A Corpus Describing Orchestral Texture in First Movements of Classical and Early-Romantic Symphonies

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ABSTRACT

Orchestration is the art of writing music for a possibly large ensemble of instruments, by blending or opposing their sounds and grouping them into an *orchestral texture*. We aim here at providing a deeper understanding of orchestration in classical and early-romantic symphonies by analyzing, at the bar level, how the instruments of the orchestra organize into melodic, rhythmic, harmonic, and mixed *layers*. We formalize the description of such layers and release an open corpus with more than 7900 annotations in 24 first movements of Haydn, Mozart, and Beethoven symphonies. Initial analyses of this corpus confirm specific roles of the instruments and their families (woodwinds, brass, and strings), some evolution between composers, as well as the contribution of orchestral texture to form. The model and the corpus offer perspectives for empirical and computational studies on orchestral music.

CCS CONCEPTS

• **Applied computing** → **Sound and music computing**; • **Information systems** → **Music retrieval**; *Data encoding and canonicalization.*

KEYWORDS

orchestration, corpus, music texture, layers, symbolic data

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1 INTRODUCTION

Orchestral music is nourished by the musical possibilities of each instrument, by those of their instrument group, and finally by the "sound" of the entire orchestra. In 1844, Berlioz, in its *Grand traité d'instrumentation et d'orchestration modernes* [3, p. 240 of the 1852 translation], wrote:

> *The orchestra may be considered as a large instrument capable of uttering at once or successively a multitude of sounds of different kinds; and of which the power is mediocre or colossal according as it employs the whole or a part only of the executive means belonging to modern music, and according as those means are well or ill chosen and placed in acoustic conditions more or less favorable.*

Writing orchestral contrasts is an art that requires care for the instruments used, and for what each of them plays. Some *composers* write orchestral music. For film music, it is also common today that one or several *orchestrator(s)* arrange, for the orchestra, music composed by others. All of them wisely choose combinations of instruments and distributions of musical parts to create the desired *"orchestral texture"*. Huron [20] defines musical *texture* by characterizing the sound material by its "volume", referring to a number of elements that are simultaneously happening, and its "diversity", meaning the homogeneity or heterogeneity of these elements. In Western music, commonly discussed types of texture are *monophony* (single melodic line), *polyphony* (interweaving melodic lines), *heterophony* (melodic line with simultaneous variations), and *homophony* (melodic line and chordal accompaniment) [10]. In orchestral music, it is the large number of instruments, with both similar and dissimilar timbres, that enables these types of texture, but also more complex ones [28].

As for other topics in music theory and composition, instrumentation and orchestration were increasingly formalized and taught starting from the 19th century. Later orchestration treaties include books written by Rimsky-Korsakov, Forsyth, Koechlin, Piston, McKay [12, 23, 28, 33, 36], or more recently Adler [1]. These treaties cover *organology* and *instrumentation* topics [16] – including abilities of each instrument. The recent ones also add a substantial part on the topic of combining instruments and describing perceptual effects stemming from these combinations. Music conservatories or music departments now offer dedicated orchestration classes.

The digital musicology challenges of analysis and generation of orchestral music come thus from the richness of the combinations of the possible instruments. Understanding and modeling orchestral scores are undeniably linked to the understanding of other musical parameters such as melody, rhythm, harmony, and form. As soon as 1960, Nordgren compared "textural patterns" by modeling parameters including instruments number, range, or register in romantic symphonies [32]. In Music Information Retrieval, works related to orchestral music tackled melody extraction from symphonic recordings [4] or orchestration of piano scores [8] with statistical learning, as well as score-to-audio alignment [30] and instrument source separation [29]. Moreover, arbitrary audio spectra – even actual sounds – may be reconstructed by combining timbres from orchestral instruments [11].

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	year	symphony (first movement)	key	bars	layers	av. len.	av. parts	
Mozart 1756 – 1791	1779	Symph. 32, K. 318	G Major	274	218	3.53	2.73	
	1779	Symph. 33, K. 319	B♭ Major	370	248	3.86	2.17	
	1780	Symph. 34, K. 338	C Major	264	269	3.11	2.47	
	1782	Symph. 35, K. 385, *Haffner*	D Major	204	170	3.95	2.56	
	1783	Symph. 36, K. 425, *Linz*	C Major	287	280	2.70	2.76	
	1786	Symph. 38, K. 504, *Prague*	D Major	302	402	2.42	2.35	
	1788	Symph. 39, K. 543	E♭ Major	309	431	2.06	2.73	
	1788	Symph. 40, K. 550, *Great G minor*	G minor	299	278	3.33	2.50	
	1788	Symph. 41, K. 551, *Jupiter*	C Major	313	360	2.71	2.60	(Figure 1)
Haydn 1732 – 1809	1793	Symph. 99	E♭ Major	202	266	2.73	2.37	
	1793-94	Symph. 100, *Military*	G Major	289	250	3.16	2.66	
	1793-94	Symph. 101, *The Clock*	D Major	351	302	3.14	2.62	
	1794	Symph. 102	B♭ Major	311	262	3.18	2.76	(Figure 3)
	1795	Symph. 103, *Drumroll*	E♭ Major	229	191	3.09	2.82	(Figure 5)
	1795	Symph. 104, *London*	D Major	294	250	3.20	2.69	
Beethoven 1770 – 1829	1800	Symph. 1, op. 21	C Major	297	344	2.19	3.01	
	1803	Symph. 2, op. 36	D Major	360	411	2.59	2.71	
	1805	Symph. 3, op. 55, *Eroica*	E♭ Major	691	610	3.44	2.41	
	1807	Symph. 4, op. 60	B♭ Major	498	353	3.46	2.85	(Figure 2)
	1808	Symph. 5, op. 67	C minor	502	368	3.22	2.89	(Figure 4)
	1808	Symph. 6, op. 68, *Pastoral*	F Major	512	284	4.99	2.33	
	1813	Symph. 7, op. 92	A Major	450	434	3.05	2.72	
	1814	Symph. 8, op. 93	F Major	373	357	3.00	2.83	
	1824	Symph. 9, op. 125	D minor	547	603	3.29	2.54	
				8528	7941	3.14	2.63	

Table 1: The annotated corpus contains 24 first movements of Haydn, Mozart, and Beethoven symphonies. The last three columns give the number of annotated layers, their average length (in bars), and the average number of instrumental parts per layer.

Studies focused on the *perception* of orchestral music, including auditory experiments. They focused on the perceptual timbral response of the combination of instruments [22], *blend* qualities of instruments based on both their own and combined timbres [38], or ways the orchestral composer has to create sounds, by playing on timbral "consonance" or "dissonance" [39]. The taxonomies proposed by McAdams and Goodchild describe orchestral music with such perceptual qualities, relying on "auditory grouping mechanisms" linked to orchestration techniques [16, 26, 27] (see Section 3.1)

Some of these studies built corpora with orchestral scores to help research on orchestration techniques and perception. The Projective Orchestral Database (POD) gathers both piano and orchestral versions of 392 pieces [8]. The Orchestration Analysis & Research Database (OrchARD, currently not openly released)[1] contains high-level auditory effects within orchestral scores. However, as such effects only happen at some places and as not all instruments are involved at each occurrence, the annotations only target a few instruments at specific parts of the score.

Goal and content. We aim at providing a deeper understanding of orchestration in classical and early-romantic symphonies by analyzing how *all the instruments* of the orchestra are organized into textures formed by *layers* with different *roles*. We propose here a first step towards this aim by releasing and analyzing a corpus with annotations, *at the bar level*, of this orchestral texture. With such systematic fine-grained annotations, we intend to provide data that can be used for empirical musicology but also for further studies involving machine learning. Previously, formalized descriptions of texture have been limited to instruments with one or very similar timbral properties, such as string quartets [14] or (on non-separated parts) piano [7]. The orchestra enables to have many more layers and roles.

We thus present a taxonomy for the bar-level annotation of melodic, rhythmic, harmonic, and mixed layers, and openly release an annotated corpus of 24 first movements in Haydn, Mozart, and Beethoven symphonies, totaling 7941 labels on 8528 bars (Sections 2 and 3). We discuss some challenges, describe our annotation and review process, and measure the agreement between annotators (Section 4). Studying this corpus, we show some properties of classical and early-romantic orchestration and give perspectives on orchestration, musicology, and computer music (Section 5).

2 THE CORPUS

Orchestration is worth studying through history. There is no such thing as *the* orchestra, as music with multiple instruments reflects the style and expectations of each era. During more than three centuries, orchestras evolved both in the number of instruments and in their individual sound properties. Baroque ensembles (a few strings, some woodwinds, and natural brass instruments) are very different from huge romantic and post-romantic orchestras such as those envisioned by Berlioz, and 20th-century orchestras

[1] orchard.actor-project.org/

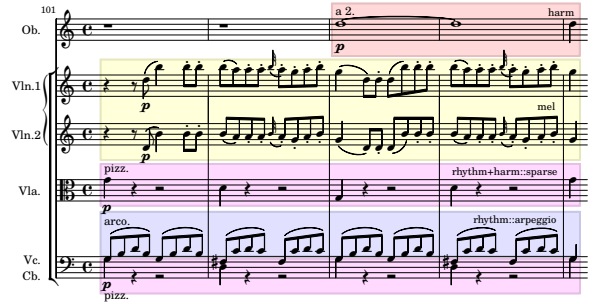


Figure 1: *Allegro Vivace* in Mozart Symphony No. 41 *Jupiter*, bars 101-105, from edition [17]. Four layers can be heard: one melodic (violins – Vln1/Vln2), one bringing some rhythm (cellos – Vc), one other with sparse elements (violas and contrabasses – Vla/Cb), and, two bars later, an harmonic layer (oboe – Ob). In the layers containing several instruments, they are here in unison or octave doubling (-u).

involving new instruments such as the english horn or various percussions [1].

We chose here to focus on the end of the 18th-century "classical orchestra" [37, 44], with strings, woodwinds in pairs, natural horns and trumpets [42], and a pair of timpani. Whereas a significant part of instrumental baroque music was contrapuntal (polyphony), classical symphonies by Haydn or Mozart relied on melodic lines supported by harmonies built on chords (homophony) [18, p. 223]. Beethoven enlarged the ensembles and sought more emotional expression through his writing techniques [18, p. 227] such as frequent and wider modulations.

The corpus contains the first movements of 24 symphonies composed between 1779 and 1824 – late Haydn, late Mozart, and all Beethoven symphonies. In such symphonies, the first movement is generally in sonata form [6, 19], and this is the case for all of these 24 movements, even if some of them have an unconventional structure[2] (Table 1). The alternation between primary and secondary theme zones as well as the unfolding of development gives opportunities for the composer to play with orchestral textures. Such a relationship between texture and sonata form has been studied for string quartets [48], and we aim to provide data to study this relationship in orchestral works (see Section 5.3).

We release under an open-source license the annotations and the Python code to produce Figures 6 and 8. The annotations are stored as both text files (with a description of their syntax) and Dezrann `json` files [13]. The git repository is available from `www.algomus.fr/data`. For further studies, Humdrum `.krn`, MIDI, or MusicXML files for all these movements, which were available through KernScores [21] and `classicalarchives.com` are distributed along with the corpus.

[2]In the Mozart 32nd symphony, a kind of sonata form is split among the first and the third movement [6, p. 93-94].

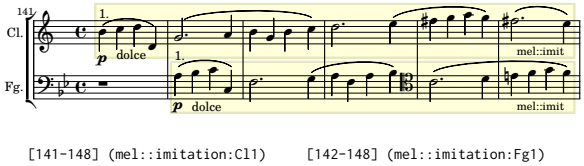


Figure 2: *Allegro Vivace* in the first movement of the Beethoven Fourth Symphony, bars 141-146, from edition [49]. The first clarinet (Cl1) and the first bassoon (Fg1) play a melody in canon, a type of imitation (`mel::imitation`).

3 MODELING ORCHESTRAL TEXTURE AT THE BAR LEVEL

We describe now how auditory grouping helps to define *layers* (Section 3.1), how we annotate layer roles (3.2), relations inside a layer and relations between layers (3.3).

3.1 Grouping Instruments into Layers

Western music is often written based on a *homophonic* texture, *i.e.* the music material can be split into a melody and an accompaniment [24]. On the excerpt of the Symphony No. 41 by Mozart (Figure 1), the violins play a melody while other instruments provide some accompaniment. However, the larger number of instruments involved in an orchestra provides various textures within both "the melody" and "the accompaniment", so that we may consider a more precise way to describe orchestral content.

One may consider the orchestral texture by the *grouping* of instruments among the melodic and accompaniment lines. Goodchild and McAdams described three auditory grouping mechanisms occurring in perception of orchestral music. The *concurrent* grouping makes sounds blend or contrast, the *sequential* grouping connects these events (by stratification or by counterpoint) into different perceived instrumental streams that we call here *textural layers*, and the *segmental* grouping enhances wider musical structure by varying orchestration between layers [15, 16]. These perceptual groupings rely on the relation between the spectra of the instruments, the vertical organization of the notes, and their placement through time [5, 9]. In Figure 1, by concurrent and sequential grouping the listener may hear four layers: the two violin sections (blended), the violas and contrabasses (also blended), the cellos, then the oboe.

Based on those perception studies, we chose here to divide the orchestra into *layers*. A layer will be described as `(role-relation:instruments)`[3]:

```
role := mel | rhythm | harm | (mixed)
relation := u (unison/octave) | p (parallel) | h (homorhythm)
instruments := instrument1 . instrument2 . ...
```

We describe in the next sections, how we detail, for each layer, its *role* among the simultaneous layers in the whole orchestra (Section 3.2) and how we may describe the *relation* of the instruments inside a layer and possibly between layers (3.3).

[3]The actual syntax, detailed in the file accompanying the corpus, allows shorthands to describe at a whole the orchestral texture, including layers identifiers and concise expressions describing instruments joining a layer at a later bar, or layers continuing previous layers.

3.2 Layer Roles

Benward and Saker describe musical texture by establishing different types and classes of textural elements. These classes mainly rely on *melodies* (primary, secondary, or in parallel motion) and *supports* (static, harmonic / rhythmic or both) [2]. Based on this classification and on concepts discussed in literature on orchestration, we assign to each identified layer zero, one, or several *roles*, using the following three basic roles: Melody, Rhythmic Accompaniment, and Sustained Harmony. The roles can be detailed with sub-roles. In the following, we indicate for each role/sub-role the ratio of bars containing that role/sub-role in the annotated layers in the corpus.

Melody (mel, 68%). A melody may be defined as a *thematic* music material perceived as the *foreground*, in opposition to the background accompaniment [47]. In many – but not all – cases, the melody is played on high register instruments [1]. Melody identification is an active field of research [41, 43].

There is usually only one melodic layer (as the violins in Figure 1), possibly written as multiple-part harmony in homorhythm resulting in a chordal texture [28], but there may be more, in particular in a polyphonic texture such as counterpoint (specialized into mel::imitation, Figure 2). There may also be segments in which "no single part has any melodic meaning" [36, p. 99]. On Figure 3, the role of the first violins on bars 40-42 is debatable but we choose here not to consider them as melody. As the other instruments, they mainly fulfill either a harmonic or a "rhythmic" role (see below). We thus restrict the melody to clearly identifiable themes, and we acknowledge that there may be *no melodies* in some segments. Finally, when there is a short rhythmic fragment *inside* a melody, that may last up to two bars, it is still annotated as melody, in order to favor longer layers.

Rhythmic Accompaniment (rhythm, 76%). The orchestra may add *"movement"* [23, III, p. 53], a *pulsating* [31] effect, a *fluttering accompaniment* [1, p. 632], some *dynamism* [33, p. 363], or *agitation* [3, p. 12] to the music, by adding instruments and/or playing "more notes" with the existing instruments. Following the "rhythmic support" category by Benward and Saker [2], we identify here by "rhythmic accompaniment" such roles, that can be, in some cases, further described as the sub-roles below. In the following, a *significant part* of the bar means "at least half of the bar", that is at least two beats in 4/4 or 3/4 and one beat in 2/4 or 3/8.

- rhythm::repeat-note (24%). Repetition of the same note (as cellos and contrabasses in Figure 3) or tremolo. A significant part of the bar is composed of the same note in quarter notes or less.
- rhythm::oscillation (11%). Oscillations around a chord note, with neighbor tones (*ondulation* [1, p. 632]) or between two chord notes (*"batterie"* [23, p. 59], *animated harmony* [33, p. 372]). A significant part of the bar is composed of at least two oscillations between the same notes in quarter notes or less, with the same rhythm.
- rhythm::arpeggio (15%). A pattern that includes chord notes (as the cellos in Figure 1). A significant part of the bar is composed of notes from one chord, with possibly one non-chord tone.

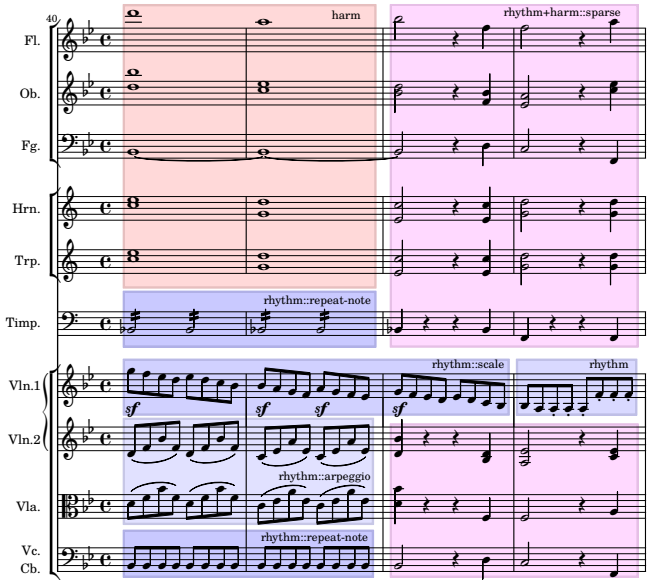
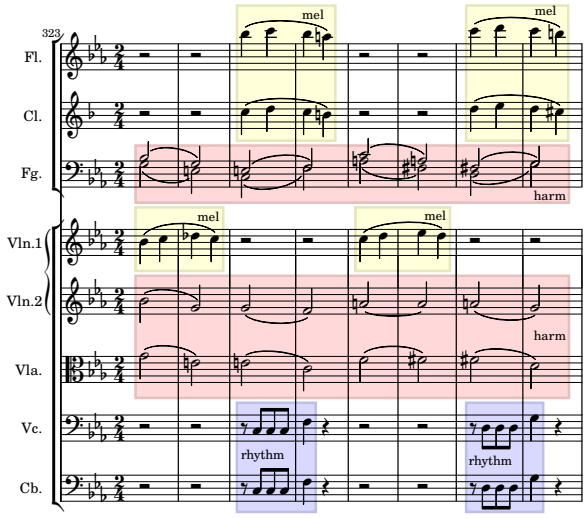


Figure 3: *Allegro Vivace* in the first movement of the Haydn 102nd Symphony, bars 40-43, from edition [34]. In bars 40-41, four layers are heard: one sustained harmony (woodwinds and brass), one with scales (first violins, see text for discussion), two adding movement with arpeggios (second violins and viola), and repeated notes (cellos, contrabasses). From bar 42, the orchestra, in (almost) tutti, plays sparse chords. The annotated layers are rounded to bars (see discussion in Section 4).

- rhythm::scale (8%). Diatonic or chromatic scales (as the first violins in Figure 3). A significant part of the bar is composed of sequences of more than four successive notes – ascending or descending.

For all these roles, the *repetition* of either the same note or an oscillation/arpeggio/scale pattern may underline the rhythmic effect. Moreover, we may depart from these conventions to bring further coherency to the annotation (see Section 4). For example, the famous pattern in the Beethoven 5th symphony (Figure 4) could be annotated as rhythm::repeat-note, but we label it only at rhythm to make it differ from other rhythm::repeat-note in the same movement.

Sustained Harmony (harm, 66%). Called "sustained tones" by Piston [33, p. 371] or "harmonic accompaniment" by Rimsky-Korsakov [36, p. 37], such parts in long notes (mostly in whole/half notes, occasionally quarter notes) are primarily sustained chord notes. Such a role can be held by one single pedal pitch supporting the underlying harmony (as the dominant D pedal on the oboe in Figure 1), or by several pitches, possibly in a multiple-part harmony, often in homorhythm (bassoons, second violins, and violas in Figure 4).



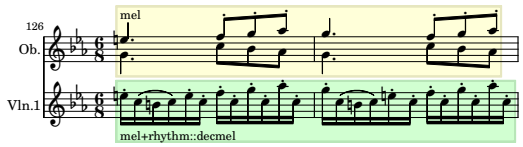

```
[323-330]            (harm-h:Fg.Vln2.Vla)
[323-324,327-328]    a:(mel:Vln1)
[325-326,329-330]    b:(mel-u:Fl.Cl1) / (rhythm-u:Vc.Cb)   {CR 2 ab}
```

Figure 4: *Allegro con brio* of the Beethoven Fifth Symphony, second thematic zone in the recapitulation, bars 323-330, from edition [49]. The melody in unison `mel-u` is played in a Call/Response scheme (`<CR>`) between the first violins `a:{Vln1}`, and the flutes and the first clarinet in B♭ `b:{Fl.Cl1}`. There is with the latter group a rhythmic layer in unison `rhythm-u` on the cellos and the contrabasses `{Vc.Cb}`, playing the famous rhythmic pattern of that symphony. There is a sustained harmony layer, in homorhythm, on the bassoon, the second violins, and the violas `(harm-h:Fg.Vln2.Vla)`.

Mixed Roles. These three basic roles are not independent – most of the time, melodic, and rhythmic parts are grounded into harmony, and harmonic layers may also present some melodic or rhythmic features. Most layers can be annotated as either melodic, rhythmic, or harmonic, but some common ambiguous cases can be better described using two particular mixed roles:

- rhythm+harm::sparse (30%). Isolated chords (often homorhythmic) called "*secco*-like chords" by Adler [1, p. 590] (as the tutti in Figure 3), or single notes (often on low register instruments, such as in Figure 1), that may emphasize either strong beats or counter-beats. Such a layer should include at most two notes in a 4/4 or 6/8 bar, and one note in 2/4 or 3/8, separated by rests.
- mel+rhythm::decmel (4%). Called "decorative variation of the melody" by Piston [33, p. 371], "harmonico-melodic phrases" by Rimsky-Korsakov [36, p. 99], or "heterophony" [28], such phrases combine at a single instrument the melody with a more (or less)"rhythmic" texture (Figure 5). We annotate such a layer when the "underlying" melody is found in another layer. Otherwise an ornamented melody is still annotated as melody.

Note that the conditions for assessing a role can be adapted depending on parameters such as meter or tempo. For example, on slow movements (or, in our corpus, introductions to first movements), what is a "significant part of a bar" or a "number of notes in a bar" can be rather evaluated on only a portion of the bar.




```
[126-127] (mel-h:Ob) / (mel+rhythm::decmel:Vln1)
```

Figure 5: *Allegro con spirito* in the first movement of the Haydn 103rd Symphony, bars 126-127, from edition [34]. The main melody is played by the first oboe (Ob), while the first violins (Vln1) are playing a "decorative variation of the melody" [33], composed of the same melody played in sixteenth notes with ornamentations on counter-beats.

3.3 Relations inside a Layer and between Layers

Relations inside a Layer. We follow [14] in describing how the parts of a layer relate to each other. Parts in the same layer can be (with increasing similarity) in homorhythm (h, 24%, as the (almost) tutti chords in Figure 3), parallel motion (p, 9%), often in thirds or in sixths, or in octave or unison doubling (u, 29%) (second violins and violas in Figure 3). Such relations are tagged when they apply to most of the parts: a parallel motion can be partly in thirds, partly in sixths, and include other notes [14].

Relation between layers: Orchestral Effects as Meta-Layers. Perceived within a *segmental* grouping, orchestral effects emerge from successive layers with varying orchestration [16]. These effects are not the focus of this study, but, as an example, we encoded "Call-and-response" (CR) schemes (see Figure 4 and syntax in the corpus files). Called "transference of passages and phrases" by Rimsky-Korsakov [36, p. 107], or "antiphonal writing" by Adler [1, p. 273], they are sequences of concurrent layers in which the instrumentation and/or the roles of involved instruments periodically change (see Figure 4). There is an average of 15.3 CR per movement.

4 ANNOTATION METHODOLOGY

The layer roles exposed in the previous section reflect common music concepts and are discussed in orchestration treatises. However, as every high-level musical concepts, they are difficult to define formally, and different annotations on the same music often make sense. The next paragraphs discuss sources of diversity between annotators (Section 4.1). Nevertheless, our annotation process aims at some consistency between annotators (Section 4.2). We finally measure the diversity of such annotations (Section 4.3).

4.1 Annotation Challenges and Diversity

It is tedious to define *rules* to prefer one analysis over another one, as the precedence rules of Lerdhal and Jackendorff [25]. Ambiguity and complexity are part of the music, and probably contribute to make it enjoyable.

When describing the orchestral texture, even in relatively simple cases [50], the same phrase can be perceived as melody or accompaniment relying on the listener's background [45]. On orchestral music where some annotators hear 3, 4, or sometimes 5 or 6 layers, there can be variations between listener perceptions and annotator choices. Moreover, the interpretation by some conductor and orchestra may emphasize some roles. Some roles do overlap, and rhythmic sub-categories can be difficult to distinguish – the results in the next section will consider together all rhythm layers. In Figure 3, where we chose to consider the timpani as rhythm, it could also be heard as harm.

Finally, layers do not follow bars exactly. The annotation at the bar level sometimes hides layer changes within a bar. Altogether, our modeling enables to formalize different analyses of the same music. The next paragraphs discuss how we designed our process to nevertheless ensure some coherency in the annotations and to enable some corpus analysis.

4.2 Annotation Process

Annotations and reviews were done by the four authors. We are researchers and PhD students in computer music, with an academic background in computer science and with a music high-school training in flute, violin, piano, music theory, and music analysis. One of us has a prize in orchestration from the Conservatoire de Roubaix (France).

The annotation and reviews were done primarily on score (both on paper and on screen) with also access to recordings. We used the Dezrann web annotation platform [13][4] to share annotations and to provide feedback to the annotators.

The modeling and the few rules – in particular on the number of elements to consider some layers – presented in the Section 3 were designed after preliminary annotations and discussions between the authors, to disambiguate some difficult cases. We found that doing a bar-level annotation helps. Indeed, "rounding" the boundaries on bars prevents difficult questions on defining precise boundaries of each layer. More importantly, such a bar-level annotation still implies looking to both other instruments and neighboring bars:

- The definition of layers can *be affected by other instruments*. As an example, the same pattern in the bass might be categorized as rhythm or as melody if another melodic layer is already present or not in another instrument. However, there might be no melody in some segments.
- Annotations *favor longer layers (several bars)*, following sequential grouping. However, a melodic or a rhythmic layer finishing on the first beat of a bar is not extended to that bar (as the layers of bars 41-42 on Figure 3).

The reviews were primarily done to enforce coherence of each annotation, mostly suggesting corrections for obvious mistakes or discussing on some groupings.

4.3 Measuring Annotation Diversity

To measure annotation diversity, several annotators independently analyzed the first movement of Mozart Symphony No. 36 (two annotators) and the exposition in the first movement of the Haydn Symphony No. 99 (three annotators), and we compared these annotations before any review.

The *grouping* is strictly the same between at least two annotators in 70% of the bars in Haydn 99 and 48% in Mozart 36. Disagreement mostly comes from splitting a layer in multiple ones or defining their limits. By counting how pairs of instruments are well combined in a bar, there are 92% of those pairs in Haydn 99 and 67% in Mozart 36 where at least two annotators agree.

Focusing on the *roles* (and gathering all rhythm subroles), the three (resp. two) annotators strictly agree on the role of 64% of instruments within a bar for Haydn 99 (resp. 76% for Mozart 36) (data not shown). Such disagreement often stems from considering a phrase as either a melody or a rhythmic accompaniment, like the violin part in Figure 3. However, there may be ambiguities in identifying layers and roles, both in mixed roles (such as between mel+rhythm and rhythm) and in not clearly affirmed roles (no role annotation for one of the annotators, as in 13% of the corpus). Taking into account these cases, agreement reaches up to 77% for Haydn 99 and 82% for Mozart 36.

This confirms that that our model and the syntax can help to identify different viewpoints and/or fragments with ambiguities, but also that our model enables a good agreement on a large majority of layers, enabling some corpus analyses.

5 RESULTS AND DISCUSSION

We now highlight and discuss properties of the corpus concerning instrument association (Section 5.1), roles (5.2), and their link to form (5.3), and conclude while providing perspectives for further work (5.4).

5.1 Instrument Association

Instruments of the same family (woodwinds, brass, strings) are more likely to play in the same layers (Figure 7, lower triangular part). Brass is more combined with woodwinds than strings: the string section is indeed rarely perceived as blended with the brass section [36, p. 61]. Timpani are more often associated with brass than with other instruments ([12, p. 46], [36, p. 117]). The pair of instruments that can be found most often together in the same layer are cellos with contrabasses (91% of the bars where both are playing).

The difference between instrument families is very significant in call-and-response (CR) schemes (Figure 7, upper triangular part). The alternation involving instruments of different families accounts for more than 70% of the annotated CR (including 48% of alternation between strings and woodwinds), whereas intra-family CR are below 25%.

5.2 Instrument Roles

Strings play 84% of the bars in the corpus, woodwinds 57%, and brass 45%. The distribution of roles among instruments confirms common knowledge that the instruments and their families play different roles (Figure 6, left).

The melody is mostly devoted to strings (73% in Mozart (M), 66% in Haydn (H) 53% in Beethoven (B)) – especially to, as expected, first violins (Vln1, 28% (M), 26% (H), 18% (B)). Note that lower instruments also take a significant part in melody: second violins

[4] www.dezrann.net

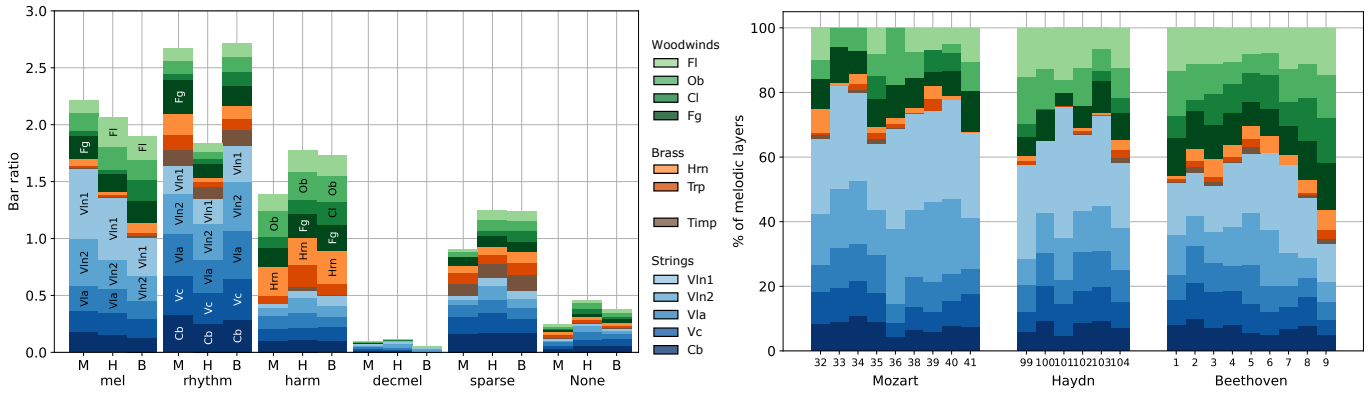


Figure 6: Distribution of instruments by role, composer, and piece. In each family, instruments with highest register are represented with lighter shades. Each area represents the number of bars in which an instrument plays the corresponding role. (Left) All roles are normalized on the total number of bars from each composer (M: Mozart, H: Haydn, B: Beethoven), but each instrumental part is counted on its own. For example, first violins (Vln1) play in a melodic bar 61% of the bars in Mozart movements in the corpus, and the number of melodic bars (considering all instruments) is 222% of the number of bars in Mozart movements. (Right) Focus on the melodic roles on each movement of each composer, normalized on the total number of melodic bars for each movement.

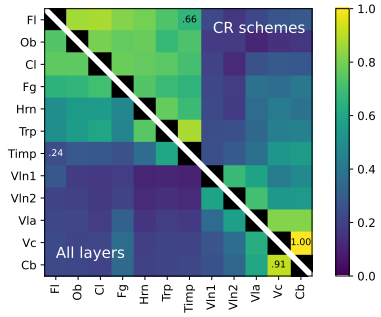


Figure 7: Association of instruments on 19 movements in the corpus. For each pair of instruments, the cells show the ratio of bars when they are in the same layer to the number of bars when are both playing (bottom left) or when they are both playing in a call-and-response (CR) scheme (top right). As an example, flutes (Fl) and timpani (Timp) are in the same layer in 24% of the bars when they are both playing, compared to 66% when one considers only the bars in CR passages when they are both playing.

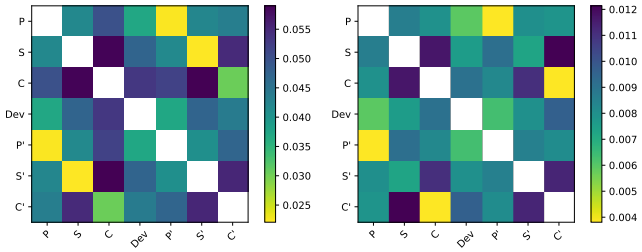


Figure 8: Textural (left) and instrumental (right) disparity of main sonata form sections (P/S: Primary/Secondary thematic zones, C: Conclusion, Dev: development). P'/S'/C' are in the recapitulation. The cells represents the mean of euclidean distance between vectors representing the occurrence of each role (left) or of each instrument (right) within each section.

(Vln2), viola (Vla), cellos (Vc), and contrabasses (Cb) account for 63% of the mel taken by strings. Most of the time, they play melody either in unison or multiple-part harmony with Vln1, but also, in 9% of the cases, they play the melody without Vln1. On the other hand, the harm role is mostly on woodwinds (46%) and brass (24%). The horn is particularly used in harm (47% of all layers with the horn, compared to an average of 21% for the other instruments) [35, p. 50]. The timpani plays rhythm and sparse chords. It also plays frequently in tutti passages (34% of layers, compared to 19% for the other instruments, data not shown).

The roles can also be studied among the composers or even the pieces. For example, Figure 6 (right) shows the distribution of *melodic* layers among the instruments. In romantic music, winds tend to have a more important place in melody [35, p. 70]: the proportion of wind instruments in melodic layers raises from about 30% for Mozart and Haydn to 47% (± 5%) in Beethoven. This rise is significantly greater than the rise of woodwinds and brass within all layers (42% M, 44% H, 48% B, data not shown).

5.3 Texture and Form

Instrumentation and texture are linked to form [46, 48]. Considering movements of the corpus that strictly follow a sonata form, we evaluated the similarities between sonata form sections based on their textural roles composition and their instrumentation. We consider the L_2 distance, normalized between 0 and 1, between two vectors containing the distribution of roles in two sections of the sonata form.

The sections having the most similar textures are primary theme zones from the exposition (P) and the recapitulation (P') (distance of 0.022 ± 0.005), and secondary theme zones from the exposition (S) and the recapitulation (S') (0.022 ± 0.009). These P/P' and S/S' couples are significantly more similar that the other couples of sections (average distance of 0.046 ± 0.003, Figure 8, left). Remarkably, this *textural* similarity between the exposition and the recapitulation is more pronounced than the *instrumental* similarities (Figure 8, right).

The recapitulation may be indeed a re-instrumentation of the exposition, but still keeping similar texture. As an example, a fragment of the first movement in the Beethoven 5th symphony in the exposition (bars 75-82, not shown here) had three layers with the melody on the first violins, whereas the related fragment in the recapitulation (bars 323-330, Figure 4) has the same layers but with a call-and-response on the melody between first violins and some woodwinds.

5.4 Conclusions and Perspectives

We proposed a taxonomy for bar-level annotation of the classical/romantic orchestral texture and created a corpus of 24 first movements of late Haydn, Mozart, and all Beethoven symphonies, with 7900+ layer annotations. Our analyses confirm the different roles of the instruments and their families in this corpus, in particular, the use of strings and the increasing importance of winds in Beethoven's works, as well as the link between texture and form.

These results may seem expected. As symbolic encoding of the full orchestra scores are available for these pieces, this corpus may enable further empirical studies on orchestration, involving scientists with more diverse expertise. Further studies could link bar-level texture to higher-level orchestral effects and style, or focus on other topics on melody, harmony, rhythm, and/or form, but also on organology and acoustics. The corpus may also enable or improve studies involving Machine Learning, both in texture analysis from scores, in (semi-)automatic transcription from audio, or in music generation tasks empowered with texture. Indeed, the layer-based representations of texture introduced in this paper could be suitable for modeling such problems. A texture model could also be used as a constraint or a conditioning variable for generative tasks.

Perspectives include improving the taxonomy, in particular to better identify and describe ambiguous cases with different analyses of the same music, while better studying inter-annotator disagreement [40]. Further studies could extend and use such bar-level annotations to romantic works such as symphonies by Berlioz or Mahler or to 20th-century music. Such orchestral music will generally have an increased complexity, with more diverse instruments, playing techniques, and textural effects. It will also be more challenging to find encodings of coherent corpora with full orchestral scores.

[5]The editions (and translations) on several treatries on orchestration span decades. We indicate here the date of first edition in the original language, or, when possible, the completion of the work (Rimsky-Korsakov and Koechlin being posthumously edited years after their completion), and the last edition used here for page reference.

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