

# COMPOSING IN THE FLESH: PERCEPTUALLY-INFORMED HARMONIC SYNTAX

*Sean Ferguson*

Faculty of Music, McGill University  
555 Sherbrooke St. West, Montreal, Quebec,  
Canada H4A 1E3  
Phone (514) 398-4535 ext. 0543  
Fax (514) 398-8061  
Email [sean.ferguson@mcgill.ca](mailto:sean.ferguson@mcgill.ca)

*Richard Parncutt*

Department of Musicology  
Mozartgasse 3, 8010 Graz, Austria  
Web <http://www-gewi.uni-graz.at/muwi/parncutt>  
Phone +43 316 380-2409 (direct) or -2405  
(sec.)  
Office fax +43 316 380-9755  
Email [parncutt@uni-graz.at](mailto:parncutt@uni-graz.at)

## ABSTRACT

A perceptually-informed harmonic syntax is described in which outer voices are harmonized according to psychoacoustic models of sensory dissonance and successive and referential pitch commonality. These models take into account the spectrums of the notated pitches of a sonority. The harmonic system is implemented using software written by the first author in the Common Lisp programming language. The user defines the relative degrees of each parameter for each member of a given set of outer voices, and the software calculates values for all appropriate chords found within a predetermined harmonic vocabulary. The paper describes one possible method of creating a harmonic vocabulary for a piece. It then provides an overview of the psychoacoustic models that correspond to the harmonic parameters and demonstrates the manner in which progressions are composed. Finally, it gives examples of progressions composed in this way from *Dans la chair/In the Flesh*, a recent piece for orchestra by the first author.

## 1. INTRODUCTION

This paper describes a perceptually-informed harmonic syntax. Outer voices are harmonized according to psychoacoustic models of sensory dissonance and successive and referential pitch commonality which correspond to three parameters of common-practise harmonic syntax: consonance/dissonance, voice leading and tonality. In the current system, however, these parameters are applied to non-triadic chordal structures. The psychoacoustic models take into account the spectrums of the notated pitches of a sonority. This harmonic system is implemented using software written by the first author in the Common Lisp programming language. The composer defines the relative values of each parameter for each member of a given set of outer voices, and the software calculates values for all appropriate chords found within a predetermined harmonic vocabulary. These chords are sorted by their correspondence to the desire value of each parameter. The process of choosing inner voices for a given pair of outer voices is interactive; the composer makes the final choice from among a user-

definable number of possible solutions. The following discussion describes one possible method of creating a harmonic vocabulary for a piece. It then provides an overview of the psychoacoustic models that correspond to the harmonic parameters and demonstrates the manner in which progressions are composed. Finally, it gives examples of progressions composed in this way from *Dans la chair/In the Flesh*, a recent piece for orchestra by the first author. This piece was premiered in Paris by the *Orchestre Philharmonique de Radio-France* during the *Presences 2003* Festival.

## 2. HARMONIC VOCABULARY

The harmonic vocabulary for a piece is defined as a three-dimensional array. The dimensions are cardinality (number of pitch classes), outer interval and specific voicing of an individual chord. Only chords that correspond to certain criteria are included in the array. The goal of restricting the harmonic vocabulary is twofold. Firstly, the set of all possible chords with a given cardinality and outer interval can become extremely large. For example, while the number of all possible 6-note chords with an outer interval of 8 semitones is only 35, there are 2,380 possible 6-note chords with an outer interval of 18 semitones. Such large numbers are both musically unnecessary and computationally inefficient. Secondly, limiting the harmonic vocabulary to related chords may help to increase the coherence of a piece.

In *Dans la chair/In the Flesh*, the harmonic vocabulary is determined by relative relatedness to the nexus set [0 1 4 6] (one of the all-interval tetrachords) as calculated using Marcus Castrén's *RECREL* similarity measure.<sup>1</sup> For each slot in the array, the chords that are most closely related to the nexus set are retained, up to a maximum of 200 chords per slot. The array contains chords with cardinalities from 3 to 10 and outer intervals up to 47 semitones for a total of 47,603 chords.

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<sup>1</sup>Castrén, M. 1994. "Recrel: A Similarity Measure for Set-Classes." Ph.D. diss., Sibelius Academy, Helsinki.

### 3. PSYCHOACOUSTIC MODELS

The compositional goal of this system is to create a harmonic syntax that is able to control the relative dissonance of chords, the relationship between successive chords in a progression and the creation of harmonic regions determined by the relationship of chords to a referential sonority. The two principal psychoacoustic models used are sensory dissonance and pitch commonality. By basing this syntax on perceptual models, a composer may be able to control the perceived harmonic stability of a progression.

#### 3.1. Sensory Dissonance

In music, the term “dissonance” has two principal meanings. The first is “stylistic instability, tension, ‘disagreement.’”<sup>2</sup> In the context of this definition, consonance refers to elements that are “stylistically ‘stable,’ ‘reposed,’ or ‘in agreement.’”<sup>3</sup> The second meaning, which may be termed “sensory” dissonance, refers to the sensation of rapid beating, or roughness, within a sonority. Consonance is the absence of such beating. These two definitions do not necessarily agree. The interval of a perfect 4th, for example, is considered to be dissonant in common-practice tonal syntax, since it is unstable when it occurs in a two-voice texture or above the bass in chords with three or more notes. In terms of sensory dissonance, however, it is consonant since it has a very low degree of perceived roughness. The minor 2nd, on the other hand, is dissonant according to both definitions.

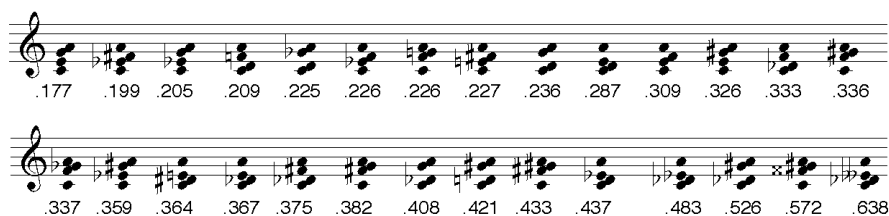


Figure 1: Chords sorted by increasing sensory dissonance.

The model of sensory dissonance used in *Dans la chair/In the Flesh* originates with Helmholtz,<sup>4</sup> who was the first to experimentally confirm the relationship between beating and dissonance. Further empirical research by Plomp and Levelt<sup>5</sup> was formalized in the research of Hutchinson and Knopoff.<sup>6</sup> The implementation used in *Dans la chair/In the Flesh* is

based on Hutchinson and Knopoff, with modifications by Richard Parncutt.<sup>7</sup>

In this model, beating is considered to be the source of dissonance. The roughness caused by rapid beating is difficult to describe in words, but is easily recognized when heard. If one plays the interval of a perfect fifth above middle C on the piano, for example, very little roughness is perceived. The interval of a minor second above the same note, on the other hand, contains a great deal of roughness, or sensory dissonance. The degree of roughness of an interval or chord depends on the extent to which it has spectral components within the same critical band. The critical band is related to the smallest frequency difference that will allow two pure tones to be perceptually identified as two autonomous tones rather than as one single buzzing unit. To illustrate, if two sine waves are generated at the same pitch, only one tone is heard. As the frequency of one of the waves is gradually raised or lowered in a continuous glissando, a periodic variation in the amplitude of the perceived tone is heard. As the frequency distance between the two pure tones gradually becomes greater, the rate and prominence of the beating in the single perceived tone increases until it takes on a buzzing character. The sensation of rapid beating then gradually diminishes until it is no longer perceived. This point - roughly the interval of a minor third in the middle register - marks the limit of the critical band. The greatest sensation of roughness occurs when the frequencies of the two pure tones are approximately one quarter of a critical band apart.

In simplest terms, the calculation of sensory dissonance involves the modeling of the combined spectrum of an interval or chord - including the pitch and amplitude of each spectral component - and the determination of the extent to which each pair of pure-tone spectral components is less than a critical bandwidth apart. The degree of dissonance depends on the “closeness and strength of adjacent pure tones in the overtone structure of complex sounds.”<sup>8</sup>

Figure 1 lists all possible 4-note chords with an outer interval of a major 6th above middle C, and their sensory dissonance. The chords are arranged by increasing dissonance according to the algorithm of Hutchinson and Knopoff. The effectiveness of the model may be judged by playing the progression on the

<sup>2</sup>W. Hutchinson & L. Knopoff, “The Significance of the Acoustic Component of Consonance in Western Triads,” *Journal of Musicological Research* Vol. 3 (1979): 21.

<sup>3</sup>Ibid., 20.

<sup>4</sup>H. Helmholtz, *On the Sensations of Tone* (New York: Dover, English Ed. 1954, Orig. 1877).

<sup>5</sup>R. Plomp & W. J. M. Levelt, “Tonal Consonance and Critical Bandwidth,” *Journal of the Acoustical Society of America* 36 (1965): 1526-33.

<sup>6</sup>W. Hutchinson & L. Knopoff, “The Acoustic Component of Western Consonance,” *Interface* Vol. 7 (1978): 1 - 29.

<sup>7</sup>[www-gewi.uni-graz.at/muwi/parncutt](http://www-gewi.uni-graz.at/muwi/parncutt)

<sup>8</sup>W. Hutchinson & L. Knopoff, “The Acoustic Component of Western Consonance,” *Interface* Vol. 7 (1978), 3.

piano and determining whether one agrees with its ranking.

### 3.2. Pitch Commonality

In common-practice tonal syntax, the number of common notes between successive chords is an important factor in determining the strength of a progression. In general, a greater number of common tones results in a “weak” or smooth progression, while a lesser number results in a “strong” or uneven progression.<sup>9</sup> In musical set theory, a similar emphasis is placed on the number of invariant pitch-classes between transpositions of a set or its inversion.<sup>10</sup> Both of these approaches to chord succession are restricted to the

*Flesh* was developed by Richard Parncutt, based on Terhardt’s concept of tonal affinity (*Tonverwandschaft*).

To calculate the degree of pitch commonality between two sonorities, one must first generate a perceptual spectrum for each; that is, an array of perceived pitches and corresponding saliences calculated according to Terhardt’s approach. Whereas a regular physical (amplitude) spectrum is a graph of SPL against frequency for each partial, a perceptual spectrum is a graph of perceptual salience against perceived pitch for each tone that is perceived within the sonority. As a result of these differences, determining pitch commonality is a considerably more complex process than is sensory dissonance. For an exhaustive description of the model, see chapter 4 of Parncutt’s *Harmony, A Psychoacoustical Approach*.<sup>11</sup>

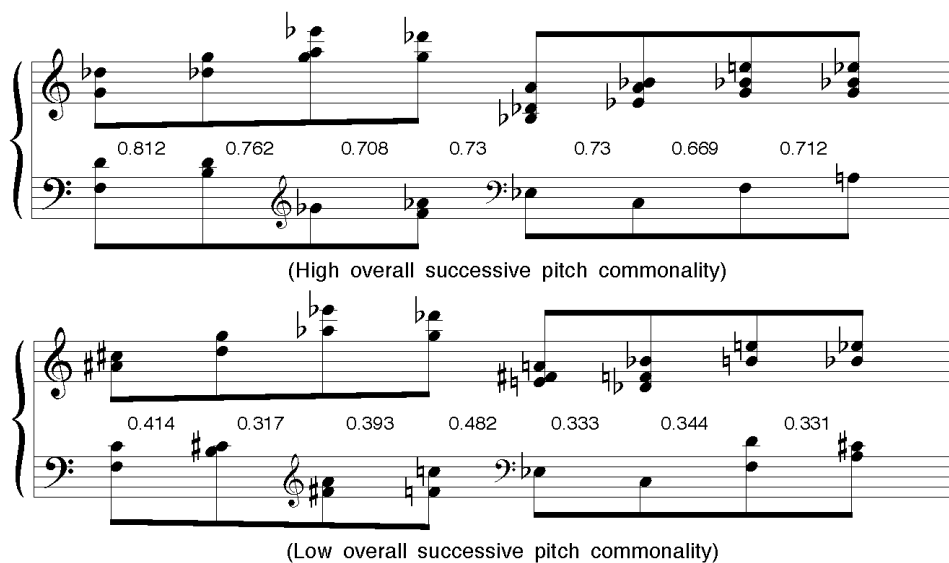


Figure 2: Two different harmonizations of the same outer voices

actual notated pitches of the chords. The model of pitch commonality used in *Dans la chair/In the Flesh* differs in that, like the model of sensory dissonance, it utilizes the spectra of chords. Qualitatively, pitch commonality is the degree to which sonorities are heard to share pure and complex tones. Pairs of chords with high pitch commonality are perceived to be more closely related than are chords with low pitch commonality.

The idea of frequencies in common as a basis for harmonic affinity between successive sounds was considered by Helmholtz but clearly does not work in the case when a harmonic complex tone with missing fundamental is followed by a pure tone corresponding to that fundamental. From this example, it is clear that a model of harmonic relationship should be based on perceived pitches, rather than notes or frequencies. The model of pitch commonality used in *Dans la chair/In the*

*In Dans la chair/In the Flesh*, pitch commonality is applied in two ways: successively and referentially. Successive pitch commonality is calculated between consecutive chords in a harmonic progression. In figure 2, each series of chords has the same outer voices. In the first harmonization, consecutive chords have high pitch commonality, while the second version has low successive pitch commonality. The pitch commonality between each pair of chords is given between the staves. Since it has higher pitch commonality, the connection between chords in the first progression should sound generally smoother than in the second.

Referential pitch commonality is calculated between the chords of a progression and a middleground referential sonority. The referential sonority may be present in the music, as a sustained chord for example,

<sup>9</sup>E. Aldwell & C. Schachter, *Harmony and Voice Leading, Second Edition* (San Diego: Harcourt Brace Jovanovich, 1989), 136.

<sup>10</sup>A. Forte, *The Structure of Atonal Music* (New Haven: Yale University Press, 1973), 29.

<sup>11</sup>R. Parncutt, *Harmony: A Psychoacoustical Approach* (Berlin: Springer-Verlag, 1989): 77-97.

or may be only suggested. A progression of chords all with a high degree of pitch commonality to the same chord should imply this referential sonority, even if it is not actually sounding. This effect will be stronger if the sonority has been previously emphasized in the piece. In figure 3, the eight-note chord is the referential sonority of the piece, and the four-note chords are sorted by decreasing pitch commonality with this sonority. These are examples of chords as they might appear in a piece of music, not of pitch-class sets. The maximum and minimum pitch commonality values are given below the



Figure 3: Chords sorted by referential pitch commonality. □

staff. Chords at the beginning of the list should sound related to the referential sonority since they share many components, while chords at the end of the progression should sound less related.

#### 4. COMPOSING PROGRESSIONS

As previously mentioned, chord progressions are composed by harmonizing an outer-voice framework. Inner voices are added to each pair of outer voices according to specific criteria. These include cardinality (number of notes), dissonance, successive pitch commonality, and referential pitch commonality. The first step in this process is to find all the chords with the desired cardinality, outer interval, and transposition level. These are not selected from all possible chords, but from the specific harmonic vocabulary of the piece. The list of chords is then analyzed for the previously-mentioned parameters and chords with the desired degree of each are returned. The process for making this selection is as follows.

other hand, is equivalent to the expression: “Of these chords, which ones have an average amount of dissonance?” To answer this question, we sort the list by increasing dissonance and retain only that segment of the list that corresponds to the desired amount. The approximate portions of the list that would be returned for several different values of sensory dissonance are given in figure 4.

Note that very high and low values return slightly fewer chords than intermediate values. In these cases the composer is indicating a strong preference:

“extremely dissonant” rather than “somewhat dissonant.” This procedure is repeated in turn for each parameter. The result of each successive “slice” is analyzed and sorted, and the corresponding portion is used for the next parameter. The order of analysis is: (1) dissonance, (2) referential pitch commonality and (3) successive pitch commonality.

The following example clarifies the harmonization process. Imagine that we are harmonizing the fourth chord out of a progression of eighth chords, and that at this point the current values of the harmonic parameters are:

- referential sonority: (60 61 64 66) or C4, C#4, E4, F#4
- cardinality: 6
- transposition level: 61 (C#4)
- outer interval: 23 semitones
- dissonance: 0.33
- referential pitch commonality: 0.67
- successive pitch commonality: 0.75

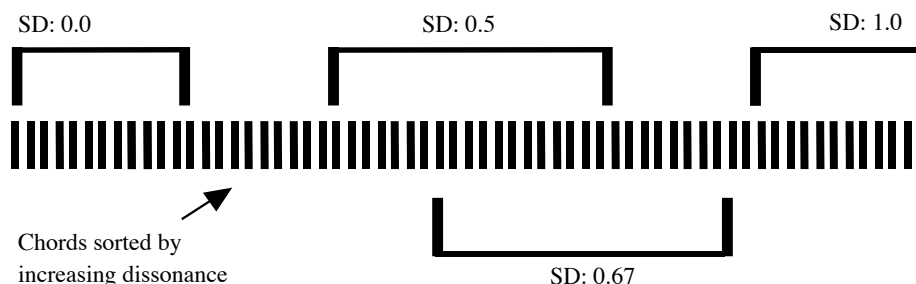


Figure 4: Selecting Chords by degree of sensory dissonance.

Values between 0 and 1 express the desired degree of each parameter, with 0 being the least possible and 1 the greatest. These values indicate the relative amount of each parameter, not the absolute value. For instance, a value of 0 for dissonance is equivalent to the following expression: “Of the chords with the desired number of notes, outer interval and transposition level, which ones are the least dissonant?” A value of .5, on the

The program returns four progressively shorter lists of chords, notated as MIDI key numbers (middle C = 60). The first list contains all the chords in the harmonic vocabulary of the Concerto with the desired cardinality and outer interval, transposed to begin on MIDI note 61. The second list contains those chords from the second list whose relative dissonance

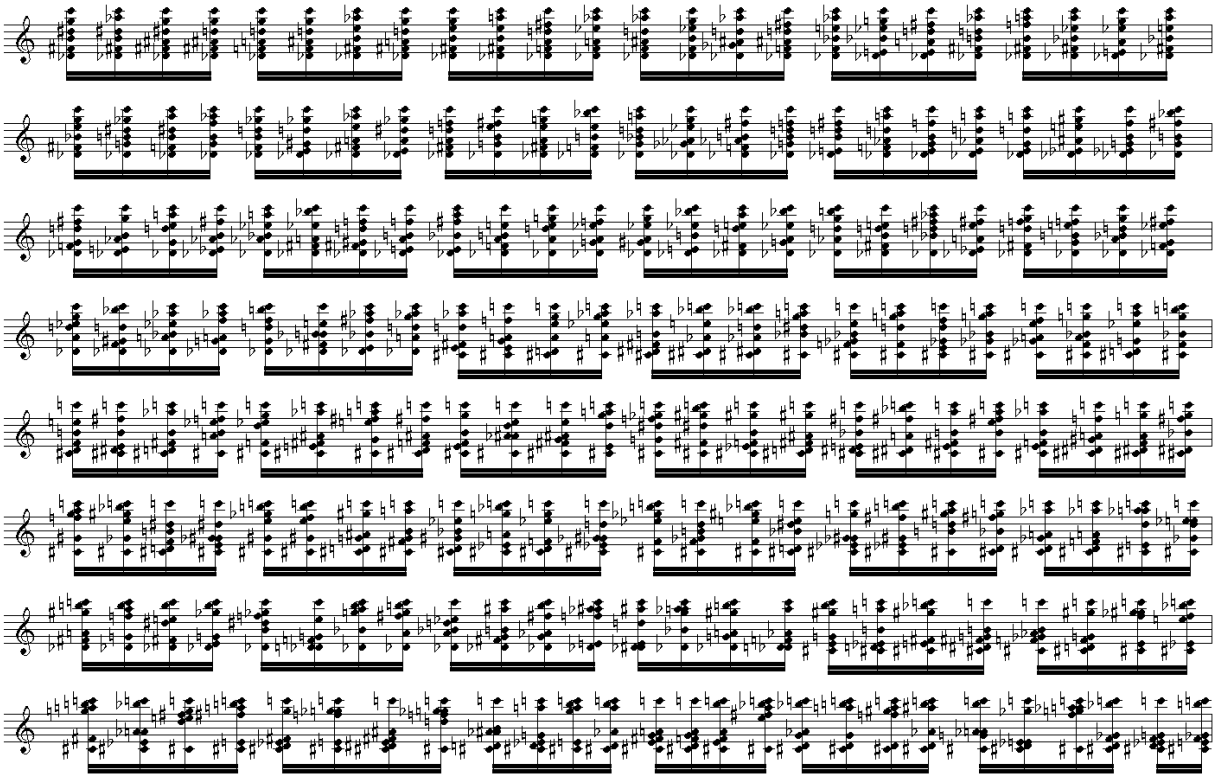


Figure 5a: All Chords

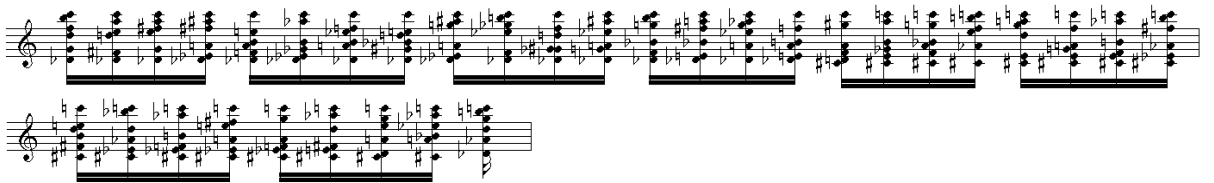


Figure 5b: Chords Selected By Sensory Dissonance



Figure 5c: Chords Selected By Referential Pitch Commonality



Figure 5d: Chords Selected By Successive Pitch Commonality

corresponds to the indicated amount of 0.33. The third list is the result of choosing chords from the previous list that have the desired degree of referential pitch commonality, and the fourth list is the result of analyzing these chords for successive pitch commonality. The composer makes a final choice from this list. Depending on the musical goals of the passage, one could choose the chord which is least dissonant, or more closely related to the referential sonority. Or, since the chords of the list are essentially equivalent in terms of the specified harmonic parameters, one can simply make a random choice.

For the above progression, the four lists (in musical notation) are given in figures 5a to 5d.

#### 4.1. Example

The following example is a reduction of measures 45-49 of *Dans la chair/In the Flesh*. The bottom two staves contain the referential sonority of the piece, which is sustained in a complex texture which has been simplified for this example. The upper two staves contain harmonic progressions whose outer voices have been harmonized using the system described above:

Both progressions begin with high sensory dissonance, low successive pitch commonality and low referential pitch commonality and gradually transform to low sensory dissonance, high successive pitch commonality and high referential pitch commonality by their endings. The compositional goal is to create musical phrases with low harmonic stability at their beginnings, but which become gradually more harmonically stable as they progress.

Figure 6: Measure 45-49 of *Dans la chair/In the Flesh*

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