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ON THE ROLE OF AMBIGUITY OF PERCEIVED PITCH IN MUSIC

E. Terhardt

Institute for Electroacoustics, Technical University, München,
P.O. Box 202420, D-8000 München 2, FRG (West Germany)

Ambiguity, and its resolution, are key elements of communication; and, in particular, of music (See, e.g., the examples discussed by L. Bernstein in his famous Harvard lectures [1]. Besides rhythmical ambiguity, it is particularly harmonic ambiguity of both simultaneous notes, i.e., chords, and of sequential notes, i.e., melodies, that play a major role. Auditory pitch comes into play through the intimate relationship that was discovered to exist between pitch (in the term's general psychophysical sense), and musical harmony. What in music theory is called a root, in psychophysical terms is a certain type of pitch, i.e., virtual pitch [6, 7]. Ambiguity of root (i.e., harmony) is synonymous with ambiguity of virtual pitch.

Those relationships are dependent on the idea that auditory pitch exists on various levels of the perceptual hierarchy. On the lowest, i.e., primary level, pitch exists as an aural representation of part-tone frequency, i.e., spectral pitch; spectral pitch can be regarded as analogous to primary visual contour [8]. On a higher level, a set (i.e., two or more) of spectral pitches ordinarily create virtual pitches; the latter are analogous to "illusory contours" in vision. As was demonstrated by Hall and Peters [3], under certain conditions even non-simultaneous spectral pitches can create virtual pitches.

The present paper is going to briefly discuss the following notions:

* Ambiguity of pitch is ordinary and gradual;
* ambiguity of pitch is confined to a finite set of alternatives;
* ambiguity of pitch creates perceptual similarity of sound objects;
* similarity in turn is a basic organisational principle of music.

PITCH AMBIGUITY IS ORDINARY AND GRADUAL

There is only one type of sound the pitch of which is largely unambiguous: a pure tone. Any other tonal stimulus is more or less ambiguous in pitch. This is a natural consequence of two basic psychophysical facts: First, each of the spectral components tends to produce its own pertinent spectral pitch. Second, the virtual pitches inevitably evoked by a set of part-tones provide additional pitch ambiguity. While the spectral pitches correspond to the fundamental and to higher (harmonic) frequencies, the majority of virtual pitches are below the nominal fundamental frequency. Fig.1 schematically illustrates the distributions of pitches (both spectral and virtual) of two harmonic complex tones whose fundamental frequencies are an octave apart (For details and theoretical and experimental foundations see [6, 10, 11]). The pitch ambiguity of harmonic complex tones (including, e.g., the human voice) as yet has only rarely been recognized. Yet by systematic listening tests such as described in [11] it can readily be verified.

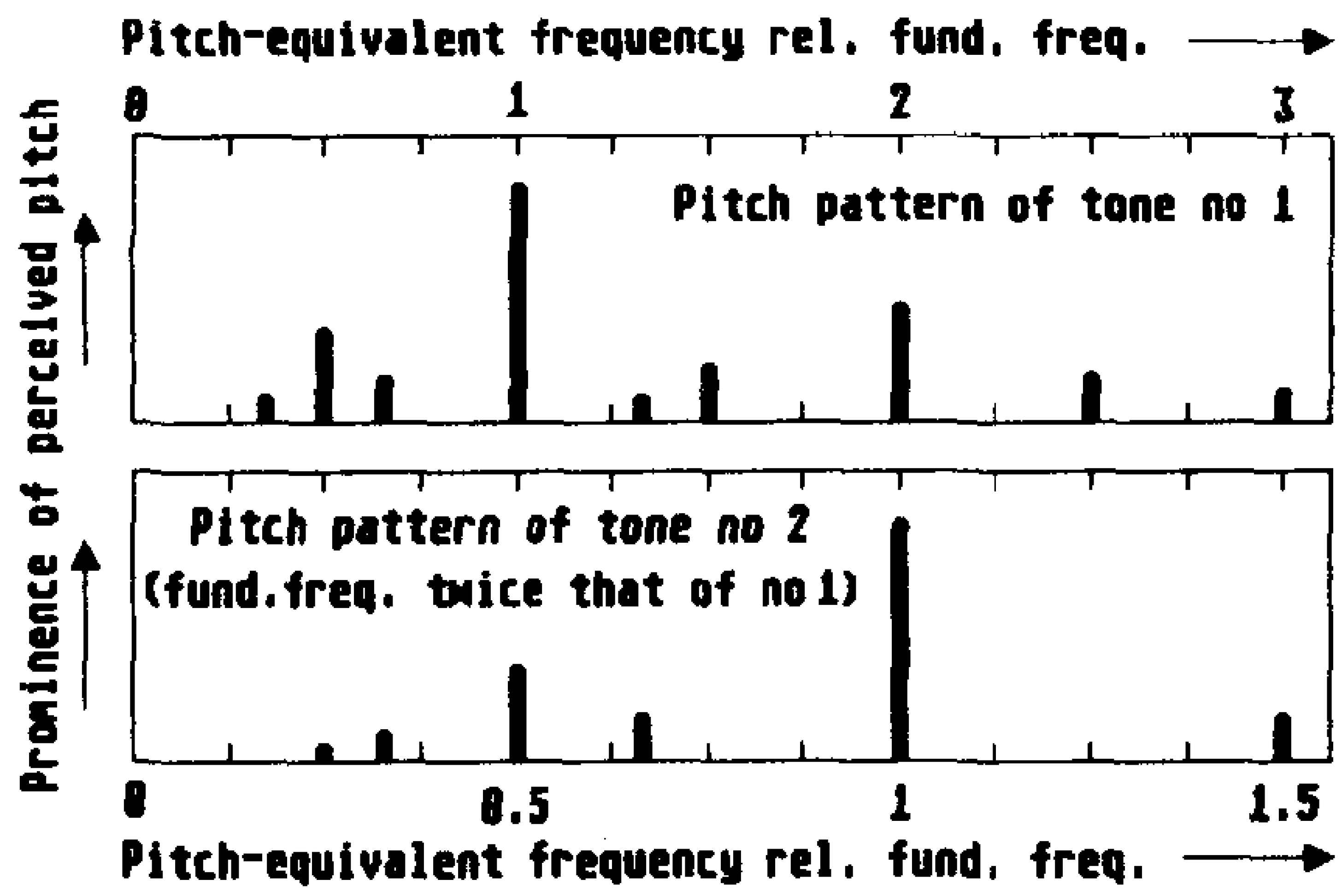

Fig.1. Schematic pitch patterns of harmonic complex tones whose fundamental frequencies are in the ratio 1:2.

A famous example of pronounced pitch ambiguity was described by Shepard [5]. It should be noted that the "Shepard tones" that are so ambiguous are not categorically different from "ordinary" harmonic complex tones; the former just are lacking harmonics which are not included in the frequency series $f=f_0 2^n$, where n=0,+/-1, +/-2, etc. As a consequence, those tones, while having a well-defined "chroma", are ambiguous with respect to the octave region of their pitch. However, even in that extreme case ambiguity is limited: Auditory matches to the pitch of "Shepard tones" show a pronounced tendency toward the frequency region of about 250 to 350 Hz [11]. That phenomenon, i.e., the preference of an absolute frequency region, suffices to explain the so-called "tritone paradox" [2], cf. [9]. The pitch of ordinary musical tones is less ambiguous just because there are included more harmonics providing additional pitch information; this however does not totally resolve ambiguity but just reduces it. So ambiguity of pitch indeed is both ordinary in its occurrence and gradual in its prominence.

PITCH AMBIGUITY IS CONFINED TO A FINITE SET OF ALTERNATIVES

Ambiguity does not mean randomness. On the contrary, the pitches evoked by a tonal stimulus - each of which provides an alternative to the other ones - are in systematic relationships to each other. Those relationships are governed both by the spectral composition of the actual stimulus and by certain strategies of the auditory system for extraction of tonal information. As a result, in the case of harmonic complex tones, the set of alternatives basically is as illustrated in Fig.1. The most fundamental musical intervals, i.e., octaves, fifths, and fourths, are established by the virtual pitches below the nominal fundamental. While in the spectral-pitch pattern (that largely provides the pitches above the fundamental) octaves and fifths are naturally included as well, there appear in addition thirds and smaller intervals (The latter are not included in Fig.1 as the pitch range displayed is restricted).

PITCH AMBIGUITY CREATES PERCEPTUAL SIMILARITY

The two pitch patterns in Fig.1 were chosen in order to demonstrate the similarity between them, i.e., the similarity that exists between the pitch patterns of musical tones which are an octave apart in fundamental frequency. Here the concept of similarity is applied in a most straightforward sense: The pitch pattern produced by a musical tone is regarded as similar to that of another tone if a **considerable number** of elements (individual pitches) coincide **more or less precisely** with any elements of another pitch pattern. So when the aspect of similarity of tones is expressed in terms of tone frequencies, it follows that similarity of musical tones is dependent on two components. First, two musical tones whose fundamental frequencies are close to each other (say, within a semitone interval) are similar, because there is "near-coincidence" of all corresponding elements of the respective pitch patterns; this is the "linear component" of similarity. Second, two musical tones whose fundamental frequencies are in such a ratio that a significant number of elements of the two pitch patterns coincide, are similar as well; this is the "harmonic component" of similarity. While the linear component is not dependent on pitch ambiguity, the harmonic component entirely depends on it. So it turns out that ambiguity of musical tones is a constructive phenomenon which creates similarity between tones that are considerably different in oscillation frequency but are in one of certain particular frequency intervals (mainly, octaves and fifths) . It is ambiguity of pitch which explains the basic phenomenon of tonal affinity, i.e., octave equivalence and fifth-similarity. A quantitative model of tonal similarity was recently proposed by Parncutt [4].

SIMILARITY AS AN ORGANISATIONAL PRINCIPLE OF MUSIC

Similarity of sensory patterns, as defined above, turns out to be a general and basic principle of organising any sensory input. Consider, for instance, visual perception of an object that moves relative to other objects and structures. Holistic perception and "tracking" of the moving object requires that at every instant the sensory input is tested for sufficient similarity between the successive instantaneous images, to justify the conclusion that it is one and the same object that is seen, though with time passing its position, angle of view, and size, may change considerably. It is continuity of the sensory input, in the above sense, which provides for "understanding".

The same principle appears to govern the organisation of music. The perceptual distance between two musical tones or harmonies may be called small if the tones are similar in the aforementioned sense. The step size from one tone or harmony to the other is determined by the vector composed of the linear and the harmonic components. In this concept, tonal music indeed progresses according to a "principle of short distances". The notion that one of the two components of the similarity vector is created by a basic (i.e., psychophysical) type of tone ambiguity provides interesting insights into the key role of ambiguity in music.

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