

Study of Instrument Combination Patterns in Orchestral Scores from 1701 to 2000

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ABSTRACT

Orchestration is the art of combining instruments to realize a composer's sonic vision. Although some famous treatises exist, instrumentation patterns have rarely been studied, especially in an empirical and longitudinal way. We present an exploratory study of instrumentation patterns found in 180 orchestral scores composed between 1701 and 2000. Our results broadly agree with qualitative observations made by music scholars: the number of parts for orchestral music increased; more diverse instruments were employed, offering a greater range of pitch and timbre. A hierarchical cluster analysis of pairing patterns of 22 typical orchestral instruments found three clusters, suggesting three different compositional functions.

I. INTRODUCTION

There exist a number of classic orchestration treatises (e.g., Berlioz, 1855; Widor, 1904; Rimsky-Korsakov, 1912/1964; Koechlin, 1954-9; Piston, 1955; Adler, 2002). These books tend to offer a survey of acoustic properties of instruments, often according to the instrument family, such as pitch range and timbral characteristics in distinctive registers. They also provide recommended or disparaged instrument combinations with little systematic discussion regarding why certain examples work whereas others do not. There is surprisingly little scientific literature on the implicit principles that might guide composers' choice of instrument combinations. This lack of existing knowledge motivated us to survey the instrumentation patterns found in orchestral music. As a first step, we took an exploratory rather than hypothesis-driven approach.

In one of few empirical studies of orchestration, Johnson (2011) examined the instrument combination patterns found in the orchestral music of the Romantic period. He coded the instruments sounding at a randomly selected moment (*sonority* hereafter) from each of 50 orchestral scores and performed hierarchical clustering based on the combination patterns. The results revealed three clusters, which he dubbed *Standard*, *Power*, and *Color* (SPC) groups. The *Standard* cluster consisted of violin, viola, cello, contrabass, flute, oboe, clarinet, and bassoon. The *Power* cluster comprised piccolo, trumpet, trombone, French horn, tuba, and timpani. The *Color* cluster included English horn, cornet, harp, bass clarinet, and contrabassoon. He suggested that the three largest instrument clusters reflect different compositional goals: *Standard* instruments represent a sort of default instrumentation; *Power* instruments are used to convey energy, forcefulness, or potency; and *Color* instruments are typically deployed to produce novel, exotic, or idiosyncratic effects.

Inspired by Johnson's study, we explore the patterns of orchestration in a more longitudinal setting within a historical context, focusing on changes between 1701 and 2000. We examine the rise and fall of various orchestral instruments in terms of *instrumentation presence* (how often an instrument is

included in an orchestral work) and *instrument usage* (how often an instrument is actually sounding in a piece).

II. METHOD

We first divided the 300 years into six 50-year epochs. Then in each epoch, 30 orchestral compositions were selected. In selecting the scores, we made use of the *Gramophone Classical Music Guide* (Jolly, 2010), *The Essential Canon of Orchestral Works* (Dubal, 2002), and the *list of composers* on Wikipedia. The composers were grouped into three tiers: Tier-1 for those listed in both the *Gramophone Guide* and the *Essential Canon*; Tier-2 for those listed in any one of the two books; Tier-3 for those listed only on the Wikipedia page. For each epoch, we started with a list of composers who might belong to the epoch, based on their birth and death years. We would sample one work per composer starting from Tier-1, based on the year of composition (or publication). If more works needed to be sampled, we would move to Tier-2 composers then to Tier-3. Sampling continued until 30 works were selected, or the list of composers was exhausted, in which case we would restart from Tier-1 composers. Sometimes a composer wrote works in more than one epoch. In such case, this composer's works would be sampled in both applicable epochs. In any case no more than three works by a single composer were sampled across all epochs. In terms of scores, we used those available at the OSU music library and the International Music Score Library Project (IMSLP).

From each score, 10 sonorities were randomly sampled and coded for instrumentation, pitch, dynamics, tempo, and year of composition. In terms of pitch, the concert pitch was coded. The dynamic level was identified according to the most immediately preceding dynamic marking, which is often an Italian abbreviation such as *mp* or *ff*. The markings of crescendo or decrescendo that modifies dynamics was also coded as "+" or "-". Hence, for example, "*p* followed by decrescendo" would be coded as "*p*-". Trills and ornaments were coded as the pitch of the main note. Articulation marks such as *staccato* or *sforzando* were ignored.

Tempo terms were coded as notated in the score by the composer. The Italian tempo terms (such as *Andante*) have become more or less a norm in Western classical music. However, many terms convolved style or genre terms with tempo—as in the term *gigue*. Although these terms might have implied specific tempos at the time they were used, from the modern vantage point the specific tempos implied are ambiguous. We also observed an increase of non-Italian tempo terms and/or tempo designation with metronome markings (such as $\text{♩} = 72$) through the years.

Over the 300 years some instruments went through stages of development. For the purposes of this study a number of instruments were deemed equivalent *a priori*. For example, the baroque transverse flute was deemed the same as the modern Boehme metal flute (hence both were coded as flute).

Additional questions of equivalence arise with regard to keyboard instruments. In some cases—such as with J.S. Bach’s concertos—keyboard instrumentation may be ambiguous with a simple part name of *Clavier* (keyboard). In practice, this may have been harpsichord, fortepiano, or organ. Since our aim is to track changes over history, we resolved to interpret the keyboard instrument according to the practices at the time of composition. Thus, we elected to code works composed during or before 1780 as for harpsichord, and those after for piano, following the keyboard music culture around Mozart’s time. Table 1 identifies instrumental equivalences for this study. The coding of continuo parts also raised special considerations. Unless the instrumentation was specified (such as bassoon, cello, and harpsichord parts designated as continuo as a group), the continuo part was encoded as simply continuo. No effort was made to realize figured bass notations. Instead, figured bass was simply coded as the bass pitch.

Table 1. List of historic instruments and their modern equivalences

Historic instruments	Modern(equivalent) instruments
Chalumeau, Basset Horn	Clarinet
Transverse flute, Flauto d’amore	Flute
Oboe d’amore, Oboe da silva, Oboe da caccia	Oboe
Hunting horn, Corno da caccia	French Horn
Baritone horn, Euphonium	Trombone
Viola da gamba	Cello
Violone	Contrabass
‘Keyboard’ or ‘Clavier’ before 1780	Harpsichord
‘Keyboard’ or ‘Clavier’ after 1780	Piano

III. RESULTS

The resulting sample set included a total of 165 parts employing 91 unique instruments. Many of these parts were of common orchestral instruments (such as violin, flute, and trumpet), whereas some parts disappeared in history (such as continuo). Some other instruments appeared more often with advancing years, including percussion and wind instruments often exhibiting extended pitch and timbre ranges (such as alto flute or contrabassoon). Analyses were carried out using instrumentation presence and instrument usage.

First, we might want to study the change in ensemble size over time. Due to the practice of sometimes having more than one instrument playing the same part, we do not have data for the total number of instruments required to perform a given piece of music. However, we can still examine the total number of parts notated in the score, which is likely to be proportional to the ensemble size. Figure 1 shows the total number of parts for the 180 orchestral scores in our sample. Each dot represents a score, with the corresponding

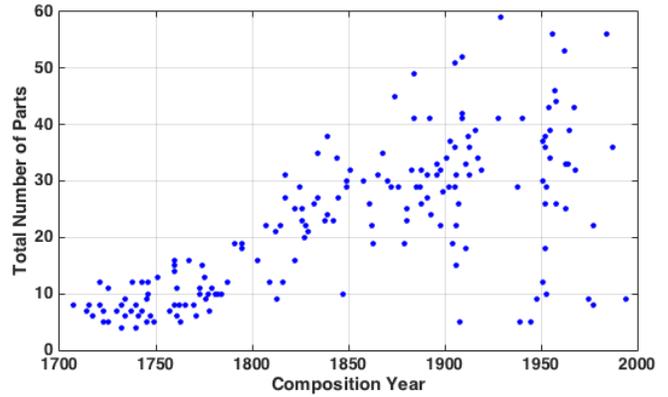


Figure 1. Scatterplot of the total number of parts specified in an orchestral score and its composition year

composition (or publication) year on the horizontal axis and the total number of parts specified in the piece on the vertical axis. We can observe a constant growth of the number of parts until around the mid-20th century, after which time smaller-scale compositions started to reappear.

Figure 2 shows the instrumentation presence (top) and instrument usage (bottom) of string instruments. Even though cello and contrabass were not typical in early 18th century orchestras, they quickly became a core member of an orchestra in the 19th century and onward. The usage patterns of these instruments show a decreasing pattern through the years.

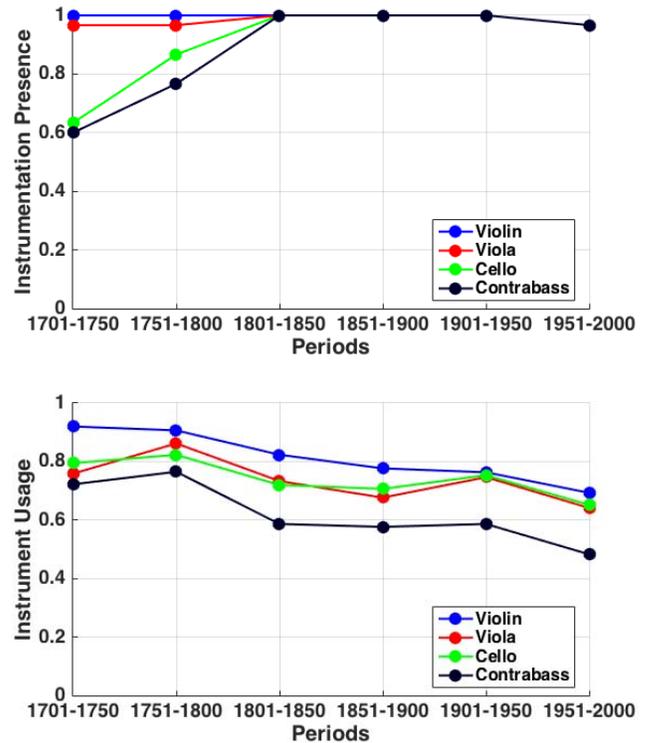


Figure 2. Instrumentation presence (top) and instrument usage (bottom) of string instruments

In Figure 3, we see that the presence of four instruments—oboe, flute, bassoon, and clarinet—is noticeably higher than others. Oboe, flute, bassoon, and clarinet were available earlier in history, which probably helped establish

their presence in orchestras, whereas the other four instruments were introduced later presumably to provide a wider range of pitch and timbre. This separation of two groups can be still observed in the usage pattern, although not as clearly.

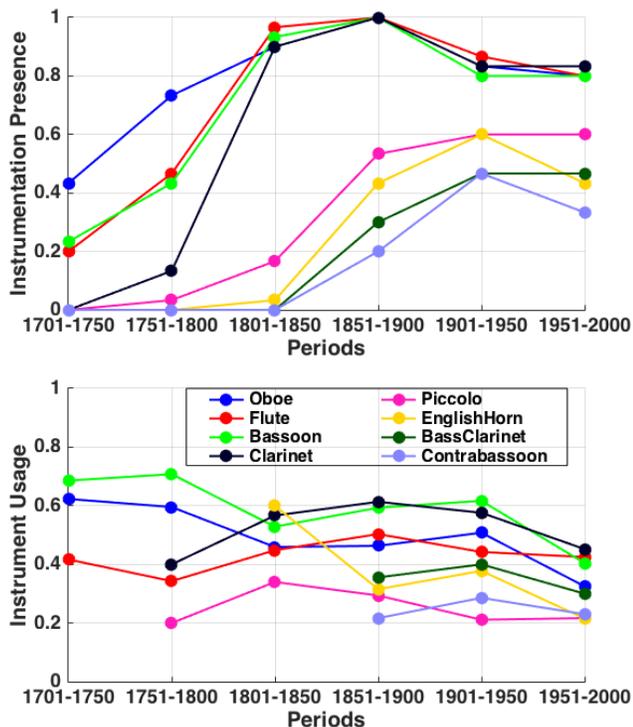


Figure 3. Instrumentation presence (top) and instrument usage (bottom) of woodwind instruments

The patterns of brass instruments are presented in Figure 4. It is interesting to see that the French horn shows the highest presence, which also tends to sound the most often. There could be various reasons behind this prominent presence and usage of the French horn. First, it became a part of an orchestra very early. Second, its timbre is multi-faceted, which makes the instrument quite versatile. For this reason many composers used the French horn in prominent solos, or to support other brass instruments, or to improve the blend of brass and woodwind instruments (Adler, 2002). Other brass instruments were increasingly more present until the early 20th century, after then their presence slightly decreased. This pattern is consistent with what we observed in the total number of parts in Figure 1.

Figure 5 presents the patterns of percussion and keyboard instruments. Perhaps the most striking is the decline of two instruments (continuo and harpsichord) in contrast to other instruments' increase in presence. Also noticeable is the higher presence of timpani above all the other instruments, although it sounded only about 30% of the duration of a musical work. In terms of usage patterns, we see that harpsichord, organ, and continuo in the 18th century were nearly omnipresent, probably because they all performed the role of continuo. It is not clear from the graph whether the piano preserved the tradition of a keyboard continuo after the decline of harpsichord and continuo parts, or it just happened to show a higher usage pattern in the 19th and early 20th centuries. Figure 5 also shows that even though more percussion instruments appeared in orchestration after the

early 19th century, their use was reserved for occasional special effects.

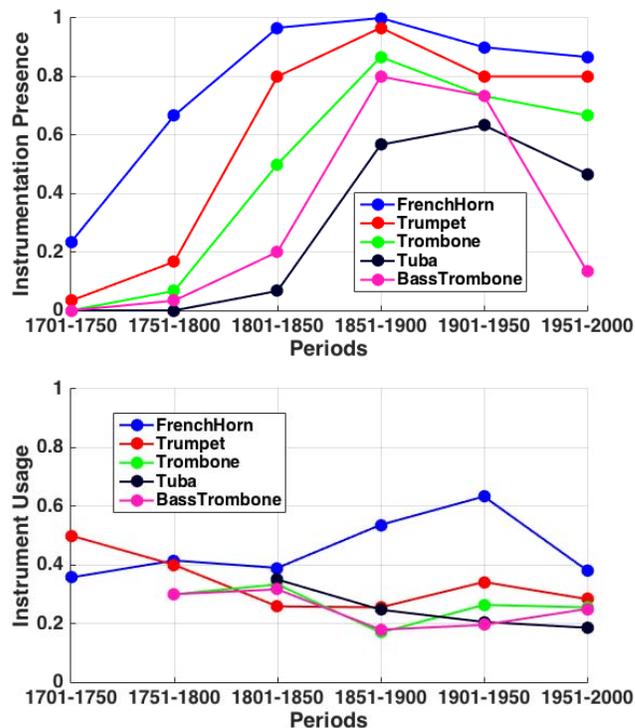


Figure 4. Instrumentation presence (top) and instrument usage (bottom) of brass instruments

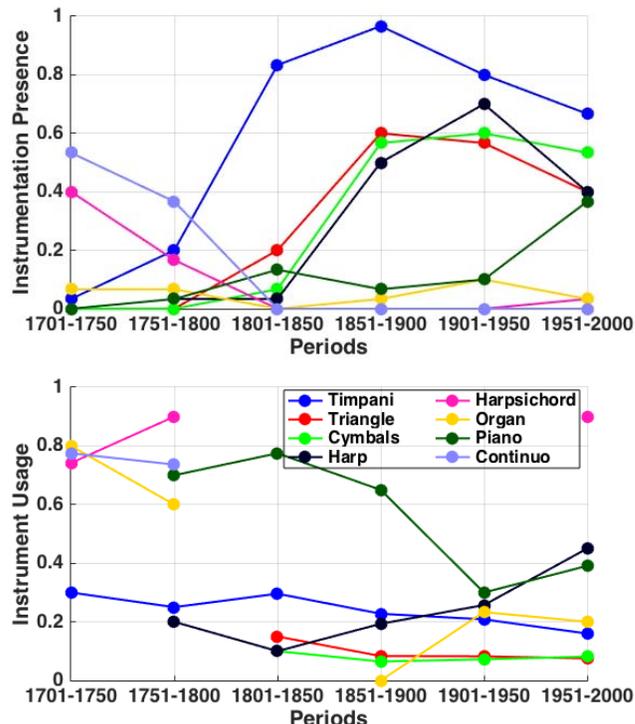


Figure 5. Instrumentation presence (top) and instrument usage (bottom) of percussion and keyboard instruments

We also examined the most common usage patterns found in our samples. Tables 2 and 3 list the results in descending order of occurrences. The standard string section combination (two violins, viola, cello, and contrabass) was the most common pattern over the 300-year period, although this exact

Table 2. Most common usage patterns in 300 years

Number of instances	Instrument combination pattern
67	Violin + Violin + Viola + Cello + Contrabass
27	Violin + Violin + Viola + Cello + Contrabass + Oboe + Oboe
20	Violin + Violin + Viola + Cello + Contrabass + Harpsichord
19	Violin + Violin + Viola
19	Violin + Violin
19	Violin + Violin + Viola + Cello
18	Violin + Violin + Viola + Continuo
17	Piano
14	Violin
12	Violin + Violin + Viola + Cello + Contrabass + Bassoon
10	Violin + Violin + Violin + Viola + Cello + Contrabass
10	Violin + Violin + Continuo
10	Cello + Contrabass
9	Violin + Violin + Violin
9	Violin + Violin + Viola + Cello + Contrabass + Piano
9	Violin + Violin + Viola + Cello + Harpsichord + Continuo

Table 3. Most common usage patterns per epoch

Epoch	Number of instances	Instrumentation pattern
1701 – 1750	19	Violin + Violin + Viola + Cello + Contrabass + Harpsichord
	15	Violin + Violin + Viola + Continuo
	14	Violin + Violin + Viola + Cello + Contrabass + Oboe + Oboe + Bassoon
1751 – 1800	27	Violin + Violin + Viola + Cello + Contrabass
	13	Violin + Violin + Viola + Cello + Contrabass + Oboe + Oboe + Bassoon
	9	Violin + Violin + Viola + Cello + Contrabass + Harpsichord + Continuo
1801 – 1850	10	Violin + Violin + Viola + Cello + Contrabass
	9	Piano
	7	Violin + Violin + Viola + Cello + Contrabass + Piano
1851 – 1900	4	Violin + Violin + Viola + Cello
	3	Violin
	3	Violin + Violin + Viola + Cello + Contrabass
1901 – 1950	17	Violin + Violin + Viola + Cello + Contrabass
	6	Violin + Viola + Cello + Contrabass
	5	Violin + Violin + Viola + Cello
1951 – 2000	5	Piano
	4	Violin + Violin + Violin + Violin + Viola + Viola + Cello + Contrabass
	3	Violin + Violin + Viola + Cello + Contrabass
	3	Cello
	3	Harp

pattern was not very popular in 1701–1750. Table 3 shows that the use of string instruments showed a slight decrease through the years, in contrast to wind instruments.

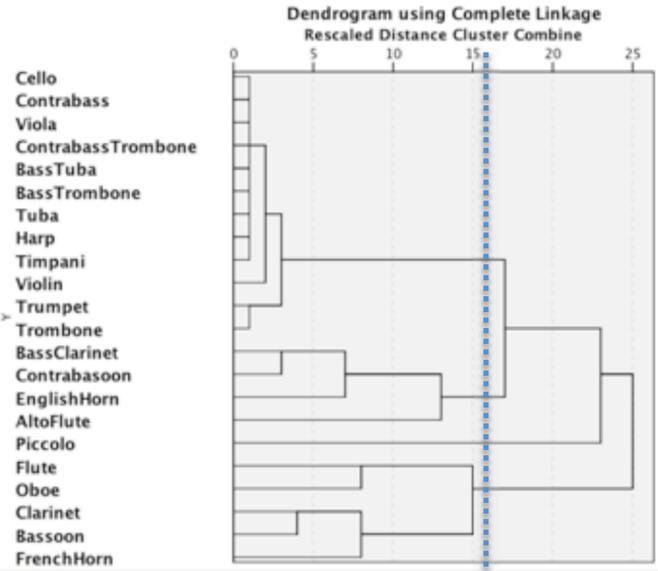


Figure 6. Hierarchical clustering of 22 orchestral instruments

Interested in how various instruments were combined with each other, we carried out a hierarchical clustering analysis on the usage patterns of every pair of 22 typical orchestral instruments (Violin, viola, cello, contrabass, piccolo, flute, alto flute, oboe, English horn, clarinet, bass clarinet, bassoon, contrabassoon, French horn, trumpet, trombone, bass trombone, contrabass trombone, tuba, bass tuba, harp, and timpani). Figure 6 shows the resulting dendrogram. At around the distance of 16, we observe four clusters: on the top is a big cluster containing all string instruments and all brass instruments except for the French horn, plus harp and timpani (cello, contrabass, viola, contrabass trombone, bass tuba, bass trombone, tuba, harp, timpani, violin, trumpet, and trombone). These instruments probably form the core of the orchestra. Next is a cluster of four woodwinds offering extended pitch and timbral color (bass clarinet, contrabassoon, English horn, and alto flute). Strangely, piccolo is in its own cluster for some unknown reason. The last cluster consists of five wind instruments (flute, oboe, clarinet, bassoon, and French horn) that showed higher presence than others (evident in Figures 2 and 3). If we take the liberty to include piccolo in the second cluster with other woodwinds, we have three clusters that reflect potentially different compositional functions. The first cluster might be called the *Core* cluster, where all string instruments seems to provide the core of an orchestral scene; the second cluster contains five woodwinds (bass clarinet, contrabassoon, English horn, alto flute, and piccolo) that offer extended pitch and timbre ranges, therefore dubbed the *Extended Woodwind* cluster; the third cluster might be deemed the *Standard Wind* cluster as it contains five wind instruments that are rather standard in orchestras (flute, oboe, clarinet, bassoon, and French horn). The second and third clusters probably reflect different purposes in instrumentation of woodwinds; the instruments in the third cluster tend to be used more consistently, complementing those in the core cluster, whereas those in the second cluster are more likely to

be used for specific effects in pitch and timbre. Our clusters did not perfectly agree with Johnson's (2011) SPC model. However, like Johnson's model, our clusters nevertheless appear to point to different compositional functions.

IV. DISCUSSION

In this paper, we surveyed the instrumentation patterns in orchestral music composed between 1701 and 2000, concentrating on instrumentation presence and instrument usage. From our samples we could clearly see the constant increase in the total number of parts required to perform a piece of music through history up until the mid-20th century. In contrast to the increase of the number of parts in an orchestral work, the usage pattern of an instrument showed a decreasing trend in general. This decline in usage may simply reflect the increased palette of instruments from which a composer might choose; that is, when the composer can choose from many instruments, any given instrument need not play constantly.

In terms of instrumentation presence, string instruments appear to show the highest presence. Strings have been a core of an orchestra since the 18th century and therefore present in nearly every piece of orchestral music (Weaver, 2006). The wind instruments in current orchestras seem to belong to three groups depending on the compositional purposes they serve—the *Standard Wind* group (flute, oboe, clarinet, bassoon, and French horn), the *Core* (brass) group (trumpet, trombone, bass trombone, contrabass trombone, tuba, bass tuba), and the *Extended Woodwind* group (bass clarinet, contrabassoon, English horn, alto flute, and piccolo). The instruments in the Standard Wind group have been available for a longer time and they tend to sound more often than others. These instruments offer a set of stable timbres to the orchestra, which steadily increased with the inclusion of instruments that provide more diversity in timbre and pitch (especially those in the extended woodwind group). The Core brass instruments add more weight to the skeleton of an orchestral image painted by the string instruments. Harp and timpani, which belong to the same cluster, also appear to serve the same purpose of adding weight. Our three clusters did not entirely replicate Johnson's SPC model, possibly because our data included samples from a longer period than the Romantic era, whereas Johnson focused exclusively on the Romantic period.

V. CONCLUSION

To our knowledge, this is the first empirical longitudinal study of orchestration. The general patterns we found mostly agree with what have been qualitatively observed by music scholars (Harnoncourt, 1988; Stauffer, 2006; Weaver, 2006). Many of our analyses were performed on the entire set of samples for the purpose of statistical power, but it might have led to glossing over possible changes observable per epoch. Therefore our findings need to be interpreted carefully. Although this study required extensive labor to sample and code 1800 sonorities from 180 works, a larger collection of data is necessary in order to survey detailed longitudinal trends. Further analysis of presence and usage patterns in relation to pitch, tempo, and dynamics are expected to follow,

as well as examination of occurrences of specific patterns mentioned in orchestral treatises.

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