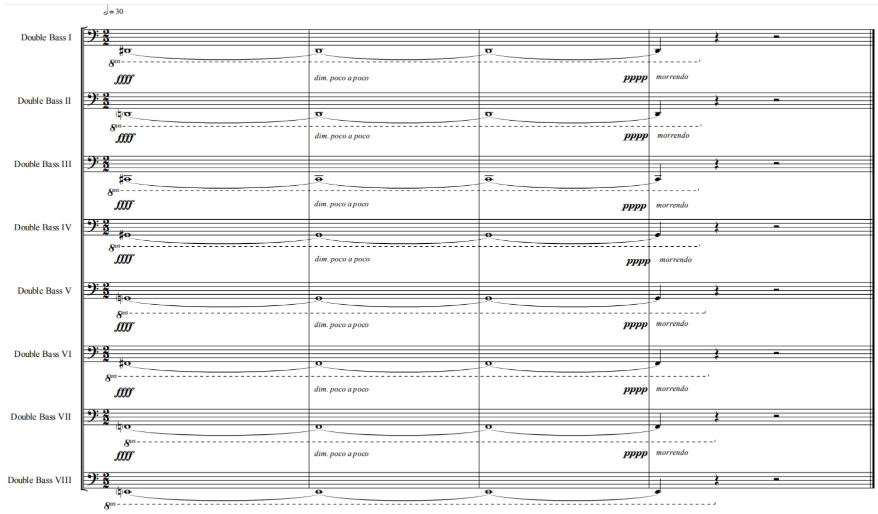
Repetition may be the simplest and most intuitive one, referred to when one event repeats along the piece. It can also happen that a group of notes is presented once again stretched or compressed in time, or even transposed vertically. Two different elements can contrast with each other, for example when a *piano* excerpt is followed by a *fortissimo* one. In this case the boundary is characterized by novelty. And finally, it can happen that the timbre, tempo or harmony remains regular within one section, which characterizes homogeneity.

Cooper et. al. 2003 applied Self Similarity Matrix (SSM) for detecting repetitive structures as a first step of summarizing a collection of popular song recordings. In a second step the authors grouped similar segments happening along the piece, and represented each song as successive transitions between a finite set of elements (chorus, verse, bridge, etc.). More recently, McFee et al. (2014) presented a method for detecting music structure by exposing the hierarchical relationship among structural components in different levels of granularity with Spectral Clustering technique. The authors mention harmonic features as suitable for detecting repetitive forms, and timbral features for checking local consistency.

Among the three possible relationships between acoustic events (repetition, novelty and homogeneity) we focus on homogeneity exclusively arising from the timbre dimension. We invert the summarizing process proposed by Cooper et. al. (2003) by firstly grouping similar frequency content in homogeneous groups, and then taking discontinuities in time as its boundaries.

6. Symbolic Music Structure

Symbolic Music Analysis approach carried out by the musical score outputs substantial results for highlighting aesthetic and conceptual aspects of the structural composition. Under the symbolic analysis circumstances, music timbre issues might be curbed by definite individual interleaving of musical instruments. Among the three possible relationships among acoustic events (repetition, novelty and homogeneity) we focus on novelty and homogeneity, both arising exclusively from the timbre dimension. From our results it is shown that different cluster settings outcome in a dynamic novelty curve profile both from spectrum and chromagram content. Definitive instrument grouping such as the Double Bass performs dissimilar music profiles in range (e.g., low register and high register), dynamic rhythmic behavior (e.g., static and moving movements) and timbre changing variation (e.g., like in *sul tasto* expression). Figure 1 displays three grouping centered on Double Bass music structures.



(a)

(b)

(c)

Fig. 1 – Double Bass groupings in three definitive instants: Double Bass chromatic cluster in low register (1a); conversely, Double Bass chromatic cluster in high register (1b) and; Double Bass grouping in a more complex pitch content, rhythmic and articulation profiles (1c).

7. Computational Method

The frequency spectrum is extracted from the the excerpt with default parameters from Librosa library[2] (Figure 2 - Top) and grouped with a clustering framework implemented by Kunumi[3] which . The separation index[4] achieved its highest value (0.6) when separating the spectral content in 5 groups with Mean Shift algorithm.

The Mean Shift method considers homogeneous groups of samples as generated typically by normal distributions, and their local maxima as candidates for the mean values. The algorithm keeps updating the means at each iteration based on nearby samples, and the calculation is interrupted when these values converge. The frequency content within each group is taken as homogeneous, according to the homogeneity relationship described previously, and each spectrum frame is associated to the cluster it belongs (Figure 2 - Middle).

The number of samples inside each group are suggested as being inversely proportional to the originality of its content, in the sense that groups of samples with few items happens less frequently and provide a higher degree of novelty during the listening experience. We build then a function for expressing the evolution of novelty, the Novelty Curve, presented in bottom of the Figure 2.

The Novelty Curve indicates the relevance of each transition according to the originality of the associated spectrum content in the context of the excerpt. The hierarchy of transitions inside the excerpt, in order of relevance, is: from cluster 0 to 4, from cluster 4 to 3, from cluster 3 to 2, and finally from cluster 1 to 0.

8. Discussion

In *Atmosphères*, mainly in the studied excerpt, the major compositional technical planning is focus on the overlapping of sound fields and sections. The Double Basses are still holding the extremely low eight-note cluster, the remaining strings suddenly enter in *ffff* piano indeed. The highly complex 28-voice canon and the 20-voice mirror canon they perform provide an archetypal example of Ligeti's celebrated micropolyphonic technique.

Even though the supersaturated canon on the excerpt is highly stressed by two melodic layering in contrary motion (a descendent sequence on the violins and another one in ascendant contour on the violas, cellos and Double Bass) (VITALE, 2016, pp. 12), the Double Bass attendance is one of the major key for the dynamic curve perception based on sound texture, timbre modifications,

[2]https://librosa.github.io
[3]https://www.kunumi.com/
[4]https://en.wikipedia.org/wiki/Silhouette_(clustering)

music dynamics (such as *crescendo* mark, and a confined range in musical pitch. The method applied by the algorithm matches with the assumption of the homogeneity relationship among elements, as all the three representative Double Bass groupings displayed dissimilar aspects in which the symbolic music features are the driving force for the mutual changing retrieved by audio recording. At the end of the excerpt all string instruments are in a more complex rhythmic context-like dynamism at the same time by a narrower range in musical pitch texture.

Additionally, the music pitch range and rhythmic dynamism complex rapport is accented by violas and cellos profiles at the beginning of measure 50 (around 25") in which these instrumental groupings perform pitch reentering at lower range (at F3 on violas and F#3 on cellos). Furthermore, at the second half of measure 51 (approximately 33") all string instruments, including the Double Bass, increase their rhythmic complexity by metric subdivisions and tuplets.

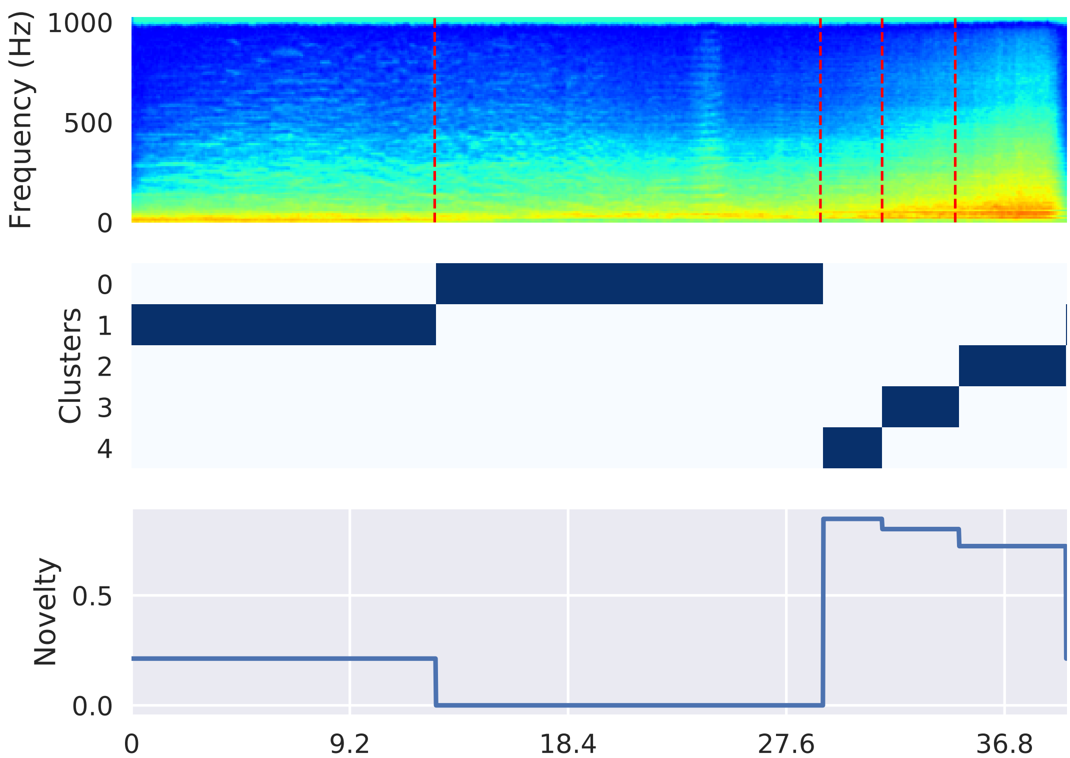


Fig. 2 – Top: the spectrum extracted from the piece recording; Middle: the clusters corresponding to each frame of the piece; Bottom: the novelty curve proportionally converse to the clusters.

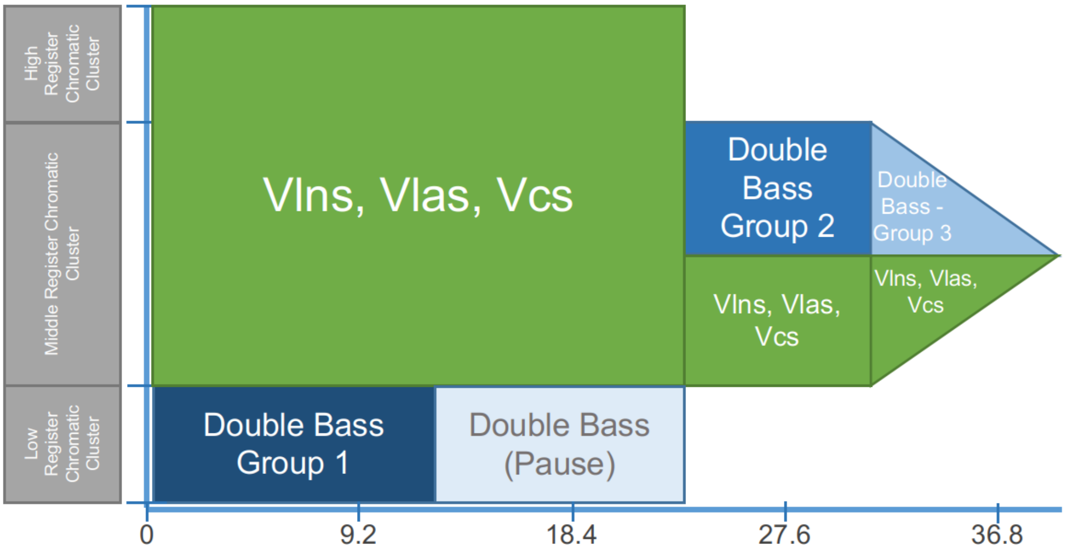


Fig. 3 – String instruments analysis in block-like structural planning highlighting the Double Bass groupings in range of musical pitches (y-axis).

9. Conclusion

The presented instrumental layers of the excerpt evinced a path towards a non-homogeneity profile concurrent an increased novelty outlook chiefly both by an attendance or the absence of a particular music instrument, such as lower string instruments, Double Bass and Violoncello. Our findings according indicate that even though the pitch material during the excerpt remains invariant and regular settled on chromatic content such as clusters of pitches, its dynamic organization from both rhythmic and metric structures aims to indite dense sound instances through spectral resultant and microvariation of chromatic management.The overall pitch range from the excerpt starts in a wider block (D2-F#6) towards a middle-range narrower block (B3-C5) mutually with an increasingly density of pitch entries.

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Symbolic music analysis approach provided substantial inputs on the profile contour for the individual instruments or instrumental groupings by range, texture or even timbre. For the computational analysis perspective, our results proclaimed a perceptual conjunction between symbolic music data and global or macro-structure based on audio recording. Future forecast of study will be centered on the method enlargement either for further Ligeti's *Atmosphères* excerpts or for music composition focused on timbre variation repertoire.

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