A Library of Orchestral Instrument Spectra

Gregory J. Sandell[1]
Northwestern Computer Music
Northwestern University, Evanston IL, USA

Standard orchestral instruments and some early music instruments were analyzed for steady-state spectra. Examining the spectra from the entire playing range of an instrument reveals patterns of change that may be essential to its timbral character. The change in the centroid over the range of the instrument is looked at in detail.

Introduction

With the advent of computers for digital analysis of sounds in the 60's, it became possible to study the complex behavior of time-variant features (especially onsets), and evaluate their importance in conveying the identity of an instrument to a listener. The practice of a previous generation of acousticians, who held the steady-state waveform of an instrument as its essential acoustic signature, was called into question. However, though later researchers such as Grey could study the fine temporal structure of instruments, they too were limited to studying only a handful of tones. Even now very little research has addressed the *macro-structure* of timbre: the perception of timbre which is apprehended by exposure to a variety of different pitches, durations, dynamics and articulations from the same instrument. Recent research has shown that when a variety of notes are presented to listeners, their ability to identify an instrument fares equally well in onset-only conditions and steady-state-only conditions. This suggests that examining the steady-state spectra of all the tones of an instrument may provide some insight into the timbral character of musical instruments.

Recently available compact disk collections, such as those by McGill University Master Samples (MUMS) or ProSonus offer the timbre researcher the opportunity to study all individual notes from the standard playing ranges of orchestral instruments. As a first step in developing a database of timbre analyses, the present author has produced steady-state spectra for all the orchestral tones in the MUMS collection. Each analysis consisted of isolating a quasi-steady-state portion of the tone, sampling the analogue signal at a 44.1 kHz rate, and submitting it to an 8192-point FFT. This provides frequency/amplitude information over the range 0-22050 Hz. with a resolution of 5.383 Hz. The energy at harmonic multiples of the fundamental (between 30 and 100 harmonics, depending on the pitch range of the instrument) were extracted from each FFT and saved in a database. The instruments analyzed included complete family of strings, played arco, pizzicato, and muted, including natural and artificial harmonics; a harp; all the members of the woodwind family, including the larger and smaller members; a family of brass, muted and unmuted; and several early instruments (crumhorn, shawm, Baroque oboes).

Viewing the Data

All the spectra of the 42 notes of the violin, in ascending chromatic order from foreground to background, are shown in Figure 1. (Note: the notes d4, a4 and e5 were all played on open strings; the absence of upper harmonics in the pitches above f5 is due to the Nyquist frequency limitations in sampling).
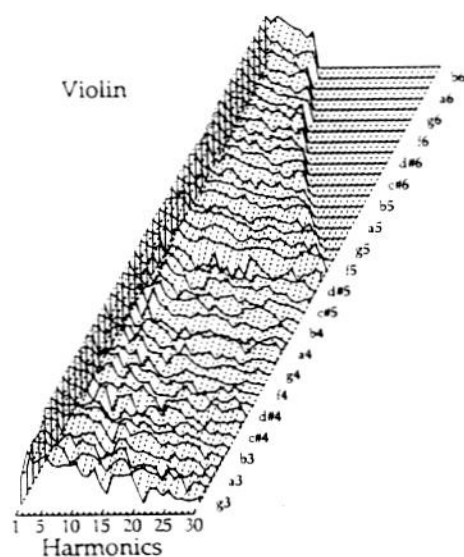
In order to visualize the changes in spectrum across the range of the violin, some simplication is necessary. The *spectral centroid* is an effective way of reducing the dimensionality of a spectrum. To calculate the centroid of a note, we weight the frequency of each harmonic by its amplitude, sum these weights, and then divide it by the sum of the amplitudes alone. This procedure factors out a single frequency which may be thought of as the spectrum's center of gravity. For many listeners, the centroid correlates to the semantic equivalents of "bright" and "dark" (high and low centroids, respectively). Furthermore, centroid has proven to be a salient perceptual dimension in a large number of studies.

A plot of all the centroids for a particular instrument reveal two interesting facts: (1) the brightness of many instruments do not increase as a simple monotonic function of their pitch, and (2) the mechanical features of the instrument (fingering, etc.) influence the brightness patterns a great deal.

Figure 2 shows the centroids for all the notes of the violin. The darkest notes appear to be around the neighborhood of the D-string, and starting with the E-string, the rate of increase in brightness with each successive note grows larger. There are a few outliers, two of which are octave mulitples of the open G-string, suggesting the influence of sympatheric resonance. The sharp peak around c6 suggests a formant in the area of 1000 Hz.

A very different pattern can be observed with the oboe (Figure 3). Here the direction changes in brightness and the effects of fingering are more pronounced. The large change from c5 to c#5, for example, probably results from the change of all holes open to all holes closed in this transition. However, it may be that large discontinuities such as this one may not be reproduced from performance to performance, or may be due to peculiarities of individual instruments. To observe the more general trends in the data, then, a smoothed version of the centroid curve has been added to each plot.

Figure 2

The centroid curves of several instruments are shown in figure 4; the line shows the smoothed solution, while the dots indicate the true centroids. Four different violin playing methods are compared. The "hammered" bow stroke (*martele*) shows less consistency in note-to-note brightness than normal playing, but not necessarily brighter quality, as one might expect. The pizzicato notes (which were sampled from the moment of onset, rather than later in the tone) show darker tones, and more consistent note-to-note brightness, as expected. The upper tones of the muted violin appear to be very bright, dispelling the notion of a violin mute as simply a "low-pass filter."
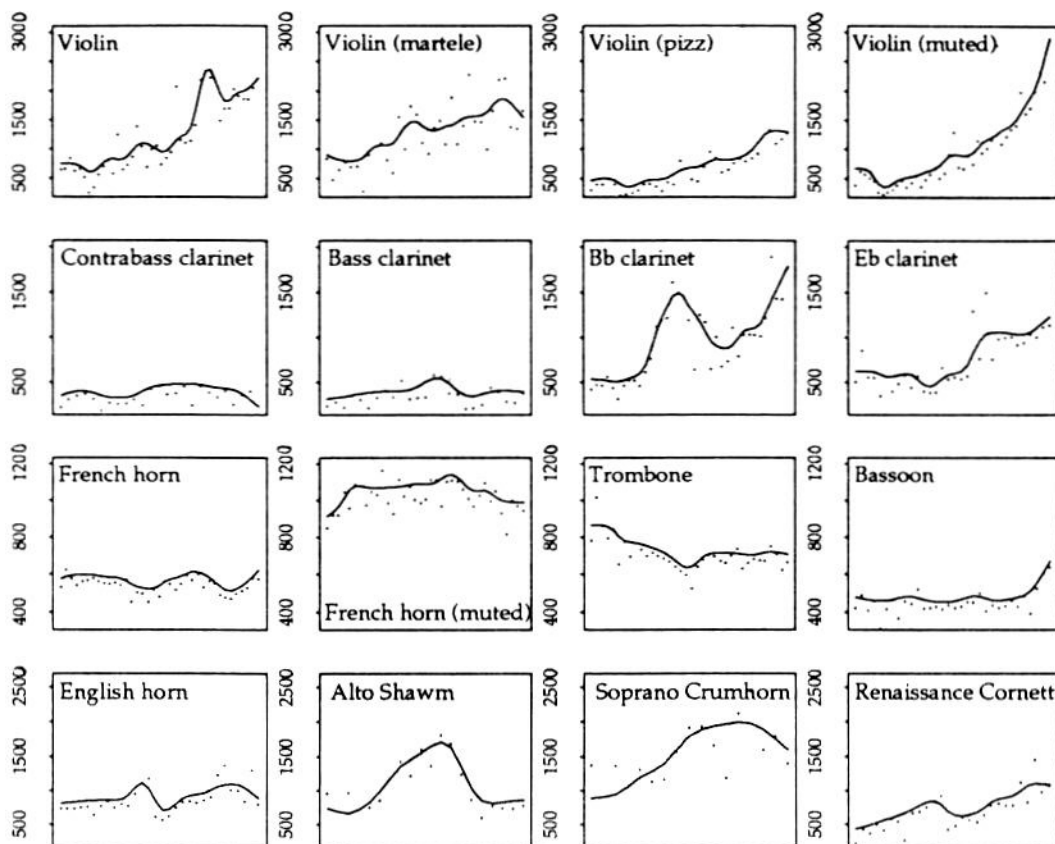
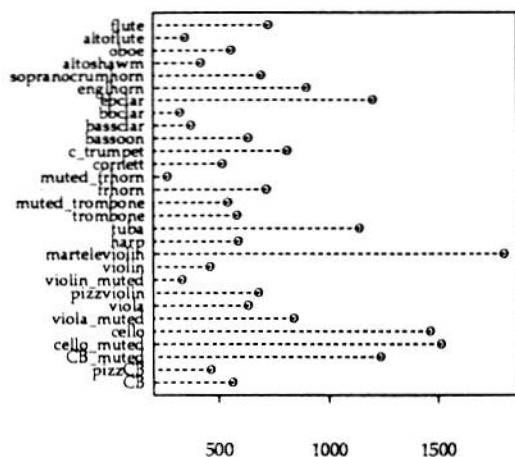

Figure 1.

Figure 3

Figure 4.

Four members of the clarinet family are compared; the starting pitches for the four instruments are (sounding) f#1, c#2, d3 and g3, respectively.   In all, the "break" between chalumeau and clarion registers seem to have been skillfully concealed by the performers, and no sharp discontinuity is found there. The Eb clarinet is surprisingly *less* bright than the Bb, but for unknown reasons both clarinets in the MUMS collection stopped at the same pitch, d6. Bassoon and French horn, known for "blending" well with other instruments, show low-lying, narrow centroid ranges, properties which are effective for obtaining blends (see Sandell 1989). The mute on the French horn produces a definite brightening effect.   The trombone shows an interesting pattern connected with slide position. It reaches its darkest note fairly far into its series of pitches; in fact the bottom of this "dip" corresponds to Bb3, the point at which the slide

is pulled all the way in; prior to that, we see that each successive shortening of the tube from e3 makes the tone darker. The last row shows the English horn and two of its ancestors, the shawm and the crumhorn, and a trumpet precursor, the cornett.   The starting pitches of the previous eight instruments are (sounding): d2, d2, e2, a#1, e3, f3, c4 and a3.

Applications

The database of spectra might be useful to either composers or music theorists. Comparing the centroids for all the instruments on middle C, as in Figure 5, might be a useful way to choose notes to shade a harmony in a particular way, or to create a *klangfarbenmelodie* on a single note. Figure 6 shows that different instruments change centroids in different directions when the pitch is changed.

Pitch c4 (261 Hz)

Pitch e4 (330 Hz)
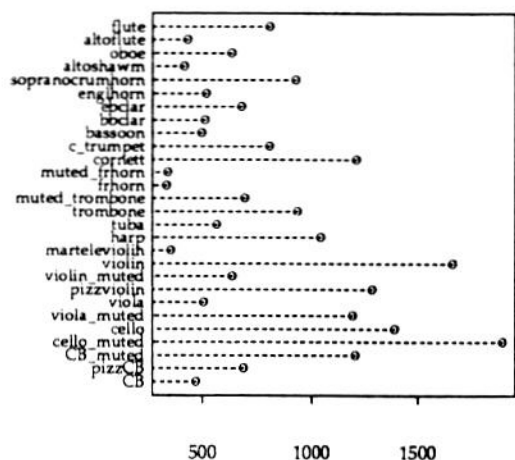
Figures 5 and 6

The database might be used for analyzing orchestration. As a possibility, consider Webern's remarkable "frozen register" passage from his *Symphonie*, Op. 21. In measures one through 25, all twelve chromatic notes cirulate regularly, but each is "fixed" in its own unique register: the pitch-class c appears always as c3, c# always appears as c#4, and so on. (The one exception of the pitch class d# which appears variously as d#3 or d#4.) However, the instrument assignment for a pitch changes upon each instance. The result is an timbral kaleidoscope against the backdrop of a static

pitch framework. Figure 7 represents this passage using the data from the MUMS tones. Each box represents a note, with its width indicating its duration. The lower limit of the box indicates the position of its fundamental frequency, while the upper limit shows the centroid. The representation illustrates how certain notes, especially those of the muted French horn, the viola and clarinet, pop to the surface from time to time, contributing to the work's shimmering quality. The tallest boxes correspond to an e5 played on the viola's A-string, a note having an expressive central position in the passage. (Piston describes the viola's A-string as "sandy, penetrating"; it is far brighter than the same pitch on the violin.)

In conclusion: the centroids which are yielded from the MUMS tones illustrate patterns of change which could be informative in orchestration and analysis. Further reseach could investigate the replicability of this data with other recordings of orchestral tones (e.g., ProSonus), or examine the effects of different dynamics. One drawback of the MUMS tones is that the dynamics and tone quality of some performers are uneven.
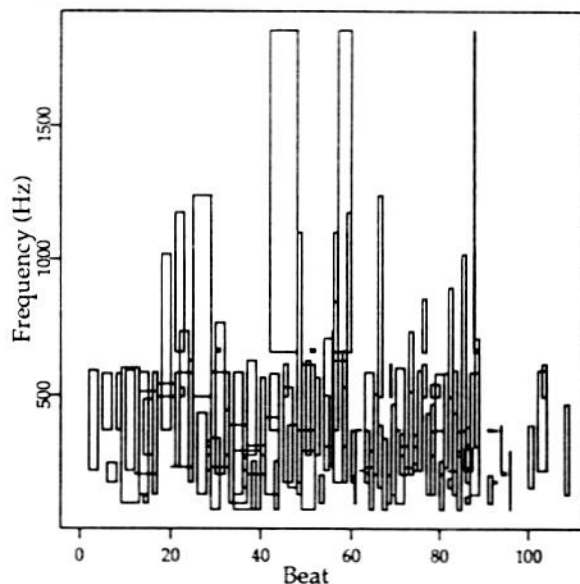

Figure 7

References

Sandell, G.J. (1989), "Perception of Concurrent Timbres and Implications for Orchestration." In *Proceedings of the 1989 International Computer Music Conference*, pp. 268-272.

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