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Consonance and dissonance in music theory and psychology: Disentangling dissonant dichotomies

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Background in music theory. Consonance and dissonance (C/D) has been central to music theory since ancient Greece. It refers to both vertical and horizontal relationships in the musical score. On longer time scales, it refers to local and global relationships. Modern thinking about C/D has been influenced by theorists such as Pythagoras, Fux, Rameau, Riemann, Schenker and Schoenberg. Tenney (1988) gave a historical overview of C/D concepts in different periods, summarizing the contribution of culture (stylistic familiarity) and changing beliefs about the role of nature.
Background in music psychology. The consonance of a sonority depends on its spectral harmonicity (cf. Stumpf, 1883), temporal smoothness (Helmholtz, 1863), and cultural familiarity (Cazden, 1945). The consonance of successive sonorities depends on their pitch commonality and proximity (Parncutt, 1989); of a tonal passage, on its perceived structure (Krumhansl, 1990). Many aspects of C/D are ultimately based on the learning and recognition of familiar pitch patterns in speech and music (Terhardt, 1974) and involve both sides of the nature/culture dichotomy.
Aim. We develop a new conceptual structure for Western C/D that brings together, balances and synergizes relevant humanities (history of music, history of music theory) and sciences, (acoustics, psychology and psychoacoustics). We clarify terminology and develop a holistic approach.
Main contribution. We cover a broad epistemological spectrum that includes the popular conception of C/D as pleasant/unpleasant and the history of C/D in Western music and music theory. We juxtapose terms, references and styles of musical and psychological discourse. We compare and contrast dichotomies that overlap or interact with the C/D concept such as tense/relaxed, primary/subordinate, centric/acentric, diatonic/chromatic, stable/unstable, close/distant, similar/different, rough/smooth, fused/segregated, related/unrelated, familiar/unfamiliar, implied/realized, tonal/atonal; our perception of these dichotomous pairs often intensifies, parallels or stands in for our perception of C/D. We consider the "atonal" music and theoretical writings of Arnold Schoenberg, and the radical interrogation of previous assumptions about C/D that he provoked. We conclude that vertically, consonance involves the creation of multiple incomplete harmonic series of partials, while dissonance involves roughness; horizontally, consonance involves perceived pitches in common while dissonance involves linear pitch distance; and in both cases consonance involves familiar patterns of pitch. The listed dichotomies lead us to perceive events separated in time either as part of a larger-scale consonant event or as a counter-foil against which such a harmonious whole is perceived. In music listening, C/D is generally holistic: it encompasses vertical and horizontal elements, which listeners have difficulty distinguishing.
Implications. C/D will continue to constrain composition in the 21st Century. Research on C/D should integrate humanities (questions about individual manifestations of music) and sciences (questions about music's nature and functions).

Keywords: Consonance, roughness, harmonicity, fusion, familiarity, pitch, tension, tonality.

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1 Introduction

Consonance and dissonance (C/D)[i], and the relationship between them, have preoccupied music theorists since antiquity. Pythagorean number ratios were an early attempt to explain C/D. Over two millennia later, Schenker (1910, 1922) asserted that consonance is fundamental and primary, while dissonance is secondary (Agmon, 1997). Both music theorists and music psychologists are challenged to find mutually acceptable accounts of C/D that will help us to understand the musical structures of diverse periods and genres.

This paper aims to bring together diverse findings from different C/D research traditions in music theory and the psychology of music. On that basis we aim to clarify confusions of concept and terminology surrounding C/D in Western music. A comprehensive conceptual foundation may help us to move toward a resolution of intellectual tensions that have existed in one form or another for generations, centuries or even millennia.

Another aim is to develop a holistic approach to understanding C/D. In everyday musical and music-theoretical parlance, C/D is tacitly assumed to apply primarily to individual sonorities (vertical pitch patterns). But in a musical context we tend to perceive the overall C/D of extended sequences. While the experience of C/D can be broken down into numerous components – each of which can be the subject of meaningful discussion, analysis and investigation – we tend not to separate them while listening.

A holistic approach to C/D is appropriate from both music-theoretical and psychological perspectives. In empirical studies, music psychologists often contrast the perception of musicians with that of non-musicians; non-musicians may have difficulty focusing their auditory attention on one element of musical structure such as a single chord and instead tend to respond holistically to extended passages. But musicians also have difficulty disentangling the components of C/D; they may be better at aural analysis, but they are also sensitive to the overall effect. Similarly, historical music theorists have varied in their tendency to focus on local versus global levels of a musical piece.

When we talk of "tonality" we tend to conflate terms such as *consonance, diatonicism* (use of tones from a diatonic scale, e.g. white piano keys) and *centricity* (the use of tonal centres or reference pitches). The same applies to their almost-opposites *dissonance, chromaticism* and *acentricity* when talking of "atonality". When a well-known composer comments that "My music is not tonal, but I often use tonal centres" (Anthony Payne, personal communication, 2010), we understand that his music is not diatonic or consonant, but often centric. We often assume that music exemplifying a high degree of consonance is also diatonic and centric, while music exemplifying a high degree of dissonance is also chromatic and acentric. While most of today's popular music is relatively consonant, diatonic and centric (the same applies to early Mozart minuets), a middle-period Bartók piece, while characterised by adherence to tonal centres, also embodies a high degree of dissonance and chromaticism. Moreover, certain passages of "chromatic" harmony in the 16th and early 17th centuries (e.g. celebrated works by Gesualdo) draw on unusual juxtapositions of triads (i.e. consonances), creating an uncertain or ambiguous sense of tonal centre – at least on the small and medium scale – which led musicologists such as Lowinsky (1961) to describe them as “atonal”.

In an attempt to come to grips with these complexities, we will analyse C/D into pairs of contrary terms or dichotomies such as diatonic/chromatic, centric/acentric, stable/unstable, tense/relaxed, similar/different, close/distant, primary/subordinate, and local/global. This will ultimately lead us to consider tonal/atonal, a pairing within which several such dichotomies are coordinated as integrated bundles. Paganini's 24th Caprice (Figure 6) provides a simple example: the sense of climax in the four bars following the double bar is achieved by chromaticism (tones foreign to the established key), acentricism (the tonic becomes unclear), and instability (each implied chord leads to a new one). The passage preceding the double bar is relatively diatonic, centric and stable. The tacit assumption of an integrated bundle of musical features in “common-practice tonality” or “major-minor tonality” (MmT) may explain why musicological literature on C/D tends to emphasize some musical styles such as the classical Germanic canon from Bach to Brahms, while ignoring or underrating others.

At a different level, we will consider the dichotomy between music theory and music psychology, and the trichotomy among humanities, sciences and musical practice. These sharply contrasting approaches to explaining C/D are addressed in the aims of the *Conference on Interdisciplinary Musicology* and the *Journal of Interdisciplinary Music Research*. The innate/learned dichotomy was the theme of the 2010 CIM in Sheffield “Nature versus culture” where an early version of this paper was presented.

On the scientific side, Helmholtz (1863) focused on dissonance (roughness), Stumpf (1883, 1890) on consonance (fusion). Roughness is an auditory sensation reminiscent of passing fingertips across sandpaper; it is familiar from harmonic musical intervals of a major or minor second, clusters in 20th-Century music such as Penderecki’s *Threnody for the victims of Hiroshima*, and deliberately distorted electric guitar sounds in rock. Fusion is a tendency for simultaneous sounds to be blend perceptually or to be perceived as one sound; it applies whenever the number of perceived elements within a sound (the sound’s multiplicity or numerosity) is smaller than the physical number of elements. This is generally true for chords of more than three notes (Parncutt, 1993) and in harmonic complex tones that are perceived to have just one pitch although many harmonics can be distinguished by the ear.

On the humanities side, Riemann’s (1893) theory of functional harmony was local, focusing on individual chords and relationships between successive chords, whereas Schenker (1906) emphasized global aspects of musical structure, considering pitch relationships between musical elements that were widely spaced in time – by as much as one hour in longer symphonic works. 19^{th}-Century theorists tended to regard C/D as natural in origin, whereas 20^{th}-Century theorists favoured cultural explanations.

Little recent literature addresses C/D in non-Western music, perhaps because any such discussion runs the risk of ethnocentricity (Huron, 2004). Kaminski (2009) considered the perceptual fusion of highly dissonant (rough) Asante ivory trumpet music. He concluded that there is no simple relationship between C/D and fusion, which contradicts Stumpf (1883, 1890). The study was not well received by his ethnomusicological colleagues because of his implicit assumption that C/D is a musical universal. Ethnomusicologists prefer to document musical cultures on their own terms; if musicians in that culture do not talk directly or indirectly about C/D, it is considered irrelevant.

Is the avoidance of questions of C/D in ethnomusicology an overreaction against the comparative musicology pursued by Stumpf and colleagues around 1900? Differences in opinion may arise from differences of definition. We prefer to define C/D in a general sense that corresponds to its Latin roots (*con-* = with, together, joint; *sonans* = sounding). Presumably, any musician in the world can be asked how certain musical elements "sound together" – just as one might universally ask whether a shirt of a certain color goes with a scarf of another color. If musicians in a given culture do not normally talk about music this way, it is still possible to statistically analyse a corpus of transcribed music to find out what tonal or rhythmic patterns or combinations happen relatively frequently. It is generally possible to approach the issue either subjectively or quasi-objectively.

If we are looking for evidence of musical universals, we must compare data across diverse musical cultures. An example is Vos and Troost (1989), who demonstrated that the most common interval between successive tones in melody is approximately a major second. In a general definition of C/D, that implies that the major second is the most consonant melodic interval (melodic tones "go together" best at this interval). It may now be timely to undertake a more general study of C/D across cultures. Infants have been shown to be sensitive to C/D (Schellenberg & Trehub, 1996), and although infant behavior researchers may talk about C/D in an ethnocentric Western way, infants may be sensitive to C/D in a more general sense of smoothness, harmonicity or familiarity. Infants are sensitive to voice timbre (Clarkson et al., 1988; Trainor et al., 2004; Tsang & Trainor, 2002), which from an evolutionary viewpoint is unsurprising: adults with consonant voices (e.g. soft cooing) are likely to look after a baby's needs, whereas those with dissonant, angry voices may be dangerous and even risk the baby's life. At this cross-cultural level, there may be universal sensitivity to C/D among adults – regardless of the role that motherese may have played in the origin of music (Parncutt, 2009). Instead of ignoring the question of C/D in non-Western cultures, ethnomusicologists could strive for a new balance between ethnomusicology and comparative musicology by documenting the musical and music-theoretical discourses of insiders about which tones and rhythms should be played together and why, and considering the political and psychological mechanisms that are allowing Western music to dominate world music (cf. Agawu, 2003).

2 C/D as a holistic phenomenon

During the history of music and its theory, terms such as "harmony", "harmonious" and "C/D" have varied considerably in their range of reference. Our proposal to describe C/D as a *holistic experience* is driven by a desire to encompass this range of reference and these levels of meaning. We have inherited 19th-Century music-theoretical and scientific traditions in which C/D is assumed to refer primarily to individual sonorities. Berger (2007) implied that this usage emerged in the second half of the 18th Century. Before that, C/D was often considered to be a broader (quasi-architectural) attribute of musical works as wholes, rather than a narrower property specific to harmonic sonorities and progressions. Before the Enlightenment, the idea of a judicious and balanced combination of consonance and dissonance to create a *harmonious whole* was the basis of the craft of harmony, in three senses:

> By 1825, the understanding of harmony seems already to have been reduced to its narrow, modern sense....the craft of constructing chords and chord progressions... [But earlier, in] a somewhat broader, still musical-technical, sense harmony also included the counterpoint, the craft of combining diverse, simultaneous melodic lines. In its broadest sense the audible harmony produced by musicians participated in the intelligible harmony of creation. (Berger, 2007, pp. 121–122)

The *locus classicus* of this pre-Enlightenment attitude is the music of Bach, as exemplified with particular force in his fugues. Berger describes fugue as “Bach’s demonstrations of what can be done with the subject contrapuntally. In the C-major fugue there are seven such demonstrations, each designed to show how the subject can be combined with itself in imitation...”. In the C-major fugue from the first book of Bach’s *Well-Tempered Clavier*, there are 22 complete statements of the subject, pitched on all seven degrees of the C-major scale. The fugue begins with the traditional series of statements (subject, answer, answer, subject) on C, G, G and C respectively. In the following series of statements, there are (as Berger asserts) seven demonstrations of “how the subject can be combined with itself in imitation”. For example, in bar 7 we have the subject on C in the soprano, with an overlapping answer on G in the tenor beginning one beat later. Bach later presents pairs of statements that overlap at a distance of 2, 3 and 5 beats; and in three cases, three statements overlap (e.g. statements on G, A and D in bars 16–18). The pairs vary in voice combinations and intervals between entries. Limited by the time-frame of a typical fugue, Bach presents only a selection from a large number of theoretically-possible combinations.

A fugue is an open-ended chain of dialectic demonstrations, judiciously balancing various different types of combinations. By analogy with language and linguistics, the form of a fugue may be considered *paratactical* – an assortment of compatible things of equal importance (Berger’s “one-after-another”). Parataxis also imposes a particular means of ending of a fugue, as Berger notes:

> A reader of Bach’s two sets of preludes and fugues *The Well-Tempered Keyboard (WTC)* will be struck by the emphatic gestures by which the composer often announces the approaching end of the fugue...For the greater part of its duration it is impossible to predict when or how soon the fugue will come to an end. Then quite suddenly ... it becomes apparent that Bach is wrapping things up ... Because the nature of the genre is essentially atemporal, because one never knows in advance how many demonstrations there will be or in which order they will be introduced, the end is in danger of seeming arbitrary and abrupt. Hence the need for emphatic gestures to announce that the end is imminent (Berger, 2007, pp. 89–91)

Berger’s wrapping-up gesture is provided by the extended dominant and tonic pedal-tones in the bass in the later stages of the C-major fugue (underpinning the last two demonstrations). This pre-Enlightenment atemporal conception of a harmonious whole is also embodied in the binary dance forms of the Baroque and earlier periods, whose antecedent-consequent phrase pairs often comprised a phrase or section cadencing on the dominant (dissonance) answered by a phrase or section cadencing on the tonic (consonance). The working-out of this essentially atemporal approach in fugue and other genres was considered in detail by Dreyfus (1996). He proposed that we should distinguish between two facets of Bach's compositional process: "invention" and "disposition". Berger summarised Dreyfus's arguments succinctly:

> The "invention" of a piece...was the sum total of the material and its transformations. Since all transformations could not be presented at once in sounding music, they had somehow to be ordered in time. But this temporal "disposition" was a matter of relative indifference...The central interest...lay not in disposition but in invention. (And, I might add, it was invention that required the most talent, skill and ingenuity; disposition was a fairly easy matter by comparison.) (Berger, 2007, pp. 99)

A third facet ("elaboration") involved the process of fitting together the demonstrations of the possibilities of the "inventions" into a plan determined by the selected pattern of "dispositions": in the case of the fugue, providing connective tissue and additional contrapuntal voices to fill the gaps between the demonstrations of the possibilities inherent in the "inventions" so as to make a coherent and integrated totality. This holistic attitude to composition can be compared and contrasted with the post-Enlightenment conception of harmony that focused more narrowly on the contrast between dissonant and consonant chords and chord progressions, on the build-up and release of harmonic tension, and on a heightened sense of drive towards cadence-points.

Pieter van der Merwe (2004) explained the historical shift with a linguistic analogy:

> One of the fundamental changes in nineteenth-century music is that climax gradually replaced antithesis as the chief organising principle. I must immediately add here that the word "climax" is here used in its original [dictionary] sense of "a figure in which a number of propositions or ideas ... [are] ... set forth so as to form a series in which each rises above the preceding in force or effectiveness of expression ..." the stock example being Caesar's "I came; I saw; I conquered" ... (Thus, for instance, the familiar pattern ... I>V ... V>I is not a climax, but an antithesis.) (Van der Merwe, 2004, pp. 311–312)

Climax is a *hypotactical* relation: it implies a form in which materials are either primary or subordinate, and exemplified by a cumulatively- and hierachically-ordered sequence of things (Berger's "one-because-of-the-other"). Berger (2007, p. 158) illustrated hypotactical form by analysing the hierarchy of cadences in a Mozart concerto to show how the cumulative effect of which Van der Merwe speaks is achieved. Since we are talking of a history of gradual change, paratactical and hypotactical understandings of harmony (the interplay between consonance and dissonance within a harmonious whole) are tendencies rather than mutually exclusive categories. There is naturally a degree of interpenetration between the pre- and post-Enlightenment approaches; our holistic approach to C/D is intended to include both.

3 Music theory versus cognitive music psychology

While both music theory and cognitive music psychology aim to understand (Western) musical (pitch-time) structure, they have different methods and different specific goals. Music theorists attempt to explain *how* musical structures work and rely on their musical knowledge, experience, and ability to imagine complex musical structures. Music psychologists tend put their musical skills in the background and attempt to explain the *why* of musical structure by interpreting results of listening experiments.

These differences in approach are reflected by terminological differences (Clarke, 1989). The way music theorists think about music has always depended heavily on specific musical styles, which have always been in a state of flux. Music psychologists have tried to draw conclusions that are independent of style. The confusion has been intensified by the increasing separation and independent development of the disciplines of music theory and music psychology in the 20th Century. As a result, most recent literature on this topic has been written either from a theoretical or a psychological viewpoint – not both.

We are aiming for a better balance and overview that will enable both theorists and psychologists to use concepts and terminology more consistently and appropriately. We argue that to grasp a complex holistic phenomenon – driven by a single underlying concept but revealing itself in a plurality of contrasting manifestations – we need the perspectives of both *foxes* and *hedgehogs*.[ii] Berlin (1953) derived this metaphor from a proverb of the ancient Greek poet Archilochus (7th Century BC): "The fox knows many little things, but the hedgehog knows one big thing". He compared Tolstoy to the fox and Dostoevsky to the hedgehog; Tolstoy tends to embody the approach of the wide-ranging generalist and Dostoevsky that of the concentrated specialist. Later, Berlin (1974, p. 326) light-heartedly attributed hedgehog tendencies to scientists and fox tendencies to humanities scholars and artists (including philosophers and historians like himself). But Gould (2003) insisted that the "two cultures" of Snow (1960) are involved in an essentially common enterprise and called for sciences and humanities to interact, applying a combination of fox-like and hedgehog-like approaches in both domains. We expect the same in investigating a phenomenon as complex and multi-faceted as C/D. It is not enough for foxes to enrich our understanding of C/D's contexts, or for hedgehogs to independently attempt to reduce C/D to simple scientific principles. Foxes and hedgehogs must work together.

By mixing contrasting epistemologies, we aim to facilitate the emergence of a new interdisciplinary synergy. Improved communication between humanities and sciences might help scientists to pose more musically relevant and legitimate questions, and humanities scholars to apply a wider range of methodologies. By humanities we mean not only music theory/analysis/composition but also music history and the history of music theory; by sciences, not only music psychology but also acoustics, psychoacoustics and computer sciences.

We are not merely theorizing about this, but actually doing it. The first author is a scientist who has published in various areas of music psychology, and the second author is a composer with a particular interest in the issues in music history and theory with which composition has no alternative than to engage. The present text is the result of a long series of negotiations to which two anonymous reviewers also contributed; like us, they represented both sides of the humanities-sciences divide. The secret for success, we believe, applies to any intercultural interaction: each participant in the discussion should strive to take the questions and suggestions of the other party seriously, even if they seem to contradict the common beliefs and traditions of humanities scholars or scientists respectively.

4 An introductory example

In many traditions of compositional practice, C/D refers not only to a single sonority or interval, but also to a whole passage or piece. Consonance tends to prevail over dissonance, which provides a foil to consonance and is catalytic in creating a (metaphorical) sense of motion. To understand this from a music-theoretic viewpoint we need to consider both individual events and how they are strung together, taking into account both small- and large-scale concatenations.

4.1 Voice leading versus harmony

To get a feel for the synergetic, complementary roles of voice leading and harmony in holistic C/D, consider the opening of Chopin's *Mazurka* in F♯ minor (Figure 1). The progressions in bars 1–2 and 3–4 involve resolution of dissonance by consonance, and a progression from subordinate to primary, (secondary) dominant to tonic, root progressions falling by a 5th. But the progression in bars 2–3 is driven not by root-progression or a sense of dissonance resolving onto consonance, but by considerations of counterpoint. We have A in the treble over F♯ in the bass, proceeding in contrary motion to B in the treble over E in the bass. Clearly, not all chord progressions involve resolution; in this case, the outer-voice movement is more salient.

The progression in bars 4–9 seems likewise to be driven not by root progression but by a contrapuntal consideration, albeit a different one from that driving bars 2–3: a series of passing-tones in parallel motion in both treble and bass (from treble C♯ over bass A in bar 4 descending chromatically to treble E♯ over bass C♯ in bar 9). Our sense of the root- progression A–D♯–G♯–C♯ (bars 4–5) is overridden by a sense of passing motions in treble and bass. In the approach of Terhardt (1976) and Parncutt (1989), the half-diminished 7^{th} on D♯ at the start of Bar 5 has three possible perceptual roots (D♯, F♯ and A), but in this context this chord seems to have no perceptible root at all.

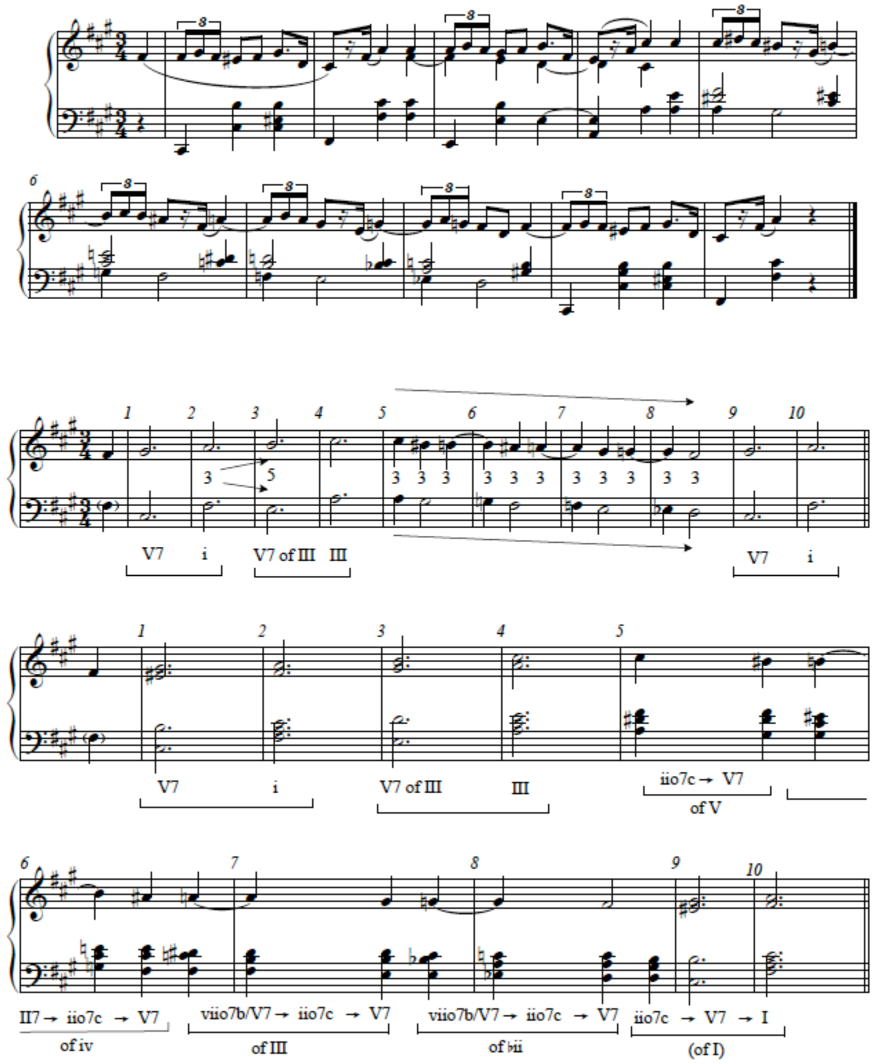

Figure 1. Chopin: Mazurka in F♯ minor, bars 1–12.

The contrapuntal progression is in the perceptual foreground, but one also hears the tension of the harmonic and tonal implications of the chords. The Chopinesque nostalgia arises from a combination of contrapuntal (horizontal) and harmonic-tonal (vertical) processes. Each half-diminished chord has pre-dominant function (dominant preparation, or in Riemann's approach, subdominant), but after that the tonic is repeatedly avoided. Instead of the tonic, we get another half-diminished pre-dominant, and so on. Similarly, the *Liebestod* of Wagner's *Tristan und Isolde* contains many sequences of *pre-dominant, dominant,* and *avoided-tonic* sonorities.

From this example, we see that events sometimes imply succeeding events, and that an implication, once set up, is sometimes realised, sometimes not (Meyer, 1956). If a dominant harmony resolves immediately to a tonic harmony, the implication-realisation effect is clear. Larger-scale factors like the passing motion in bars 4-9 set up a sense of tension that is maintained over 5 bars but eventually complemented by relaxation. This situation appears psychologically related to the resolution of a dominant triad or seventh onto its tonic. Such passages are driven by a variety of forces related to – but not identical with – C/D, which we shall attempt to identify, distinguish and evaluate.

4.2 Tonicization versus passing modulation

Another salient feature of the passage in Figure 1 is the tonicization (turning into a temporary tonic) of the mediant triad (A major) in bar 4 by its secondary dominant, the E-major triad in bar 3. That may also be considered a passing modulation to the key of A major. In a Schenkerian interpretation, however, the music does not modulate, but remains in F♯ minor throughout.

Theorists driven by a sense of organicism tend to analyse passages or whole works in terms of one principal tonality, subsuming tonicizations under a kind of monotonal umbrella. Schenker and Schoenberg, despite their different approaches to theoretical questions, shared this approach. Schoenberg (1948, 1969) spoke of harmonic "regions" to capture this sense of a single tonality controlling the whole, and Schenker's graphic analyses describe the structure of whole compositions in terms of a single tone-centre. They were reacting to the widespread tendency in 19th-Century *Harmonielehre* to consider every small harmonically supported departure from the diatonic scale of the principal tonality as a passing modulation. But a fragmentary view of musical structure, in which passing modulations can occur as often as every bar, is inconsistent with the assumed unity and integrity of great musical works.

The concept of passing modulation was quantified in music psychology by Krumhansl (1990) and in music information sciences by Toiviainen and Krumhansl (2003). In an empirical approach, one might play a passage of music up to a given point (e.g. the start of bar 4 in Figure 1) and ask a listener to rate how well a following probe tone goes with the preceding passage – an empirical measure of scale-step stability. In this method, originally developed by Krumhansl and Shepard (1979), 12 chromatic probe tones were presented at different times, enabling a *tone profile* to be constructed. Theoretically, Parncutt (1989) and Huron and Parncutt (1993) predicted tone profiles of chord progressions using a model that combined Terhardt's virtual pitch theory with exponential memory decay. The tonal distance between two key areas, represented by two tone profiles, can be estimated by the correlation coefficient between them: the lower the coefficient, the greater the tonal distance.

The robustness of this kind of empirical data, and the success of the models that have been developed to calculate them, support the psychological reality of passing modulations and seem to oppose the idea of tonicization. But closer examination reveals a different picture. The tone profile of a major or minor tonality (Krumhansl's key profiles) is mathematically close to the tone profile of the tonic triad (Parncutt, 2011). If we accept Schenker's idea that any piece or passage of tonal music is a prolongation of its tonic triad, we may regard these two profiles as functionally identical – as two different measures of the same thing. Relatively fast or fleeting changes may be considered tonicizations, while slower, longer-term changes are modulations. It is possible to regard the A-major chord in bar 4 as a passing tonic, but given its short duration it is more appropriate to speak of tonicization.

Krumhansl and Schenker diverge for another reason. Their epistemological backgrounds and underlying goals are different. Music analysts usually examine pieces with which they are intimately familiar, expounding upon well-known excerpts. The history of analysis shows theorists going over and over the same paradigmatic masterpieces (e.g. our Chopin Mazurka). By contrast, psychologists tend to analyse random, representative samples and the perception of random, representative listeners. Analysts focus on scores from the past, psychologists on people from the present. The more holistic approach of analysts is related to the organicism of post-Enlightenment composition, as implied by Berger and Van der Merwe in the above quotes and culminating in Schoenberg and Schenker.

The relationship between two musical keys or chords, as quantified by music psychologists, may be subsumed under the more general concept of *pitch commonality* (Parncutt, 1989), which in turn may be considered part of C/D in a holistic approach. If pitch is equated with notes in a musical score, the pitch commonality of two keys is simply the number of common tones. If it is equated with spectral frequencies, pitch commonality is the degree to which two sounds have spectral frequencies in common (tonal affinity: Helmholtz, 1863; Terhardt, 1974). If, however, pitch is defined psychoacoustically in terms of subjective experience, we must consider missing fundamentals and the perceptual salience (or tonal stability) of coinciding pitches. Seen this way, an appropriate measure of the relationship between two musical keys is the correlation coefficient between their key profiles (more precisely, their scale-step stability profiles). The peaks of these profiles correspond to scale steps, but the profiles also contain additional information about the relative stability of the (seven) scale steps as well as the relative (in-) stability of the (five) non-scale tones.

5 Dissonant musical dichotomies

Given this background, we are now in a position to address in detail and clarify a series of dichotomies associated with general concept of C/D in Western music: *tense/relaxed, primary/subordinate, centric/acentric, diatonic/chromatic, stable/unstable, close/distant, similar/different, rough/smooth, fused/segregated, related/unrelated, familiar/unfamiliar, implied/realized,* and *tonal/atonal*. In general, conceptual dichotomies play an important explanatory role whose philosophical foundation is the dialectic of *thesis, antithesis* and *synthesis*; the terms in dialectic pairs (including our C/D-dichotomies) are generally not exact opposites, and their conceptual synthesis enables understanding at a higher level. We consider it necessary to disentangle dichotomies applying to C/D, which in spite of their evident differences and historical/cultural specificities are often implicitly equated with it, and hence often imply each other (Tenney, 1988). Not only music psychologists, but sometimes also music theorists fail to distinguish clearly between these dichotomies.

We will begin by addressing overarching concepts: the terms *consonance* and *dissonance* themselves (§5.1), and their close relatives *tension* and *relaxation* (§5.2). We will then consider musical pitch hierarchies from various perspectives. A pitch hierarchy may be said to exist whenever some pitches in a piece of music are perceived or considered to be more important or stable than others. A musical element such as a chord may be considered *primary* (e.g. a tonic triad) or *subordinate* (§5.3); and a musical passage may be *centric* (organized around a reference tone, pitch or pitch class) or *acentric* (§5.4). More generally, the pitches of a musical scale may be *stable* or *unstable* (§5.6); in most Western music, this distinction is equated with the *diatonic/chromatic* dichotomy (§5.5). Beyond hierarchies, C/D depends on whether musical elements are perceived as *close* or *distant* (§5.7), and as *similar* or *different* (§5.8).

All of these dichotomies are related either directly or indirectly to C/D, and all of them may be addressed from either a cultural (humanities) or psychological (scientific) perspective. All of them ultimately have their origin in the music-theoretic literature, and all have been the subject of scientific experimentation. For example, the perception of tension and relaxation in chord progressions was investigated in empirical psychological studies by Bigand and Parncutt (1999), and Bigand, Parncutt and Lerdahl (1996). Various aspects of the hierarchical structure of MmT have been investigated empirically (Krumhansl, 1990). The close/distant and similar/different dichotomies underlie the mathematical formulations of pitch distance and pitch commonality (respectively) that were developed in conjunction with empirical data by Parncutt (1989).

5.1 Consonant versus dissonant in Western music

The everyday vocabulary of the average person contains the word "discord", and possibly also its antonym "concord". These are understood to refer to sounds that are somehow "pleasant" and "unpleasant" respectively. For all the sophistication of centuries of formal and informal music theory, "pleasant" and "unpleasant" are still with us, as the following remarks of our dedicatee, James Tenney, demonstrate:

> Allen Forte, in *Tonal Harmony in Concept and Practice* (New York: Holt, Rinehart and Winston, 1962), says (pp. 16-17): "In music the terms consonant and dissonant have nothing whatsoever to do with the pleasant or unpleasant quality of a sound. They are technical terms applied to phenomena of motion." One must ask: in what music? – and in whose view? This was certainly not the view of the major theorists who first formulated the concepts and practices of tonal harmony (Tenney, 1988, p. 32).

The value judgment inherent in "pleasant/unpleasant" is regrettable, given that compositional techniques of the 20th Century (many of them characterized by a high level of dissonance) generated what we consider to be some of the world's greatest music. But in attempting to define C/D (or any other concept), it is important to avoid unnecessary abstraction and to make simple, concrete links with everyday language where possible.

Like many things, the concept of C/D is brought into clearer focus by considering its negative: music in whose production the distinction plays no part. The necessity of a concept of C/D was famously cast into doubt by Schoenberg's (1926) "emancipation of dissonance". Schoenberg's practice came at the end of a long 19th-Century Romantic tradition in which an ever-increasing sense of motivic unity and development (organicism) became the driving force. In Schoenberg, this tradition culminated in what might be called *hyper-motivicization,* where motivic unity embraced the treatment of harmonies as well as melodic/rhythmic units. One could say that an all-embracing organicism *replaced* C/D (Schoenberg, 1975, "Brahms the progressive").

During the 20th Century, new dissonant musical styles developed in multiple directions. At the same time, musical styles that respected the traditional distinction between consonance and dissonance remained the most popular way of structuring the pitch domain in both popular and "classical" worlds. It appears that to most people, the consonant and dissonant qualities of such styles have continued to be more perceptible than their organic qualities – regardless of whether they listen attentively in concert halls or in the background at the cinema, where dissonant music might intensify their experience of horror movies.

C/D is one of the principal components of MmT, which now dominates the music of the world (including so-called World Music; Nettl, 1985). As much as people appear to love music in major and minor keys, we may also regard such domination as a regrettable form of cultural impoverishment that can be explained by a combination of political and psychological considerations. Politically, Westerners have for a long time had more resources and weapons (Diamond, 1997). Psychologically, music based on MmT may have some kind of cognitive advantage over music whose tonal structure is less clear or more complex: a clear tonal structure makes music easier to encode, store and recall musical structures, so they place less load on the cognitive system (Deutsch, 1980; Tillmann et al., 2000). The cognitive facilitation is a byproduct of tonal centricity and tonicization (see below). Cognitive processing may also be facilitated by the use of melodic steps rather than leaps (Eriksson, 1984). However, cross-cultural comparisons of this kind are highly problematic. Quite apart from ethical problems, the role of "cognitive efficiency" is unclear and difficult to evaluate across cultures.

Although the authors of this article subscribe to the view that the diverse dissonant Western musics of the 20th Century belong to the most valuable achievements of our culture, the enduring popularity of MmT and its traditional treatment of C/D, together with the basic facts of music history, confirm for us a central point, namely that C/D – in its most general sense – has been an important force driving the historical development of Western musical structure for at least a thousand years. In a broad definition that applies to both simultaneous and successive tones, C/D has played a central role in the development of Western music since antiquity. C/D was a principal factor in the emergence of polyphony around the 12th Century, which was heavily influenced by the principle that dissonant intervals should resolve to consonant intervals in specific ways (Tenney, 1988). The importance of C/D for musical structure continued unabated, albeit in contrasting ways, through the “common-practice period” until Schoenberg. Even he failed to stop, or even to slow, C/D’s hegemonious march through music history: C/D surely influences the *perception* and *reception* of all musical styles of the 20th Century – regardless of the composer’s intention with regard to C/D. C/D will presumably continue to influence music well into the 21st Century.

5.2 Tense versus relaxed

C/D is sometimes regarded as a property of isolated sonorities that is independent of what precedes or follows them. In most Western music, however, dissonances are held to *resolve* onto following consonances, and the principle of resolution is tacitly considered integral to C/D (Bharucha, 1984).

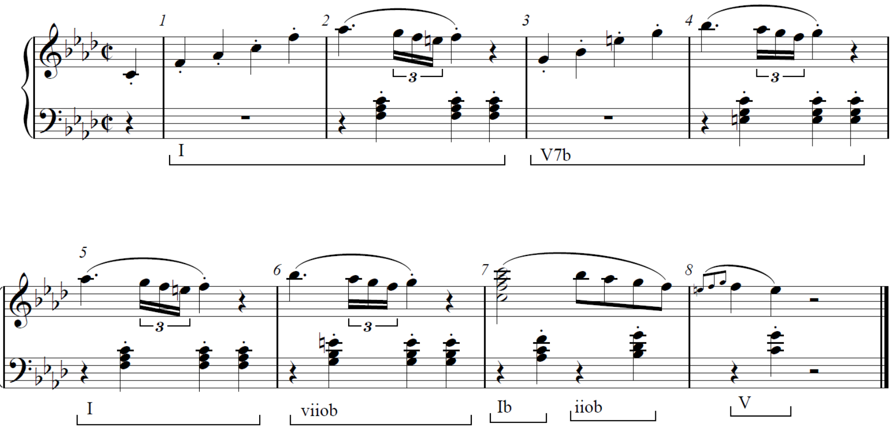

Figure 2. Beethoven: Piano Sonata in F minor, op. 2 no. 1, bars 1-8.

If that is true, the terms consonance and dissonance are equivalent to *tension* and *relaxation*. A cadence is (among other things) a place where tension is resolved; hence the long tradition of thinking of a musical phrase as consisting of a cadence and a passage of gradually accumulating tension leading up to it. In the opening of Beethoven’s first piano sonata op. 2/1 (Figure 2), the gradually-increasing harmonic rhythm, the rising bass line, the shortening of the motif by halving in measures 5-6 and the climax in the penultimate measure all contribute to a general build-up of dissonance/tension which is released by the supertonic-to-dominant half-cadence in bars 7-8.

In species counterpoint, a pedagogical tradition derived primarily from Johann Joseph Fux (1660 –1741) but much earlier in origin and represented in such modern texts as Salzer and Schachter (1969, 1989), a student adds new voice(s) to an existing melody, using a formulaic incipit, a formulaic cadence and a climax placed strategically between them,

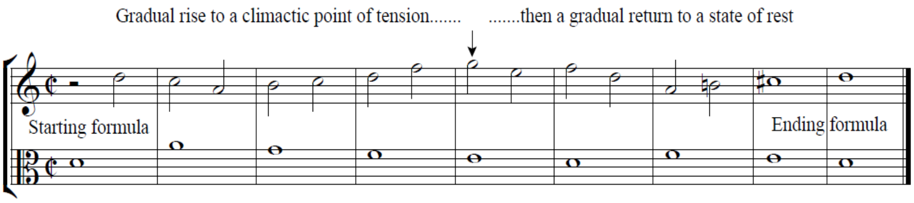

Figure 3. Species counterpoint exercise from Salzer and Schachter (1989, p. 23).

and attempts to write a contrapuntal line that passes convincingly from a state of rest via a state of tension back to a state of resolution. This pedagogical task embodies the tradition that C/D is contrapuntal as well as harmonic, involving temporal context, as Figure 3 shows.

Musically untrained listeners can consistently rate changes in tension and relaxation in a chord progression (Bigand & Parncutt, 1999). This observation is evidence for the psychological reality of musical tension and relaxation and raises the question of whether tension/relaxation might be a better term for C/D when we wish to emphasize the role of temporal context.

Figure 4. Schubert: Six German Dances D.970, No. 1 in E♭.

5.3 Primary versus subordinate

A chord is often considered dissonant relative to a following more consonant chord, implying that a dissonance is a prefix to a consonance. But canonic repertoire also provides examples of *suffix* dissonances. Schubert's dance movements contain many such examples, often in the context of a four-unit pattern of the form diatonic triad, suffix dominant (seventh), prefix dominant (seventh), diatonic triad. In Figure 4, the submediant (C minor) triad (bars 9–10) is *followed* by its dominant seventh (bars 11–

12) and the tonic (E♭ major) triad (bar 14) is *preceded* by its dominant seventh (bar 13). The juxtaposition of suffix and prefix dissonances involves a chromatic inflexion (here: B♮ to B♭) – a typically Schubertian harmonic piquancy. In either case, the dissonance is subordinate and the consonance primary. The very term "secondary dominant" embodies the primary/subordinate pair.

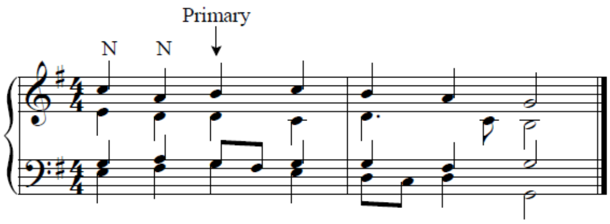

Figure 5. The final two bars of J. S. Bach's harmonisation of the chorale *Erschienen ist der herrliche Tag.*

The primary/subordinate dichotomy overlaps with – but is not identical with – C/D. A subordinate chord is not necessarily vertically dissonant relative to a primary consonance. For example, consider the first bar of Figure 5. The Cs and the A in the first bar of the melody are neighbour-tones (upper and lower, prefix and suffix) to the B on the third quarter-note, a hierarchy reinforced by the subordination of chords 1, 2 and 4 to chord 3 (the tonic), despite the fact that all 4 chords are consonant triads.

Forte, as quoted by Tenney above, linked C/D to musical motion, which in turn involves primacy/subordination and stability/instability. The idea that a dissonant sonority calls for resolution suggests that it refers forward to an approaching goal sonority.

5.4 Centric versus acentric

Centricity refers to the top level of a hierarchical tonal structure – the implied central position of a pitch or pitch class as a cognitive reference point – related to psychological concepts of exemplar and cognitive economy (Garner, 1970; Goldmeier, 1982). Unlike the primary/subordinate dichotomy, centricity is not usually used to refer to intermediate levels relative to lower levels, such as the tones of a diatonic scale relative to non-diatonic tones. A passing tone is subordinate to its two framing harmony tones, but we would not normally call those harmony tones "centres". Another distinction is that the centric/acentric dichotomy applies primarily to tones and pitches, whereas the primary/subordinate dichotomy applies primarily to sonorities or events. When Salzer (1952, 1962) extended the concept of "passing tones" to "bunches of passing chords", the principle evoked was that of primary and subordinate.

A sense of centricity can be created by *tonicization*, which in a broad definition is any process that confirms or establishes a tonal centre. In Schenkerian theory, tonicization happens when a diatonic scale degree is sharpened to create a leading tone, which turns the following pitch into a temporary tonic. Tonicization is primarily a local phenomenon, but Schenker also assumed that it can occur across longer time-spans. From a psychological viewpoint, tonicization may involve at least two separate processes: intervallic implication, of which sharpened leading tones are examples, and repetition/duration: pitches that act as tonal centres tend to occur more often or have greater cumulative duration than other pitches in the same passage (Krumhansl, 1990; Lantz & Cuddy, 1998). In harmonic tonality, tonicization often involves the resolution of some form of dissonance onto some form of consonance. Even without a dissonant seventh, a dominant triad may be considered a dissonance in the sense that the dominant tends to resolve to the tonic and includes the unstable leading tone.

Historically, tonicization (in the broad sense of attracting attention to any pitch by semitone motion towards it) emerged in Medieval polyphony, from about the 14th Century. From the 17th Century, major and minor triads started to function as tonal centres and could also be tonicized as sonorities (Parncutt, 2011). Schoenberg's twelve-tone technique relegated centricity (and more generally tonality) to a peripheral or even negative role.

5.5 Diatonic versus chromatic

Most of the music that we hear in the West, and are implicitly referring to in this text, is based on MmT. That means essentially that at any point in the music, it is possible to identify a tonic triad and an associated major and minor scale. Tones that belong to that scale are considered "diatonic" and are often considered consonant for that reason.

But the matter is not that simple. From a psychological and structural viewpoint, tonality is generally ambiguous: there may be more than one candidate for the perceived tonic (Browne, 1981). Modulations (key changes) are also ambiguous: music theorists vary along a continuum from those in the Schenkerian tradition who regard entire pieces as remaining within one tonality (of which chromaticisms are an integral part) to those who regard every chromatic tone as a potential short-term or passing modulation. Those who favor the idea of passing modulation may conceive the tonality of a piece of music to move through a cognitive space of musical keys (cf. Toiviainen & Krumhansl, 2003). Moreover, the pitches of the 6th and 7th degrees of the minor scale are generally ambiguous (consider the rising and falling melodic minor scale), so even if the current key is clear, it is not necessarily clear whether a given tone is diatonic or chromatic.

Diatonic scales have been with us since antiquity, but MmT only consolidated itself in the 17^{th} Century. Since then, tonic triads may have implied diatonic scales in the sense that missing fundamentals within tonic triads correspond to scale degrees (Parncutt, 2011). This theory accounts for all tones in major and minor scales except the leading tone, which has a different kind of tonicizing function. Its ultimate origin may be the *mi-fa* relationship in Gregorian chant, of which *fa* is more stable because it corresponds better to a fundamental frequency of other diatonic tones, and consequently occurs more often (Parncutt & Prem, 2008). Of course there is no leading tone in chant itself; the basic materials of medieval music are not so much the 7-note scale as the 6-note hexachords *ut-re-mi-fa-sol-la* (*naturale* CDEFGA*, molle*

FGAB♭CD, and *durum* GABCDE).

Late romantic music was *moderately* chromatic in the sense that it was generally clear which tones belonged to the prevailing diatonic scale and which did not – even if the turnover of twelve pitch-classes was quite rapid. Schoenberg's serial music is considered *extremely* chromatic due to the combination of emancipation of dissonance and disappearance of tonal centres. Both his tonal and serial music also tended to have a fast harmonic rhythm. To some extent, these aspects of C/D can be varied independently.

5.6 Stable versus unstable

The music-theoretic concept of stability may be applied either to individual pitches (pitch classes, scale steps) or sonorities. Regarding pitches, the leading tone is considered unstable because perceptually it "wants" to resolve to the stable tonic. Listeners may expect a leading tone to resolve in the usual way and feel a sense of satisfaction when it does (Bharucha, 1984). Regarding sonorities, a dissonant sonority that arouses an expectation of moving to a more stable sonority, and chromatic chords are typically less stable than diatonic chords. The concepts *stability* and *centricity* are similar, the difference being that centricity tends to be applied only to the most stable pitches in a tonal system, whereas stability can be applied to any pitch.

Krumhansl and Shepard (1979) and Krumhansl and Kessler (1982) operationalized the stability of musical scale steps by presenting listeners with musical passages followed by probe tones at all 12 pitches of the chromatic scale, and asking how well each tone followed or went with the passage. Their tone profiles showed that stability is not a black-and-white phenomenon, as music theory implies, but is dominated by shades of grey: diatonic tones tend to be more stable than chromatic, and the tones of the tonic triad tend to be more stable than other diatonic tones. In a given tonal context (not only MmT), the stability of each tone in the chromatic scale can be accurately estimated on a continuous scale. We are unaware of any clear difference between the term *stability* as it is used in the theory of MmT and in the cognitive approach developed by Krumhansl, and therefore consider the two to be essentially identical.

The stability of a tone in a melody also depends on pitch intervals in the melody. A tone following a leap is unstable because there is a tendency to continue in the opposite direction, and a tone near the top or bottom of the (previous) range of a melody tends toward the middle of the range (cf. Huron, 2001). Both kinds of stability – tonal and melodic – depend on musical familiarity. If a tone in a given context tends with relatively high probability to move or resolve in a given way, the tone is unstable. That suggests a further way to operationalize stability – by statistical analyses of musical scores (Meyer, 1956; Huron, 2002).

Stability is related to other C/D dichotomies. For example, the tension or dissonance of a sonority in a chord progression may be considered a combination of instability, roughness and harmonic/melodic distance (Bigand & Parncutt, 1999).

5.7 Close versus distant

A secondary dominant seventh chord (e.g. D7 or B7 in a context of C major) may be considered more distant from the tonic triad than diatonic chords by virtue of its chromaticism (borrowing from a foreign scale). It is not only dissonant and subordinate, but also harmonically distant. Secondary dominant harmony is – by definition – borrowed from a scale other than the principal scale of a given passage, so that it also embodies the *close-distant* dichotomy.

Figure 6. Paganini: Caprice no. 24 in A minor, theme.

Consider for example the theme of Paganini's celebrated *Twenty-fourth Caprice* and its variations. Bars 9-12 establish a sense of distance from the tonic via secondary dominant harmony (borrowing from scales other than A minor), even though the melodic/rhythmic motifs are simply variants of the motif used in most of the other bars in the theme, and there is little chromaticism.

Such distancing harmony often follows the (passing) modulation to the dominant or relative major midway through a piece in a binary form. The sense of distance may be intensified by the introduction of new melodic/rhythmic features. On a larger scale, the development section of a movement in sonata form usually moves away from and returns to the "home key" (a term which to our knowledge is without equivalent in other European languages); the German term *Durchführung* better embodies this sense of distance, while the English *development* emphasizes the motivic treatment.

Music psychology has investigated proximity/distance in pitch from two distinct perspectives. First, the individual voices may traverse smaller or larger intervals when moving from one chord to another; we will return to this later under the heading *pitch distance* (or linear distance). Second, the chords may be closer or further apart in tonal space, that is, in a space of musical keys. In common musical parlance, chromatic chords are chords that depart from the local key or key signature, and may be considered "borrowed" from other keys which lie at varying degrees of "distance" from the "home" key. This is distance in an abstract theoretical space as considered by Euler (1739) in his *Tonnetz* and developed by Oettingen (1866), Riemann (e.g. 1893), Schoenberg (1969) and Lewin (1987); Lerdahl's (2001) *tonal pitch space* was additionally inspired by Krumhansl's (1990) empirical approach.

5.8 Similar versus different: Musical organicism

If familiarity is an important aspect of C/D, similarity must also play a role. A musical event only sounds familiar if it is similar to previously heard events, which are also similar to each other. By analogy with our comments on other dichotomies, we might anticipate a connection between similarity and consonance, and between difference and dissonance.

We have already referred to the concept of musical organicism and its influential early 20th-Century protagonists, Schenker and Schoenberg. The ambition of organicism is to create works in which everything is an outgrowth of a basic (work-specific) idea. Organicism gives a musical work unity (including "the unity of musical space"; Schoenberg, 1975, p. 223), which – in the broadest sense – could be considered an aspect of consonance. From a psychological viewpoint, organicism can only be perceived if recent musical events are perceived to be similar to earlier musical events that have been stored in memory.

The idea of musical organicism in its post-Enlightenment interpretation is related to Goethe's (1790) idea of the *Urpflanze* ("basic plant") – an *archetype* (or theoretical plan) for all possible plants. Organicism's musical roots in the 19th Century are exemplified by Berlioz's *idée fixe* and Wagner's *leitmotif*, in which a motif reappears in various different transformations over the course of a long work. The musical connection was made explicit by the radical modernist Anton Webern (1963). The archetype idea is common to Goethe's *Urpflanze*, Schenker's *Ursatz* and Schoenberg's *Grundgestalt*, despite evident differences in detail. Like the *idée fixe* and the *leitmotif*, more comprehensive embodiments of organicism involve both similarity and difference: everything is an outgrowth of an underlying basic idea, but this idea always appears in a different (evolving) form. Schoenberg used the term *developing variation* to refer to the process by which such an organic musical structure was implemented (Haimo, 1997).

In the aforementioned 19th-Century examples, organicism also refers to *melodic and rhythmic* shapes and their evolution. Schoenberg's included *harmony* in this scenario (via "unity of musical space" – the companion principle to "emancipation of dissonance"). Again, 19th-Century examples might be interpreted as precursors. The Tristan chord (and the idea of *leitmotif* in general) can be construed as a move in the organicist direction, but it is also a functional (pre-dominant) dissonance. A totally organicist piece might treat the Tristan chord *exclusively* in terms of its unique intervallic characteristics, as Schoenberg does with motifs (melodic, rhythmic *and* harmonic) in his later atonal pieces. The focus on intervallic content culminated in Forte's (1973) categorisation of all 234 possible chords according to their unique intervallic characteristics with no mention of C/D; Carter (2002) proceeded along similar lines, sweeping thematic and harmonic entities under a single (motivic) umbrella, combining emancipation of dissonance with unity of musical space.

In Schoenberg's later music, the creation of a harmonious whole meant the creation of a comprehensively integrated totality, based on a limited pool of work-specific motifs (melodic, rhythmic and harmonic) presented in hundreds of guises. One can see why dissonance had to be emancipated to achieve this organicist utopia. In the world of unemancipated dissonance, a motif presented melodically might be capable of becoming a harmony (e.g. if it were triadic), but not if it were a Bartókian motif of (say) 6 adjacent semitones. Totally dissonant harmony was the engine in which thematic and harmonic domains could be unified into an organic whole.

But this brings us to a paradox: a harmonious whole in Schoenberg's sense needed abolition of the distinction between consonance and dissonance for its realization. Schoenberg disregarded traditional rules for the treatment of dissonance, but not arbitrarily, because his combination of a *motivic* sense of harmony and *the unity of musical space* could only be achieved if dissonance was "emancipated" from its role in *functional* harmony. This contradiction forces us to consider the extents and limits of our C/D-dichotomies because it shows that one interpretation of the same general concept of a harmonious whole can conflict with another. Recent ("post-Schoenbergian") treatments of C/D (the "consonant avant-garde" of Glass, Reich, Tavener, Skempton, Abrahamsen; others such as Andriessen, Rouders, MacMillan), have retreated from Schoenberg's extreme position, and try to achieve a balance between C/D in *both* the broad and the narrow senses suggested by Berger (2002, 2007).

6 Psychological foundations

Consonance and dissonance are not exact opposites (although in many cases it may be expedient to treat them as such), because they are enhanced by different physiological and psychological processes: consonance by harmonicity and dissonance by roughness. In a holistic approach, consonance can be promoted by spectral harmonicity (vertical), harmonic proximity or pitch commonality (horizontal), and familiarity (both vertical and horizontal); dissonance by roughness (vertical) and linear pitch distance (horizontal). The complementary role of fusion and roughness in the C/D of isolated sonorities was recognized for example by Malmberg (1918): "When the two tones of a two-clang tend to blend or fuse and produce a relatively smooth and pure resultant, they are said to be consonant" (p. 108).

A psychological theory of harmonic tonality should account for simple properties of tonal music, such as the frequency of occurrence of chord types. That depends in turn on C/D. In the music of the Renaissance and the following common practice period, there was a general tendency for the most prevalent triads to be the major, followed by minor, suspended and diminished, in that order; diminished triads on the leading tone became more prevalent in the Baroque as they were perceived as incomplete dominant sevenths. Moreover, root position major and minor triads were more prevalent than inversions.

These tendencies can in part be explained by contrapuntal conventions, but where did those conventions come from? If we assume that vertical C/D is a mixture of spectral harmonicity (i.e. harmonicity in the frequency domain) and temporal smoothness (smoothness in the time domain), we might first explain that major, minor and suspended triads are preferred because they include the harmonic interval of a perfect fifth or fourth. We might then observe that the major triad is closer to the harmonic series than the minor. The reason why the suspended triad is less prevalent than the minor triad evidently involves roughness. In the following, we will consider each of these psychological components of C/D in detail.

6.1 Fused versus segregated

Psychological approaches to C/D in Western music have often assumed a relationship between the harmonic series in music and non-musical sounds. For Rameau, the discovery of a relationship between the harmonic series as part of "nature" and music as part of "culture" was a revelation. But the aesthetic status of "nature" was seriously questioned in the 20th Century, and today's music researchers – in particular music psychologists – will only consider an explanation to be convincing if it involves a demonstrable causal relationship.

A typical psychological approach might be to ask if C/D depends on the harmonic microstructure of music and speech – and if so, how. To address such a question, we must understand how pitch is perceived at the fundamental of a harmonic series of audible partials. This happens often in everyday settings, such as the *cocktail party effect* in which we can follow what a party guest is saying although most of the harmonics (often including the fundamental) of individual speech sounds are inaudible due to masking. Similarly, we have no trouble understanding speech when talking on the phone, although the fundamental frequency of the voice that we hear is usually physically absent.

Fusion (Stumpf, 1883, 1890) is a tendency for many simultaneous sounds to be heard as one. When we perceive a harmonic complex tone such as a voiced speech sound or musical tone, our ear distinguishes the frequencies of several partials, but we usually hear only one pitch. This phenomenon can explain how musical chords blend into one sound. Major and minor triads fuse well in our perception, which may explain why they are so common in Renaissance polyphony (Palestrina, Lassus, Josquin, Gesualdo) although these composers evidently conceived of triads as combinations of intervals rather than unified entities.

Stumpf explained musical C/D in terms of perceptual fusion, suggesting that fused sounds are generally consonant, while segregated sounds are dissonant. But J. S. Bach consistently avoided fusion in otherwise contrapuntal textures, which facilitates the perception of individual contrapuntal lines (Huron, 1991); and highly dissonant clusters can be perceived as fused (Kaminski, 2009). Terhardt's (1972) *virtual pitch* corresponds to the fundamental of a harmonic series of audible partials – even if the series is incomplete, the fundamental is missing, or the partials are out of tune. Perceptual fusion may not be clearly related to consonance, but it is evidently a prerequisite (or corequisite) for virtual pitch perception. The tone sensation that accompanies the holistic perception of a sound source may be called a "complex tone sensation" (Parncutt, 1989); it has not only a pitch (called "virtual") but also timbre, loudness and/or perceptual salience.

Hindemith (1937) explained chord roots in terms of combination tones, whose origin is *peripheral* and *physical*: they are non-linear distortions on the basilar membrane of the inner ear. Terhardt rejected this explanation because combination tones are generally inaudible in musical contexts due to masking by other tones; moreover, if they do become audible (e.g. the as a buzzing sensation in the ears of recorder ensemble members), they generally sound dissonant and out of tune, whereas a chord with a clear root is generally perceived as consonant (Parncutt, 1989). Terhardt (1976) instead explained the roots of musical chords in terms of a *central, experiential* phenomenon: virtual pitch. A typical chord evokes many virtual pitches, only some of which correspond to the root (in different octave registers). Chord roots are special in two respects: they tend to have higher salience than other tones, and the partials at harmonic positions above them tend to originate from different musical tones. So the chord can fuse and its main (low) pitch can be the root. This is possible because the intervals between the chord tones correspond to intervals in the harmonic series.

Terhardt's claim that the root "is" a virtual pitch is true but misleading, since a chord typically evokes many virtual pitch classes. It is truer to say that chord roots, while ultimately based on virtual pitch, are also part of Western musical culture and as such culturally transmitted from one generation to the next. The connection between chord roots and virtual pitch is indirect and historically mediated. In historical retrospect, chord roots gradually entered musical structure and listeners' perceptions during the Renaissance, but they were first identified as such later, by theorists such as Lippius (1610) and Burmeister (1606).

6.2 Rough versus smooth

The main contribution of Helmholtz (1863) to music theory was his theory of roughness. We experience roughness when we play C and D♭ together on the piano keyboard. Roughness explains why vertical major and minor second intervals are normally regarded in Western music theory as dissonances that should be resolved.

Roughness may be considered a side-effect of the frequency analysis to which the inner ear subjects all incoming sounds. Frequencies must be more than a few semitones apart (a critical bandwidth) in the central or high frequency range to be clearly separated by the ear. Frequencies that are not easy to separate are associated with roughness – the auditory analog of rubbing your fingertips across a piece of sandpaper. The grains of sand correspond to fluctuations in the amplitude envelope (beats), which cannot be individually heard above about 20 Hz.

Terhardt (1974) analysed C/D into roughness and "harmony", the latter involving virtual pitch but also musical experience (since the ability to recognize harmonic patterns of audible partials may itself be learned by exposure to speech). His "harmony" concept overlaps with Stumpf's "fusion" and Riemann's "harmonic function". Recent experimental work by McDermott et al. (2010) has suggested that spectral harmonicity is more important than roughness for modern listeners. If that is true, two possible explanations present themselves. First, the sensation of roughness associated with the fast beating of two partials of similar frequency falls rapidly as their amplitudes become more different (Terhardt, 1968; Plack, 2010). Second, 20th-Century listeners were exposed to increasingly complex (dissonant) tonal styles. As their tolerance for roughness gradually increased, roughness was increasingly perceived as timbral, superficial, or cosmetic.

A theory of the C/D of individual sonorities that is based on roughness and harmonicity (or fusion) can explain some central observations in music theory. First, it can explain the central role of major and minor triads in MmT, rendering competing theories such as harmonic dualism obsolete. Second, it can explain why music theorists from the Middle Ages to the 19th Century regarded the P4 as more dissonant than the P5, and the m6 as more dissonant than the M6 (Malmberg, 1918; cf. Tenney's CDC-3). According to Parncutt (1988, 1997), the root of an isolated sonority is determined by a combination of two factors: *interval relationships* (the bass tones of the root-support intervals P1, P5, M3, m7 and M2 tend to be roots) and *voicing* (other things being equal, the lowest tone tends to be the root). The vertical P4 and m6 are the only intervals in the chromatic scale whose root can be, and often is (depending on context), perceived in the upper voice (at least in two-part writing); perceptual fusion is reduced when the upper and lower tones of a harmonic interval compete for the listener's attention.

6.3 Related versus unrelated

Successive sonorities in tonal music may be perceived to be related or unrelated in two different ways, both of which are central to horizontal C/D. Harmonically, a C-major triad is more closely related to G major than to F♯ major. Melodically, two sonorities are perceived to be related if the voice leading between them conforms to convention; often that means that the voices move through the smallest possible intervals.

Why do successive isolated tones spanning octave, fifth and fourth intervals sound more related than successive tones spanning major seventh or tritone intervals? Why is a C-major triad perceived to go with a D-minor triad although the two have no tones in common? Why are the chords C7 and F♯7 considered harmonically remote although they have two tones in common? These questions are often answered by reference to diatonic scales or the cycle of fifths. If two chords belong to the same diatonic scale, we may perceive them to be related because the scale and its diatonic progressions are very familiar. If two chords are close on the cycle of fifths, we may perceive a relationship for that reason – assuming that this theoretical construct is cognitively internalized, as argued by Tillmann et al (2000).

Pitch commonality (Parncutt, 1989, 1993) is an attempt to explain the ultimate origin of such relationships. It is based on *perceived* pitch (not *notated* pitch or frequency), because that is all that a listener has access to. Perceived pitch includes pitches of audible partials (spectral pitches) and pitches at (missing) fundamentals (virtual pitches). Pitch commonality is independent of prevailing tonality (diatonicism, centricity), although it also contributes to it. Consider for example the chord progression from CEG to DFA (I-ii in C major, or V-vi in F major). CEG evokes virtual pitches at D, F and A; DFA at G and B♭. So the two chords have pitches D, F, G and A in common. Neglecting the upper partials and assuming octave equivalence, CEG implies A, because E corresponds to the 3rd harmonic of A, and G to the 7th. It implies F, of which C is the 3rd harmonic and G is the 9th. And it implies D, of which

C is the 7th harmonic and E is the 9th. The most salient missing fundamental is A, because the corresponding harmonic numbers are relatively low (3 and 7) by comparison to those for F (3 and 9) and D (7 and 9). The chord DFA implies B♭, of which F is the 3rd harmonic and D is the 5th; and it implies G, of which D is the 3rd harmonic, F is the 7th, and A is the 9th. In this process, the auditory system tolerates quite large mistunings between partials and fundamentals; the difference of about a 1/3 semitone between the ratio 7:4 and the equally tempered minor seventh has little effect on the salience of derived virtual pitches (cf. Moore et al., 1985).

Pitch commonality depends on categorical perception. Most Western tonal music is perceived in twelve pitch categories per octave of roughly equal width, regardless of tuning (Burns & Ward, 1978). Two sounds are perceived to have a pitch in common if a pitch in the first lies in the same pitch category as a pitch in the second (regardless of whether the pitches are spectral or virtual). The more salient the pitch, the more it contributes to pitch commonality.

The approaches of Parncutt (1989) and Krumhansl (1990) may be combined to explain the relationship between any tonal sound and its tonal context. Pitch commonality can be modeled as the correlation coefficient between the tone profile of a given chord (the perceptual salience of each pitch class when that chord is heard in isolation) and the tone profile of the local key (the tonal stability of each pitch class). Krumhansl's (1990) explanation of interkey relationships is a specific example of this general idea (Huron & Parncutt, 1993).

Mathematical formulations based on pitch salience that convincingly account for *asymmetries* in key relationships have not yet been developed. Music in C major moves more often toward the key region of G major than F major; sharps relative to a key signature are more common than flats (Parncutt & Sapp, 2011). Generally, modulations to flat-side keys (such as the subdominant) seem more harmonically distant than modulations to sharp-side keys (such as the dominant) (Cuddy & Thompson, 1992). A possible explanation is that flats relative to a given key signature sound more salient than sharps, because they tend to lie at major third and perfect fifth intervals below the tones represented by the key signature, which makes them more likely to function as chordal roots (cf. Parncutt, 1988).

Linear pitch distance (Parncutt, 1989) is an attempt to formulate the overall distance between two sounds (tones or chords) – regardless of the number of tones or pitches within them, their voicing, whether pitch trajectories jump across each other and so on. Pitch distance is zero for identical sounds and corresponds to interval size in semitones in the ideal case of successive pure tones. In the general case of two complex spectra, one must account for all successive intervals between all perceived pitches and weight each interval with the salience of the pitch at both ends. Such a formulation is consistent with well-known music-theoretic conventions: voices (especially inner) should move as little as possible, and contrary motion is preferred over similar motion between the outer parts.

The perception of pitch commonality and pitch proximity between successive sonorities contributes to the global C/D of a passage. If listeners are expecting a given overall level of C/D, there can be trade-off between the two: if the pitch commonality between successive sonorities is high, their pitch proximity can be low, and vice-versa. In other words, it is more important to adhere to conventions of voice leading in complex chromatic progressions than in simple diatonic ones.

6.4 Virtual pitch

Before proceeding, allow us to explain Terhardt's (1972, 1974) theory in more detail. It has the potential to provide a basis for different scientific approaches to C/D, because it generalizes the idea of familiarity with pitch-time patterns as they occur in speech and music – establishing a link between the two.

The basic idea is that the harmonic series is learned from voiced sounds in speech in early life – probably before birth (cf. Clarkson & Clifton, 1985; Lecanuet, 1996). The ability to detect harmonicity or periodicity may also be genetically transmitted, as suggested by temporal models of pitch perception. Learning can be said to have occurred if there is an influence on later behavior. In this case, the behavior involves interactions with musical sound. In Western culture at least, we have learned to prefer sounds that include harmonic patterns (subsets of the harmonic series, with considerable tolerance for mistuning).

Under what conditions do we perceive a "virtual pitch" corresponding to the fundamental of an incomplete harmonic series? First, the elements of the series must be *audible* in the sense that the sonority will sound different if one of them is removed (even if our attention is not drawn to the partial in question); the more clearly audible, the better. Second, several relevant partials should correspond to a harmonic series; the more the better. Third, they should correspond to low harmonic numbers; the lower, the better. Fourth, they can be a bit out of tune, but not too much; the less, the better. In Terhardt's concept, the probability of consciously noticing a pitch at a missing fundamental depends on all four factors.

Regarding the last factor, psychoacoustical experiments have demonstrated that a partial can be mistuned by up to about a semitone (6%) relative to a harmonic series and still contribute to the perceived pitch at the missing fundamental (Moore et al., 1985). This applies only to pure tones within a complex spectrum and not to whole complex tones or notes. Consider for example a pure tone that lies an equally tempered minor seventh above another pure tone corresponding to the 4th harmonic of a missing fundamental. The higher tone can be perceived as the 7th harmonic of the same missing fundamental, even though it is about a third or a semitone out of tune. Here, we are assuming that the listener perceives the spectral pitches *unconsciously*, which increases the chance of *consciously* perceiving the pitch at the missing fundamental. In any case, differences between traditional tunings and temperaments have little effect on the perception of missing fundamentals or chord roots. A D-minor triad is perceived as a D-minor triad regardless of whether it is played in Pythagorean tuning, just tuning or equal temperament – and even if it is noticeably out of tune. Tuning variations within a few tens of cents changes the sound quality but not the chord's musical identity.

What is the relationship between Stumpf's fusion and Terhardt's virtual pitch?

Perceptual fusion happens when a simultaneity of pure tones approximates a harmonic series. If the spectrum is inharmonic, part of the spectrum may correspond to an incomplete harmonic series. This part can fuse, leaving the rest of the spectrum unfused, or fused relative to a different fundamental. The more clearly we hear a virtual pitch at the fundamental of an incomplete harmonic series, the less clearly we hear the corresponding harmonics.

Schneider et al. (2005) and Seither-Preisler et al. (2007) investigated individual differences in the perception of missing fundamentals. Terhardt had assumed that some listeners are more likely to hear missing fundamentals (virtual pitches), while others were more likely to hear isolated harmonics. Seither-Preisler and Schneider showed that these individual differences were large and consistent. They also found that *fundamental listeners* tend to have more practical musical experience, while *overtone listeners* are more likely to be non-musicians – consistent with Terhardt's assumption that the perception of pitch at the missing fundamental is learned by interaction with environmental sounds, especially speech.

Terhardt's theory is based on simple assumptions that most researchers in pitch perception would agree on. When these simple assumptions are applied systematically to any musical chord, pitches at missing fundamentals emerge automatically. But musicians with highly developed aural skills deny hearing missing fundamentals. Presented with the chord ACE, they hear exactly those tones and no others. This is true even if temporal cues are removed: if the three tones begin exactly simultaneously and there is no amplitude or frequency modulation, or if there is so much reverberation that onsets are inaudible, e.g. when listening to a distant choir in a large cathedral.

These observations are nevertheless consistent with virtual pitch theory. It is practically impossible to focus attention on missing fundamentals (such as D, F or A in the chord CEG) for two reasons. First, these pitches (or pitch classes) are less perceptually salient than pitches corresponding to partials that are physically present (the notes). Second, virtual pitches tend to disappear when one focuses one's attention on them, just as the boundaries of the ghost triangle in the Kanizsa illusion (Figure 7) disappear when we focus attention on them. The pitches at missing fundamentals of musical chords are similarly ephemeral.

Beyond that, most music is not directly attended to. The attention of concert audiences wanders: they think about recent events, hopes, conflicts, worries, dreams. And even if they focus on the performance they may be more interested in the appearance and movements of a performer or the timbre of the brass section than the pitch-time patterns of the musical structure. The behavior of audiences at concerts also varied historically, and the extent to which 18th-Century audiences listened at all is a subject of debate (Weber, 1997). From this we may conclude that musical structures are generally perceived *holistically* and *unconsciously*, so these modes of perception are likely to play an important role in the evaluation of musical performances. They affect the musical survival of works and their composers, and hence (in an evolutionary approach involving memes, cf. Jan, 2002) musical structure.

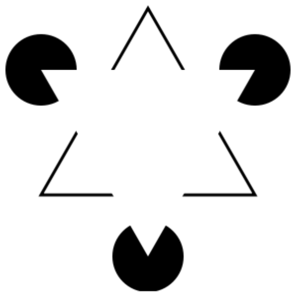

Figure 7. Visual demonstration of the Gestalt principle of closure.

Musicians spend many years learning the relationship between pitch patterns heard in music and notes in musical scores or keys pressed on keyboards. Learning this relationship is not an easy task. Many music and musicology students visit ear training courses for years. The present theory offers a plausible explanation. It is difficult to hear the "real" pitches in a musical chord due to their inherent ambiguity: for every "real" pitch, there is an "implied" pitch not far away. It takes years of training to ignore the implied pitches and focus on the real ones.

Music theorists may question the need for virtual pitch theory to understand C/D. In a set-theoretic approach, a major or minor triad is simply a three-tone collection from the seven-note diatonic scale that excludes scalar adjacencies (roughness) and includes the simplest consonant interval, the perfect 5^{th}. So the concept of root may not be necessary to explain the origin of triads. But different theories can be constructed to explain the same observations, namely the dominance of major and minor triads in Western tonal music. According to the principle of parsimony, the best theory reduces the greatest number of observations to the smallest number of axioms. Terhardt's theory sheds light on chord roots, chord progressions, tonal hierarchies, the relative prevalence of chord types, the pitches implied by a chord (e.g. in jazz theory), and stability relationships in MmT (Parncutt, 2011).

6.5 Familiarity

The aesthetic evaluation of roughness and fusion in a musical context depends crucially on cultural context, both locally and globally. From a psychological perspective, cultural context is essentially a matter of familiarity. From a historical perspective, sounds that are initially perceived as dissonant (such as an unprepared dominant seventh chord in Monteverdi) can be perceived as consonant if heard often enough, suggesting that exposure, familiarity and learning are an important aspect of consonance (Cazden, 1945, 1980). Schoenberg (1911) claimed that the history of consonance was one in which progressively higher members of the harmonic series were gradually recognized as consonant as they became more familiar. Today, we would argue that it was not harmonics but dissonant pitch patterns in real music that became more familiar, and therefore more consonant. But listeners' tolerance of roughness has not always increased over the centuries; counterexamples include simultaneous false relations in the music of Tallis (Trendell, 2007).

Moreover, exposure cannot cause *any* kind or degree of dissonance to become consonant. The atonal music of recent decades (e.g. “New Complexity”) includes dissonant sonorities that may never be heard as consonant, no matter how often they are heard. Bebop jazz experienced a rapid increase in harmonic complexity in its first decade or two, but the pace has slowed: the style is still dominated by basic ii–V–I progressions, now-familiar chord extensions, and bitonal chords; and jazz theorists and arrangers such as Dobbins (1994) emphasize the aesthetic value of simple variations on familiar harmonic formulae. When increasing exposure does not increase liking of or tolerance to dissonance, it may instead enhance sensitivity to tonal microstructures and the ability to perceive them in different ways. New musical styles and C/D concepts emerge as performers, improvisers and composers experiment within cultural and psychological constraints.

6.6 Implication versus realization

In one of the most convincing theoretic approaches to musical emotion, Meyer (1956) suggested that as we listen to music we are constantly *expecting* given structural continuations. These expectations may be either *fulfilled*, which may evoke positive emotion such as the feeling of success, or *denied*, which may produce negative emotions such as disappointment, frustration or yearning. This allowed him to posit a conceptually simple relationship between traditional music-theoretic concepts such as authentic (perfect) versus interrupted cadences and the complexity of the emotional experience of music listeners.

Many different structures can act as implications or realizations (Narmour, 1990). A rising leap in a melody can imply a falling step, if only because rising leaps are often followed by falling steps. Harmonic implications may be primarily driven by the bass line in both its melodic shape and harmonic foundation. The implication-realisation idea can explain the feeling that tonal music “progresses” from point to point with an element of predictability.

That raises the question of whether an implication can generally be regarded as a form of dissonance, and its realisation as a form of resolution or consonance. If the non-realisation of an implication evokes either a negative emotion akin to disappointment/frustration or a neutral emotion akin to surprise, as Meyer’s theory suggests, any unrealised implication may be considered a form of dissonance, and may be avoided for that reason – for example, a melodic leap that is not resolved by stepwise motion in the opposite direction. Even a stepwise ascent may be considered a dissonance if it implies a further stepwise ascent that is not realised; if, however, a stepwise ascent does not imply further movement in either direction, it may be considered consonant.

Meyer’s idea of implication and realization is compatible with our approach to C/D because it balances music-theoretical and music-psychological ways of thinking. It also enables C/D to be contextualized within a broader theoretical treatment of musical emotion. It is beyond our scope to explore that possibility in detail but allow us to present some preliminary ideas.

Schenker (1935) regarded a tonal work as a prolongation of its tonic triad. This suggests that a passage of music in a given major or minor key implies that triad, and that the arrival of that triad at the end of the passage (at a cadence) is a realization of that implication, and hence a form of consonance. Conversely, a tonic triad in the context of a tonal work may be regarded as an implication that is realized when the work continues in the key corresponding to the triad. A connection between this idea and Meyer's may enable theorists and psychologists to better understand the emotional qualities of tonal music and their relationship to C/D.

In the MmT of the 18th and 19th Centuries, there was a pronounced asymmetry in progressions between successive chord roots. Falling fifth intervals between successive chord roots were much more prevalent than rising fifth intervals. The same applies to diatonic thirds: for example, C major fell more often to A minor than it rises to E minor. This applies regardless of the tonal context in which the chords occur (Eberlein, 1994). Progressions in which roots fall by fifths and thirds may therefore be considered more consonant. Some music theorists have attempted to explain this phenomenon but no theory enjoys wide acceptance.

Table 1. Analysis of tonal styles by psychological aspects of C/D.

	Individual sonorities (vertical)		**Pairs/groups (horizontal)**	
	fusion	*smoothness*	*harmonic proximity (pitch commonality)*	*linear pitch proximity*
Renaissance polyphony	high	high	high	high
Baroque counterpoint	medium	medium	medium	medium
Surprising progressions (Gesualdo, Liszt)	high	high	low	high
Wagner, Debussy	medium	medium	medium	medium
"Atonal" Schoenberg	low	low	low	medium
Bebop	medium	low	medium	high
Reich	medium	medium	medium	high

We explained above how a C-major triad *implies* pitches at D, F and A (missing fundamentals). Given Meyer's theory of emotion, we could regard these tones as being *realized* when a C-major triad progresses to D minor, F major or A minor, but not when it moves to E minor or G major. Similarly, a C-minor triad implies pitches at F and A♭. Is that the ultimate origin of the rising-falling asymmetry in harmonic progressions? On the one hand, there is empirical evidence for the existence of the implied pitches (e.g., Parncutt, 1993) and a comprehensive, general theory that predicts them (Terhardt et al., 1982). On the other hand, the effect could be the combined result of other forces in the history of Western tonal syntax, particularly in the 16th and 17th Centuries when the asymmetry emerged. Alternative candidates for an explanation include traditional rules of counterpoint and their psychological foundation (Huron, 2001), but as yet no predictive model has been formulated. An additional problem is that while the asymmetry is particularly strong in Baroque and Classical music, it may be absent in rock (de Clercq & Temperley, 2011).

7 C/D and musical style

A theory that separates C/D into different aspects can be used to characterize different musical styles (see Table 1). If such a classification is successful, it may be considered as evidence for the central role of C/D in Western music.

In Renaissance and Baroque polyphony (Palestrina to Bach) and classical tonality (e.g. the instrumental music of Mozart, when reduced to harmonic progressions), as well as modern popular music, sonorities are predominately major and minor triads, which have high harmonicity (due to the octave, fifth and fourth intervals) and low roughness (high smoothness, due to the lack of second, seventh and tritone intervals). Harmonic progressions are often confined to diatonic scales or are otherwise strong (high pitch commonality) and each voice tends to move to the closest pitch in the next chord (low linear pitch distance, or high pitch proximity). Exceptions can be found in the unaccompanied vocal textures of Gesualdo, in which triadic chord progressions proceed in unexpected directions (with low pitch commonality); Liszt was also fond of horizontally surprising, vertically consonant progressions. The chromatic tonal music of the late 19th and early 20th Centuries, by composers as different as Wagner and Debussy, explored more dissonant sonorities (medium fusion and smoothness). The atonal music of Schoenberg and his followers tended to disregard or systematically avoid “natural” aspects of consonance including fusion, smoothness, pitch commonality and even pitch proximity (consider Webern Op. 27); but global consonance (called “global coherence” by Mullin, 2005) was still an important ingredient of the compositional recipe.

One of the most interesting tonal developments of the 20th Century was the emergence of *bebop harmony* during the 1950s. As an example of C/D, it has barely been explored by psychologists; a new collaboration between theory and psychology could lead to new insights. Its complex and often bitonal chords fuse to a medium degree; fusion is an important element of the style, but is compromised by harmonic complexity. Roughness tends to be high (smoothness is low). Harmonic relationships between successive chords and between each chord and the prevailing tonic are perceptible but complex, so pitch commonality may be described as medium. Insofar as voice leading is important, linear pitch distance is low (proximity is high), which compensates for the roughness and complexity of the individual sonorities.

Table 1 shows that different aspects of C/D can vary almost independently of each other across different styles. They can also vary independently within styles. Consider the polyphonic keyboard style of J. S. Bach. Huron (1991) regarded Bach’s choice of harmonic intervals in this repertoire as the outcome of two parallel goals: promoting consonance (by which Huron primarily meant local lack of roughness) and avoidance of fusion (which prevents the voices from being heard independently). The resultant levels of smoothness and fusion are medium by comparison to earlier and later music.

That raises the question of whether the independent motion of voices in a Bach fugue – called *auditory stream segregation* in auditory psychology and regarded as the (near-) opposite of *perceptual fusion* – is a form of dissonance. That is what we might expect if fusion in Palestrina is a form of consonance. McDermott et al. (2010) found that the perceived C/D of a wide range of sounds was more consistently influenced by the presence of harmonic pitch patterns (suggesting a role for fusion due to spectral harmonicity) than by roughness. But Wright and Bregman (1987) observed the opposite: the perceived roughness of a chord presented in isolation may be reduced by placing it in a contrapuntal context that makes the individual voices more clearly audible, i.e. segregation increases consonance. If true, that would contradict the theory of Stumpf that consonance is enhanced by fusion. These findings paint a complex picture and raise the old, general question posed by Stumpf of whether, how and to what extent fusion is a form of consonance. In what contexts is fusion perceived as consonant? How important is this kind of consonance by comparison to roughness?

8 Temporal relationships

In everyday musical, musicological, music theoretical and (consequently) music psychological discourse, C/D is often tacitly understood to refer to individual sonorities. If we are to extend the concept to incorporate relationships between successive sounds, we must reconsider the terms used to refer to temporal relationships in everyday musical, musicological, music theoretical and music psychological discourse.

8.1 Vertical versus horizontal

Simultaneous relationships within individual sonorities are often referred to as *vertical,* by allusion to conventional music notation. Some vertical intervals are consonant, others are dissonant, and in a tonal context "dissonances" (i.e. dissonant notes and chords) tend to resolve to "consonances" (see *primary–subordinate*). When we speak of vertical relationships in a chord, we usually mean that the *onsets* are simultaneous (at least in the score), but it is also possible that one or more tones are held from the previous chord; if these are considered dissonant relative to the chord, they may be termed *prepared dissonances*. The term "vertical" may also apply on a longer time-scale to relationships between simultaneous melodies or contrapuntal lines (cf the first quote from Berger 2007 above).

But the concept of C/D has always implied temporal, successive, linear, or melodic aspects, which may also be referred to as *horizontal*. In music theory, these span a wide historical, epistemological and stylistic time span from the Pythagorean concept of C/D at one end to 19th-Century European music theory on the other, the latter involving harmonic and voice-leading relationships between successive sonorities, the perception of whole contrapuntal textures or chord progressions, and relationships between passages in different keys. Any relationship between non-simultaneous sounds in music may be considered horizontal, regardless of the temporal distance between them. So horizontal C/D also includes the multiple local and global aspects of harmonic and melodic relationships (and perhaps even rhythmic and formal relationships) that we tend to bundle together and call “tonality”.

Consider the following simple examples. An A-major triad in first inversion sounds more consonant when it functions as the tonic than when it functions as a Neapolitan sixth in the key of G♯ minor. A half-diminished seventh chord on F sounds more consonant as a diatonic supertonic seventh in the key of E♭ minor than as the Tristan chord (in A minor, assuming enharmonic equivalence). In both cases, holistic C/D is a combination of vertical (the consonance of the major triad, the dissonance of the half-diminished seventh) and horizontal (linear pitch distance between successive chords as dissonant tones are resolved by step; harmonic distance between chords and their temporal context). Holistic C/D also involves tonal primacy/subordination (the resolutions of dissonance are more likely to be perceived as tonal references) and the relationship between global and local (the C/D of a chord in isolation is different from its C/D in context.

In the numerology of Pythagoras and his followers, the C/D of an interval depended on its number ratio, which is the same for vertical (“harmonic”) and horizontal (“melodic”) presentation. But the consonance of an interval can differ considerably when presented vertically or horizontally. The difference is most extreme for the minor second interval. A vertical m2 is typically very dissonant (due to roughness), but a horizontal m2 may be considered consonant due to the pitch proximity of the two tones, whose psychological basis may be accounted for by Gestalt psychology and auditory scene analysis (Huron, 2001). Said another way: melodic tones in stepwise progressions sound well together (are *con-sonant*) because they help the melody to hang together in our awareness as a single perceptual object. When the inherent dissonance or instability of a leading or neighbour tone is “resolved” by melodic motion through a m2, it is not the interval but the first tone that is dissonant.

For music theorists, these ideas are truisms – which can explain why, to our knowledge, no music theorist has ever written about the C/D of the m2 and M2 in this fashion. Psychologists prefer such points to be made clearly and to look carefully for a possible exception. We do not have to look far to find one: in Medieval chant, the horizontal *mi-fa* relationship may have been perceived as dissonant due to the roughness produced by almost-coinciding harmonics in resonant performance spaces. That can explain why modes with semitones against the final (B, C, E, F) were generally less common than modes without semitones against the final (G, D, A; Parncutt & Prem, 2008). The avoidance of tritones and minor sixths between successive tones in chant may be a combination of this effect and a general avoidance of larger intervals (leaps).

In MmT, tones that form vertical intervals of a second, a fourth or a seventh with the bass are considered dissonant. Horizontally leaps through a seventh, ninth or tritone may be dissonant, but not through a second or perfect fourth. The reference to “leap” (paired with ‘step”) evokes the concept of the scale: the second is not dissonant because of scalar adjacency, but the ninth is. Dissonant chromatic leaps may be dissonant not only because they are leaps but also because they evoke a background memory of more than one scale; a dissonant chromatic leap could be a leap from a tone of one (implied, diatonic) scale to a tone of a different (implied, diatonic) scale. For example in the penultimate bar of the Paganini theme in Figure 6, the melody proceeds directly from F (submediant of A minor) to D♯ (leading-note of E minor): a dissonant chromatic leap of an augmented sixth. We also have the concept of an altered tone (in some styles, lower neighbour tones usually form a semitone with the tone which they ornament), which implies a more local kind of dissonance (possibly a better explanation of the D♯ in the Paganini example). The leap may be considered dissonant for yet another reason: the underlying implied harmony (arguably an augmented sixth chord) is dissonant.

The idea of horizontal dissonance sometimes reaches beyond immediate melodic adjacency. In Medieval chant, the dissonant tritone interval (F and B in modern parlance, or E and B♭ in transposed melodies) was avoided between pitches in any proximate vicinity. In MmT, the solecism that we call *false relation* depends on the existence of a dissonant chromatic interval (diminished or augmented octave) between adjacent – not simultaneous – notes, if they are in different contrapuntal voices, and the solecism is usually corrected by placing the notes in question in the same voice, so that chromatic stepwise motion in a single voice replaces the diminished or augmented octave between different voices.

Tenney (1988) identified five different C/D concepts or CDCs (see Table 2). With one exception, his CDCs refer to individual sonorities (vertical C/D). The exception is CDC-1, which applies to relationships between successive tones in unaccompanied melody – the simple ratios of octaves, fifths and fourths (horizontal C/D). These can be explained by tunability (string-length ratios), consistent with Wolfe and Schubert (2010), who argued that musical scales comprising discrete scale steps or pitch categories arose from the constraints of tunable musical instruments. But similarity ratings of successive tones suggest that CDC-1 also involves pitch commonality and the pitch ambiguity of isolated harmonic complex tones (Parncutt, 1989; Terhardt, 1974).

Table 2. Tenney's consonance-dissonance concepts (CDCs)

	Tenney's definition	**Historical period**	**Possible perceptual account**
CDC-1	Melodic affinity	Ancient-medieval	Perceived spectral pitches in common
CDC-2	Sonority of isolated dyads	12th-13th Century	Roughness? fusion?
CDC-3	Clarity of lower voice	14th Century	Pitch salience of lower voice
CDC-4	Property of individual tones in chord	18th Century	Dependence of overall roughness on amplitudes of individual tones
CDC-5	Smoothness or roughness	19th Century	Roughness of whole sonority

Tenney's other CDCs apply to individual sonorities. CDC-2 and CDC-3 apply to harmonic dyads in two-part counterpoint; CDC-2 can be explained by harmonicity and smoothness, and CDC-3 by the clarity of the lower voice (which in turn can be explained by Terhardt's *pitch salience*; see the above discussion of the dissonance of the perfect fourth). CDC-4 applies to early MmT and refers to tones relative to roots (e.g. a dissonant seventh); it can be explained by Rameau's *basse fondamentale* (the basis for Terhardt's *virtual pitch*). CDC-5 (19th Century) refers to whole sonorities, timbres and intensities and can, according to Tenney, be accounted for by Helmholtz's *roughness*.

That horizontal C/D is psychologically important is clear from experiments reported by Krumhansl (1990), in which listeners were asked to judge how well a tone "follows", "goes with" or "completes" a musical element or passage (*probe-tone technique*). In a general definition of C/D, these experiments can be regarded as experiments about C/D. Consonance originally means "sounding with", and if listeners had been asked to evaluate the consonance of the probe tone relative to the preceding context, the results would have been quantitatively similar. Such "converging operations" may be combined on the assumption that there is a common underlying cause (Garner et al., 1956).

From a music-theoretical viewpoint, listeners in Krumhansl's probe-tone experiments were also evaluating the *centricity* or tonal *primacy/subordination* of the probe tone (its tendency to function as a tonal point of reference). Alternatively, if the major and minor scales are considered to be overlearned (Deutsch & Feroe, 1981), listeners may have been responding to *diatonicism* (the likelihood that the probe tone belongs to the same diatonic scale as the context). Parncutt (2011) argued that the values in Krumhansl's key profiles primarily reflected pitch salience within the tonic triad, which may either be directly perceptible, historically mediated or a mixture of both. The listeners in her experiments presumably also responded to the probe tone's melodic proximity (linear pitch distance) to (immediately) preceding sounds, but her use of octave-complex 'Shepard tones' (Shepard, 1964) and carefully balanced experimental designs presumably eliminated such proximity effects.

In this context it is also useful to consider the idea of *diagonal* relationships (Boulez, 1963; Lerdahl, 1989). From the point of view of the score, "diagonal" essentially means *arpeggiated*. More generally, it refers to any temporal extension of a sonority. An arpeggio is generally local, because it is perceived as a single event; but long-term arpeggiation may be either local relative to longer-term developments or global relative to shorter-term developments. In a Schenkerian approach, a diagonal relationship may extend over an entire piece.

As an example of diagonal relationships consider the well-known Purcell aria in Figure 8. The top part of the figure shows the bass line, which can be seen as an elaboration of an arpeggiated tonic triad (marked with asterisks). The tones of the triad are separated and joined by diatonic and chromatic passing notes. The lower part is the harmonisation. The diagonal G minor triad in the bass is reinforced by vertical harmonisations by means of tonic and dominant triads. More elaborate dissonances harmonise the interspersed notes at different levels. A diagonal consonance (the arpeggiated triad in the bass) forms a framework for the vertical sonorities, and the interplay between horizontal, vertical and diagonal creates a harmonious whole. The chord progression is global in relation to the initial vertical G minor sonority, but local in relation to the whole Passacaglia. The same diagonal triad recurs in the bass many times over, allowing Purcell to choose less circumscribed vertical reinforcements at subsequent repetitions.

Figure 8. Purcell: Dido and Aeneas, "When I am laid in earth".

8.2 Harmonic versus melodic

Harmonic C/D is like vertical C/D but can also refer to arpeggiated (diagonal) chords whose C/D is similar to that of their simultaneous counterparts. This kind of comparison has presumably been possible since the beginnings of Western polyphony, or at the latest since the 14th Century; consider the unaccompanied arpeggiated harmonies in the music of Machaut, or Bach's solo violin sonatas. Music theorists may consider the comparison to be trivial, but psychologically it is interesting: vertical C/D depends crucially on roughness/smoothness, and roughness is largely absent from unaccompanied arpeggiations (except in highly resonant performance spaces). So such C/D relationships must somehow have been transferred by memory or familiarity from simultaneities to arpeggiations – consistent with our assumption of a central role of familiarity in C/D perception. "Harmonic C/D" may also refer to harmonic distance within chord progressions; for example, C major is relatively close to D minor but distant from F♯ major.

If *melodic C/D* means "C/D within melodies", it may either involve tones that hang together to make a melody because they are nearby in pitch (pitch proximity and the difference between steps and leaps; Huron, 2001), or successive tones spanning perfect intervals (fourths, fifths, octaves), which according to Terhardt (1976) and

Parncutt (1989) have pitches in common or tonal affinity. But pitch commonality could also be regarded as harmonic, because it involves the intervals among the lowest elements of the harmonic series. In real musical contexts harmonic and melodic structure are always interdependent. We refrain from using the terms "melodic C/D" and "harmonic C/D" in this article due to their ambiguity and interconnectedness. But the continued use of terms such as harmonic and melodic in both general and specialist-theoretical discourse (e.g. *melodic charge* and *harmonic charge* in the model of expressive timing and dynamics by Friberg et al., 2000) implies that the distinction can still be useful.

The terms melodic and harmonic have also been applied to the concept of tonality. Dahlhaus (1968) described MmT as harmonic because the tonal centre is the root of a harmony (the tonic triad) and tonality is substantiated or confirmed by harmonic progressions. Dahlhaus's approach is consistent with the harmonically oriented thinking of Rameau and Riemann. Fétis (1840) developed a contrasting concept of melodic tonality and applied it to non-Western musics that were not based on polyphony and vertical C/D. From a psychological viewpoint, the tonal centre of a melody is determined primarily by repetition and duration (Smith & Schmuckler, 2004).

8.3 Local versus global

The words "horizontal" and "vertical" refer to the score and are associated with music theoretical ways of thinking. In a Schenkerian approach, it is not possible to disentangle the vertical from the horizontal; each affects the other. The term "horizontal" might refer to both simultaneous and successive events (reminiscent of the more psychological term "global"). Schenker even had a term (*Stufe*) for a single consonant vertical sonority which exerts its influence over a span of time, encompassing many vertical and horizontal events. But we can clarify the discussion by reserving "vertical" and "horizontal" for relationships *in the score,* and "local" and "global" for corresponding *perceptions*. Thus, vertical/horizontal may refer to theoretical observations and local/global to psychological observations.

Global may refer to extended temporal patterns that may include different groupings at different hierarchical levels such as phrases or sections of a piece (cf. the hierarchical structure of a piece's phrasing; Lerdahl & Jackendoff, 1983; Todd, 1985). If the terms local and global are defined relative to each other, *local* can be thought to mean "more local than the current usage of the term global". A local event can include more than one sonority – and hence both vertical and horizontal aspects. From a psychological viewpoint, a local event may be confined by the duration of echoic, short-term, or working memory (Baddeley, 2003), and the perception of global relationships enabled by medium- or long-term memory. *Global C/D* may refer either to the overall C/D of a passage or to the global aspect of the C/D of an event within that passage.

Tonality is generally considered a more global phenomenon than consonance. Consequently, tonality (in our sense of a bundle of relationships) is often considered to be more learned (cultural) and less innate ("natural") than vertical C/D (in the sense of single chords considered in isolation). That raises the more general question of which is more important: local or global C/D? In common usage, C/D is often tacitly assumed to be local, suggesting that local C/D is more important. Tillmann et al. (1998) showed that local processing of harmonic cadences prevails over global processing, and their data suggest that the temporal duration of global C/D in real listening situations is often limited to a few seconds. But we our perception of C/D is generally influenced by both local and global elements, which are difficult to separate when listening to music.

The idea that C/D is perceived holistically is also consistent with Gestalt psychological (Koffka, 1955) and Gibson's (1979) theory of ecological perception. We tend to perceive (or be aware of) objects in the world as wholes and their affordances, that is, their function with respect to our "selfish genes" (Dawkins, 1976). Analytic perception of perceptual attributes is the exception rather than the rule. A related example is the perception of timbre in music performance. A performer – such as a flautist – is considered to play with good timbre if the intonation is good, and vice-versa; the audience has difficulty separating these two parameters (Wapnick & Freeman, 1980). This judgment is global in the sense of mixing parameters, but local in another sense: it can be made within a few seconds, just as a piece of music can often be identified and described in a fraction of a second (Krumhansl, 2010).

These various arguments and observations are consistent with the following two broad conclusions. First, global and local aspects of C/D are not significantly different in importance. Second, our perception of C/D tends to be holistic, mixing global and local aspects. In our experience, this point applies equally for composers, performers, concert audiences, and users of mobile MP3-players.

9 Tonality and "atonality"

To understand the relationship between tonality and C/D, we must first consider definitions of tonality. In a broad definition, tonality involves all pitch relations in all music; almost all of the world's music has perceptible tonal organization. In a narrow definition, tonality refers to MmT. Fétis (1840) investigated tonality in diverse world musics; much later, neo-Schenkerians (Felix Salzer, Saul Novack and two generations of mostly American theorists) regarded the modal system in Medieval and Renaissance music (from Gregorian chant to Palestrina), and the expanded tonality of 20th-Century composition (in works by composers such as Stravinsky, Hindemith and Bartok), as sub-classes of tonality.

In a global approach to C/D, Schoenberg's tone-row technique suggests that tonality (more precisely, centricity) can be avoided by presenting all 12 pitch classes once only before repeating any of them, which may be considered a form of dissonance. But Schoenberg's primary interest lay in comprehensive organicism based on the post- Romantic tradition from which his music sprang. Nevertheless, in an "atonal" context, tonality (more precisely, diatonicism) can be fleetingly evoked by isolated interval relations among successive or simultaneous pitches, as the tone-row at the start of Berg's violin concerto famously demonstrates. The GDAE pattern recalls someone tuning a violin, but the accompaniment directs our attention to relationships other that which this pattern might suggest in a diatonic context.

In atonal music, the familiar hierarchical structure and perceptible prolongation relationships of tonal music disappears (Dibben, 1994). Moreover, familiar tonal elements take on a different character when they appear in "atonal" contexts, as Straus (1990) explained:

> When triads occur in contexts other than the traditionally tonal one, careful attention must be paid. The presence of triads on the musical surface need not imply a triadic middleground and background as well. Many observers naively transfer the theoretical categories of tonal music to a post-tonal context. To some extent, of course the amount of tonality one hears will depend on the amount of tonality one brings to one's hearings. It is possible, even in the remotest of contexts, to insist on a tonal hearing. To do so, however, is to impoverish the musical experience. Our experience will be richer if we can simultaneously sense the triad's tonal implications and the countervailing urge toward redefinition provided by the post-tonal context (p. 74).

Even when music is composed entirely from tone rows in which familiar tonal patterns such as triads are systematically avoided, each individual tone attracts attention to itself, and in that way becomes a fleeting tonal centre for its local context. Every musical interval in the chromatic scale (assuming typical variations in tuning; Burns & Ward, 1978) is part of a diatonic scale and can remind us of diatonic pitch relationships that may also point to a possible tonic (Van Egmond & Butler, 1997). Every chromatic musical interval is also part of the harmonic series and can remind us of the pitch relationships within individual complex tones and point to a possible fundamental. On this basis we might claim that, with the possible exception of long-lasting silence or white noise, there is no such thing as pure acentricity. Nor is there pure atonality, because tonality involves several partially independent components; it is impossible to simultaneously eliminate all of them from a passage of music. In 1922, in the second edition of his (1911) *Harmonielehre*, Schoenberg suggested "pantonality" and "polytonality" as possible alternatives to "atonality", partly in response to the use of the term "atonality" in Hauer (1920) (cf. Simms 2000, pp. 7–9). "Schoenberg.....preferred to call his music 'pantonal', suggesting a single transcendent, all-encompassing tonality rather than mere avoidance of custom, but the term failed to catch on" (Taruskin, 2005, p.312). A merging of tonalities is consistent with other transcendental Schoenbergian concepts such as the unity of musical space (merging of horizontal and vertical) and the emancipation of dissonance (merging of consonance and dissonance).

The compositional developments provoked by Schoenberg's theory and practice were complex and subtle. The change from centricity to acentricity did not necessarily coincide with or depend upon the change from diatonicism to chromaticism or from consonance to dissonance. Was the transition gradual or sudden? An "evolution" of musical style might imply seamless transitions in respect of all three features: diatonicism-into-chromaticism, centricity-into-acentricity as well as consonance-into-dissonance. But if we understand diatonicism, centricity and consonance as three partly independent features of tonality, Dahlhaus's (1978) pronouncement that "it is hard to avoid concluding that Wagnerian tonality evolved into Schoenbergian atonality" seems open to doubt. To be sure, Schoenberg's music shares with Wagner's (notably *Tristan and Isolde*) a progressively-increasing degree of chromaticism, and as a result of continuously-moving tonal centres or what Schoenberg (1999, p. 133) called "roving" harmony, an ambiguous sense of centricity (albeit often balanced by passages of clearer centricity). But in Wagner the sense that dissonance eventually resolves to consonance is still maintained, even though he clearly played with the idea that resolution could be long-deferred and build up immense tension, and thus create a corresponding sense of fought-for-and-achieved-only-after-a-struggle relaxation at the release of such tension in the long run. But once dissonance cannot be heard to resolve, even in the long run, we sense a break from canonic practice. Indeed, much higher levels of dissonance than those of Tristan and Isolde sometimes appear in early Schoenberg and contemporaneous works, for example the ear-splitting 9-note dissonance at bar 206 in the first movement of Mahler's Tenth Symphony, or the stack of 6 fourths which opens Schoenberg's First Chamber Symphony. But these examples can be reconciled with canonic practice, because the function of dissonance is clear: Mahler's chord is an extended dominant (Paccione 1988 called it a dominant 19th!), and although there is no textbook nomenclature for Schoenberg's fourth-chord it can be heard as a prefix-dissonance to the F major triad which follows. To a concert audience that hears Schoenberg's romantic *Verklärte Nacht* before the interval and his atonal *Piano Concerto* after the interval, the break from canonic practice is obvious: the dissonances of the Piano Concerto demand interpretation in the motivic way (similarity versus difference, see §5.8) rather than in contradistinction to consonance (tension versus relaxation) – a much more challenging listening task.

10 Nature versus culture

Returning to the theme of the conference at which an earlier version of this paper was presented, innumerable theorists and psychologists have asked whether C/D is "natural" or "cultural", or whether it is innate or learned. The discussion continues despite the inherent fuzziness of the distinction, both within and outside musicology. "Natural" does not mean the same as "innate", but alludes to a musical structure whose origin lies in the natural world – perhaps in human physiology or the human physical environment. "Innate" alludes to some kind of perceptual musical sensitivity, ability or preference that is present in new-born babies, implying in turn that it emerged from an interaction between genetic predisposition and the contingencies of the human prenatal environment. Since both nature and nurture are clearly important, and the dividing line between them has never been clear, a balanced approach should consider both sides.

In the late 20th Century, the humanities tended to support explanations based on "nurture": our perception of music depends on the structure of music to which we have been exposed as well as its culture-specific contexts – historical, cultural, social (Cazden, 1945, 1980) – consistent with the *memetic* approach (Jan, 2002). The sciences have traditionally focused on nature in the form of perceptual universals, which incidentally can also be learned if they reflect universals of the human environment (Parncutt, 1989; Thompson & Balkwill, 2011). Psychological research since the 19th Century has converged on a consensus that vertical C/D has two natural components, smoothness and harmonicity (fusion). They are considered "natural" because of their apparent perceptual universality: they influence the everyday auditory experience of every hearing human (not to mention other animals; Fishman et al., 2001). Like critical bandwidth, smoothness/roughness is an inevitable byproduct of frequency analysis in the inner ear. Fusion (in the sense of several pure tones being perceived as one tone) enables the direct perception of sound sources and is in this sense an integral part of everyday environmental interaction. The cultural component is simply familiarity with the music to which an individual has been exposed as well as speech and environmental sounds.

11 Conclusion

C/D is a multi-faceted phenomenon that can best be addressed by combining a humanities approach that acknowledges the richness of its detail and refers repeatedly to specific examples, and a scientific approach that searches for general principles and refers to statistical regularities. We cannot understand C/D without considering both its simplicity (our spontaneous "gut reactions" to music) and complexity (the diversity of possible reactions to the same musical event and the kaleidoscope of ineffable experiences that can accompany music).

Thinkers and researchers of the past have tended to emphasize one or the other side of the listed dichotomies, leading to conflicts or *cognitive dissonance* whose later (or continuing) reconciliation advanced understanding of C/D. Wikipedia defines cognitive dissonance as:

> ... an uncomfortable feeling caused by holding conflicting ideas simultaneously. The theory of cognitive dissonance proposes that people have a *motivational* drive to reduce dissonance. They do this by changing their *attitudes, beliefs, and actions*. Dissonance is also reduced by *justifying, blaming, and denying* (1 Nov 2010; our emphasis)

The authors of this paper are similarly *motivated* to reduce the cognitive dissonance between the traditional approaches of the humanities and the sciences to C/D in order to come closer to its essence. This involves questioning entrenched and cherished *attitudes and beliefs* (conventional wisdom) of both sides, from generalities about the nature of truth and how it can be acquired right down to specific details of the analysis of musical passages. It involves breaking through hidden walls of *justification, blaming and denying*, since each side has developed sophisticated verbal means of justifying its own approach, indirectly blaming the other side for its failure to address central issues, and denying that its own limited approach may be part of the problem. We are trying to open up these hidden agendas by acknowledging that a long history of conflict between humanities and sciences exists in this area, and emphasizing that these conflicts tend to be denied or ignored by both sides (Snow, 1960; Clarke, 1989). Our solution is to place the arguments in the open and to constructively pit them against each other.

Harmony and consonance are held to be beautiful, and many people devote their lives to creating music that exhibits harmony and consonance. Tenney clarified the history of this uniquely human behavior, but avoided the ultimate question of its essential origin and nature; in the humanities tradition, he presumably regarded any attempt at a single clear answer as positivist and therefore unrealistic. Terhardt aimed for a single clear answer, but his emphasis on discovery and clarity may have alienated music theorists and even some psychologists. Moreover, his way of expressing his concept was fundamentally scientific; he did not communicate the cultural subtleties in a way with which humanities scholars could connect.

We believe that both protagonists, who to our knowledge never met, were essentially correct; and that their approaches, for all their differences, did not contradict. On this basis it is now becoming increasingly possible to formulate a general answer to the broad question of why we like harmony and consonance. Consider first the vertical aspect. While it is clear that the avoidance of roughness has always played an important role, it cannot be regarded as the ultimate basis of vertical C/D, because its contribution is negative. The positive quality and power of harmony can only come from a positive factor – otherwise we would not like it. In the case of individual sonorities, that factor is what we have called *harmonicity*. It involves the creation of multiple incomplete harmonic series of partials that originally belong to different tones. It also involves changing the timbre of a sonority by adding tones such that harmonics overlap. This procedure is reminiscent of the principle of combining organ stops, but the goal in the case of harmony is not necessarily to reinforce an existing fundamental. It may also be to create missing fundamentals at other pitches: new tone sensations that arise only from the combination and not from the original tones. The different colors created (timbres based on different amplitude envelopes) may be part of the appeal.

Seen this way, Stumpf's concept of fusion (or the way in which it is understood today) and Terhardt's related concept of virtual pitch can be misleading as bases for understanding harmony. While it is true that the number of tones consciously perceived in a harmonious mix of voices is typically less than the actual number of tones, it is also true that the number of tones that *could* be perceived if our attention were directed to them is *larger*. Harmony is not only about fusion around a pitch that may correspond to the music-theoretic root (e.g. the C in CEG); it is also about the ambiguity that is created by new missing fundamentals within a sonority (e.g. F, A and D in CEG).

Both vertical and horizontal aspects of harmony involve familiarity and, consequently, similarity. Patterns of sound that are familiar at some level, from the harmonic series within a single tone to the complex voice-leading patterns typical of a given musical style, can be perceived as consonant. But the most general and hence important aspects of C/D, at least in the Western tradition, are tied to the human voice: the harmonic series within each voiced sound, and the limited size of pitch intervals between successive phonemes. That in turn can explain why so many people still put so much energy and time into music based on major and minor triads – despite the extraordinary multiple developments in tonal syntax during the 20th Century. All pitches involved in the perception of simple triads, including the missing fundamentals, may be associated with the human voice, since the voice is the most important sound in human social life and – in an evolutionary explanation – in reproduction (sex and childcare). The appeal of harmony may also lie in the playful way we engage with these pitches when performing and listening to music. It is a game with pitch in which we repeatedly try to trick the auditory system.

Missing fundamentals are not consciously perceived in the sense that a musician could transcribe them, but the experiments and models that point to their psychological reality and the evident appeal of harmony and consonance suggests that they are somehow felt. That in turn suggests that harmony is an experience that lies at the interface between sensation and emotion. But any such explanation must remain speculative as long as both the involved sensations and the involved emotion are unclear.

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This paper was inspired by the work of James Tenney (1934–2006) and is dedicated to his memory. An American composer and theorist, his later compositional procedures (from the mid-1970s) involved the harmonic series, just intonation and alternative tuning systems. His book *A History of "Consonance" and "Dissonance"* is one of the most important contributions to C/D research in the 20th Century. Originally published by Excelsior Music Publishing Company, New York, it is now available for free download at http://www.plainsound.org/pdfs/HCD.pdf along with some of his other publications and information about his compositions. The journal *Contemporary Music Review* devoted a special issue to his work in 2006 (vol. 27, no. 1). We thank Renée Timmers, Matthew Woolhouse and two anonymous reviewers for their thorough, careful reading.

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[i] Although the expression "consonance and dissonance" is grammatically plural, we treat C/D as a singular concept and write for example "C/D is…" rather than "C/D are".
[ii] Since both authors are expatriate Australians it may be more appropriate to speak of dingos and wombats.

Biographies

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