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12 MUSICAL STRUCTURE

Tonality, Melody, Harmonicity, and Counterpoint

Daniel Shanahan

When the melody in Figure 12.1 rings on my mobile phone, I'm able to infer a sense of stability and repose when it has reached its conclusion, and the final note, C-natural, sounds like a resting point: a tonic. Yet, from looking at the melody, it's not really clear why that would be the case. The melody doesn't begin on C, and the note that it does begin with (G) occurs more frequently than C. In fact, the only time C occurs before the final measure is in a position not emphasized rhythmically, as a part of descending motive that I've already heard twice before. For some reason, however, I'm able to hear closure and rest on the C at the end of the phrase, as if the melody has "arrived home." Thus, our perception of tonality is a complex network of relationships that are often not apparent upon first glance.

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We are able to infer a tonal center from the melody in Figure 12.1 in large part because we've learned the organizing principles that govern the Western tonal system in which that melody is composed. Of course, such organizing principles vary across time and cultures, but there are many that remain consistent. For example, most cultures employ scales that contain between 5 and 7 tones in an octave, even in cultures that employ microtonal tuning systems; there is a ubiquity of five-note scales across cultures (Van Khe, 1977). Additionally, intervals between adjacent notes of these scales rarely extend beyond the range of 1–3 semitones, and most scales employ some sort of asymmetry in interval size (Nettl, 2000); scales containing only one interval (such as the "whole tone" scale) are quite rare, as they prevent the listener from hearing a "perceptual anchor" (for reasons to be discussed below).

Tonality (in any culture or epoch), defined here as a series of relationships between notes or pitches that creates a "pull" toward a musical "center," provides the listener with a set

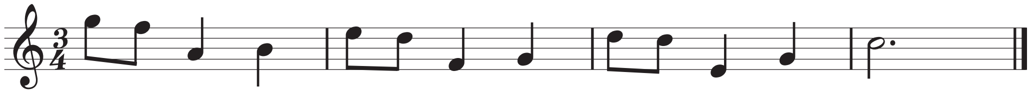

Figure 12.1 Excerpt from Francisco Tarrega's "Grand Valse" (1902), commonly known as the Nokia ringtone.

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of organizational principles which they might latch onto. This chapter discusses the factors that contribute to our understanding these relationships governing a musical idea in a tonal idiom. Such factors include how physical and linguistic constraints can influence melodic features, how listeners learn to understand these features, relationships and grammars, the role of hierarchical relationships within a tonal framework, the comprehension of co-occurrent sounds (harmonicity), and finally a listener's ability to disentangle multiple melodies performed at once (counterpoint).

Melodic Structure

The fact that certain principles of musical organization seem to be consistent across cultures might lead us to conclude that music typically contains a number of inherent elements that allow for a listener to more readily perceive and organize it. The construction of melody provides us with an interesting case study on how certain organizational aspects of music exist not as the result of something outside of human actions and experience, but rather as related to phenomena found in physiological and linguistic domains. Melodic contour and trajectory, for example, display a number of features paralleling those seen in linguistic prosody and phonology: Notably, just as vocal utterances tend to decline in pitch—the result of a decrease in air pressure as air is let out of the lungs (t'Hart & Cohen, 1973)—melodies decline in pitch. Shanahan and Huron (2011) similarly found that, in European folksongs, the size of intervals in a melody also decreased over the melody's course, similar to the intervallic compression that occurs over the course of a vocal utterance. Melodic rhythm has also been linked to linguistic factors. Patel and Daniele (2003) found a correlation between the rhythmic variability—the note-to-note differences in duration—of instrumental themes drawn from Western "classical" music and the variability of the spoken language of the theme's composer. Such connections, however, are not absolute. For example, musical melodies incorporate fixed interval sizes, whereas speech uses variable interval sizes (Patel, 2008, p. 205). The many connections between the sound patterns of language and music, however, suggest that musical practices don't exist in a vacuum, and are shaped by the sounds that already surround us in our daily environment. Melodic ideas are, at least in part, more understandable to a listener because they can be related to non-musical aspects of the listener's life, such as speech.

Much of the research on the perception of melodies within a tonal framework revolves around a listener's expectations while hearing music. Meyer (1956) argued that emotion in music was conveyed when an expectation—a listener's sense or prediction about how the music would proceed—was either fulfilled or inhibited. Meyer's student and colleague Narmour (1990) expanded upon this theory, arguing that the repetition of a melodic idea implies that it will continue, while a changing melodic idea implies that further change will occur (for example, A+B→C, but A+A→A). This might be thought of as a "bottom-up" approach to melodic structure and comprehension, in that it argues that a listener's expectation is provided by a melody's note-to-note relationships, rather than beginning with its larger-scale contour or shape. In a contrasting vein, Dowling (1978) proposes a "top-down" approach to melodic learning, proposing that listeners grasp melodic contours first, and specific notes and intervals later as the melodies became more familiar. These approaches are hardly mutually exclusive, and are in fact quite complementary—Narmour provides a prospective approach whereas Dowling's is retrospective. Examining both approaches, however, illustrates the points that melodic

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structure is comprised of both the note-to-note interactions, and a broader, more "structural" set of interactions.

Many theorists have discussed the role of "structural" as opposed to "ornamental" notes in melodies (Schenker, 1905/1980) and there is experimental support for this distinction: listeners are able to accurately recognize a melody when ornamental tones are removed, but are unable to do so when structural tones are removed (Dibben, 1994). Structural tones serve as anchors for pitches of lesser importance, and tones that are understood to be stable (such as the first, fifth, or third scale degrees) can serve as cognitive reference points for the composition as a whole (Bharucha and Krumhansl, 1983). It's quite likely that this anchoring is facilitated by small pitch movements (such as $\hat{2} \rightarrow \hat{1}$ or $\hat{7} \rightarrow \hat{1}$; the caret above the number is a common way of denoting scale degree): Deutsch (1978) found that participants were better able to discriminate between pitches if they were interrupted by pitches that were separated by only a small number of steps (rather than skips or leaps), concluding that participants were able to perform better if they heard the tones as anchoring pitches that were separated by smaller intervals. In Figure 12.1, for example, it would be a fair assumption to say that most people might hear the G, E, D, and C on the downbeat of each bar to be the structural tones, because of the emphasis heard on a downbeat—what music theorists call a "metric accent"—as well as the motivic repetition.

Tonality and Key

Hierarchy and Centricity

To hear a hierarchy of pitches within a key is to hear that some pitches are more important in, central to, or prototypical of that key than others. For example, $\hat{1}$, $\hat{3}$, and $\hat{5}$ in the key of C (C, E, and G) are more easily identified with the key of C than they are with F major, where they also occur (as $\hat{5}$, $\hat{7}$, and $\hat{2}$). Krumhansl's work on key profiles (perhaps best summarized in Krumhansl, 1990) might be thought of as a musical analogue to Rosch's notions of prototypes (Rosch, 1975), which argued that prototypes or "cognitive reference points" have an elevated status within a category of objects or events. In this framework, less prototypical members of a category are judged as being more similar to a more prototypical member than a prototypical member is judged to be similar to a less typical one; in other words, these similarity relationships are asymmetrical. To study relationships between musical events in a tonal framework, Krumhansl and Kessler (1982) focused on using chord progressions in both major and minor keys, and asked participants how well certain tones (called "probe tones") "fit" within the context. Their results demonstrated what might be expected: The tonic of a key was perceived as the best fitting tone, followed by the other notes in the tonic triad, followed by the four remaining diatonic pitches, and finally the five chromatic pitches (in decreasing order of "goodness of fit").

While these probe-tone results are widely accepted, a number of points have been made regarding the analysis of pitch-class distributions as an indicator of key. Firstly, a listener's ability to understand what key a piece of music in is strongly dependent on the order in which they experience pitches. Deutsch (1984) found that listeners could confidently hear a melody as being in either C major or E minor, depending on whether it was played forward or backward, and West and Fryer (1990) found that when the diatonic scale was presented in a random order, the tonic of the key was judged as the tonal center just as often as scale degrees $\hat{3}$, $\hat{4}$, and $\hat{5}$. Brown (1988) found that 86% of listeners were able to correctly identify

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the key of Schubert's Sonata in D major, D.644, but only 41% could do the same task when the pitches were re-ordered, indicating again that the order of pitches is important in establishing their tonal relationships.

An alternative to the pitch-class distribution approach focused not on the statistical distribution of pitches in a key, but on the relationship between a perceived tonic and the intervals that occur least frequently in a piece. Butler's "theory of intervallic rivalry" argued that the perception of tonality was not the result of a hierarchy of tones, but rather a pull toward a tonic provided by rare intervals (such as a minor second or a tritone), stating that "any tone will suffice as a perceptual anchor—a tonal center—until a better candidate defeats it." (Butler, 1989, p. 238) This theory allows for a temporally ongoing aspect to key-finding, drawn upon the notion of "tendency tones". Whether we determine key based on presence of common pitches or the salience of rare intervals, it's clear that the statistical distribution of a piece plays a part in our perception of the key, although our perception of tonal centricity requires a contextual understanding, as well as the input of several other musical factors including how tones are likely to resolve, and overall sense of stability (or lack thereof) that certain intervals might provide.

Focus Point: Key-Finding Algorithms

What seems like an inherently straightforward, fundamental question ("what key is this excerpt in?") proves, on further investigation, to be multi-faceted and replete with complexities that listeners never need to consider when hearing a piece of music. Any musician would tell you that the answer to this question cannot be answered by simply providing the pitch that appears the most frequently, nor can it be addressed by providing the pitches that come first or last (pieces begin away from the tonic quite a bit, whether the piece is a Brahms *Intermezzo* or the excerpt in Figure 12.1). Therefore, the computational exercise of key-finding has frequently served as a means of modeling the complexities of the perception of tonality. In a way, this is not unlike what computer programmers refer to when they speak of "rubber duck debugging." in which (as legend has it) one would talk through lines of code to a (literal) rubber duck—a hearer who understands nothing of the situation, and to whom everything must be explained completely and in detail. In doing so, the programmer would find any errors as the difference between what the program was supposed to do and what it actually does as written come to light. In a sense, a computational approach to key-finding, whether used as a stand-alone computer program or taken as a model for human key finding processes, is akin to the rubber duck debugging of tonal perception.

Perhaps the first key-finding algorithm (a process or program for finding a definitive solution to a problem) was Longuet-Higgins and Steedman's *shape-matching algorithm* (Longuet-Higgins & Steedman, 1971), which used an exclusionary approach, eliminating key possibilities as pitch classes were introduced over the course of a musical passage. For example, in Figure 12.1, the opening G would fit into seven major keys (G, C, D, F, Bb, Ab, Eb); six of those keys would include the opening two notes; and three of those six would still be possible when presented with the first three notes. By the end of the first measure, however, the only major key that would encompass all four melody notes would be C major. If more than one key was still available however, the algorithm would place more weight on the pitches present at the start of the piece. This worked quite well on pieces that were overtly tonal, but it was less effective for pieces that contained non-diatonic pitches.

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Krumhansl and Schmuckler (Krumhansl, 1990) later devised an algorithm that tallied up the pitch classes of an excerpt and compared the distribution of these pitch classes to ratings from earlier probe-tone research (Krumhansl and Kessler, 1982; see above). Other key-finding algorithms have taken a similar approach, but have generated the original distribution of pitches from large sets of musical works, rather than from experimental data. For example, Aarden (2003) generated key-profiles from the Essen Folksong collection, whereas Bellman (2005, discussed in Sapp, 2011) employed distributions generated from compositions of the 18th and 19th centuries. Albrecht and Shanahan (2013) trained a key-finding algorithm on nearly 500 classical music scores, used a Euclidean distance measure in which pitches were mapped onto coordinates in space, and the distance between the distribution of a certain piece and the distributions of each of the 24 major and minor keys was calculated. This algorithm performed more accurately on pieces with greater variation in pitches.

Although the goal of key-finding algorithms was originally to model the perception of a listener, they often stray from this purpose, instead striving for the highest accuracy possible. Albrecht and Shanahan (2013), for instance, tried to obtain the highest possible accuracy for pieces in both major and minor keys, for the purpose of adding key signatures to large collections of pieces, but it's likely that listeners do not perform as well in minor-key identification as they do with major keys, in general (see Temperley and Marvin, 2008; 207). A modeling algorithm would not strive to have an equal level of accuracy between major and minor, due to this difference seen in human listeners. The goals of an algorithm can therefore be seen as ranging from the practical (such as ascribing a key-signature to pieces without notated key signatures) to the more theoretical (e.g., a modeling of perception). It can be argued that key-finding algorithms present a solution that is, in many cases, too unidimensional and simplistic. Listeners hear dynamically, and pieces contain tonicizations or modulations (a temporary emphasis on another key area, or a change to another key, respectively) that are often not reflected by a single algorithm. A windowed approach, such as Temperley's Bayesian model (2007), which infers a key from a musical surface's pitch classes within a given timeframe, might be a more accurate representation of the dynamic nature of musical listening.

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Multiple Voices: Harmony and Counterpoint

The study of harmonics, vibrations, and consonance/dissonance predates Western tonality by centuries, going far beyond the study of music and reflecting changing attitudes in scientific and empirical thought, while also informing the sciences outside of music (see Lee, this volume). In an example of an early, empirically-derived theory of consonance, Mersenne argued that the pleasant nature of musical consonance was the result of the frequency of the vibrations produced by strings as they hit the ear. The perception of a pleasant interval, Mersenne wrote, was the result of the coinciding of vibrations, generally referred to as the "coincidence theory of consonance" (Mersenne, 1636/1975; quoted in Gouk, 2002).

Two centuries later, Helmholtz (1863) would provide both scientists and theorists with an explanation for consonance and dissonance that could be extended to tonal harmony, and was published at a time when it could influence many music theorists looking for a science of harmony. Helmholtz's theory was based on the physiology of the ear, comparing the hairs of the basilar membrane to a series of tuning forks, each tuned to its own

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frequency, which corresponded to the vibrations of sound, and argued that sensory dissonance was the result of beats that occurred when two frequencies generated an out-of-phase relationship between themselves. Georg von Békésy would later win the Nobel Prize for expanding on this physiological approach to consonance and dissonance, providing a cochlear mapping of the interaction of the hairs in the basilar membrane ("a *tonotopic map*"; 1960). Greenwood (1961) would expand on these theories, providing a frequency mapping of the cochlea, and positing that when two tones were close in frequency, the perceived roughness of their combination was the result of pitches co-occurring within a *critical band,* where the distance between the hairs of the basilar membrane is short enough so that there might be some interaction between them. Plomp and Levelt (1965) found that composers arranged chordal voicings in correlation with the tonotopic map of sensory consonance and dissonance, leading them to conclude that critical bandwidth was directly related to chordal spacing.

Unlike the theories above, which suppose that scale construction is the result of perceived consonance and dissonance, other theories have argued that perceived consonance and dissonance are the effect of harmony and tonal elements. Terhardt (1974) argued that consonance was the product of "harmonicity," in which the perceived consonance might be associated with how similarly the frequencies of a sonority reflect a harmonic series. Parncutt's theory of harmony (1989) extends Terhardt's work, arguing that chordal perception is the result of "tonalness" (how much a sonority is able to sound as a single tone), multiplicity (the number of perceptible tones in a sonority), and salience (the perceptual noticeability of a pitch within a sonority). Parncutt also looks at harmonic progressions, which he discusses in terms of pitch commonality and pitch distance (similarly to how parsimonious voice-leading is taught in music theory class, in which students are encouraged the find the "smoothest" possible options that require voices to leap and skip as little as possible). Progressions are analyzed depending on the consonance of the individual chords in a progression, how well two successive chords work together (the consonance between them), the melodic streaming, and the strength of the tonal structure (Parncutt, 1989, p. 75). Experimental work has further investigated the relationship of consonance, dissonance, and chordal progressions. Tillman, Bigand, & Pineau (1998) found that participants were more accurate and quicker to identify consonance in a final chord when that chord was of great "structural" importance (for example, a tonic chord). This is also the case with untrained listeners and children (Bigand and Poulin-Charronnat, 2006). These studies provide a way with which we might discuss the logical extension of consonance and dissonance to the perception of chords, and finally to the perception of chordal progressions.

Harmonic Progressions

The order in which harmonies occur—their harmonic progression—is often considered to be guided by the foundational grammar of tonal music (but for an alternate viewpoint, see Gjerdingen, this volume). For example, many theory textbooks use as their foundation a flow chart that indicates which chords may follow each other (see Kostka & Payne, 1995; Piston, 1987). To some extent, this makes sense, as the harmonic progression of a piece is nearly impossible to ignore. In fact, even melodies with no accompaniment are analyzed and heard as containing *implied* harmonic progressions. Returning to Figure 12.1, we see that,

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in addition to the duration of the final note, the perception of C being the tonic hinges upon a certain implied harmony: $\hat{5}$ going to $\hat{1}$ on the downbeat of the final measure allows for us to infer a dominant harmony (V) moving to a tonic harmony (I), creating a cadence. Although this seems as though it might be difficult for a listener to process, children are able to manage this apparently complex task of understanding implied harmony by the age of seven (Trainor & Trehub, 1994). This task is quite a bit simpler when chords are present, but whether in melodic or chordal contexts, the governing principles are present.

A listener's processing of harmonic progressions seems to overlap somewhat with a hearer's processing of linguistic syntax (Patel, 2008). For example, Patel et al. (2008) found that patients afflicted with Broca's aphasia (in which the processing of linguistic syntax is impaired) also struggle with the processing of harmonic progressions and identifying out-of-key chords. Drawing another linguistic comparison, listeners are able to learn (and prefer) completely unfamiliar harmonic grammars after relatively little exposure, even when hearing harmonic structures in an unfamiliar tuning and scale, much like listeners are able to do with language (Loui, Wessel, & Kam, 2010; Saffran, Aslin, & Newport, 1996).

Methods of musical analysis that are informed by methods from linguistics, such as in Lerdahl and Jackendoff (1983), provide a framework for the analysis of harmonic progressions that analyzes harmonic structure, as well as the analysis of harmonic tension and relaxation. Dichotomies such as tense/resolved, stable/unstable, and the like are crucial to understanding harmonic progressions in Western art music—to understanding harmonic motion, expectation, and closure. The harmonic distance between two keys (that is, how far one key is from another, for example on the circle of fifths) corresponds with the amount of tension perceived by a listener in a harmonic progression (Bharucha & Stoeckig, 1986; Bigand, et al., 1999), and both the interruption of a harmonic progression and a key change can generate the sense of increased tension in a progression (Krumhansl, 1996). The harmonic quality of a chord, such as major, minor, or dominant, is style-dependent (see de Clerq & Temperley, this volume). For example, a dominant seventh chord sounds like an unresolved sonority in Western art music, but may sound as if it's at rest in a twelve-bar blues or in Jimi Hendrix's "Purple Haze." Tension, relaxation, and a general motion from stable to unstable, and back to stable, are dependent upon context, and the heuristics of how chords follow one another—of harmonic progressions—provide an important part of that context.

Counterpoint

As we've seen, the perception of tonality depends on the understanding of sequential (melodic), as well as concurrent (harmonic) relationships. These two dimensions, however, don't exist in isolation. Listeners must discern the melodic alongside the harmonic, and musical ideas must "work" both sequentially and concurrently. A final case-study might therefore be one with which musicians are likely to be most familiar: Western counterpoint and part-writing, where the goal of the composer is to create an independence of voices, despite a co-occurrence of tones (for more on this, see Gjerdingen, this volume). Huron (2001) argued that many of the rules of counterpoint and voice-leading—including the avoidance of unisons, parallel fifths and octaves, movement to the closest available pitch (often called parsimonious voice-leading), the avoidance of leaps, part-crossing, and the even

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spacing of voices—are not an historical accident. They achieve the goal of independent voices by reinforcing certain perceptual principles, namely *toneness*, *temporal continuity*, *minimum masking*, *tonal fusion*, *pitch proximity*, and *pitch co-modulation*. *Toneness* simply refers to a listener's ability to perceive pitches clearly, but it also explores one of the first aspects of any harmony or counterpoint class: the range in which melodies may be written. The perceived clarity of a tone can be measured in terms of a "pitch weight," which is greatest from about 80 to 800Hz, or roughly E2 to G5 (this actually corresponds with the range of the bass and treble clef range in Western music notation). In both Western and non-Western music, the average pitches used fall very near the center of this spectrum, leading Huron to state ". . . 'middle C' truly is near the middle of something" (Huron 2001, p. 9).

In order to allow for a melodic line to be perceived as a single entity, there should be an element of *temporal continuity*, in which there is rarely a gap in time between notes (see Bregman & Campbell, 1971). Additionally, in order to maximize the perceptual independence of voices, composers are urged to minimize *masking*, which occurs when the perception of one sound affects the perception of another (see Von Békésy, 1960). Because auditory masking is reduced when partials—the components that make up complex sounds—are evenly spaced, it would make sense that chord tones should be spaced evenly but with wider intervals occurring between the lower voices (Huron, 2001, p. 33). Similarly, one would want to minimize tonal *fusion* (e.g. the coherence of multiple tones into a single entity), which occurs most frequently at the unison, followed by the octave, and the perfect fifth (see Greenwood, 1961; Plomp & Levelt, 1965). Therefore, effective counterpoint should minimize such intervals, demonstrating a nice conflation of perceptual principles and music-theoretic rules (Huron, 2001, p. 19).

A great deal of work has been carried out that investigates the role of *pitch proximity* in the perception of melodic ideas. Dowling (1973) found that, when given melodies of randomly distributed tones, listeners prefer those that employ smaller interval sizes. Additionally, it seems that the proximity of pitches is more important to the perception of auditory streaming—the perceptual grouping of tones in a complex auditory signal into different "melodic lines"—than direction and trajectory of a melody (see Bregman, 1994, pp. 417–422). Deutsch (1975) and Van Noorden (1975) found that listeners tend to hear a "bouncing" of melodies whose trajectories cross. That is, listeners seem to infer melodic separation, rather than a crossing of two melodic lines, when possible. Therefore, effective counterpoint would strive to minimize voice crossing when possible. Lastly, the principle of *pitch co-modulation* argues that listeners perceive tones as a single unit if they change to a similar frequency, as for example when simultaneous melodies move in similar or parallel motion. Avoiding such parallel and similar motion, therefore, creates a sense of independence between voices (and minimizes the effect of tonal fusion), which is also in keeping with compositional rules favoring contrary motion (where voices move in opposite directions) and forbidding parallel perfect intervals (see Huron, 2001, p. 30).

Conclusion

This chapter has focused on what we mean when we speak of tonality, how we perceive and understand tonal structures, and how such structures influence the organization of music. In Western music, this involves the interaction of vertical (concurrent) and horizontal (sequential) tones, in conjunction with a hierarchical structuring for these tones and their employment in a goal-directed framework. These organizing principles are learned early on by

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children, but can also, when necessary, be learned quickly, and influence a listener's sense of tonal organization. In this sense, the "why" of tonality is understood as enabling a listener to navigate through a complex network of tones, understanding hierarchies and relationships as she goes, and is just as interesting as the "how" of tonality. Listeners to the Blues music of the Mississippi Delta will be able to infer structural principles that differ from those in a Mozart sonata or a pop song. The fact that a single listener can infer these principles from disparate styles demonstrates that most of music's organizing principles are cognitively malleable and are learned through experience with specific musical styles and cultures, but many are consistent cross-culturally. Tonality (defined informally here) provides listeners with a way of parsing the musical environments they encounter, using processes derived from physiological, linguistic, cognitive, and cultural constraints and facilitating a perception of centricity, hierarchy, and goal-directedness.

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