Harmony Perception by Periodicity and Granularity Detection

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EXTENDED ABSTRACT

Background

Music perception and composition seem to be influenced not only by convention or culture, manifested by musical styles or composers, but also by the psychophysics of tone perception (Parncutt, 1989). Early mathematical models express musical intervals by simple fractions. This helps to understand that human subjects rate harmonies, e.g. major and minor triads, differently with respect to their sonority. Newer explanations base upon the notion of consonance, dissonance or tension (Plomp and Levelt, 1965; Cook and Fujisawa, 2006). They correlate better to empirical results on harmony perception, but still do not explain the perceived sonority of common triads (major > minor > suspended > diminished > augmented) very well.

Aims

It is well-known, that periodicity is encoded in the auditory system, and information concerning stimulus periodicities is still present in short-term memory. Periodicities of complex chords can be detected in the human brain (Cariani, 1999; Langner, 2007). Furthermore, the just noticeable difference of human pitch perception is about 1% for the musically important low frequency range (Zwicker *et al.*, 1957). Here, we want to apply these results from neuroscience and psychophysics consistently, obtaining a concise theory of musical harmony perception.

Main Contribution

We set up the following hypothesis: The perceived sonority of a chord decreases with the ratio of the period length of the chord (its virtual pitch) relative to the period length of its lowest tone component − called harmonicity h (Stolzenburg, 2009). In addition, we consider the number of extrema in one period of its lowest tone component (the least common overtone) − called granularity g. The combination of both values in one measure $\Omega(g \cdot h)$, counting the maximal number of times that the whole periodic structure can be decomposed in time intervals of equal length, gives us a powerful approach to the analysis of musical harmony perception.

Implications

Interestingly, the periodicity-based analysis presented here demonstrates, that it does not matter much whether tones are presented consecutively (and hence in context) as in scales or simultaneously as in chords. Periodicity detection seems to be the universal mechanism for the perception of all kinds of musical harmony: chords, scales, and also chord progressions, where simpler periodic patterns are preferred. The periodicity-based approach yields meaningful results for all cases: The results obtained for dyads and common triads on the one hand and classical diatonic scales on the other hand all show highest correlation ($r > 0.9$) with known empirical results, e.g. the ones by Malmberg (1918), Roberts (1986), and Cook (2009a).

Tables 1 to 3 (see next page) show the consonance rankings for dyads, common triads, and classical heptatonic scales for different theoretical models. The respective numbers of semitones wrt. 12-tone equal temperament are given in braces there, raw values of the respective measures in parentheses. Cook (2009b, Tab. 1) reports rankings (for triads) of other models, which all have yet worse correlations, however. The value $\Omega(g \cdot h)$ introduced in this paper lists all church modes, i.e. the diatonic scale and its inversions, in the very front ranks of 462 possible scales with 7 out of 12 tones (see Table 3).

Keywords

Harmony perception; periodicity; mathematical music theory; chords and scales.

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Table 1: Consonance rankings of dyads.

interval		emp. rank	Sethares	Gill and Purves		harmonicity		$\Omega(g \cdot h)$	
unison	{0, 0}	1	1-2	1-2	(100.0%)	1-2	(1.0)	1	(0.0)
octave	{0, 12}	2	1-2	1-2	(100.0%)	1-2	(1.0)	2	(1.0)
perfect fifth	{0, 7}	3	3	3	(66.7%)	3	(2.0)	3	(2.0)
perfect fourth	{0, 5}	4	4	4	(50.0%)	4-5	(3.0)	5	(3.0)
major sixth	{0, 9}	5	5	5	(46.7%)	4-5	(3.0)	4	(2.0)
major third	{0, 4}	6	6	6	(40.0%)	6	(4.0)	6	(3.0)
minor sixth	{0, 8}	7	10	8	(30.0%)	7-8	(5.0)	8	(4.0)
minor third	{0, 3}	8	8	7	(33.3%)	7-8	(5.0)	7	(3.0)
tritone	{0, 6}	9	11	12	(13.7%)	12	(14.1)	9	(4.5)
minor seventh	{0, 10}	10	7	11	(16.7%)	11	(9.0)	12	(6.0)
major second	{0, 2}	11	12	9	(22.2%)	9-10	(8.0)	10-11	(5.0)
major seventh	{0, 11}	12	9	10	(18.3%)	9-10	(8.0)	10-11	(5.0)
minor second	{0, 1}	13	13	13	(12.5%)	13	(15.0)	13	(6.0)
correlation r			.911	.944		.945		.971	

Table 2: Consonance rankings of common triads.

chord class		emp. rank	Helmholtz	Cook et al.		Gill and Purves		harmonicity		$\Omega(g \cdot h)$	
major	{0, 4, 7}	1	3-4	1	(0.62)	1-2	(46.7%)	2	(4.0)	2	(4.0)
	{0, 3, 8}	3	9-10	5	(0.81)	8-9	(37.8%)	3	(5.0)	5	(5.0)
	{0, 5, 9}	2	1-2	4	(0.78)	5-6	(45.6%)	1	(3.0)	1	(4.0)
minor	{0, 3, 7}	4	3-4	2	(0.74)	1-2	(46.7%)	7	(10.0)	3	(4.0)
	{0, 4, 9}	5	1-2	3	(0.76)	5-6	(45.6%)	8	(12.0)	4	(4.0)
	{0, 5, 8}	6	9-10	6	(0.84)	8-9	(37.8%)	9	(15.0)	8	(5.0)
susp.	{0, 5, 7}	8	5-7	8	(1.18)	3-4	(46.3%)	4	(6.0)	6	(5.0)
	{0, 2, 7}	7	5-7	11	(1.22)	3-4	(46.3%)	5	(8.0)	7	(5.0)
	{0, 5, 10}	9	8	9	(1.19)	7	(38.9%)	6	(9.0)	10	(6.0)
dim.	{0, 3, 6}	10	13	12	(1.43)	13	(26.8%)	13	(26.0)	12	(6.3)
	{0, 3, 9}	12	11-12	7	(1.11)	11-12	(31.2%)	10	(16.6)	9	(5.7)
	{0, 6, 9}	11	11-12	10	(1.20)	11-12	(31.2%)	12	(19.9)	11	(6.0)
augm.	{0, 4, 8}	13	5-7	13	(2.00)	10	(36.7%)	11	(19.7)	13	(6.7)
correlation r			.617	.830		.694		.791		.918	

Table 3: Rankings of common heptatonic scales (church modes), i.e. with 7 out of 12 tones.

mode	semitones	Gill and Purves		harmonicity		$\Omega(g \cdot h)$	
Ionian	{0, 2, 4, 5, 7, 9, 11}	1-2	(37.4%)	1	(59.8)	1	(10.3)
Dorian	{0, 2, 3, 5, 7, 9, 10}	5-6	(35.8%)	3	(66.9)	3	(10.6)
Phrygian	{0, 1, 3, 5, 7, 8, 10}	5-6	(35.8%)	8	(74.7)	4	(10.6)
Lydian	{0, 2, 4, 6, 7, 9, 11}	1-2	(37.4%)	2	(63.1)	2	(10.3)
Mixolydian	{0, 2, 4, 5, 7, 9, 10}	7-8	(35.0%)	4	(68.5)	5	(10.7)
Aeolian	{0, 2, 3, 5, 7, 8, 10}	31	(33.9%)	11	(76.3)	7	(10.9)
Locrian	{0, 1, 3, 5, 6, 8, 10}	7-8	(35.0%)	10	(75.6)	6	(10.7)