# MUTOR *TiddlyWiki* Unit 6 on Timbre



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*johnmac*, 10 October 2006 (created 8 June 2006)

tags: Unit



## Unit6Introduction

*johnmac*, 10 October 2006 (created 18 July 2006)

tags: Unit

The definition of timbre (pronounced *tamber* or *tombre*) is often vague, such as the American Heritage Dictionary: The combination of qualities of a sound that distinguishes it from other sounds of the same pitch and volume. As an example, if a clarinet plays middle C, and a piano plays the same note at the same volume, timbre is the quality (or set of qualities) that allows us to identify and distinguish those two instruments. Common synonyms for timbre include color, quality, tone, and descriptions of an instruments timbre often include bright, dark, full, rich, thin, piercing, hollow, etc. A clarinet, for example is often described as dark and hollow, while an oboe sounds bright, thin, and piercing. It is typical to talk about the timbre of an instrument in terms of its spectrum which is where we will start here, although as we will see below, there are other factors that influence our perception of timbre.

## LargeScaleFeatures

*johnmac*, 10 October 2006 (created 10 October 2006)

no tags

**Large-scale Features of the Spectrum**

The large-scale features of the spectrum give us information about how energy is distributed across frequency. These features allow us to talk about timbral characteristics such as brightness but don't tell us much about important aspects such as pitch. In the case of vowel sounds produced in speech or song, the pitch can change while the large-scale features of the spectrum remain relatively constant (as in someone changing pitch while singing the vowel *a*), just as the large-scale features can change while the pitch remains the same (as in someone changing vowel sounds while remaining on the same pitch).

## SpectralEnvelope

*johnmac*, 10 October 2006 (created 28 September 2006)

no tags

Figure 1 is the spectrum of a trumpet playing 440 Hz (A4 above middle C) mezzo-forte and represents a typical instrumental spectrum.

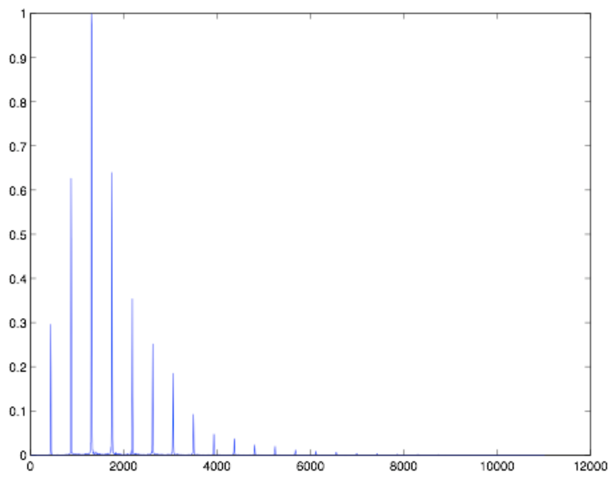



Figure 1. Spectrum of a trumpet playing A4.

Although this image will be very helpful as we begin our discussion, it is important to remember that we are only looking at the average of a very brief instant in the evolution of the trumpet spectrum. As we will see below, the way in which an instrument begins and ends its tones has an important impact on its timbre. The first large-scale feature of the trumpet spectrum is the spectral envelope (red dashed line in figure 2).

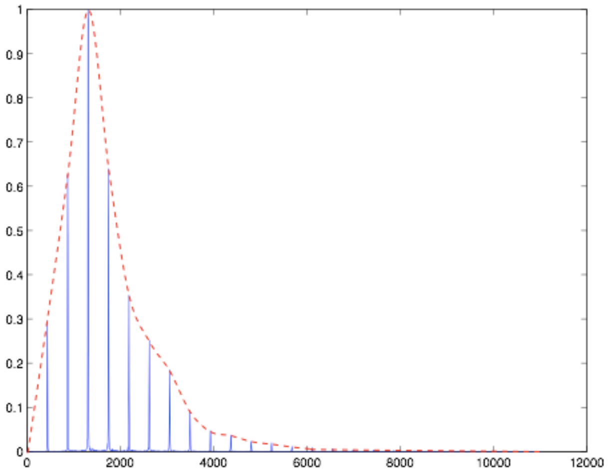


Figure 2. Spectral envelope of a trumpet playing A4.

The spectral envelope gives us information about how the energy of the spectrum is distributed across frequency. Note that the spectral envelope for the trumpet above has a single peak at 1320 Hz or around the 3rd harmonic.

## SpectralCentroid

*johnmac*, 10 October 2006 (created 10 October 2006)

no tags

The next measurement of the spectrum that we will look at is the spectral centroid which is the weighted average of the spectrum:

$$c_i = \frac{\sum f_i a_i}{\sum a_i}$$

Figure 3 is the spectrum of a trumpet playing A4 *fortissimo*—the spectral centroid is plotted in red. Compare this with figure 4 which is a trumpet playing A4 *pianissimo*. It is a typical characteristic of many instrumental sounds that as they get louder, they also get brighter. We can see in figure 4 that the *fortissimo* trumpet indeed has much more energy distributed accross the upper harmonics than the *piannissimo* trumpet.

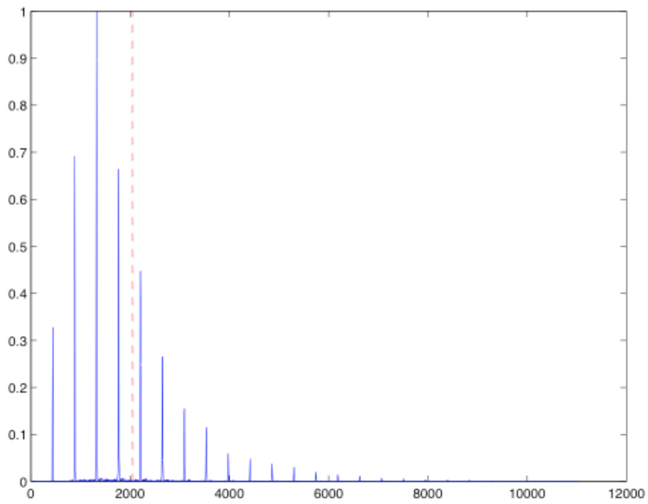


Figure 3. Spectrum and spectral centroid (in red) of a trumpet playing A4 fortissimo.

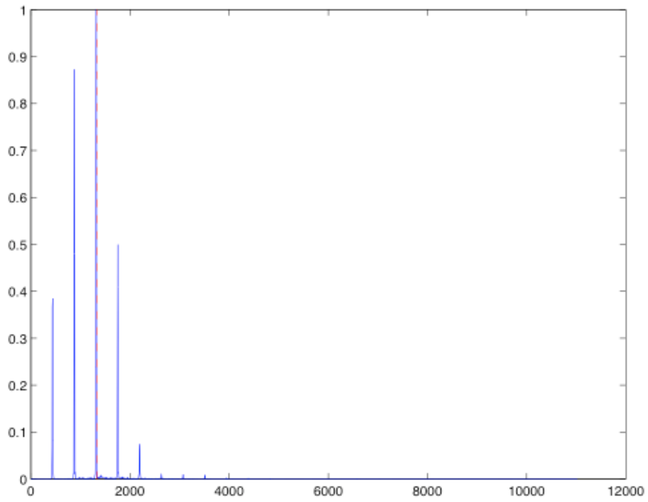
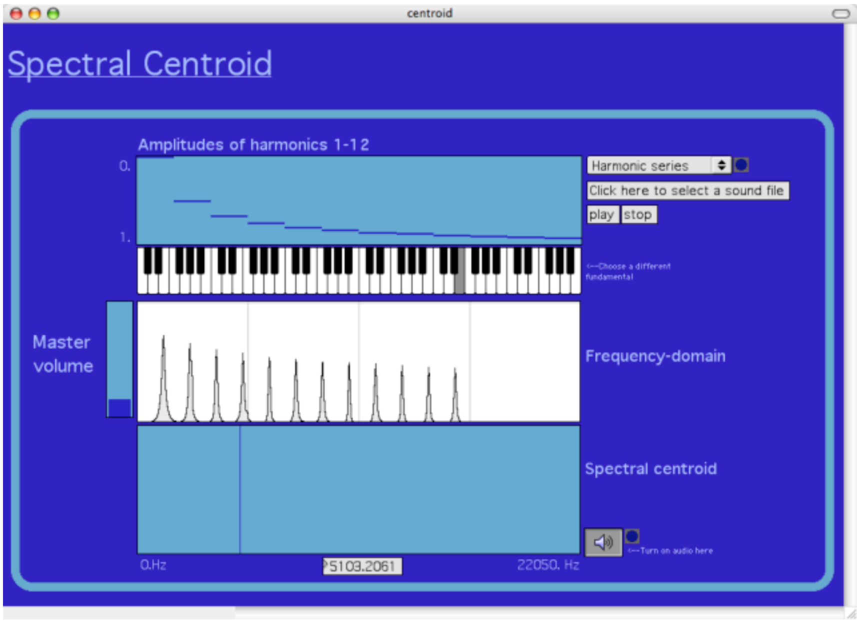



Figure 4. Spectrum and spectral centroid (in red) of a trumpet playing A4 pianissimo (the centroid is exactly in line with the third harmonic).

In the demo called "centroid", you can adjust the weight of the harmonics of a complex tone and see how the centroid is effected.




## FormantS

*johnmac*, 10 October 2006 (created 10 October 2006)

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The spectral centroid measurement is a good estimate of the perceptual characteristic of brightness. Although this measurement works well for many instrumental sounds which tend to have one peak, the human voice has multiple peaks called *formants* (figure 5). Formants are resonances in the vocal tract that are responsible for the differen vowel sounds and the differences between male and female voices. In order to fully understand formants and how they are produced in the voice, we must review how the voice works. Sound is produced in the throat by the vocal folds:

[For more videos and information, see voicemedicine.com]

The sound that is produced by the folds in the vocal tract is very spectrally rich and is often synthesized using a triangle wave. That sound source is then filtered in the vocal cavity by altering the position of the tongue and shape of the lips. Singers will also alter the position of the soft pallet at the back of the throat. This is called a source-filter model where the source is the vocal tract and the filter is the vocal cavity that shapes that rich spectrum that the vocal folds produce.

Although we all have different voices and there are subtile variations (especially regionally) in the ways that we produce vowel sounds, some generalizations can be made as in figure 5 and table 1.

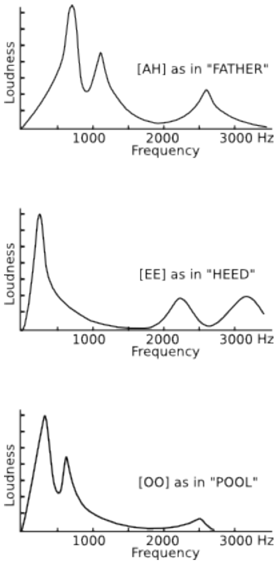



Figure 5. Formants for three different vowels (after Benade, pg. 373).

| | Formant | heed | head | had | hod | haw'd | who'd |
|---|---|---|---|---|---|---|---|
| **Men** | F1 | 270 | 530 | 660 | 730 | 570 | 300 |
| | F2 | 2290 | 1840 | 1720 | 1090 | 840 | 870 |
| | F3 | 3010 | 2480 | 2410 | 2440 | 2410 | 2240 |
| **Women** | F1 | 310 | 610 | 860 | 850 | 590 | 370 |
| | F2 | 2790 | 2330 | 2050 | 1220 | 920 | 950 |
| | F3 | 3310 | 2990 | 2850 | 2810 | 2710 | 2670 |
| **Children** | F1 | 370 | 690 | 1010 | 1030 | 680 | 430 |
| | F2 | 3200 | 2610 | 2320 | 1370 | 1060 | 1170 |
| | F3 | 3730 | 3570 | 3320 | 3170 | 3180 | 3260 |

Table 1. Average resonance frequencies of the first three formants (F1, F2, F3) of the vowels of men, women and children (from Appleton and Perera, eds., *The Development and Practice of Electronic Music,* Prentice-Hall, 1975, p.42; after Peterson and Barney, *Journal of the Acoustical Society of America,* vol. 24, 1952, pp. 175-84).

Some composers such as Charles Dodge have used the idea of formant filtering in compositions. Furthermore, some rock and blues guitarists have used a voice box or talk box that plays sound through a tube into their mouth which allows them to filter their guitar sound by changing the shape of their vocal cavity.

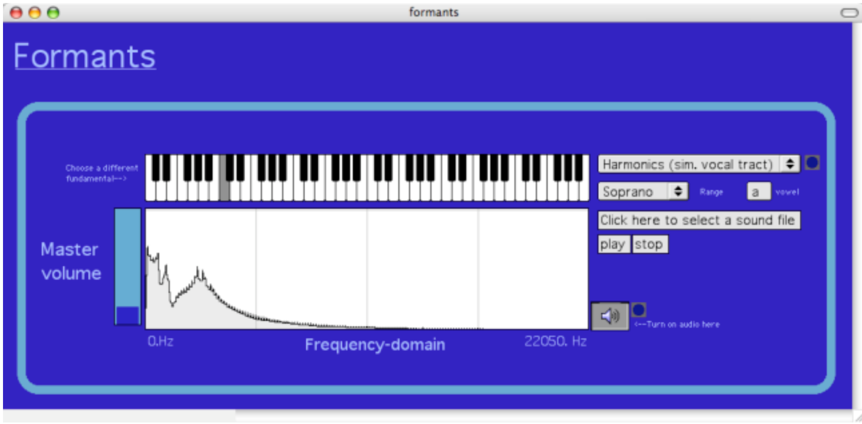
Using Mel Frequency Cepstral Coefficients (MFCC), we are able to separate the source from the filter in cases such as vocal analysis. Although a complete description of how *MFCCs* work and are computed is beyond the scope of this unit, it is worth giving a quick overview. The cepstrum (cepstrum is spectrum with the first four letters rearranged) is the Fourier Transform of the log (with unwrapped phase) of the Fourier Transform—literally, the spectrum of the spectrum.


Figure 6. Calculation of the Cepstrum.

For use in speech, the step where we convert to log frequency is replaced by a conversion to the Mel scale which we introduced in unit 1.


Figure 7. Calculation of the Mel Frequency Cepstral Coefficients.

In the demo called formants, you can choose sources (sawtooth wave, noise, or a sound file) to pass through a simulated formant filter.




## SmallScaleFeatures

*johnmac*, 10 October 2006 (created 10 October 2006)

tags: Unit

The spectral features we have discussed so far deal with the overall shape of the spectrum, but there are some important small-scale features that contribute to the timbre of a sound such as the *odd-even balance*. Figure 8 is the spectrum of a clarinet (in blue) and a cello (in red). Notice that while the cello has significant energy across most of its first 10 harmonics, there is very little energy in the even partials of the clarinet spectrum. This contributes to the 'hollow' sound of the clarinet and is so significant that even a very rudimentary simulation using a harmonic series consisting of the first 12 partials with the even harmonics removed will begin to take on that hollow quality of the clarinet. Try this by opening the centroid example patch above and remove the even harmonics.

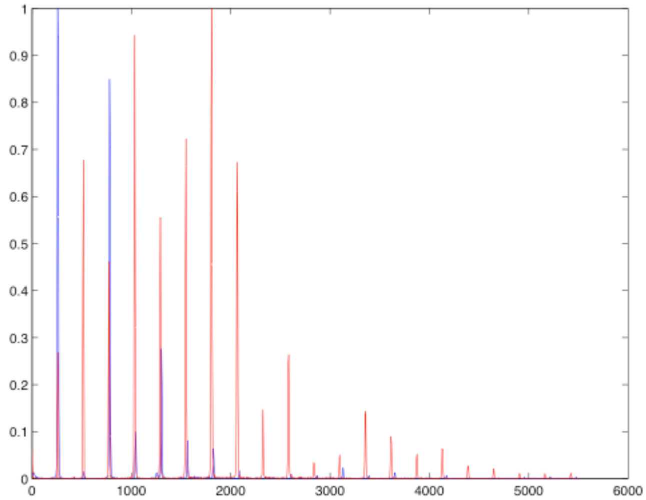



Figure 8. A clarinet spectrum in blue superimposed over a cello spectrum in red. Notice that the even harmonics of the clarinet are much weaker than those of the cello.

While the large-scale features contribute mainly to the sense of timbre, issues of harmony and consonance / dissonance are found in the details of the spectrum. For example, students of orchestration are often told that bassoons in thirds in the low register don't sound good. When we take a look at the spectra of two bassoons playing a third apart (G2 and B2), we can see why this is. In figure 9, there are two string partials in each of the bassoons that are out of tune with each other. Compare this with the two cellos in figure 10; although the cellos also have strong partials that conflict with each other, they aren't nearly as exposed as those of the bassoons.

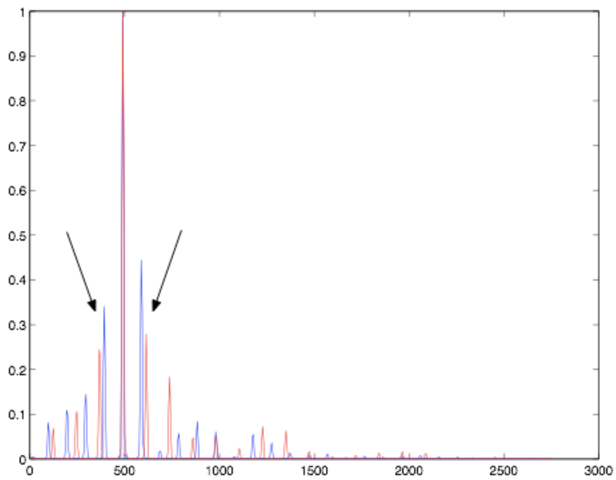



Figure 9. Bassoons playing G2 and B2. Notice that the next to the major spike around 500 Hz, the four other most prominent spikes (two from each instrument) conflict with each other.

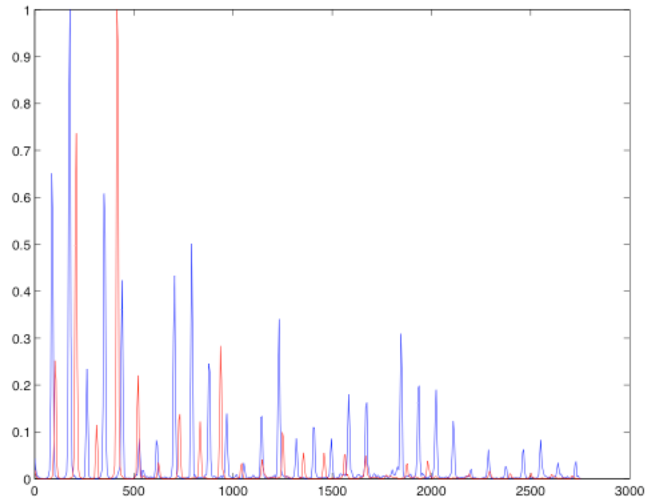


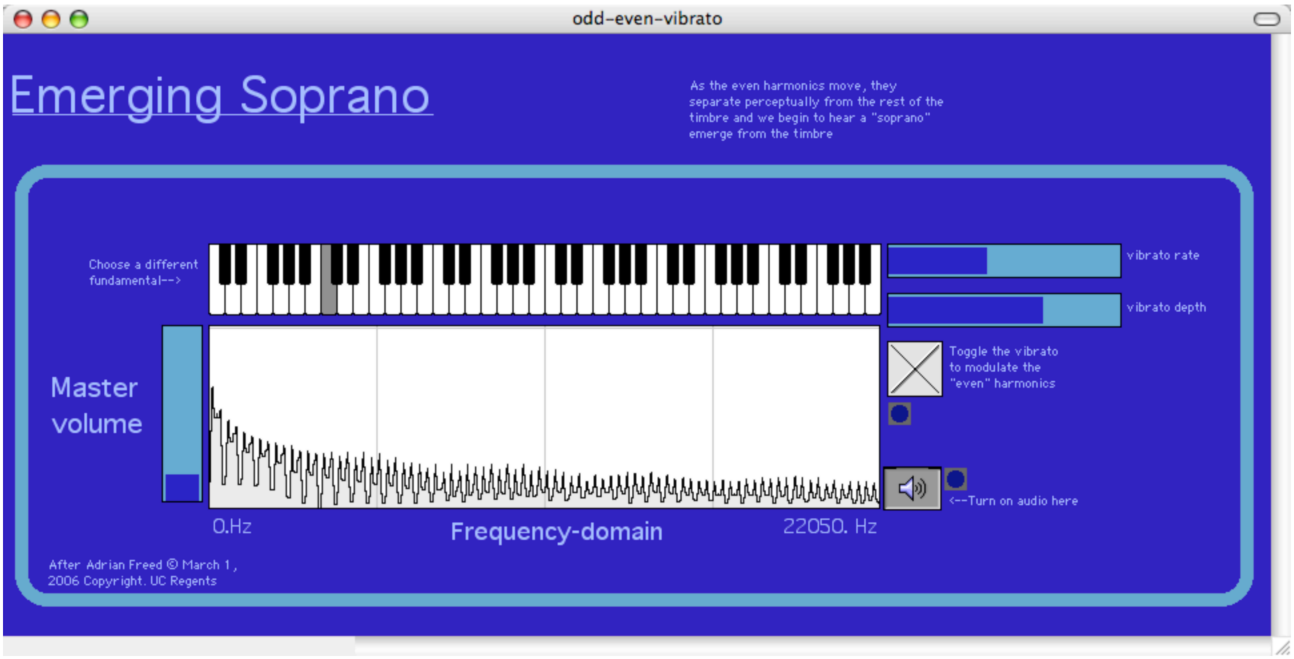

Figure 10. Cellos playing G2 and B2.

## TimbralFusion

*johnmac*, 10 October 2006 (created 10 October 2006)

no tags

Because a timbre consists of many pitches, we must ask the question: what is the difference between timbre and harmony? What is it about those pitches of a trumpet spectrum that cause them to be heard as a perceptual unit, rather than as a chord? Some answers to these questions have come from Albert Bregman's work on [Auditory Scene Analysis](). He has shown that sounds that form a harmonic series and begin together (or very nearly together) tend to be grouped together and fuse into a timbre (the beginning of a sound and it's impact on timbre will be discussed further below). Sounds that move together also tend to be heard as part of the same timbre. In the demo called odd-even-vibrato, you can apply vibrato to only the even harmonics of a timbre which will cause the even harmonics to be heard as a distinct percept separate from the timbre which they were originally a part of.




## TemporalEnvelope

*johnmac*, 10 October 2006 (created 18 July 2006)

tags: Unit

Although it is tempting to think that timbre is only in the details and features of the spectrum, the temporal envelope, i.e. the way in which the sound evolves over time, plays an important role in our perception of the timbre of a sound. The temporal envelope is usually classified according to four parameters: Attack, Decay, Sustain, and Release (figure 11).

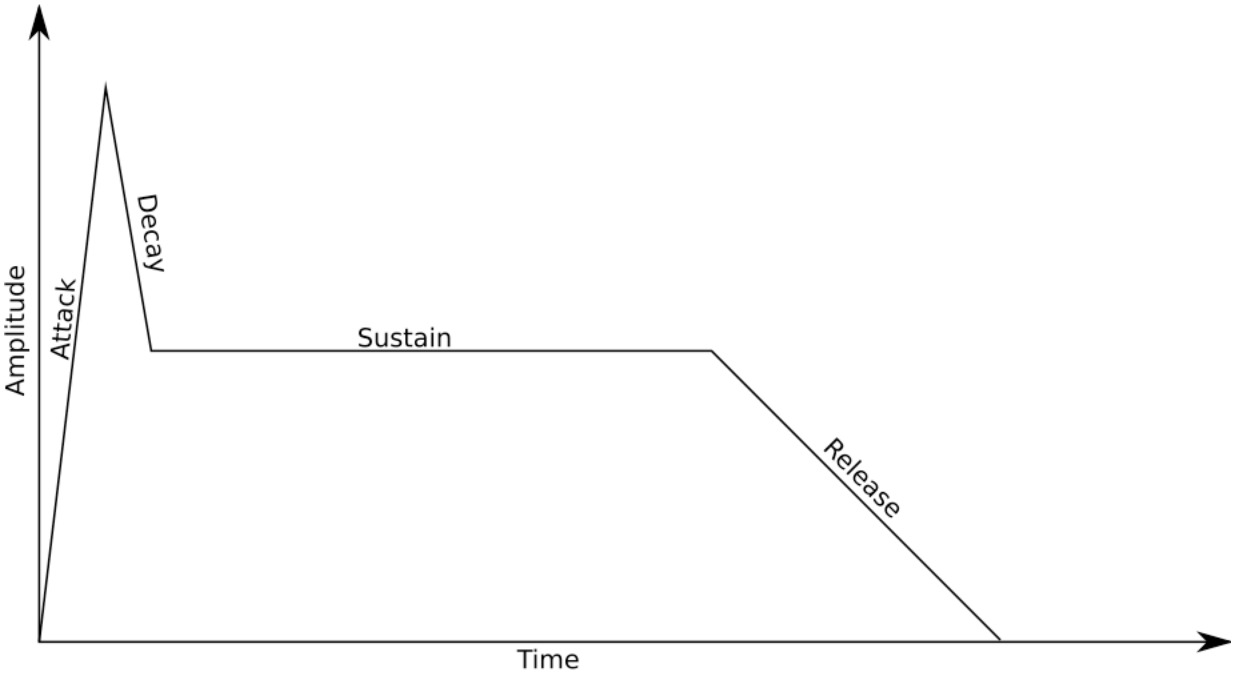



Figure 11a. Typical temporal envelope of a sound consisting of an Attack, Decay, Sustain and Release (ADSR).

This is a typical ADSR pattern for a sustaining instrument like the clarinet or violin. A percussive instrument like a bell or the piano will have an envelope that looks like figure 11b. The decay pattern here is exponential and represents the dissipation of energy, while the ADSR shape in figure 11a requires the player to shape the envelope. Here, there is no distinct initial decay, sustain, or release, just the gradual loss of energy in the system.

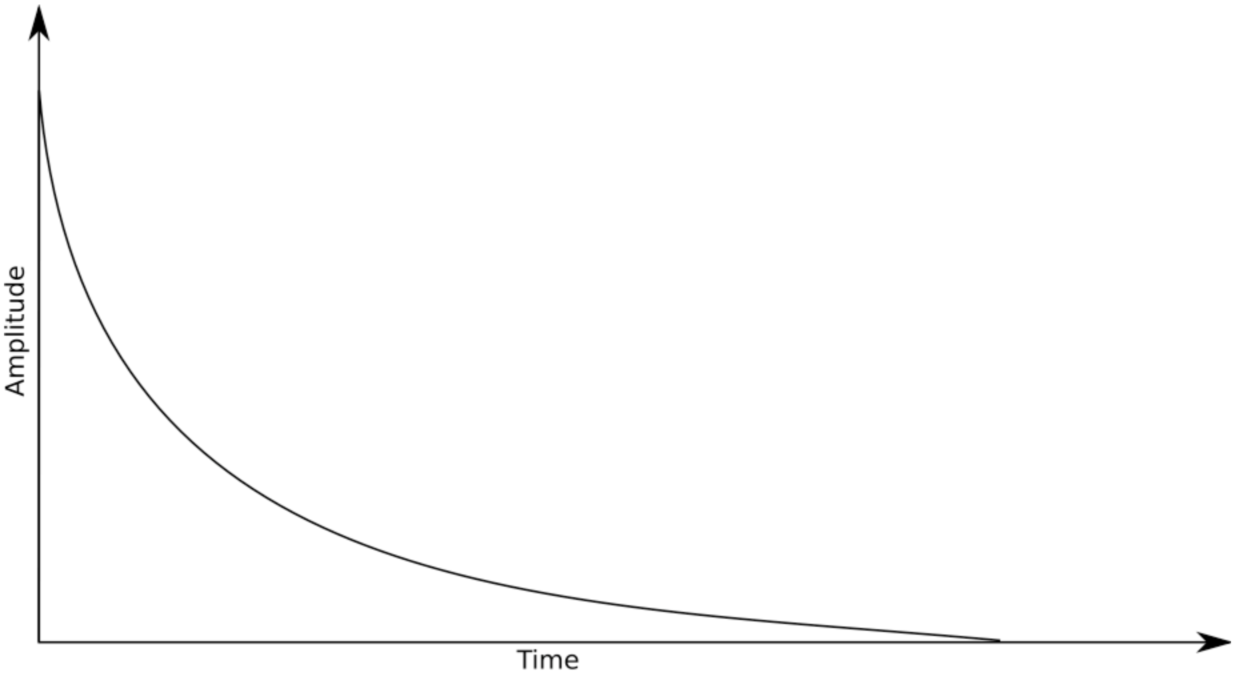



Figure 11b. Typical attack of a percussive sound like a bell or a piano.

## AttacK

*johnmac*, 10 October 2006 (created 10 October 2006)

Listen to the following instruments with their attacks removed and see if you can guess which instruments they are.

no tags

Without the attacks, it is surprisingly difficult to identify the instruments. The answers are at the end of the unit (and no, the sounds were not synthesized, they came from http://theremin.music.uiowa.edu/). The sounds you heard were taken from the sustain portion of the ADSR model above. Let's look now at the effects of the attack. Sounds with an attack that lasts less than 30ms tend to sound percussive. Figure 12 is a sonogram of a Bb clarinet playing A4—notice that the main part of the attack lasts for around 100ms and a final partial enters around 200ms after the fundamental.

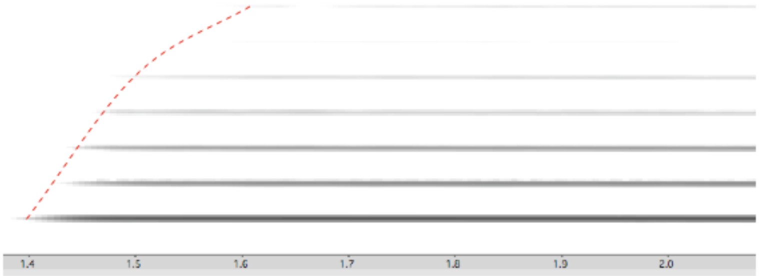



Figure 12. The attack of a clarinet—the main part of the attack lasts around 100ms.

In the next example, you will hear that same clarinet that was used to make the image in figure 12 followed by the same clarinet with the attack removed so that all the partials enter at the same time.

Although the second sound is fairly identifiable as a clarinet, it has taken on a more bell-like quality and matches the attack of the bell in figure 13.


Figure 13. Sonogram of a bell showing that all the partials enter at once.

Composers such as *Jean-Claude* Risset and Tristan Murail have made use of these features compositionally. In Gondwana for example, the opening section features a brass timbre played by the orchestra that is gradually transformed into a bell timbre by changing the pitches and aligning the players at the beginning of the attack.

Sound example: The opening of *Gondwana* by Tristan Murail

Although we think of the attack as a fixed event that begins a sound, under certain circumstances, it may not be clear when exactly the sound begins.

## KlangFarbenMelodie

*johnmac*, 10 October 2006 (created 10 October 2006)

Translated as *Tone-Color-Melody*, this is a technique coined by Arnold Schoenberg and employed in the third movement of his *Fünf Orchesterstüke*. In the opening bars of the movement, the same chord alternates orchestration; this is also seen in Anton Webern's orchestration of Bach's Musicalische Opfer.

no tags

Sound example: The opening bars of the third movement of Arnold Schoenberg's *Fünf Orchesterstüke*.

As we have seen above, the voice, with it's ability to change timbre in such a flexible way, can be considered an excellent Klangfarben instrument. This aspect of the voice has been used extensively by composers in the 20th century, most notably in Luciano Berio's *Sequenza III*.

## TimbreSpace

*johnmac*, 10 October 2006 (created 10 October 2006)

no tags

Often, timbre is thought of as being secondary to other more important musical features such as pitch and rhythm. Timbre can, however, influence the ways in which we group musical material. In the following listening example, you will hear three notes: C4, E4, and G4. These pitches will be played by two alternating timbres as shown in figure 14a. As the listening example goes on, the speed at which the notes are played will increase and the way in which we group the pitches will become like figure 14b. This phenomenon is described in a paper called [Timbre Space as a Musical Control Structure](http://xenakis.ircam.fr/articles/textes/Wessel78a/)

WE NEED THE LISTENING EXAMPLE HERE.

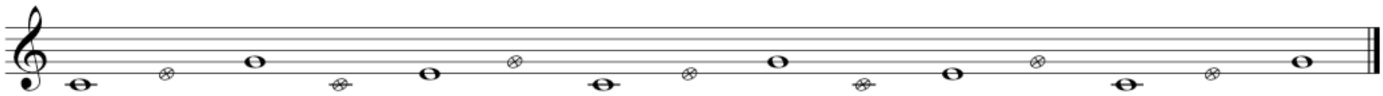


Figure 14a. Three notes are played in an ascending pattern with two alternating timbres.

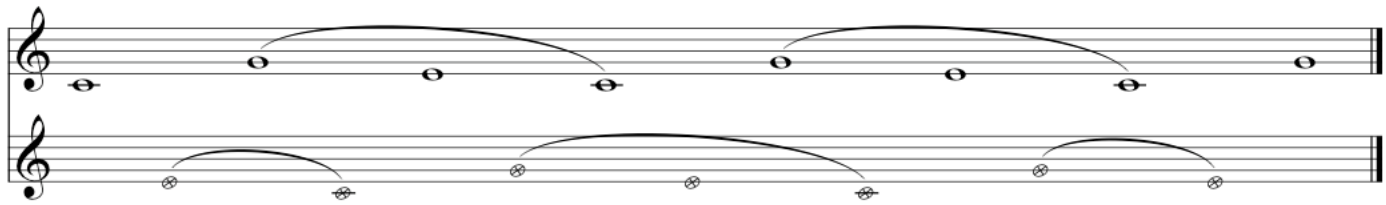


Figure 14b. If the pattern in figure 14a is played fast enough, we will begin to group the pitches according to timbre producing two distinct descending lines.

## SumMary

*johnmac*, 10 October 2006 (created 10 October 2006)

no tags

Timbre is one of the more mysterious qualities of sound, but also, as it has been exploited by composers in the 20th and 21st centuries, one of the richest as well. Although we are often left to describe the timbre of a sound with vague terms such as *bright* or *hollow*, there are some quantitave aspects that we can measure such as the spectral envelope and the spectral centroid which both give us information about how the energy is distributed across frequency. For certain instruments and the voice in particular, we can look at the formant structure. We can also look at how the partials relate to one-another (for instance, the odd-even balance) and how the amplitudes of those partials might be shaped by a resonating body such as the vocal cavity or the body of a violin. Finally, we have seen that the issue of timbre concerns much more than just the spectral details. The evolution of the sound over time gives us important clues about the sound and in particular, the way in which a sound begins can greatly influence the way we hear it.

## ReferenceS

*johnmac*, 10 October 2006 (created 10 October 2006)

no tags

Benade, Arthur H. (1990), Fundamentals of Musical Acoustics. New York: Dover.

## LinksnDownloads

*johnmac*, 10 October 2006 (created 10 October 2006)

no tags

Max patches:
[unit6]()

Timbre Space as a Musical Control Structure:
[http://xenakis.ircam.fr/articles/textes/Wessel78a/](http://xenakis.ircam.fr/articles/textes/Wessel78a/)

Videos of the vocal folds in action:
[http://www.voicemedicine.com/normal_voice_functioning.htm](http://www.voicemedicine.com/normal_voice_functioning.htm)

## QuizItems

*johnmac*, 10 October 2006 (created 10 October 2006)

no tags

- What are some large-scale features of the spectrum and what do they tell us about the spectrum?
- Describe the source-filter model of vocal production.
- What is a characteristic of the clarinet's spectrum? What words might you use to describe the timbre of a clarinet.
- What happens to the spectrum of a brass instrument such as a trumpet when it gets louder? What words might you use to describe the timbre of a brass instrument?

## AnswersToTheTimbreIdentificationListeningExample

*johnmac*, 10 October 2006 (created 10 October 2006)

no tags

1. Oboe

2. Trumpet
3. Violin
4. Alto Saxophone

How did you do?