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The Role of Orchestration in Shaping Musical Form: Theory and Practice of a Methodological Proposal and Its Computational Implementation

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ABSTRACT

We introduce a method for computer-assisted analysis of orchestration. We also look into the role that texture and orchestration have in structuring musical form. The method comprises a numerical representation, a hierarchy of 'textural situations' and measures for heterogeneity, diversity and complexity of orchestral-textural configurations.

Keywords: musical analysis, orchestration, musical texture, computational musicology, audio analysis

IZVLEČEK

Predstavimo metodo za računalniško podprto analizo orkestracije. Pregledamo tudi vpliv teksture in orkestracije na izgradnjo glasbene oblike. Metoda vključuje številčni prikaz, hierarhijo »teksturnih situacij« in merila za heterogenost, raznolikost in kompleksnost orkestrsko-teksturnih konfiguracij.

Ključne besede: glasbena analiza, orkestracija, glasbena tekstura, računalniška muzikologija, avdio analiza

1 Orchestration, a Challenge for Musical Analysis

From the end of the nineteenth century, composers began to adopt increasingly systematic orchestration strategies that tended to actively involve this dimension in the structuring of the work, and thus in the expression of musical thought and its consequent perception.[1]

Makis Solomos[2] observes that Rimsky-Korsakov, in his *Treatise on Orchestration* of 1891, insists on the use of instruments "in relation to the categories of *écriture*." Solomos cites, for instance, a paragraph in which Rimsky-Korsakov discusses "the amplification [...] of sound qualities, a technique by which the resonance of two different groups (or the different timbres of a single group) is contrasted [...] to transform a simple timbre into a complex timbre."[3]

Our objective is to establish and evaluate, through experimental applications, a theory and method of analysis that would, by hypothesis, make it possible to evaluate the impact of these techniques on formal dynamics. Even briefly, Walter Piston, in his book on orchestration published in 1955 and now a classic, underlines the relevance of such an undertaking:

> *The objective in analysis of orchestration is to discover how the orchestra is used as a medium to present musical thought.* [...] *It is a means of studying how instruments are combined to achieve balance of sonority, unity and variety of tone color, clarity, brilliance, expressiveness, and other musical values. Ultimately, the analytical process shows the differences in orchestral style between various composers and periods.*[4]

Piston then lists the steps by which he believes a method of orchestration analysis should be carried out.

We can also mention the monumental *Traité* that Charles Koechlin published at the same time.[5] Based exclusively on his immense empirical knowledge, Koechlin advances as far as possible in the systematization of the relationships between the various acoustic parameters that define the sound of an instrument, in particular volumes, intensities, and densities, for which he manages to constitute gradual "scales" that make it possible to put in a situation of relative comparison various instrumental configurations, an approach unprecedented in this field.[6]

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[1] Pioneers preceded them, who formed a genealogy that had not yet been studied extensively, which, starting as far back as Rameau, reached Debussy, passing through the Mannheim School, Gossec, Haydn, the post-revolutionary musical practices in France (Cherubini, Méhul), Beethoven, Berlioz, Meyerbeer and Wagner. The tool we present here aims to help analyze the history of the evolution of orchestration as an active dimension of composition.

[2] Makis Solomos, *De la musique au son: L'émergence du son dans la musique des XXe-XXIème siècles* (Rennes: Presses Universitaires de Rennes, 2013).

[3] Ibid., 31.

[4] Walter Piston, *Orchestration* (New York: Norton, 1955), 355.

[5] Charles Koechlin, *Traité de l'orchestration en quatre volumes* (Paris: Max Eschig, 1954).

[6] Ibid., 288.

In 1985, the Editions Moeck published *Instrumentation in der Musik des 20. Jahrhunderts: Akustik – Instrumente* by Walter Gieseler, Luca Lombardi and Rolf D. Weyer.[7] Unlike traditional treatises, this book understands and approaches instrumentation through the concrete study of the acoustics of instrumental and vocal sounds, considering the manipulation and organization of the sound material as an integral and interactive part of the compositional process – and not as an isolated activity. The extraction of instrumentation data from a large number of contemporary representative works is not intended to establish a catalogue of empirical prescriptions, but rather to provide a basis for understanding the techniques of producing "sound colors" (*Klangfarben*). Instrumentation as a compositional technique is approached by conceptual categories of compositional results, such as comprehensibility (*Fasslichkeit*), distinctness (*Deutlichkeit*), intention (*Absicht*) ..., an approach that breaks with the tradition of the genre and which moreover allows the incorporation and combining of any sound resources, not only of those presented in that book.[8]

As for the most innovative part of the book *Sonic Design*,[9] written about ten years earlier, it resides in the project to develop a theory of "sound color" and orchestration. The authors' criticism of the "common practice" of the musical analysis of their time is striking and reveals their confidence in the validity of their approach:

> *Analysis of sonic design adds a new dimension to musical understanding. It provides a rationale for such features as instrumentation and orchestration, registration*[10] *and dynamics*[11] *– crucial aspects of music, which, until now, have largely escaped analytical understanding. Sonic design is a mode of analysis that accounts for the complete sound of music.*[12][...] *Interference phenomena (especially beats), tone modulation, and noise, regarded so often in the past as negative or irrelevant properties of sound, are now found to be necessary, positive features of sound experience. Indeed, they are fundamental constructive elements of music* [...]. *Ultimately, it must be acknowledged that those modes of analysis and understanding that ignore the supranotational elements*[13] *and the total sound of music are limited and (to say the least) often misleading.*[14]

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[7] Walter Gieseler, Luca Lombardi, and Rolf-Dieter Weyer, *Instrumentation in der Musik des 20. Jahrhunderts: Akustik, Instrumente, Zusammenwirken* (Celle: Moeck Verlag, 1985).

[8] Ibid., 119.

[9] Robert Cogan, and Pozzi Escot, *Sonic Design: The Nature of Sound and Music* (New Jersey: Prentice-Hall, 1976).

[10] I.e. the distribution of sounds between different regions of the instrumental range.

[11] In our approach, we prefer to call them *intensities*.

[12] In italics in the original.

[13] By this they mean elements that are not explicitly codified in the score but are activated at the time of the performance of the work.

[14] Cogan, *Sonic Design*, 397.

Aware that their undertaking was taking them to the "limits of our present knowledge" the difficulties they experienced show how far we have progressed on certain technical aspects – for example, in the analysis of the timbre of the instruments and the various factors involved in the constitution of their sound identity, data that are now widely available, but whose insufficiency was cruelly felt by these authors at the time[15] – although the practice of orchestration analysis has not become so widespread as to occupy the space they called for in the range of tools that should nowadays be commonly used in musical theory, composition or analysis.

In a way, our intentions inherit these *insights* and pursue a similar objective. In this article, we present an experimental theory of orchestration analysis and a practical method of application, followed by a description of our tool to assist in this analysis developed for the *SOAL* library in *OpenMusic*. In a way, our intentions inherit these insights and pursue a similar objective.

SOAL is intended to be useful for a range of analytic purposes, in situations where a 'top bottom' approach is more or equally pertinent that a 'bottom-up' one. The root of SOAL background concept is the *compound sonic unit*, technically defined as the combination and interaction of musical 'primary' components (a collection of pitches) with 'secondary' components – namely intensities, ranges, registering, densities, modalities of statistical distribution of pitches or other low-level elements, e.g. deviations, entropy and others. Being modular, any other *ad hoc* analytic component can be add at any time. The idea is to infer musical structures by comparing the relative sonic qualities of a sequence of such units, which are ranked onto a 'relative complexity' vector. As the reader will see, our proposal will present new functions for SOAL that are able to integrate the *orchestration* dimension into the arsenal of analytical tools already proposed.

Our method is intended to systematically elucidate how orchestration strategies come into play in the formal structure of a work, and what would be its impact in all the dimensions of the compositional practice that contribute to the construction of a musical form based on sound. The field of application can range from the first symphonists to the most recent large-scale productions.

The methodology is based on the information provided by the composer in the score. It involves both quantitative and qualitative evaluation of the various instrumental configurations by means of which the composer articulates a sound dynamics over time, and the way in which they are organized to create more or less dense or complex textures. To do this, we use "Partitional Analysis," which provides the agglomeration and dispersion indices of the instrumental parts.

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[15] Ibid., 365.

In a second stage, if there is one, an audio recording of the work is used, which is analyzed in order to assess the concrete effect of the written prescriptions, and to see to what extent their impact on the form reflects it.

Finally, it is suggested how a synthesis of these two approaches could be achieved. We are of course aware of the difficulty of addressing a field whose "rational and scientific approach is still to be done", and for which "the obstacles that must be overcome in its analysis and formalization are considerable", especially when dealing with music from the second half of the twentieth century, for which "spectral and noisy revolutions have reshaped the relationship with traditional orchestration."[16]

To illustrate our approach in concrete terms, we have chosen, for this publication, to concentrate most of the musical illustrations on Webern's *Variations* Op. 30 (1940), which as we know mark a fundamental milestone in the consolidation of serialism as a composition technique. It is the high level of "timbral chromaticism" of its orchestration that seemed to us to provide a privileged field for experimentation.[17] A sound fragmentation pushed to the extreme – because it sometimes goes down to the note-for-note – offered us the possibility to sharpen the tools under development and to test their sensitivity to this dimension of the compositional technique. However, we are simultaneously experimenting on other corpora, including Beethoven, Berlioz and Rameau, as well as, Murail and other contemporary composers closer to us. However, in order to save on reading and consulting scores, we have preferred to limit ourselves to asking the reader to follow us on an excerpt from this opus 30, in this case bars 56 to 82 of the Edition Philharmonia.

The remainder of this document is organized as follows: the following section elaborates step by step on the proposed model, illustrating it with real musical examples; the third section describes the implementation in *OpenMusic*. The fourth section outlines the analytical conclusions that should be possible to draw from this method and addresses the question of the future interaction between the analysis of written prescriptions and that of the sound recording of the work.

2 A Model for Analyzing Orchestration

We conceive this project as being part of a global project of analysis based on "sonority," or, more precisely, on the concept of a *compound sonic unit*, a term that identifies, at a given moment, a certain sound state, a "instantaneous

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[16] Yann Maresz, "Pour un traité d'orchestration au XXIe siècle," *L'Etincelle*, no. 11 (2006).

[17] Jinho Kim, "Représentation et analyse musicale assistée par base de données relationnelle de la partition des variations pour orchestre op. 30 d'Anton Webern: Vers un système d'analyse musicale assistée par base de données relationnelle" (Doctoral Dissertation, Université Paris IV, 2006), 426 and 434.

synthesis of a certain number of components [of the compositional technique] that act and interact in complementarity."[18] In other words, what we call at the bottom of this flowchart the "Orchestration Relative Complexity" will have to or will be able to interact with other aspects of the compositional technique that we have already modeled and implemented in the SOAL library, such as achronic and diachronic relative densities, harmonicity and sonance rates, periodicity, relative entropy, etc.[19] The objective of this data set is to systematize the qualification of a *compound sound unit* in all aspects relevant to sound, including that of the *orchestration dimension*, when it plays a structuring role.

The orchestration is evaluated on two levels. First, we identify the prescriptions recorded by the composer in the score. We have formalized them within a hybrid component – *LSS Relative Complexity* in the flowchart – which counts the various instrumental combinations used during the work and qualifies them according to the way in which the instruments "agglomerate" or on the contrary "disperse" to generate more or less complex textures. In a second part – on the right side of the flowchart – the audio files of these same configurations are examined using ad hoc statistical and psychoacoustic descriptors in order to assess the concrete effect of the prescriptions, and to see to what extent their impact on the form reflects it. The measurement of the interaction between symbolic prescriptions and concrete sound results is given by the synthetic component *Orchestration Relative Complexity*.

In other words, it is a question of approaching the object of study at the same time at the abstract/symbolic level of the written code and at the concrete level of its effective sound realization, two angles of approach whose convergence and synchrony we feel will not always be the case. The objective is to make the model capable of withstanding these possible dichotomies as intrinsic to the *orchestration* dimension, since the endless uncertainties that can arise in the performance of a work for orchestra in concert situations have never inhibited composers in their desire to fix on paper the smallest details of the performance, as if they were as objective and stable as a metronomic indication.

2.1 Score Analysis: Identification of Instrumental Configurations

2.1.1 The Sonic Resources Index

For the first part of the model, the analysis at the symbolic level, the process consists in identifying, in the score, all the sound configurations selected by the composer. To do this, we first establish a *Sonic Resources Index* (SRI),

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[18] Didier Guigue, *Esthétique de la sonorité: L'héritage de Debussy dans la musique pour piano du XXe siècle* (Paris: L'Harmattan, 2009), 40.

[19] Ibid., 52 and 391; Didier Guigue, "Sonic Object Analysis Library: OpenMusic Tools for Analyzing Musical Objects Structure," Version 5.0. (MacOS, 2016).

which is the non-ordered set of sound resources that are deployed during the work. It takes the form of a textual list corresponding to the nomenclature of sound producing sources mentioned or described. These are, in most cases, and always in the traditional repertoire, the instrumental parts indicated at the top of the score (*Orchestral Parts*), to which is added a list of all the information, textual or symbolic, which aims to produce a particular sound for a given instrument or desk, and which the composer mentions, either in *incipit*, for a permanent effect, or in the score during play, for specific effects - which is probably the most frequent case. This may include, in particular, the various modalities of sound modification by mechanical means (mute or other), electroacoustic means (distortions, transformations by digital processes …), or specific techniques (*flatterzung*, *col legno battuto*, etc.). In some circumstances, the *solo* and *divisi* indications of a desk may be considered sound decisions and are therefore included in the index. In the flowchart, this information is defined as *Instruments, Timbres & Effects*. The listed *Sound Resources* can be constituted, in addition or alternately, by *ad hoc* groups of instruments or objects producing sounds,[20] or by themes, patterns, motifs.[21] For the analysis of Hermeto Pascoal's *Sinfonia em Quadrinhos* (1986) made by our collaborators,[22] an enumeration by group and topics proved more relevant, since the composer conceived his orchestra by blocks of complex sounds, very rarely isolating one or another instrument.

The index therefore encompasses the universe of sounds from which the composer will draw the subsets that will mold the sound plastic of the work over time. Part of Webern's SRI list of *Variations* Op. 30 is shown in the Table below. It is noticeable that there are two different Sound Resources for the

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[20] In future developments of the model, it will be necessary to be able to systematize the inclusion of noninstrumental sounds in the index, whether they have been fixed on a support or whether they are produced in real time, from an acoustic or digital source. To do this, it will be necessary to group them into distinct sound categories according to their physiognomy. Each of these categories will be incorporated into the index as an additional resource. For an overview of the possible techniques for this classification, see Stéphane Roy, *L'Analyse des musiques électroacoustiques: Modèles et propositions* (Paris: L'Harmattan, 2004). However, the reader should keep in mind that, in this part of the analysis, knowledge of the concrete sound characteristics of the resources is not taken into account.

[21] The concept of Sonic Resource is quite close to Tagg's "participant," which "refers to the source (the oboe, lead vocals, kick drum track, scratch sample, alto voice, etc.) that participates in the generation of a strand […] and/or a layer." Participant is a useful notion in music semiotics because it acknowledges the "[…] music as socially constructed activity." In Tagg's model, a "strand" is a wider and not so euroclassical-connoted substitute for "voice," while a "layer" roughly matches our *Local Sonic Setup*. See Philip Tagg, *Music's Meanings: A Modern Musicology for Non-Musos* (New York and Huddersfield: Mass Media Music Scholars' Press, 2012), 447 and 449.

[22] For a first approach to this work see Didier Guigue, and Thiago Cabral, "Entropia e Textura Rítmica na Sinfonia em Quadrinhos de Hermeto Pascoal," abstract, paper presented at *XXVI Congresso da Associação Nacional de Pesquisa e Pós-Graduação em Música (22–26 August, 2016)*, https://docplayer.com.br/121008799-Entropia-e-textura-ritmica-na-sinfonia-em-quadrinhos-de-hermeto-pascoal.html.

flute, depending on whether it is played normally or *flatterzung*. Also observe the two resources for the harp and timbals, and the many differentiated resources for the first violins.[23]

2.1.2 The Local Sonic Setups

A *Local Sonic Setup*[24] is a particular configuration at a given time. A new *setup* is identified each time the composer changes the previous instrumental configuration or modifies a timbre or playing mode of one or more instruments or includes or modifies an electronic intervention. Since, according to our theoretical premises, the *compound sound unit* is the product of the combination of a varied number of components, "the rupture in structural continuity of at least *one of these components* implies […] a rupture in sound continuity and, consequently, identifies a new structural articulation, that is, a new unit."[25] This means that each new orchestral setup has the ability to generate a new unity, since it causes a break in continuity on the sound level. In other words, a *local sound setup* is both a marker of sound discontinuity and a *compound sonic unit* defined by the orchestration criterion.[26]

This reading, which depends only on a careful reading of the score,[27] provides the initial database. Figure 1 illustrates the setup tracking process for some measures of the selected extract from the Webern's *Variations*. In this excerpt, the segmentation process uses 8 LSS, respectively: bars 68 and 69 (the thicker box indicates the most prominent sound unit in the sequence), 70.3 (the segmentation is caused here by the break in the continuity of intensity – change of "nuance" in violas and cellos), 71.2, 72, 73, 74 and 75. The reader will find this sequence in the table in Table 1.

Some scores are more fluid, more progressive than others, manifesting a less clear-cut sonic structure. This means that the segmentation process may have to deal with sequences where the LSS interlock, link together in tiling, rather than by juxtaposition. We show in Figure 2 a page from *Akrata* (1964–1965) by Xenakis with its segmentation.

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[23] For the sake of space saving, the index in the table is interrupted. It actually contains a total of 78 *Sound Resources*.

[24] In this text, *LSS* and *setup* can be used alternatively as synonymous shortcuts.

[25] Didier Guigue, *Esthétique de la sonorité: L'héritage de Debussy dans la musique pour piano du XXe siècle* (Paris: L'Harmattan, 2009), 58.

[26] If other criteria were to complete the analysis, they would be subordinate to it, i.e. they would not have the ability to re-segment the piece into different and contradictory units from the one caused by the orchestration.

[27] The implementation of a computer support for this task makes it necessary to encode the score into a MIDI file in which each of the sound resources is the subject of an independent track. But it is quite possible that this may not be possible in all cases, making human control essential in any case.

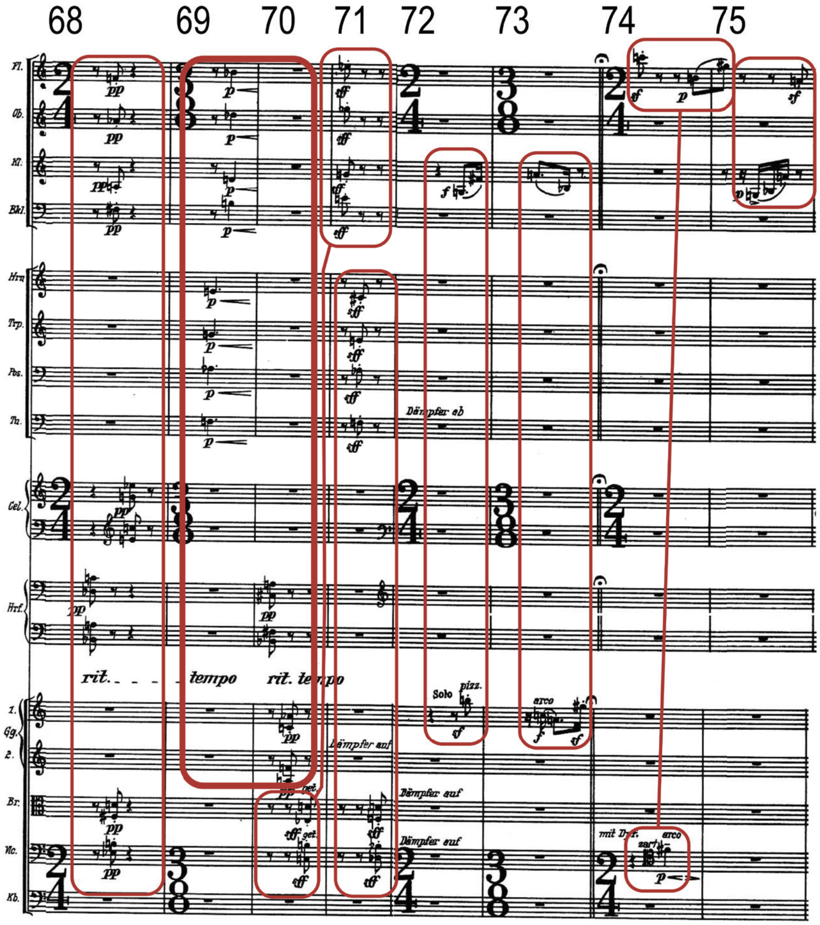

Figure 1: Anton Webern, *Variations*, Op. 30, bars 68–75: segmentation process by local sonic setups.[28]

This listing is formatted in a table in which the list of all the sound resources identified is placed in a column and the setups are arranged in line in sequential order of appearance, labelled with the bar number where they begin. An integer is inserted for each active resource in each *setup*. This integer is equivalent to the maximum number of simultaneous sounds played by the instrument in the analyzed *setup*[29] (1).

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[28] Copyright: Universal Edition.

[29] This information has not yet been incorporated into the model. It would function as an additional

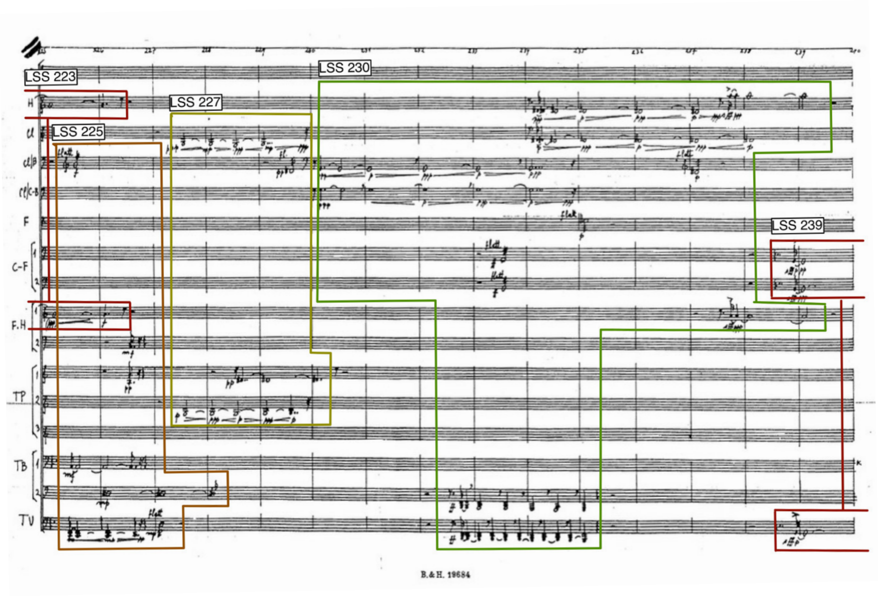

Figure 2: Iannis Xenakis, *Akrata*, bars 225–239: segmentation process by local sonic setups.[30]

This table can be used to map the distribution of instruments during the work (from the information provided by the "Recur" column) and to obtain statistical data on the frequency of their use by the composer. It also allows, using pattern recognition algorithms, to identify how many times and which configurations are repeated, to classify LSS according to the number of SRs they contain, in order to know the most frequent solutions, etc.

If the number of SRs is not disproportionately high, this table can also be displayed as a clock. In this case, each SR is placed on a point on the circle and each LSS is represented by the junction of the points corresponding to the resources used. Figure 3 shows, for example, 4 neighboring LSS in a passage from Beethoven's Trio from the Scherzo of the 3d Symphony, whose SRI contains 24 resources.[31] The instruments are classified from top to bottom according to their register, on the left for strings, on the right for winds. This representation makes the sound contrasts caused by the composer's orchestral writing very visible.

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but "virtual" sound resource (since it does not require a new concrete resource); it also acts, to an extent yet to be studied, on the sensation of "agglomeration" of textures (we define this term below).

[30] Copyright: Boosey & Hawkes for the score.

[31] Namely: woodwinds by two, three horns, two trumpets, timpani, and the string desks that we have chosen to separate from the point of view of sound rendering on the basis of the playing technique (L=*ordinario* and/or *legato*, S=*arco staccato*).

2.1.3 The Weighted Number of Resources (WNR)

The next step is to weight the setups according to the number of sound resources they contain, assigning them a relative value called *Weighted Number of Resources*, or WNR. The basic information is obtained by summing the

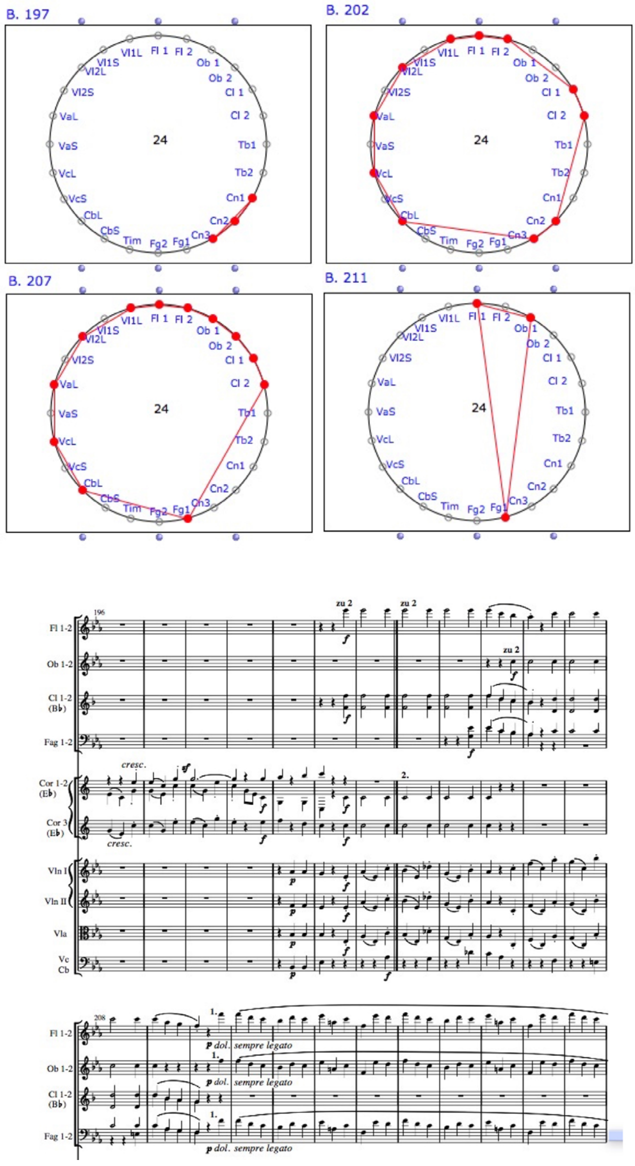

Figure 3: Ludwig van Beethoven, excerpt from the “Trio” from the Symphony No. 3: 4 LSS in clock representation.

non-empty cells of the table (line Total Resources).[32] This must be normalized in order to reach the maximum (1) when this sum is equal to the maximum number of *Sound Resources* that can be used in the same *setup*. The calculation of this maximum will depend on how the Index is calculated. In general, classical symphonic writing induces a selection by desk. The total number of possible resources is therefore over. But in the case of works such as Pascoal's symphony, for which the index is composed not of individuals but of subsets of instruments, the potential number of groupings, based on the available instrumental complement, is close to infinity because there is practically no combinatory impossibility. We are therefore not currently considering a single solution for obtaining the standardization paradigm applicable to WNR.

Table 1: Structured data from orchestration and textural analysis of Anton Webern's *Variations for Orchestra*, Op. 30

Header column refers to the SRI of the work, while the header row indicates the bar numbers. For improved readability, sound resources not employed are hidden. The column recurs refers to how much the specific sonic resource is used during the entire piece.

Recur.	Sonic Res.Index (SRI): bars >	68	69	70.3	71.2	72	73	74	75
35	Fl	1	1	1				1	1
39	Ob	1	1	1					
44	Bb Cl	1	1	1		1	1		1
19	Bass Cl	1	1	1					
14	Hn F sord.		1		1				
34	Tp C sord.		1		1				
18	Tbn sord.		1		1				
11	Basstuba sord.		1		1				
35	Celesta	4							
52	Hp	4	4						
14	Vln I solo arco						1		
4	Vln I solo pizz.					1			
15	Vln I tutti arco		2						
9	Vln II tutti arco		2						
3	Va div. 1 arco			1	1				
3	Va div. 2 arco			1	1				

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[32] Also, it is not obtained by summing the values contained in these cells (see note 19).

9	Va tutti arco	2							
3	Celli div. 1 arco								
2	Celli div. 2 arco			1	1				
10	Celli tutti arco.	2							

Total resources	8	11	8	8	2	2	1	2
WNR	0,64	0,74	0,64	0,64	0,2	0,21	0,2	0,21
Agglomeration	-7	-13	-12	-12	0	0	0	0
Dispersion	21	42	16	16	1	1	1	1
Difference	14	29	4	4	1	1	1	1
Setup Complexity	0,82	1	0,69	0,69	0,2	0,21	0,2	0,21

In the current state of our experiments, and in cases where the SRI is established from individual instruments or desks and the timbre effects applied to them, we have worked with two normalization values: the first is the simple result of the sum of the *Sound Resources* contained in the index. This calculation probably satisfies all works, which contain little or no special sound effects. But it is very likely that in many cases from the twentieth century onwards, this sum will be much higher than the actual number of performers. In *De Natura Sonoris* (1966), Penderecki prescribed eight string playing modes: *sul tasto*, *sul ponticello*, *col legno*, *legno battuto*, three unconventional bow effects, in addition to *ordinario*. Moreover, the first two flutes must play the piccolo alternately. Besides, several types of vibratos and tremolos are described. Finally, the six percussionists must have a very large arsenal of instruments and mallets. Thus, there are many distinct sound resources to index, resources that cannot be played simultaneously, at the same time. The procedure then consists in establishing, on the one hand, the list of the number of instruments prescribed by the composer, classified by desk, and, on the other hand, the total number of sound effects that each instrument is called upon to perform. From this double list we extract the minimum value for each desk. Indeed, either the number of sound effects is less than the number of instruments on the desk, in this case the number of SR corresponds exactly to the number of different timbre effects, or the number of instruments is less than the number of effects requested, in which case it is this number that imposes its limits. The sum of these minima constitutes the normalization paradigm. The Table 2 shows how the *De Natura Sonoris*[33]index could be

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[33] This table is presented for illustrative purposes only and is not intended to be a reference for the analysis of this work.

hypothetically realized. The nomenclature prescribes 86 instruments (Penderecki indicates precisely how many strings he wants for each desk, which is not always the case). The sum of the prescribed different sound effects is 60,[34] but only 52 different sounds can be played at the most at the same time. It is this last value that will be used to normalize the number of resources used for each LSS.

Table 2: *De Natura Sonoris*, no. 1, Sound Resource Index. The score specifies 86 instruments, including the exact number of string instruments needed for each section. The score indicates a total of 60 different sound effects, of which only 52 different sounds can be performed simultaneously.

name	**# instr.**	**# sonic res.**	**n. max simul. res.**
4 fl (2 picc)	4	2	2
ob	3	1	1
eh	1	1	1
cl	2	1	1
bcl	1	1	1
sax	2	1	1
bn	3	1	1
cbn	1	1	1
hn	6	1	1
tpt	4	1	1
tbn	3	1	1
tba	1	1	1
perc	6	24	6
pf	1	1	1
harm	1	1	1
flexatone	1	1	1
vn	24	8	8
vl	8	8	8
vc	8	8	8
db	6	6	6
Total	**86**	**60**	**52**

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[34] Probably much more if we went into detail about the different playing modes and timbres of the percussion.

The formula we have chosen and implemented in *SOAL* for the factoring of these two values (the number of SRs of each LSS and the constant denominator) is logarithmic. Indeed, the logarithmic curve introduces a compensatory equilibrium, by giving more visibility to *Setups* with fewer resources – and for which we hypothesize that they tend to be, as a general rule, the most used – and by bringing as close as possible to (1) those that are close to the maximum. So, for each Local Sonic Setup, we have,

$$\mathrm{WNR} = \frac{\ln(\rho)}{\ln(P)} \qquad (1)$$

where WNR (*Weighted Number of Resources*) is the weighting, ρ is the number of Sonic Resources in the *Setup*, and P is the total number of *Resources* identified according to the methodology adopted.[35]

2.2 An Application of Partition Theory

The impact that the manipulation of sound resources can have on the formal dynamics over time is directly affected by the way the composer organizes them into more or less autonomous flows. It can be said that from quantitative data, the composer makes qualitative choices, and that these choices have an impact on quantitative decisions. The distribution in polyphonic flows characterizes what is known as *texture*, a dimension that signs a composer's personal style of orchestration, because it reflects his way of negotiating instrumental individualities and more or less stratified sound masses. In his classic *Structural Functions in Music*, Wallace Berry proposes a representation of texture according to the degree of independence or interdependence of the voices that compose it.[36] According to him, a texture would be composed, on the one hand, of *real components*, each of which would correspond to a "voice" – i.e. a part that individualizes in general polyphony – and of *sound components* that represent the sum of the sound resources used in what I call here a *setup*. It is the measurement of the degree of independence/interdependence of a resource that groups it into a real component or leaves it outside as an isolated flow.

Although he does not mention it, this reasoning, as well as the numerical representation it proposes, offer obvious convergences with the classical mathematical theory of the partition of integers, initially developed by Euler as early

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[35] The reader can compare the lines *Total Resources* and *WNR*, for a demonstration of the impact of the logarithm on the weighting of the number of sound resources: *Setup* 63, for example (AR column), uses only 16 of the 78 *Sound* Resources indexed.

[36] Wallace Berry, *Structural Functions in Music* (New York: Dover Publications, 1987), 184.

as 1748.[37] According to this one, number 5, for example – a setup of five sound resources, let's say, to stay in our field of study – has seven partitions ($p(5) = 7$), i.e. seven ways by which it can be represented by the sum of other integers, in this case: (5,4 + 1,3 + 2,3 + 1 + 1,2 + 2 + 1,2 + 1 + 1 + 1,1 + 1 + 1 + 1 + 1). A standard form of representing this set in an abbreviated form consists in grouping the "real components" into vectors: 5,41,32,311,311,221,2111,11111, or according to a formula in which the base indicates the part and the exponent its multiplicity $5, 1^4, 2^3, 1^2 3, 12^2, 1^3 2, 1^5$.[38]

We have adapted the first of these representations so that it can be directly read and understood in *OpenMusic*, which is written in Common Lisp. This is how we will write ((5)(4 1)(3 2) … (1 1 1 1 1 1 1 1)). In this case, the scores with the most numbers are those with the highest rate of *dispersion* – Berry speaks of *independence* – hence it follows that representation (1 1 1 1 1 1 1) means that each of our five instruments plays an independent part. In Berry's terminology, we have here a texture with five real components. The nominal value of each figure reflects the *agglomeration* rate, which corresponds to Berry's *interdependence*. In this case (4 1) would be the way to represent a texture with two real components, a soloist accompanied by a chord played by the other four instruments.

In music, however, the possible number of partitions of a finite set of sound resources is much higher than that obtained by partitioning the total, because it is necessary to include all possible partitions of subsets that can be constituted by groups that use only a part of the resources. To use the same scenario, the possibilities of partitions, and therefore textural configurations, of five resources, amount to 18.

The complexity of a texture is therefore directly related to the dispersion rate of its components, as well as being proportional to the number of them. To calculate the rate of agglomeration or dispersion of a given Local Sonic Setup, firstly we need to count every combination, or rather every possible relation of any two elements of the LSS. We can do it by referring to the general formula for finding the number of combinations of p objects from a set of n objects, known as *n* choose *p*:

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[37] George Andrews, *The Theory of Partitions* (Cambridge: Cambridge University Press, 1998); Pauxy Gentil-Nunes, "Análise Particional: Uma mediação entre composição musical e teoria das partições," in *Simpósio de cognição e artes musicais (20–26 May, 2009)*, 343–354; Pauxy Gentil-Nunes, "Particiograma e indexograma: Topologia e dinâmica das progressões particionais," paper presented at *XXI Congresso da Associação Nacional de Pesquisa e Pós-Graduação em Música (22–26 August, 2011)*, https://anppom.org.br/anais/anaiscongresso_anppom_2011/ANAIS_do_CONGRESSO_ANPPON_2011.pdf. In the field of composition, Milton Babbitt is known to have been the first composer to make exhaustive use of the total number of partitions of the number 12 in serial music, by inventing the all partition table. See Robert Morris, "Mathematics and the Twelve-Tone System: Past, Present, and Future," in *Mathematics and Computation in Music*, eds. Timour Klouche and Thomas Noll (Heidelberg and Berlin: Springer-Verlag, 2009).

[38] Gentil-Nunes, "Análise Particional"; Gentil-Nunes, "Particiograma e indexograma"; George Andrews and Eriksson Kimmo, *Integer Partitions* (Cambridge: Cambridge University Press, 2004).

$$C(n,p) = \frac{n!}{p!(n-p)!} = \frac{n(n-1)(n-2)\dots(n-p+1)}{p!}. \qquad (2)$$

For instance, in a setup composed of 4 sonic resources playing agglomerated parts, let's say a woodwind quartet, represented by the singleton list (4), there is a total of 6 unique pairs as

$C(4,2) = 6$, that is
(Fl Ob) (Fl Cl) (Fl Fg) (Ob Cl) (Ob Fg) (Cl Fg)

On the other hand, in a LSS of four soloists playing independent parts, that is (1 1 1 1), when we consider any of its individual real-components or instrument, we find a total of zero unique pairs as $C(1,2) = 0$.

We will refer to the total number of unique pairs of any resource or real component of a given setup as T_2 or simply T. By reworking the equation given at (1), we will define it as a function in the following way:

$$\begin{aligned} T_2 &: \mathbb{N}^* \to \mathbb{N} \\ n &\mapsto \frac{n(n-1)}{2} \,. \end{aligned} \qquad (3)$$

This way, the sucessive total unique pairs when n is mapped to the first eight positive integers, that is $T2$ * (1 2 3 4 5 6 7 8) = ($T2$ (1), ... , $T2$ (8)) is equal to (0 1 3 6 10 15 21 28).

It follows that, in order to calculate the rate of agglomeration of a given local setup, we need to sum the $T2$ value of each of its components. For instance, the rate of agglomeration of the setup represented by the list (211) is given by ($T2$ (2) + $T2$ (1) + $T2$ (1)) which results in 1. It is formally defined by the following function:

$$\begin{aligned} \mathcal{A} &: \mathbb{N}^r \to \mathbb{N} \\ (a_0 \dots\ a_{r-1}) &\mapsto \sum_{i=0}^{r-1} T_2(a_i) \,, \end{aligned} \qquad (4)$$

where the list ($a0$ ... ar–1) represents an LSS, ai each of its elements, that is, its real-components, and r the length of the LSS.

The dispersion index (*d*) is the result of the difference between (*a*) and T[9].

$$D\colon N^r \to N$$

$$(a0 \ldots ar{-}1)\ 7{\to}T2(\rho)\ {-}A(a0 \ldots ar{-}1), \qquad (5)$$

where ρ is the sum, the number of sonic resources of the LSS, that is, $\sum_{i=0}^{r-1} a_i$.

We then obtain a pair of indices (*a, d*) whose visual arrangement in the form of an indexogram contributes to the interpretation of the dynamics of textural configurations on the time axis, by means of a symmetric presentation of *a* and *d* around zero, made possible by transforming (*a*) into negative values.

But the negative of (*a*) has another virtue. When added to (*d*), it forms the sum I, so

$$I(a0 \ldots ar{-}1) = (D{-}A)(a0 \ldots ar{-}1). \qquad (6)$$

This produces a synthetic evaluation that shows the *trend* of the texture, either to agglomeration (when the sum is negative) or to dispersion (positive sum). And, of course, the values give us the graphic plot of this trend. This synthesis seemed to us to be of significant interest for our model because, intended to weight a quantitative data – the number of instruments or resources used – it has the power to modulate it possibly *less*, i.e. to weaken its qualification, when its agglomeration index weighs more than that of its dispersion. In other words, if, as we have argued above, it is the dispersion rate that defines the complexity of a texture, the integration of the calculation of its agglomeration rate allows a more precise calibration. It is therefore this synthesis *I* that we will preferably use.[39] The lower graph in the Figure 4 provides an example of *I* for an excerpt from Rameau, the beginning of the aria "Un Horizon serein," from his opera *Les Boréades* (1764). The upper graph shows the indexogram of values from which the values for *I* (the textural tendency) originate. The analysis will show that the orchestra only produces clearly agglomerated textures to characterize certain events related to dramaturgy. The rest of the time, it is the dispersion of the instrumental parts into rhythmically independent flows that tends to dominate. The comparison of the two representations shows that each can make a specific contribution to understanding the texture of the objects analyzed and their relationships in the overall form.

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[39] It is possible that in some contexts, it is the indices (*a*) or (*d*) alone that may be more relevant. The implementation in *OpenMusic* offers all the alternatives.

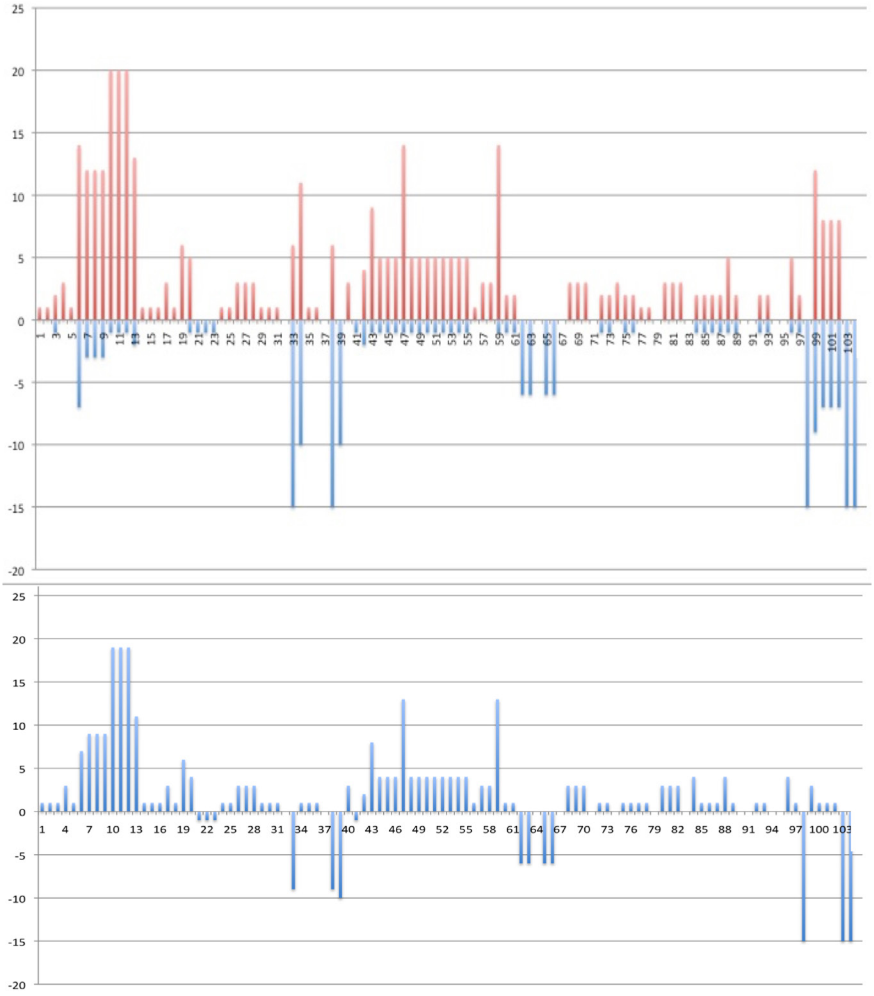

Figure 4: Jean-Phillippe Rameau, "Un Horizon serein" (*Les Boréades*, Act I, Scene IV), bars 1–105. Top: Indexogram of conjugated indices *a* (blue) and *d* (red). Bottom: The tendency *I* of the texture complexity.

2.3 A Qualitative Evaluation of Textures

2.3.1 Relative Voicing Complexity

In order to integrate orchestration into a general model of analysing musical morphologies based on the concept of a *composite sound unit*, it is necessary to place the descriptors and measurements on a single axis of "relative complexity." A solution to obtain a normalization is to divide *I* by the value *T* of the *setup* that has the highest (*max*) number of *Sound Resources*; in other words, by the greatest number of binary relationships possible in a given set of setups. A configuration with a dispersion index equal to this number would in fact represent the greatest possible complexity in the context. We therefore obtain a relative index *RVC* (*Relative Voicing Complexity*).

$$\mathrm{RVC}(a_0 \ldots a_{r-1}) = \frac{\mathcal{I}(a_0 \ldots a_{r-1})}{T_2(\rho_{\max})} \;. \qquad (7)$$

The RVC value is scaled through the application of $\frac{(\cdot)-\min\lambda}{\max\lambda}$, where λ stands for $(a_{0}..ar-1)$.

The partitional analysis, however, is neutral as to the musical criteria that would define the agglomeration and dispersion rates. Berry essentially takes responsibility for the rhythm, direction of contrapuntal lines and interval content. It recognizes three categories of interaction identified by the prefixes *homo-*, *hetero-* and *contra-*, the first of which reflects the "identity" of the parties (interdependence or agglomeration), and the other two, two levels of dispersion (independence or dispersion), the most pronounced of which is characterized by opposing movements.[40]

If heterorhythmia seems in many cases to be the most effective criterion for provoking a dispersion of voices, there are examples for which the textural writing requires other parameters and strategies. Below is a list of the criteria that we have used to date in our various analytical experiments. We have tried to rank them in descending order of effectiveness in terms of their ability to cause dispersion in LSSs.[41]

(1) dominant heterochromy, when the dispersion is caused by the splitting into streams of different sounds – e.g. high-pitched woodwinds against low-pitched brass. It can encapsulate an undetermined number of other criteria which have a less effective influence on complexity; they are placed on a lower hierarchical position;
(2) dominant heterorhythmy (divergence of rhythmic structures, phase asynchrony); It can encapsulate an undetermined number of other criteria, which operate in a lower hierarchical position;
(3) heterokinesis; (divergence of melodic direction) includes contrary motion *stricto sensu*, to which we do not see the need to assign a different weight as Berry does;
(4) heteroarthria (divergence of articulation, typically *legato* versus *staccato*);
(5) heterophony (understood as a homokinetic and homorhythmic texture, but with interval divergences).

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[40] Berry, *Structural Functions in Music*, 193.

[41] This effectiveness is measured primarily by estimating the impact that the criterion has on listening. Further studies are needed to make this classification less subjective.

We hypothesize that the last three criteria only contribute significantly to the qualification of texture complexity in the absence of the first two.

This classification is not static: on the contrary, it is context-sensitive, which means that it may be appropriate to modify it according to the music, and to add or remove criteria.[42] It is also not uncommon to find that in some cases more than one criterion can be considered equally effective in causing dispersion.[43]

To implement this hierarchy, the solution adopted consists in "increasing" [to weight] by a certain percentage the relative indices according to the criterion by which they will have been evaluated. The musicologist decides to which aspect of the texture he will assign each percentage. In the proposed ranking above, a minimum percentage of 5% could be established for criterion (5) and increased in steps of 5% to 25% for criterion (1).[44] These rates are applied to the *RI* values to give the overall *Relative Voicing Complexity* (*RVC*) rate.

2.3.2 Local Sonic Setups Relative Complexity

As mentioned at the beginning of this text, these two groups of data – the weighted number of sound resources used (*WNR*), and how they interact to modulate the sound texture (*RVC*) are closely interdependent. Indeed, the quantity of voices in which a texture can be stratified obviously depends on the number of resources made available. A setup consisting of a single monophonic instrument can only produce a technically "null" texture. On the other hand, it was established that the maximum dispersion – which was assumed to configure the most complex textures – was produced when each of the sound resources played an independent part. But it is quite obvious here too that the complexity effect is once again put into perspective by the number of instruments involved. If there are only two, it is much more likely that their parts will have a higher degree of independence than in a tutti of sixty instruments, which will not prevent the texture of our duo from remaining thin despite this greater independence. In both logical and algorithmic terms, it is therefore clear that RVC weights only make sense as qualitative modulators of *setups*. Because it is the instrumental configurations that, in the first place, determine the possibilities of polyphonic composition. In practice, RVC weights multiply those of WNR, in a way as a metaphor for the *frequency modulation* process. More precisely, the result of this multiplication is added to the value of WNR. The weight of the modulator can also be adjusted, up or down. The result configures what we will call the *Local Sonic Setup Relative Complexity*, a simplified acronym SRC, hence

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[42] For Webern, we have adopted the hierarchy (1) heterorythmy, (2) heterokinesis, (3) heterophony (which rarely occurs); for Xenakis and Pascoal, only heterochromy is considered.

[43] In this case, we apply the criterion that gives the most dispersed partition, i.e. returns the highest quality of complexity.

[44] The steps we are currently adopting in our experiments range from 5 to 12.5.

$$\mathrm{SRC} = \mathrm{WNR} + (\mathrm{WNR} \times \mathrm{RVC}_{\mathrm{w}}) \qquad (8)$$

where w is a weight (a percentage) of the RVC modulator.

The result of this modulation corresponds to a formalization of the complexity of the orchestral texture that reflects the compensatory play between the two components of analysis, the quantitative and the qualitative balance.

The reader should note that the evaluation does not take into account a priori the duration of *setups*, although this can be included, for visual information, in the graphical representations in *OpenMusic* (see Figure 6), since LSSs are segmented according to their sound configuration. They therefore last as long as it does not change. This process can generate segments of very different duration, from a fraction of a second to several minutes. The musicologist may therefore feel the need to refilter the value of SRC according to the relative duration of the LSS, following a logic where the longer ones should acquire more weight. The information required for this support is the intervals between the *onsets* (starting points of the LSS). The unit of evaluation of the size of these intervals can be a beat - this choice is only satisfactory if the work has a stable tempo – or absolute time (for example in milliseconds). This information can only be extracted from a MIDI or audio file of the work.[45] This file must first have been segmented in accordance with the LSSs identified in the partition. It is obviously sensitive to the performers' agogic choices.

The relative duration of each LSS is obtained by dividing its individual duration, either by the duration of the longest LSS of the work, or by the total duration of the work, this second choice generating generally very small values.[46] These values modulate the SRC. If this operator is the multiplication, the previous formula will be rewritten as follows, where t is the relative duration:[47]

$$\mathrm{SRC} = \mathrm{WNR} + (\mathrm{WNR} \times \mathrm{RVCw}) \times t\mathrm{w} \qquad (9)$$

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[45] The MIDI file must contain the tempo data and its variations.

[46] This function is available in SOAL under the name of relative span.

[47] Like RVC, *d* can be weighted by a percentage p.

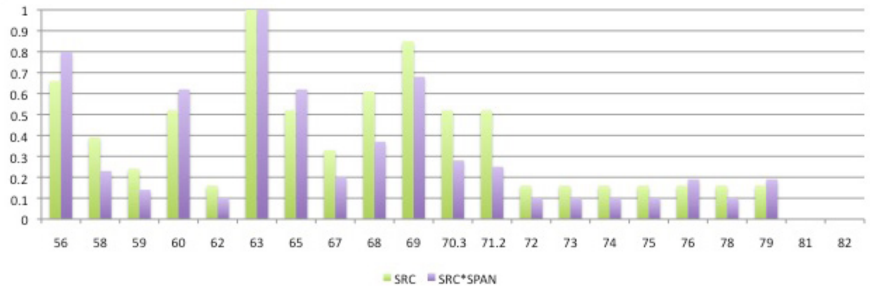

Figure 5: Histograms showing the evolution of SRC weights with or without the inclusion of the relative duration or span (Anton Webern, *Variations for Orchestra*, Op. 30, bars 56–80).

This methodological process therefore emits a final weighting that aims to qualify each sound unit on a complexity vector related to the orchestration strategies adopted, as they can be identified from the score.

3 Implementation in *OpenMusic* and Procedure

In the current state of our work, this process is assisted, initially, by a spreadsheet, in which information of the score is collected. These are then exported to an *OpenMusic* patch. We have implemented a function called soal-texture-complexity, which is located in the "Partitional Analysis" folder of SOAL. Equation *T* was also made available. The *soal-texture-complexity* function gathers all the algorithms and patches developed for this project. The SOAL library is implemented using the Common LISP language and a standalone, python version also exists.

Figure 6 shows the compiled function, in a patch analyzing the Webern extract we have chosen for demonstration. The numbers and letters refer respectively to inputs and outputs, as described below. Some steps and secondary outputs will not be detailed here.

3.1 Inputs

(1) As a main entry, the list of *setups*, described by two arguments (encapsulated list), the first of which contains the partition of each *setup* and the second the partition criterion sequence number.
  (a) First argument: the sequence of integers in the score corresponds to the number of real components, and their value to the number of sound resources each contains. The format adopted is that described in section on partitional analysis.[48] Their sum must correspond to the total number of resources counted in the *setup*.

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[48] By convention, *setups* with zero resources (*Gran Pause*) are identified by the value (0.9) and not (0) which would produce a division error.

(b) Second argument: the order number of the criterion chosen for the score. It starts at 1 (the most "effective" criterion). There are as many order numbers as there are criteria, plus one that will be assigned to the setups without any dispersion, i.e. containing only one real component.[49]

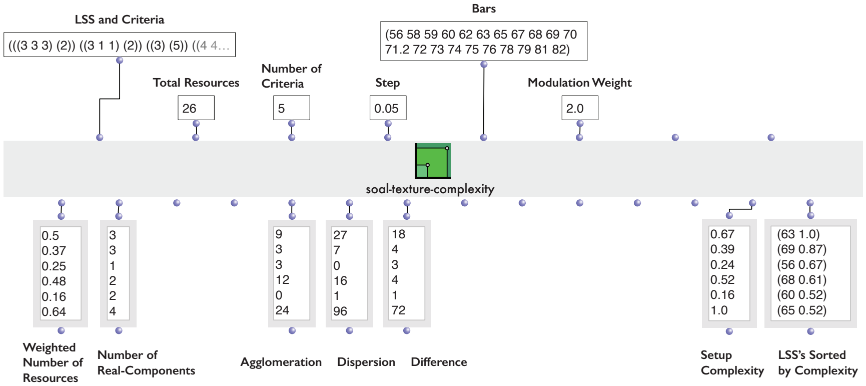

Figure 6: OpenMusic patch with the soal-texture-complexity function prototype in use to analyze bars 56–82 of Anton Webern's *Variations for Orchestra*, Op. 30.

3.2 Resources

The process is currently done manually, in the same table where the various sound resources and setups have been annotated (see Table 1).

Thus, in Figure 6, we can see that the first three setups have the following format:

((3 3 3)(2)) ((3 1 1)(2)) ((3)(5))

What it says: the first setup totals 9 sound resources distributed between 3 real components each containing 3 of these resources, according to partition criterion (2) (in this case, according to our personal choice for Webern, heterokinesis). The second, 5 resources distributed equally among 3 real components according to the same criteria, but of which two components have only one resource each. The third setup is a chord of 3 sounds (3 agglomerated sound resources); the number 5 precisely indicates that no partition criteria are applicable – in an analysis where in this case we adopted 4 hierarchical partitioning criteria.

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[49] In the *Dispersion Criteria* section, we give an example of a hierarchy with 5 criteria. In this case, 6 order numbers will therefore be required.

(2) Here we enter the total number of sound resources indexed in the complete work (*Sonic Resources Index*) – 78 in this case, for the *Variations*.
(3) An integer corresponding to the number of criteria chosen, plus one (see above, 1b).
(4) The step of progression of the percentages that will be added according to the hierarchical weight of the chosen partition criterion; in the figure: 0.05 = 5%.
(5) Receives the list of setup labels (bar numbers).[50]
(6) The Modulation weight of WNR output by RVC output, a number (2.0 in the figure).
(7) The user's choice for Partitional Analysis: (1) relative agglomeration index (*a*); (2) relative dispersion index (*d*); or (3): index of relative sum of ((*a**(-1)) + *(d*)).
(8) Either remove duplicates or not when calculating the real-components.

3.3 Outputs

(A) WNR: Weighted Number of Resources. This is the quantitative part of the orchestration analysis. The figure shows, below the output of the function, in the form of a column in a filebox, the results obtained for the Webern extract, as well as, at the very bottom, these same values represented in a curve (*breakpoint function*).
(B) Real Components: number of real components per LSS. Similarly, the values obtained are shown below.
(C) The *T* index of the total number of resources (a single integer) – for Webern in this case, this index is 120.
(D) Outputs 4, 5 and 6 inform respectively the absolute indices of agglomeration (*a*), dispersion (*d*), and their sum *I*. The values referenced to Webern are shown in the corresponding boxes below.
Output 7 returns the sum a*(-1) + d. Outputs 8 to 10 return the same calculations as (D) but in normalized, i. e. relative values (from 0.00 to 1.00).
(E) RVC (Relative Voicing Complexity): the texture (voicing) complexity, according to Partitional Analysis user's option in input 7.
(F) RSC (Relative Setup Complexity): This is the main function's output. The *Relative Setup Complexity* corresponds to the WNR list (output A) weighted by the RVC list (output E). The figure shows both the list of Webern's RSCs in a filebox and a graphical representation of them (bottom).
(G) orders the setups (labelled by their bar number or string name) according to their relative complexity (the F list values): most complex ones at beginning. In our sample, the most complex setup occurs in the bar 63, and the simplest is the bar 82's. These bars are shown in the figure.

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[50] We have chosen to label the *setups* with the bar number where they start. But a *string* of any kind (alphabetical list, words ...) can be used.

(H) This is not a soal-texture-complexity output, but the combination of that two *OpenMusic* basic tools, x->dx then dx->x, provided the former is fed by the sequence of bar numbers, or any other data relative to the position in time of the LSSs, can be used as the x-coordinates of a breakpoint function curve, thus displaying the points on the horizontal axis according to their relative durations. However, we prefer histograms to curves, because the former induce a linear progression from one point to another, which does not correspond to reality: we are indeed in the presence of configurations that change without transition. The build histogram function allows this representation, in which the width of the histograms is a function of the relative duration of the LSSs.

4 Audio Analysis

4.1 Preparing the Audio Material

The segmentation of the score into units that are coherent from the point of view of orchestration, explained above, must be reproduced identically for the audio file of the work: these segments are called *Local Audio Units*. LAUs are indeed replicas of LSS in the audio file. The aim is to analyse how and to what extent the written prescriptions are implemented, and to evaluate the convergences and divergences between them.[51] The segmentation task is automated thanks to the *Generate Markers* function available in the *Audiosculpt* software.[52] Proper programming of the generator parameters requires some testing and depends in any case on the work and its recording. In our experience, *Positive Spectral Difference* segmentation detects very finely the changes in energy, which, as a general rule, correspond to changes in sound, i. e. *setup*. Then we manually adjust the markers that would not be placed exactly where we want them to be a written simultaneity on the score may not be as synchronous in the real world of its acoustic performance – we add the segments that the score has induced but that have passed unseen to spectral detection (or we reset the function so that it recognizes them), we remove those that do not match the pre-established segmentation – unless we prefer to incorporate them into the original cutting (and return to the previous step).

The next step, still in *Audiosculpt*, uses the *Chord Sequence Analysis* function and its method of calculating the *average spectrum*. For orchestral music, we used a maximum number of between 40 and 60 partials, and an amplitude threshold of -70 dB or related to the sonogram. The results of the analysis

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[51] It is also by this means that comparative analyses of different recordings of the same work can be carried out.

[52] *Audiosculpt* is of course not the only software on the market to offer an automatic generation of markers. But it is the complementary features we use that make it preferable for our project.

(such as the one shown in Figure 10) are saved on the one hand as a collection of small audio files, each of which corresponds to a segment, therefore to a LAU, and on the other hand as a single SDIF file. It is this material that will be required for the analysis of the orchestration itself, in *OpenMusic*.

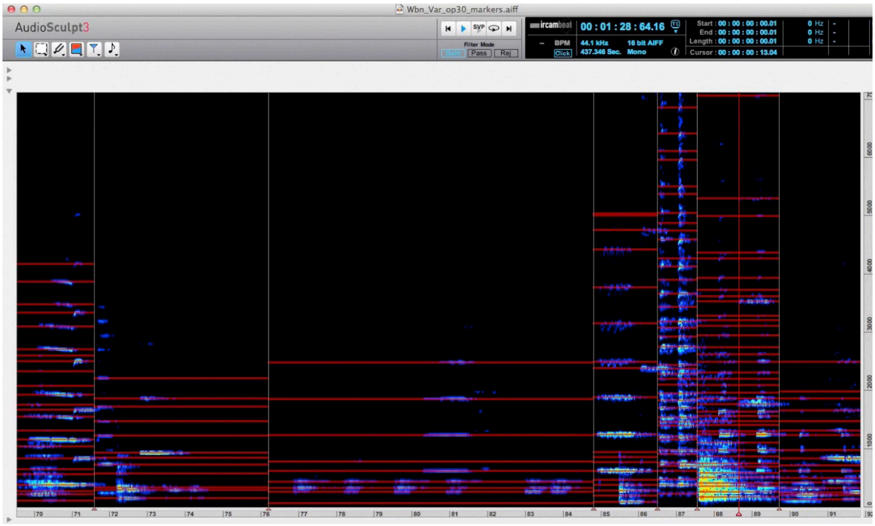

Figure 7: A screenshot of *Audiosculpt* showing the LAU segmentation and the results of the Chord Sequence Analysis by Average Spectrum, for an extract from the same work by Webern. The LAUs are identified by the vertical markers, and each horizontal line corresponds to one of the partials preserved by the analytical process.

4.2 The LAU's for Orchestration Analysis

The main function of setups in their audio format (LAU) is to allow, if the musicologist so wishes, to compare the prescriptions set by the composer with the work. In particular, as we announced at the beginning of this article, it is a question of measuring the real impact of these requirements on the form, and of observing how they are perceived in various performance and audience contexts. This branch of the theoretical model requires computer tools that deal with the sound signal, first and foremost psychoacoustic descriptors. As Philippe Lalitte has already clearly shown in his analysis of *Sequenza VII* de Berio, "the extraction of sub-symbolic information operated by psychoacoustic descriptors offers the possibility of approaching the perception of several musical dimensions such as time […], height (roughness, salience, […], etc.) and timbre (brilliance, inharmonicity, envelope, spectral clarity, etc.)."[53] Many

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[53] Philippe Lalitte, "Du son au sens: Vers une approche sub-symbolique de l'analyse musicale

of them may be adequate to highlight the area of timbre that is most affected by the composer's orchestration, or the one that offers the most salience to perception. The problem lies in the quantity of descriptors available, and the heterogeneity of the information produced. Indeed, it is important to keep in mind that the basic concept of a descriptor is to "flatten" a multi-dimensional component, the stamp, on a single dimension. In other words, it makes a generic and oriented reduction of the signal, depending on the information they are supposed to return. Therefore, relying on them alone would not provide the analysis we need. The idea is therefore to constitute a modular network of descriptors that would be used according to contexts, and to standardize their results on the same vector of relative complexity to which the other components of the model have been subjected. This variable network of descriptors is standardized in our model by the *LAU Relative Complexity* component, acronym *ARC*. The advantage of this formatting is that it can produce a more synthetic, holistic vision of the behavior of sound configurations over time. Indeed, it is not so much a question of qualifying *local audio units* in absolute terms, but rather of evaluating the degree of difference, or *distance*, between one unit and the other in a given field.

However, the development of *ad hoc* descriptors seems essential and is part of the specifications of our future steps. In the meantime, or in parallel, some of the statistical analytical tools offered in the *SOAL* library may be of some help, thanks to its ability to read both MIDI and SDIF files and extract data sets, all standardized on the simplicity-complexity vector. For audio sources, one may speculate that some of the following capabilities of *SOAL* could be useful in our specific context: the calculation of the relative range of the LAU – that is, the distance between its lowest and highest extracted partials; the manner in which the partials are distributed along the spectrum, giving if necessary a statement of the number of partials for each selected frequency band, and a weighting of the LAUs according to the register of occupied bands;[54] how harmonically and/or linearly that partials are distributed along the spectrum; estimates of the relative average amplitude of each LAU and their relative duration.

This last information is already available if you want to weigh the *setups* according to their relative duration. We have mentioned above the possible relevance of this factor and how it could be integrated into the model. One of its most immediate uses is to compare various recorded versions of a work according to the musicians' interpretations of time and tempo indications. For example, we compared the relative durations of two recorded versions of our

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assistée par ordinateur," *Musurgia* 18, no. 1 (2011): 116.

[54] These frequency bands and weights are user-defined. It may be thought that an analysis may wish to weight *setups* with a majority of very low or very high frequencies more heavily, for example, because, in general, they are noisier and have a greater impact on overall sound complexity.

Webern extract with the durations induced by writing time in the score. These are the recordings by Pierre Boulez (1969) and Hans Zender (2007).[55] Figure 8 shows the data. From top to bottom, the first histogram shows the representation of the relative complexity of the LSSs (RSCs) as a function of the relative durations deducted from the number of time/measures each occupies. Remember that the width of the histograms is a function of the value assigned to the durations. The second and third histograms compare these same *setups* according to the relative durations adopted by each of the two conductors in the recordings. The last two repeat the comparison, but this time including the relative duration as a weighting of complexities in the calculation. Our goal here is not to start an analysis of this data, but only to show one of the functionalities of including the analysis of the works' audio support.

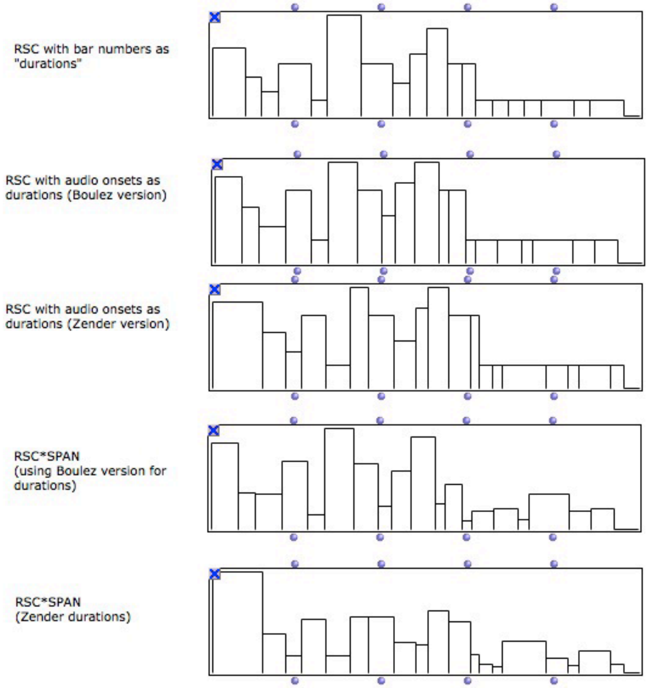

Figure 8: Anton Webern, *Variations*, Op. 30, bars 56–82: comparative analysis of two recorded versions of the work with the relative durations induced by writing.

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[55] Pierre Boulez (conductor), *Variationen für Orchester Op. 30*, London Symphony Orchestra (recorded live in London, 1969), in *Webern Complete Works* (Sony Classical, 1991); Hans Zender (conductor), *Anton Webern: Variations For Orchestra Op. 30 & Franz Schubert: Symphonies No. 1 & 4*, SWR Sinfonieorchester Baden-Baden und Freiburg (SWR Classic, 2007).

5 Conclusions

The aim of the method, whose theoretical bases and practical procedure we have outlined here, is to offer the possibility of evaluating the involvement of orchestration in the structuring of the work. To do so, we started from the axiom that each local sound configuration (an orchestral configuration in the case of symphonic music), or *Local Sonic Setup*, delimits a sound unit. The qualification of these setups according to the number of *Sound Resources* used and the way in which they are distributed to create more or less polyphonic complexity is information that comes in addition to the other dimensions that contribute to the elaboration of the form through sound. Its formatting, a vector on an axis of relative complexity, allows it to be integrated in a way that is compatible with the other dimensions that we have already formalized in our previous research. Correlations and other statistical calculations can be applied to allow a better understanding of the interaction of all these elements in the construction of a musical form based on the articulation of sonorities.

Analysis at the symbolic level, which isolates written prescriptions from the sound results they are supposed to produce, reveals the orchestral technique, style and aesthetics of the composer under study. After all, as we have pointed out, it is on paper that composers orchestrate. The analysis of the concrete results of these prescriptions, based on one or more recorded media of the work, then makes it possible to confront them with the real world of performance, a dimension that is beyond the absolute control of the composer. The creation of a formal flow therefore involves a complex dialectic that this analytical model aims to shed light on.

The results, obtained on these *Variations* by Webern's well as on the other composers in our research program, encourage us to continue our exploration of the multi-instrumental or mixed repertoire with the experimental methodology presented here, focusing, for the time being, on the development of more specific tools for the analysis of the sound carriers of the selected works.

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POVZETEK

Vloga orkestracije pri oblikovanju glasbene oblike: Teorija in praksa metodološkega predloga ter računalniške implementacije le-tega

Predstavimo metodo za računalniško podprto analizo orkestracije. Naš cilj je vzpostaviti formalno razumevanje teh simbolnih dimenzij, ki bi lahko bile enakovredne obstoječim računalniškim pristopom k ritmu in tonski višini. Prav tako poskušamo raziskati vlogo, ki jo ima kontrola teksture in orkestracije pri izgradnji glasbene oblike. Naša raziskava je osnovana na teoretičnih opažanjih o glasbeni teksturi, ki jih je predstavil Wallace Berry v klasičnem delu Strukturne funkcije v glasbi (Structural Functions in Music), in posledičnem številčnem prikazu ter kombinatorični manipulaciji, osnovani na matematični teoriji razčlenitve naravnih števil (integer partititions), ki jo je opredelil Pauxy Gentil-Nunes.

Metoda vključuje: 1) splošni številčni prikaz ki omogoča abstrakcijo in posledično računalniško obdelavo teksturnih konfiguracij; 2) hierarhijo 'kriterijev disperzije' ali 'teksturnih situacij,' ki omogočajo stratifikacijo glasbene površine v različne realne komponente; 3) merilo, ki omogoča kvantifikacijo heterogenosti odnosov v teksturnih konfiguracijah; 4) merilo, ki ocenjuje, kako so različni zvočni viri uporabljeni pri realizaciji teksturnih konfiguracij; 5) model relativne teksturne kompleksnosti, osnovan na diverziteti orkestracije in kompleksnosti alokacije realnih komponent v določenem glasbenem delu. Računalniški postopki so bili implementirani v programskih jezikih Common Lisp (Open Music) in Python. Da bi opredelili vlogo orkestracije v glasbeni obliki, smo predpostavljali, da vsaka zvočna konfiguracija (oz. orkestrska konfiguracija v primeru simfonične glasbe), lokalna zvočna postavitev, predstavlja formalno enoto. Kvalifikacije teh postavitev glede na število uporabljenih zvočnih virov ter načinov njihove razporeditve, s katerimi ustvarjajo večjo ali manjšo polifonično kompleksnost, potem pretehtamo skupaj z ostalimi dejavniki, ki pripomorejo k formiranju glasbene oblike skozi zvok.

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