The Structural Role of Distortion in Hard Rock and Heavy Metal

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This article uses an analytical tool called dist-space to examine the structural role of guitar distortion in hard rock and heavy metal. Dist-space facilitates categorizing, comparing, and graphing the changes in a composition's distortion structure, which demonstrate distortion's capacity to generate motivic and formal structures. An application of Robert Morris's generalization of contour theory, dist-space couples sequential time to a sequentially ordered dimension of discrete distortion regions whose foundation is the distortion function F(A)=D and spectral analysis. While the process of categorizing, comparing, and graphing distortion sounds is partially subjective, the distortion function F(A)=D underlying dist-space's sequentially ordered dimension of distortion regions provides an objective foundation for measuring, identifying, and comparing distortion sounds that informs subjective judgments leading to greater intersubjective agreement between theorists, analysts, and performers. Although the primary analytical focus of the dist-space tool is guitar distortion, it has a wider range of applications. For example, it can provide analytical insights into the distortion sounds recording engineers produce from microphones, tape machines, and digital or analog signal processing, which have become an integral process of producing tracks in a studio. In fact, this study demonstrates that the guitar distortion heard on recordings is often a product of both guitar amplification and recording studio techniques.

Keywords: Timbre, distortion, rock, contour theory, pc-set, guitar, spectral analysis, Metallica, Korn, Dream Theater, Pixies.

> Common Sense would seem to hold that if some properties of a thing were taken away from it, it would no longer be the same thing. Further, it seems to hold that this is not the case for all properties of the thing. This intuition is the basis of the distinction between essential and accidental properties of a thing.
>
> —Richard M. Rorty

In the 1990s, the scope of theoretical inquiry widened as many scholars either shifted their analytical focus from classical and/or contemporary music to rock music, or added rock compositions to their analytical canon.[1] In general, the analyses and theoretical models have centered on rhythmic and tonal structures. Perhaps the perception of these relationships as essential properties shared by rock and classical music narrowed the breadth of inquiry. Since the languages of rock and classical music contain common tonal syntactic structures, many scholars analyze rock music using classically oriented analytical methodologies and theoretical tools, such as voice-leading graphs, classifications of tonal systems, and neo-Riemannian graphs of harmonic structure.[2] The explanatory power of these theories reinforces the perception of pitch-class relationships as essential, often at the expense of other aspects of rock music. For example, the unique timbres produced by both the electronic instruments that partially define the genre and the studio techniques that are an integral part of producing rock recordings appear to be nonessential properties. Timbre only appears analytically relevant when it highlights, supports, or reinforces pitch-class relationships.[3]

Some rock music scholars, however, assert that the "precise details of timbre and articulation can be essential properties of a musical work."[4] Others employ theories that unintentionally subvert the preeminence of pitch-class relationships and potentially shift the analytical focus to another musical dimension. Walter Everett, for example, constructs a modular model of the tonal systems structuring rock music for the purpose of dislodging "the single monolithic view of rock harmony."[5] His model also potentially removes pitch-class theories from their dominant position and elevates timbre from its subordinate role of reinforcing pitch-class relationships. Everett statistically measures the degree to which a composition's voice-leading

1 Many contributors of essays to *Understanding Rock* (Covach and Boone [1997]), such as John Covach, Walt Everett, Daniel Harrison, David Headlam, and Matthew Brown, are also scholars of classical and/or contemporary music. For example, Covach and Headlam are specialists in the area of contemporary music, while Everett and Brown are specialists in Schenkerian theory. In fact, Brown notes the shift in his essay on "Little Wing": "After considerable resistance from the scholarly community, rock music has recently emerged as a legitimate subject for academic discourse" (1997, 155).

2 Brown (1997) and Everett (2004) both apply Schenkerian voice-leading analysis to the music of Jimi Hendrix and Billy Joel, respectively, while Capuzzo (2004) analyzes pop and rock music using neo-Riemannian techniques.

3 For example, Covach writes: "organization schemes in the melodic, timbral, textural, and rhythmic dimensions frequently reinforce those found in the harmonic and lyric dimension of a song." (2005, 66).

4 Zak (2001, 22).

5 Everett (2004).

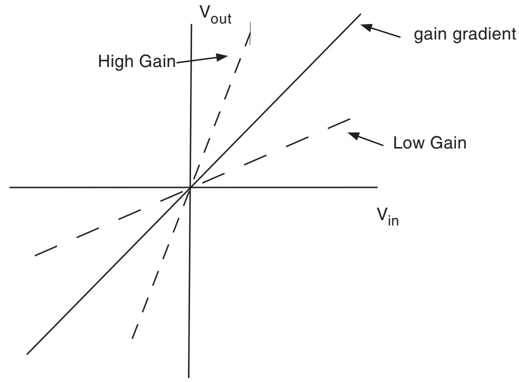
and harmonic structures adhere to or deviate from tonal norms. Compositions with perfect harmonic and voice-leading scores of 60/60 are amenable to Schenkerian analytical techniques, as Everett demonstrates by producing insightful voice-leading models of several compositions, while compositions with scores of 10/10 are better modeled by the chromaticism of system 6. Figure 24 in Everett's article illustrates modern popular music's variegated approach to tonal structure by statistically ranking thirty albums across a wide variety of styles/genres from 1999 to 2000.[6] The scores of albums in the lower left- and upper-right-hand corners demonstrate low and high adherence, respectively, to tonal norms.

The scores for many heavy metal and hard rock compositions fall in the chart's lower left-hand corner. For example, the circle labeled "u" represents the album *Issues* (1999) by Korn, a nu metal band. Everett is careful not to make a value judgment based on the degree to which a composition conforms to common-practice tonality, claiming that low-scoring compositions may be perceived negatively because they lack complex voice-leading and harmonic structures.[7] His study may demonstrate that pitch-class centric theories produce few analytical insights into the structure of some rock compositions. A reduction in the complexity of pitch-class relationships might conversely indicate an increased focus on timbre relationships, such as using distortion to generate motives and form.

THE STRUCTURE OF DISTORTION

Rock musicians acknowledge the importance of timbre, particularly guitar distortion, as an essential component of their music. *Guitar Player* magazine, for example, devoted the October 1992 issue to investigating distortion's quintessential role in rock music. The issue features articles by guitarists either acknowledging the critical role distortion plays in achieving their sound or explaining their techniques for creating guitar distortion. James Hetfield, rhythm guitarist and vocalist for Metallica, explains his approach and demonstrates his discerning ear for identifying different types of distortion:

> Distortion always starts with the amp . . . you can recognize Marshall distortion in an instant; that's why I shied away from that and went with MESA/Boogies. I basically use the Boogie's distortion with a non-programmable studio-quality Aphex parametric EQ to fine tune certain frequencies, dipping out some of the midrange, though my tone isn't quite as "scooped" as it used to be. On my old records there's some serious low-end chunk. . . . I've been trying to get more clarity but still have the chunk, so I've been adding more mids. Just adding low end isn't enough; you can have lots of it without getting any crunch.[8]



EXAMPLE 1. *Transfer function and linear amplification. Based on Figure 3.1 from Jones (2012, 156).*

Hetfield's ability to identify the distortion produced by different amplifiers suggests that distinct aural properties of sounds can be categorized. In fact, rock musicians informally categorize distortion sounds by assigning their distinct aural properties qualitative descriptors, such as crunch, overdrive, grind, warm, fat, and dirt.[9] The plethora of descriptive terms and the multitude of signature amplifiers, stomp boxes, and digital modelers purporting to capture the distortion tone of an individual guitarist or recording suggest that distortion in rock music is a complex phenomenon that resists simple categorization.[10] An analysis of distortion's structure, however, lays the foundation for modeling this phenomenon with a few perceptual categories.

Distortion is any change between the input and output of a signal in a system. The transfer function equation $y(t) = F(x[t])$ characterizes a noise free or distortion free system since the signal at the system's input, $F(x[t])$, equals the output, $y(t)$ (Ex. 1).[11] The transfer function equation $y(t) = A \bullet x(t-T)$ characterizes a linear amplifier with perfect gain and delay free of distortion; the signal at the amplifier's input equals the output but with increased amplitude.

Audio amplifiers, however, are rarely perfectly linear. They produce either linear or nonlinear distortion. Linear distortion alters the shape of a waveform without adding frequencies to

6 Ibid. A letter designation accompanying a circle identifies each album in the ranking while Table 4 lists the albums associated with each letter in Figure 24.

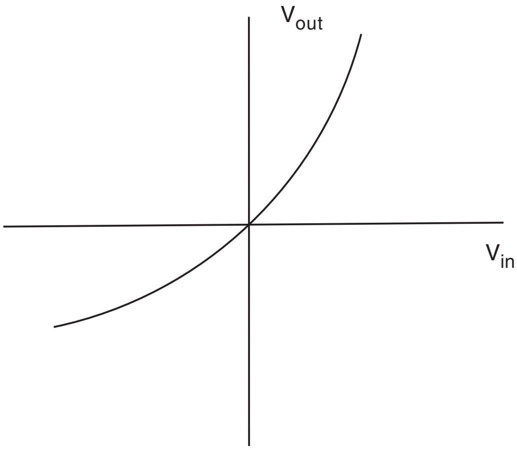
7 Fred Lerdahl expresses this opinion in an article in which he states that the "best music utilizes the full potential of our cognitive resources." However, not all tonal music satisfies the criteria underlying his aesthetic claim: "all sorts of music satisfy these criteria—for example, Indian raga, Japanese koto, jazz, and most Western art music. Balinese gamelan falls short with respect to its primitive pitch space. Rock music fails on grounds of insufficient complexity" (1988, 255).

8 "Decoding Distortion," *Guitar Player* (1992, 59).

9 Ibid., 46.

10 A stomp box is an electronic circuit housed in a small usually rectangular and metal enclosure. Most stomp boxes are placed between the guitar's output and the input of the amplifier. A Stomp box can house any type of circuit, but the most common types are distortion, reverb, chorus, and delay. Modeling amp use Sharc DSP chips to digitally model the circuit behavior and sound of tube amplifiers.

11 Jones (2012, 156).



EXAMPLE 2. *Transfer characteristics for a nonlinear device. Based on Figure 3.1 from Jones (2012, 156).*

the signal, so the transfer characteristics of the amplifier are still linear.[12] Nonlinear distortion also alters the shape of a waveform. However, changes in amplitude either add frequencies to the signal output not present at the input or greatly increase the amplitude of the audio signal's harmonics. A graph of a nonlinear amplifier's transfer characteristics does not produce a straight line (Ex. 2).[13] The greater the amplitude of a signal increases in a nonlinear amplifier, the greater the distortion in the signal. Increases in amplitude, therefore, determine changes in a signal's waveform, spectrum, and timbre.[14]

Vacuum tubes (or valves) are the nonlinear component in most guitar amplifiers. They increase amplitude, change the waveform's shape, and alter an audio signal's timbre. The process of altering an audio signal with vacuum tubes modeled by the distortion function F(A)=D becomes the foundation for measuring, identifying, comparing, and categorizing distortion sounds. The three main elements in a vacuum tube are the cathode, grid, and plate.[15] The grid lies between the cathode and plate and functions as a valve controlling the electron flow moving from the negatively charged cathode to the positively charged plate. When the grid is negatively charged, it repels electrons flowing from the cathode and the flow stops. When the grid becomes positively charged, electrons flow from the cathode to plate. The electric guitar's pickups are transducers that convert the vibration of the strings into a very low voltage electrical analog of the audio signal. The signal sent from the guitar pickup to the input tube positively charges the grid causing electrons to flow. The voltage of the plate is very high, so as the small grid voltage increases, the large plate voltage increases proportionally and amplification occurs. The primary method of increasing grid voltage is to increase the volume control on the amplifier. Another method is plucking the guitar strings with more force, which increases the amplitude of the string and increases the voltage of the signal.

Example 3(a) illustrates the transformation the electrical analog of a sine wave undergoes as it is amplified by a vacuum tube. If the voltage at the grid exceeds the tube's voltage limit, depicted by the dotted lines in Example 3(b), then the tube does not accurately reproduce the entire waveform. First, the tube compresses the waveform's peak and then, as amplitude and consequently voltage increases, removes or "clips" the peak. The shape of the waveform continues to change (Ex. 3(c)) as the voltage continues to increase until the sine wave morphs into a new waveform, a square wave (Ex. 3(d)). Since a sine wave only contains the fundamental frequency (Ex. 4(a) and Sound Ex. 4(b)) and a square wave contains the fundamental frequency and all the odd harmonics (see Ex. 4(a) and Sound Ex. 4(c)), the process of amplification adds frequencies to the audio signal's change in timbre.[16]

The waveform produced by an electric guitar is essentially a triangle wave (see Ex. 5 and Movie Ex. 5(a)), which, like the square wave (Ex. 5), only contains odd harmonics. However, the amplitudes of the harmonics in a triangle wave decreases by the square of the harmonic number while the amplitude of the harmonics in a square wave decreases by the proportion of the harmonic to the fundamental. For example, the seventh and ninth harmonics in a triangle wave have 7^2 or 1/49 and 9^2 or 1/81 the amplitude of the fundamental, respectively, and the seventh and ninth harmonics of the square wave have one-seventh and one-ninth the amplitude of the fundamental, respectively.[17] When the volume control of the amplifier gradually

12 Ibid.

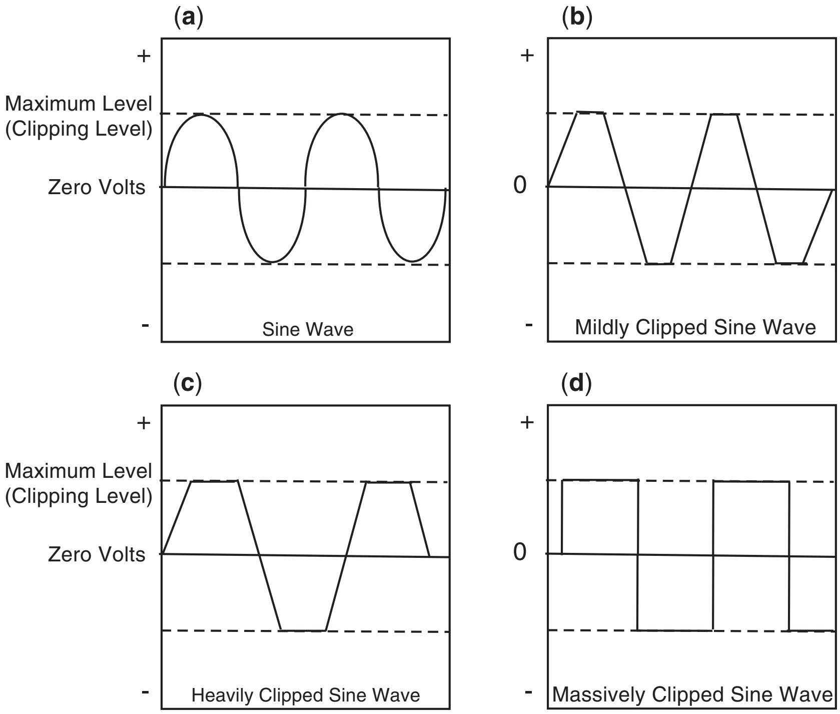
13 Ibid.

14 Early engineers did not build amplifiers for the purpose of distorting a signal. Guitar pickups in the 1950s and 1960s had a wide range of signal strength. Since the engineers had no way of predicting what guitar pickups would supply the signal to the amp, they included a volume control to accommodate the wide range of input signal strengths. Early rock and roll guitar players discovered the link between volume and timbre. For example, Goree Carter's 1949 record *Rock Awhile* featured a guitar whose unusual overdriven sound may have been produced by turning up the volume of the amplifier.

15 "How Does a Vacuum Tube Amplifier Work?" This website contains illustrations of the components of vacuum tubes along with animations of how a tube works as well as detailed explanations of how a tube amplifies a signal.

16 Dodge and Jerse (1997, 46).

17 The acoustic guitar is a coupled system of string and soundboard. The vibrations from the parts of the coupled system interfere with each other amplifying and suppressing harmonics of the fundamental frequency. Plucking position determines the harmonics present for a given frequency. For example, plucking an open string at its midpoint creates one antinode at the strings midpoint in relation to the two nodes produced by the nut and the bridge. No nodes will be present at the position of the antinode, so no harmonic will be present at 2n where n equals the fundamental. Therefore, a string plucked at its midpoint will only contain odd harmonics whose amplitudes in relation to the fundamental produce a triangle wave. The force the string exerts on the bridge produces an asymmetric square wave. Although the spectra of the string and bridge/force waveforms are similar, the amplitude and phase relationships between the harmonics are different, which produces a more complex waveform. Essentially, the waveform resulting from plucking a string at its midpoint is very similar to a triangle wave. Unlike the acoustic guitar, the



EXAMPLE 3. *Clipping an audio signal. Adapted from Keen (1993–2000).*

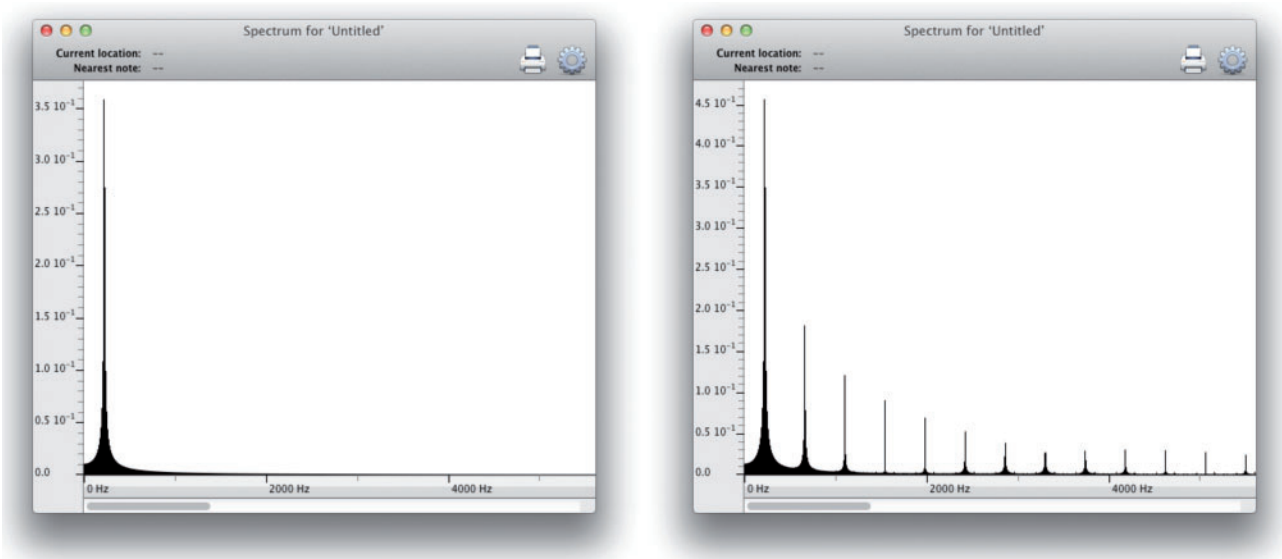
changes from its minimum to maximum position, the amplitude of the fifth harmonic of the triangle wave, for example, will change from 1/25 to 1/5 the amplitude of the fundamental and will transform the guitar's triangle wave into a square wave. Guitar distortion, therefore, could be defined as the progressive transformation of a triangle wave into a square wave by gradually increasing the amplitude of a signal.

Since distortion and amplitude are inextricably linked and form a coupled system, distortion is a function of amplitude denoted $F(A) = D$, where an incremental increase in the volume/gain control on an amplifier results in a corresponding range and degree of distortion scaled from 0 to 1 (Ex. 6). Any point between 0 and 1 indicates the amount of change in the waveform as it morphs from triangle wave to square wave, so as the amplitude of the signal increases it gradually becomes mildly clipped, heavily clipped, massively clipped, and then morphs into a square wave (Movie Ex. 7). Spectral analysis can precisely determine a distorted sound's location on the graph in Example 6 by measuring the degree of change to a waveform's shape and the frequencies added to the original waveform. For example, David Lewin's timbral GIS for developing spectrum objectively compares the spectra of two sounds, and it could precisely plot the position of a distorted sound on the graph.[18] Therefore, the distortion function provides an objective foundation for identifying, comparing, and categorizing distortion sounds.

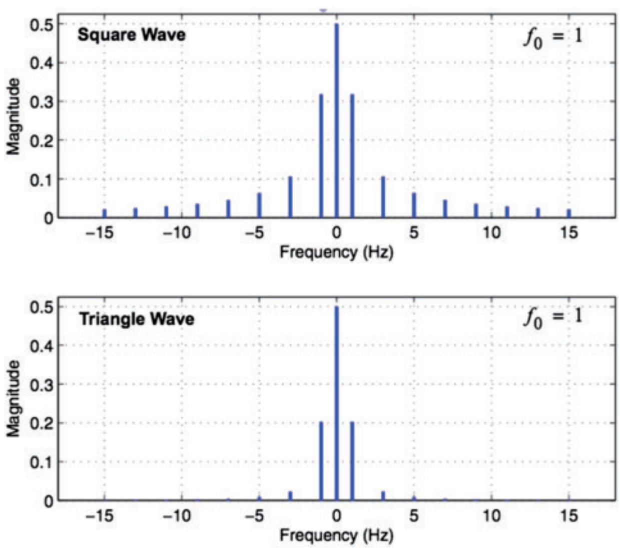
Besides symmetrically clipping waveforms, amplifiers can also produce asymmetrical clipping, which flattens only one-half of the waveform (Ex. 8). Asymmetrical clipping adds even-order harmonics or octaves to an audio signal. Combining symmetrical and asymmetrical clipping increases an audio signal's distortion level since this process involves all possible harmonics transforming a square wave into a pulse wave, which lies between the square wave and the end point 1 on the distortion graph. Distortion produced by clipping a waveform is called harmonic distortion because the harmonics are all integer multiples of the fundamental. Intermodulation distortion, produced by double stops and chords, is inharmonic because it adds frequencies at multiples of the sum and

solid body electric guitar reflects rather than absorbs the string vibration, so the body interferes less with the harmonic structure of the string. Therefore, the waveform that the guitar's pickups replicate is closer to the strings triangle waveform. For a more in-depth analysis of the waveform produced by a guitar, see Schneider (1985, 11–50).

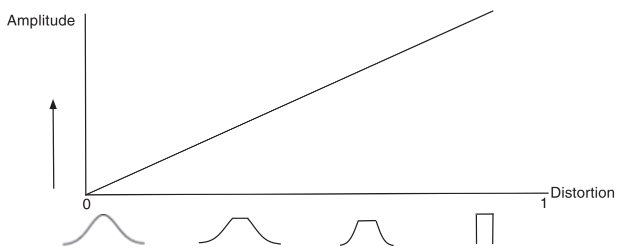
18 David Lewin's timbral GIS for a developing spectrum: "GIS_1 . . . considers partials #1-through-#8 of harmonic sounds. We shall call an element $s = (s(1), \ldots ,s(8))$ of GIS_1 a 'pertinent spectrum.' Now let us take as GIS_2 a familiar GIS involving the space S_2 of 'time points.' . . . Let us explore the direct product $GIS_3 = GIS_1 \otimes GIS_2$. The elements of $S_3 = S_1 \text{ X } S_2$ are pairs (s, a), where $s = (s(1), \ldots ,s(8))$ is a 'pertinent spectrum' and a is a time point. The pair (s, a) models a class of sound having pertinent spectral profile s at time a. A finite set of such pairs, say the set $DVSP = ((s_1, a_1), (s_2, a_2), \ldots ,(s_n, a_n))$, models a class of sounds that have spectrum s_1 at time a_1, spectrum s_2 at time a_2, . . . and spectrum s_n at time a_n. . . . Supposing the time points a_n to be reasonably close, then DVSP will model a class of sounds with a certain 'developing spectrum.' Each sound of this class has pertinent spectrum s_n at time a_n" (Lewin [1987, 82–83]).



EXAMPLE 4A. *Spectra for sine and square wave. (The waveform generator function in the audio processing program Amadeus Pro examples generated the examples.)*



EXAMPLE 5. *Spectra for square and triangle waves. Reprinted from Wickert (2013).*



EXAMPLE 6. *Graph of the distortion function F(A) = D*

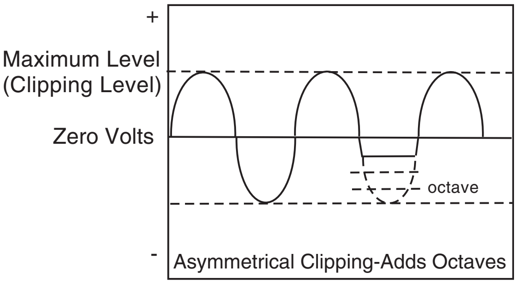
differences of the interval or chord's pitches. Intermodulation distortion further increases the distortion level of an audio signal. In fact, combining waveform clipping with intermodulation distortion completely saturates a signal producing pink noise or white noise. This phenomenon adds another stage to the distortion function after the square wave where the signal continues to distort eventually becoming pink or white noise as the distortion level approaches 1.[19]

DIST-SPACE: COUPLING CONTOUR THEORY TO THE STRUCTURE OF DISTORTION

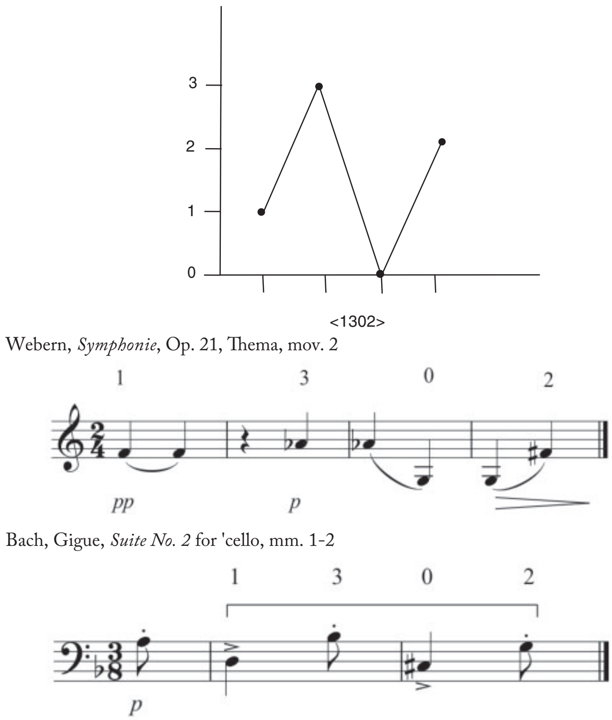
Robert Morris's formalization and generalization of contour spaces or C-spaces is the foundation for modern contour theory. Contour pitches or c-pitches indicate the relative highness or lowness of pitches without specifying their exact intervallic distances.[20] C-space is a two-dimensional space where the x-axis indicates sequential time, and the y-axis sequentially orders the c-pitches from low to high. C-pitch 0 is the lowest pitch in a segment, and the remaining pitches are sequentially numbered from lowest to highest. The ordering of the

19 Distortion can also have a qualitative component. An amplifier's equalization controls can alter the sound of the distortion by either boosting or attenuating certain frequencies. Even though two distorted sounds may have identical amounts of waveform deformation, they can sound different. For example, the waveforms of two distorted sounds may both be mildly clipped, but the filtering of one sound boosts midrange frequencies while the filtering of the other sound attenuates the midrange. Each sound would be located at the same position on the graph of the distortion function, but the filtering of each signal produces a qualitative difference in their sound. Essentially, the perception of the qualitative difference between distortion sounds is analogous to hearing the same pitch played by two timbrally distinct instruments, such as violin and flute.

20 Morris (1987, 23).



EXAMPLE 8. *Asymmetrical clipping. Adapted from Keen (1993–2000)*



EXAMPLE 9. *C-space interpretation of the opening four notes of the* Thema *from Symphonie, Op. 21 by Anton Webern and the Gigue from Suite No. 2 for Cello by Bach*

c-pitches in sequential time and space produces a contour segment or c-seg. Among other things, contour theory facilitates comparing c-segs from different pitch-class systems. For example, despite their different pitch systems (tonal as opposed to serial), a segment from the *Thema* of Symphonie, Op. 21, second movement, by Webern and a segment of the Gigue theme from Suite No. 2 for Cello by Bach produce the same c-seg, <1302> (Ex. 9).[21]

Morris defines a sequential dimension as any musical attribute whose points (or states) can be linearly ordered and can be

	P (P dynamic class = 0)				f (f dynamic class = 1)			
	PPP	PP	P	MP	mf	f	ff	fff
Contour Pitches	0	1	2	3	4	5	6	7
Contour Class Pitches	0.0	0.1	0.2	0.3	1.0	1.1	1.2	1.3

EXAMPLE 10. *Dynamic markings ordered to form a sequential dimension*

heard as such without specifying the exact distance (or change) between the points. The c-pitch axis of C-space is a sequential dimension because it contains a sequence of pitches ordered from low to high that does not specify the exact intervallic distance between pitches. The linear time axis becomes sequential time (i.e., a sequential dimension) by considering time to be a series of time-points without specifying the exact durations between time-points. Since both sequential dimensions have the same structure, the sequential time-dimension (s-time) is isomorphic to the sequential c-pitch dimension.[22] The isomorphism allows time to order or be ordered by any other sequential dimension. Contour theory, therefore, can model aspects of timbre as long as these attributes map onto a sequential dimension. For example, brightness is a sequential dimension because the incremental changes in tone color morphing from bright to dull can be linearly ordered without specifying the exact distance between each incremental change.[23] Moreover, any sequence of c-pitches can be modeled as a c-seg, and c-seg comparisons are the foundation for analyzing contour based motivic and formal structures.

The structure of the contour models of loudness (dyn-space) and dist-space are nearly identical, so the dyn-space model serves as a template for the dist-space model. Although amplitude changes can be precisely measured, perceptions of amplitude changes are relative. Therefore, changes in the perceived loudness or softness of a sound form a sequential dimension because each change is a point in a linear progression of increasing or decreasing amplitude that does not specify the exact change in amplitude between any two points. For example, C is louder than A, and B is softer than C but louder than A. The dynamic markings of Western art music are a direct analog of the sequential dimension of loudness since they are essentially a set of linearly ordered points indicating a progression from soft to loud without specifying the exact change between points. Each dynamic mark, therefore, is equivalent to a c-pitch. The collection of dynamic c-pitches correlating with the sequential dimension of loudness and matching the sequences of points <0 1 2 3 4 5 6 7> coupled to s-time form dyn-space (Ex. 10).

Dyn-space only contains eight c-pitches, but the quantitative loudness spectrum contains many more discrete amplitude

21 A c-seg is an ordered set of contour pitches or c-pitches in contour space or c-space (Marvin and Laprade [1987, 228]).

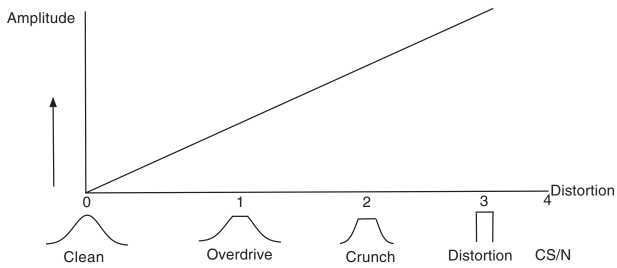
22 Essentially, higher than/lower than equates to sooner than/later than (sequential time). See Morris (1987, 281).

23 Elizabeth Marvin, for example, demonstrates how a generalized contour theory facilitates modeling aspects of timbre in Stockhausen's *Kontakte* (1995, 159–61).

changes between extremely soft and loud sounds. Each dyn-space c-pitch reduces a sequence of discrete amplitudes to a dyn-space c-pitch (essentially a many-to-one mapping) perhaps modeling the relative perception of dynamic changes. For example, *forte* (c-pitch 5) may represent the 70 to 85dB region of a loudness dimension with a range of 0 to 120dB, so dynamic c-pitches do not correlate with a single decibel measurement the way a pitch name correlates with a single frequency. Dyn-space c-pitches can also form classes. The dynamic markings including the letter "p" are members of the *piano* class while the dynamic markings including the letter "f" are members of the *forte* class. Adapting octave decimal notation from computer music produces a more precise model of dyn-space c-pitches and classes by partitioning the loudness range into two broad categories that are themselves partitioned into finer shadings of dynamics.[24] For example, integers 0 and 1 indicate the *piano* and *forte* classes, respectively, while decimals following a class integer indicate class members, so the contour class c-pitch 0.1 indicates the dynamic marking *pianissimo*.

Dist-space also converts a quantitative dimension into a sequential dimension. The distortion function and spectral analysis precisely measure changes in distortion, but perceptions of those distortion changes are relative. For instance, C is more distorted than A, but B is less distorted than C and more distorted than A. Nevertheless, the distortion function's quantitative dimension informs relative perception.[25] The perceptual difference between an undistorted and a heavily distorted sound is analogous to the perceptual difference between consonant and dissonant intervals. Amplification increases the audibility of the upper harmonics whose frequency ratios produce the ratios of dissonant intervals, so a heavily distorted guitar can sound buzzy or very dissonant. Moreover, a single guitar note or consonant interval will sound incrementally more distorted or dissonant as the amplitude increases morphing the sound's triangle wave into a square wave and eventually into noise (Movie Ex. 7). The progression of distortion sounds, therefore, qualifies as a sequential dimension because it is linearly ordered and heard as linearly ordered without specifying the exact change between the sounds.

Linearly partitioning the sequential dimension produces distortion regions or categories that become the c-pitches of dist-space. The formation of distortion categories or c-pitches is analogous to the formation of a perceptual linear ranking of



EXAMPLE 11. *Contour categories for distortion*

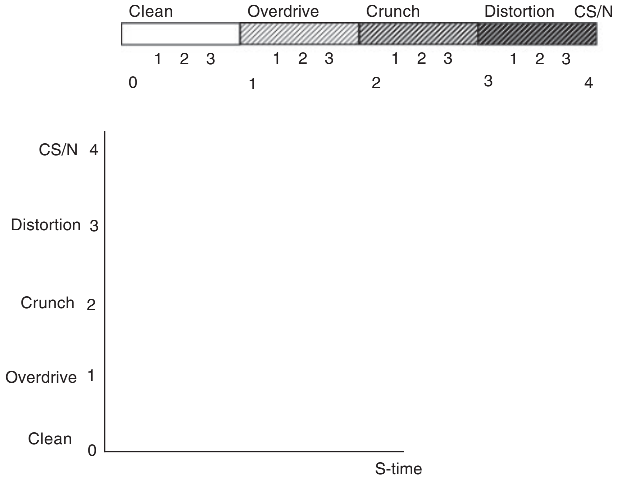
all intervals from most consonant to most dissonant.[26] Moreover, the c-pitches of dist-space and dyn-space are analogous because they are both linear partitions of their quantitative dimensions. A guitar sound with a distortion level of 0 in Example 6 that changes to a distortion level of 1 is analogous to a dynamic change of *ppp* to *fff*. While the change from 0 to 1 is binary, several points along the continuum produce a perceivable change in the distortion timbre as the triangle wave incrementally morphs into a square wave (Ex. 11). The first point occurs when the triangle wave loses its peak. The second point occurs when the peak becomes broader and the sides of the mildly clipped signal become more vertical producing a massively clipped waveform. Finally, the triangle wave becomes a square wave. The last and fourth point occurs at the end of the graph when the fully saturated waveform changes into a pulse wave and eventually pink or white noise. The perceptual change from one point to another is analogous to the perception of diphthongs in the English language where there is a noticeable change of sound within the same vowel.

The five perceptual steps corresponding to the sequence of points <0 1 2 3 4> are the c-pitches of dist-space. A heavily clipped sound (2) is heard as more distorted than a mildly clipped sound (1), and a mildly clipped sound is heard as less distorted than a heavily clipped sound but more distorted than an undistorted sound (0). Coupling s-time to the collection of c-pitches produces dist-space (Ex. 12). Associating dist-space c-pitches with appropriate terms from the distortion lexicon of rock musicians creates a familiar, precise, and analytically useful taxonomy. The label for c-space pitch 0 is "clean" because that is how rock musicians describe a sound with little or no distortion. Similarly, "overdrive" corresponds to c-pitch 1 denoting a sound that is mildly clipped, while "crunch" corresponds to c-pitch 2 denoting a sound that is heavily clipped.

24 Computer music programs, such as Csound, often use octave decimal notation. For example, 4.1 would indicate the pitch C♯ above C_4 where 1 indicates pitch-class C♯ and 4 indicates the octave beginning with middle C.

25 Lewin makes a similar distinction between his timbral GIS and Wayne Slawson's timbral theory: "In both GIS 4.2.1 and GIS 4.2.2, the formal relations involved match our sonic intuitions only to a certain extent. In either GIS, that is, we may have $\text{int}(s_1, t_1) = \text{int}(s_2, t_2)$, while the intuitive proportion between s_1 and t_1 does not much 'sound like' the intuitive proportion between s_2 and t_2. The models suffer here by comparison with the constructs of Wayne Slawson, who has developed an elegant model for an 'intuitive' timbral space" (1987, 85).

26 Paul Hindemith's Series 2 is an ordering of pitch-class intervals that begins with the most consonant interval, the octave or unison, and progresses to the most dissonant interval, the major seventh or minor second: "The value-order laid down in Series 2 brings us close to the question of the consonance or dissonance of intervals. . . . The consonant intervals would then appear at the beginning of Series 2 and the dissonant at the end. . . . Between the octave as the most perfect and the major seventh as the least perfect intervals, there is a series interval-pairs which decrease in euphony in proportion as their distance from the octave and their proximity to the major seventh increases" (1942, 84–85).



EXAMPLE 12. *Dist-space*

"Distortion" corresponds to c-pitch 3 denoting a sound that is massively clipped.[27] The terminus CS/N corresponds to c-pitch 4 denoting a pulse wave or noise. Dist-space c-pitches like their dyn-space counterparts also form classes since perceivable changes in the distortion level can occur without changing the overall c-pitch. Rock musicians adjectivally describe the changes as light, medium, or heavy. Therefore, each dist-space c-pitch is a class containing the members .1 = light, .2 = medium, and .3 = heavy. The dist-space c-pitch 2.2, for example, indicates a medium crunch sound (Ex. 12).

ANALYTICAL APPLICATIONS

In this article, the dist-space analytical examples model the distortion structure of studio track versions of rock compositions from original CDs or albums. Of course, many rock compositions have multiple performance versions, such as a studio track on a CD, live performances, or recordings of a live performance, but the studio track often serves as the referential model for performance comparisons. Albin Zak, for example, claims that "songs may be performed in multiple versions, but their primary identity and their place in the galaxy of rock works is fixed by an original recording."[28] Hetfield's aforementioned comment comparing his less "scooped" sound to the serious low-end chunk on his *old records* supports these claims. Furthermore, it may be difficult to replicate the guitar distortion heard on recordings in a live performance. Recording engineers use studio microphone placement and processing, with multiple tracks of the amplifier producing different distortion sounds (even multiple amplifiers), and equalization or compression may also be added to a track to exaggerate an amp's distortion sound. These manipulations create a unique distortion waveform that the amp alone may not be able to replicate in a live performance. Moreover, a mix engineer can enhance the subtle shifts and contrasts in distortion to clarify motivic and formal structures by carefully balancing the musical elements in a track.

Even though the primary identity of rock compositions may be fixed by CD tracks, the comparison of studio tracks and live versions of the same song can add another dimension to the structural analysis of distortion. The ensuing analyses of two compositions include brief comparative analyses of the studio track and the live versions of "Nothing Else Matters" (1990–93) by Metallica and the studio track, live, and acoustic versions of "Freak on a Leash" (1998) by Korn. The fact that the electric guitars and amplifiers present in the studio track are absent from the acoustic version of "Freak on a Leash" might imply that distortion is perhaps a nonessential component of the composition's structure. Albin Zak, however, maintains that the analytical relationship between a composition's recorded studio track and a highly modified arrangement is more nuanced than their dissimilarities might suggest: "While most recorded songs can easily be separated from their specific context and performed in any number of ways, arrangements are often more dependent upon the particularities of the recording, and an analytical division between track and arrangement may sometimes be artificial and misleading."[29]

Consequently, electric and acoustic versions of "Freak on a Leash" do not necessarily indicate an analytical bifurcation. An acoustic arrangement of a song that is dependent on the particulars of the recording can still suggest distortion's structural importance even if electric guitars and amplifiers are absent from the arrangement as will be demonstrated below.

In addition to lead, rhythm, and bass guitars, other instruments in rock ensembles use distortion to alter their timbre. The vocal timbre of heavy metal singers, for example, often has a range that moves between precisely sung pitches to grunting vocalizations and screams that mirror the guitar's move from 0 to 4 in dist-space. Moreover, the pink noise spectrum of the cymbals underscores, supports, and imitates the sound of the higher harmonics of the distortion sounds found at the upper end of dist-space. As stated earlier, recording engineers in the studio make an essential contribution to the sound of the guitar distortion heard on tracks. They also create other types of distortion that have become an essential part of a track's sound. Distortion also known as saturation, for example, can be part of the spatial component of recording tracks in the form of instrumental placement in the stereo field. A recording engineer locates the instruments of the ensemble in the stereo field, so each instrument is distinctly heard, but also a creates a balanced sound between the instruments.[30] On

27 Stomp boxes names often describe their level of distortion. For example, the Maxon OD-808 produces mild clipping and is considered an overdrive pedal (the OD in the name). The Boss DS-1 (DS is an abbreviation for distortion) and the Boss Metal Zone MT-2 both massively clip a signal and are considered distortion pedals.

28 Zak (2001, 31).

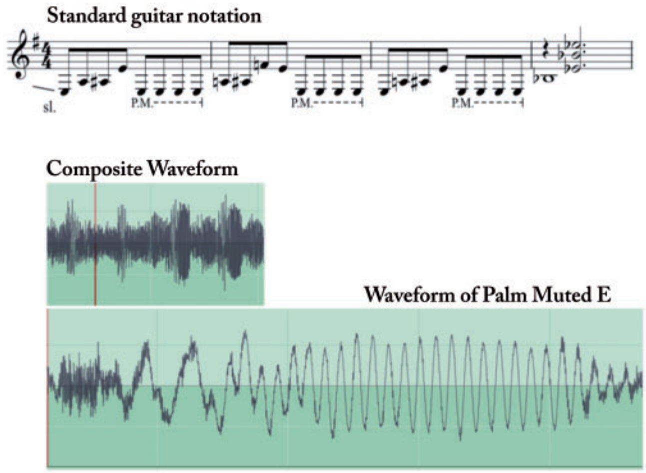
29 Ibid., 32.

30 White (1997, 91); Zak (2001).

many hard rock and heavy metal tracks, the producer records the guitar to three tracks, once each for the right, left, and center portions of the stereo field, thereby saturating the space and enhancing the effect of the amplifier's distortion sound. Recording engineers also use tape saturation to add distortion to the overall sound of the ensemble by raising the levels on the master tape deck until the limits of the recording device start to compress and clip the overall sound.[31]

Dist-space is most effective as an analytical tool when distortion in the c-pitches in a composition traverses a portion or the entire range of dist-space. Nevertheless, single c-pitches can function structurally. For example, as well as establishing an endpoint for dist-space, c-pitch 4 or CS/N performs an important structural function in heavy metal. The envelope of a sound contains several sequential states labeled attack, decay, sustain, and release, or ADSR that can be graphed as amplitude changes over time. The envelope of a guitar pitch is essentially a ramp with a very fast attack that immediately starts to decay.[32] The pick displaces the string generating potential energy. When the pick is released, it creates a sudden burst of noise energy that forms the majority of the attack portion of the envelope. The transient or noise portion of the attack occurs very quickly and disappears once the string begins vibrating periodically. The amplitude of the transient is usually very low, so it is barely audible. However, the high gain amplifiers (i.e., amplifiers producing very high levels of distortion) used by heavy metal musicians greatly increase the volume of the transient, making it a very audible part of the guitar sound. Since the transient is the noise portion of a distorted guitar sound, it occupies the CS/N region of dist-space.

Heavy metal musicians often feature the transient or the CS/N c-pitch prominently in their compositions. Moreover, c-pitch CS/N often performs a specific function. The interlude from "Blackened" in Example 13 from the album *And Justice for All* (1988) by Metallica alternates a motive based on sc 4-8[0156] with a palm-muted ostinato figure based on pitch E_2, the lowest string on a six-string guitar in standard tuning (Sound Ex. 14).[33] The ostinato figure accentuates the transient or CS/N contour pitch heard as the "chu-chu" part of each repeated pitch while the motive based on sc 4-8[0156] does not accentuate it. The technique of palm muting draws attention to the "chu-chu" sound of the transient by inhibiting a string's



example 13. *Guitar interlude from "Blackened" from the CD* And Justice for All *by Metallica*

ability to vibrate, which decreases the amplitude and upper frequency content of the pitch.[34] Palm muting, however, does not affect the transient. In the composite waveform, the palm-muted E is darker than the 4-8[0156] motive indicating its higher level of distortion while the expanded view of the palm-muted E waveform shows the noise burst before the string assumes its periodic shape. Besides their different pc content, the transient timbrally differentiates the ostinato and the motive based on sc 4-8[0156], which creates a compound motivic structure consisting of two distinct antiphonal lines.[35]

The introduction to "As I Am" from the *Train of Thought* CD (2003) by Dream Theater contains another example of distortion's motivic function as well as another function for c-pitch CS/N. To begin with, the opening synthesizer chord provides an excellent example of amplification adding frequencies and altering a sound. The synthesizer, like the electric guitar, requires an amplifier, and the synthesizer's amplifier produces the same effect of adding distortion and frequencies as the electric guitar's amplifier. The envelope of the waveform in Example 15 shows the dynamic range of the chord as it starts from near silence and crescendos (possibly using a volume pedal) to *fortissimo* (Sound Ex. 16). Although the

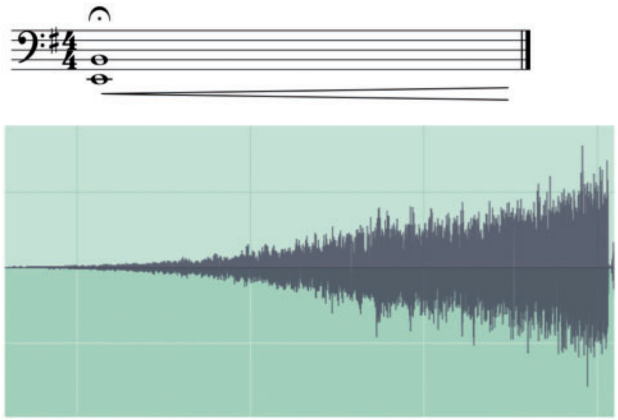
31 Most modern studios using digital audio workstations (DAWs) do not record to tape, but they do use digital signal processors that model the tape compression effect.

32 Schneider (1985, 32).

33 While the overall "key" for "Blackened" is E minor, as indicated by the key signature in Ex. 15, the pc material for the interlude could be attributed to E Locrian mode. While the scale E Locrian indicates the source of the material, it does not adequately indicate its function. For example, pc E does have the centrist function in the passage indicated by the scale E Locrian, but the other pcs do not really perform scalar functions. Labeling the motive as a member of sc 4-8[0156] puts emphasis on the intervallic structure of the motive (ics 1 and 6) rather than the scalar function of the pcs.

34 To palm mute a string, a player places a portion of the palm (either the portion closest to the pinky or the portion nearest the thumb) against the string at or near the bridge of the guitar. Contact with the palm limits the range of the vibrating string.

35 Later heavy metal bands, such as Meshuggah, featured the transient CS/N contour pitch even more prominently in their music by further amplifying it and by developing additional playing techniques to accentuate it, such as holding the pick at a 45-degree angle rather than traditional 90-degree position. Fredrik Thordendal, guitarist for Meshuggah, is credited with creating the onomatopoeia "djent" as a descriptor for the transient CS/N contour pitch, and bands whose compositions prominently feature this sound, such as Periphery and Veil of Maya, form the subgenre of heavy metal known as djent.



EXAMPLE 15. *Distortion crescendo-opening synthesizer interval of a fifth and waveform from "As I Am" from the CD* Train of Thought *by Dream Theater*

synthesizer player only depresses the interval of a fifth (E_2/B_2) on the keyboard, the amplified sound contains a prominent G♯, so the opening chord sounds like a major triad.[36] Example 17(a) is a spectral analysis of the chord at the lower dynamic level. The frequencies in the spectrum are mostly harmonics of the pitches E_2 and B_2, so even though the synthesizer player is not playing a G♯ amplification greatly increases the amplitude of the fifth harmonic of E, G♯, which is why the chord sounds like a major triad.[37]

Besides generating the harmonics of the pitches E and B, the spectrum in Example 17(a) reveals the amplification process and generates small amounts of intermodulation distortion (the spikes in Ex. 17(a) that are not harmonics of E and B). The intermodulation distortion along with the frequency modulation quality of the synthesizer patch locates the chord in the overdrive region of dist-space at the start of the crescendo. Amplitude and distortion are inextricably linked, as demonstrated in Example 6, so the crescendo's rising volume also increases the distortion level. The volume crescendo, therefore, simultaneously creates a distortion crescendo that moves through nearly the entire range of dist-space. Example 17(b) is a spectral analysis of the chord at its highest dynamic level, which shows that the saturation of the spectrum has dramatically increased with the rising amplitude, adding new harmonic and nonharmonic frequencies that increase the distortion level (compare Exx. 17(a) and (b)). Especially noteworthy is the addition of frequencies in 2000Hz range, which, in part, accounts for the increased dissonance heard as the "sizzle" in the sound that becomes more prominent at the loudest dynamic level.

After a short solo bass interlude, the guitar enters and repeats the synthesizer chord's distortion crescendo within the range of dist-space c-pitch 3 (Ex. 18, m. 1 and Sound Ex. 19). Following the C_5 power chord, the dyads G/C and F♯/C generate increasingly higher levels of intermodulation distortion (i. e., nonharmonic frequencies producing dissonant intervals). The dist-space c-pitches of the C_5 power chord, the G/C dyad, and the F♯/C dyad are 3.1, 3.2, and 3.3, respectively. A sonogram uses the density of a color, such as blue, to show the frequencies of a sound having the highest amplitudes.[38] The sonogram of the G/C dyad shows a noticeable density increase at 1.0k, 2.0k, and approximately 3.5k frequencies. The sonogram of the C/F♯ dyad shows an even higher level of distortion produced by the addition of new frequencies as indicated by a further increase in density of the darker areas. Finally, the addition of the cymbal roll during the sustained C/F♯ dyad takes the distortion level to dist-space c-pitch CS/N. After repeating the power chord double-stop motive four times, the guitar performs an unfolded version of the motive that slightly "transposes" the dist-space c-pitches down (see Ex. 18, mm. 2 and 3 and Sound Ex. 20). Nevertheless, the additions of vibrato, feedback, and eventually a quarter-step bend at the end of the pitch motive replicate the distortion crescendo motive that will continue to structure later parts of the composition.

Besides generating motives, distortion can also structure the form of a work. According to John Covach, "in a verse-chorus song . . . the focus of the song is squarely on the chorus . . . the verse serves primarily to prepare the return of the chorus."[39] Brad Osborn notes in his study of terminally climactic forms that "the shift from acoustic or clean guitars in the verses to electric or distorted guitars in the choruses" is a formal paradigm in rock music.[40] The change to the distorted guitar timbre in the chorus accentuates it, thus supporting the role of the chorus as the focus of a song. The alternation of clean and distorted guitars in a verse/chorus work essentially creates a modular-binary-cyclic form because two formal sections (chorus and verse) alternate between two dist-space c-pitches (0-clean and 3-distortion) to form a modular unit that repeats.

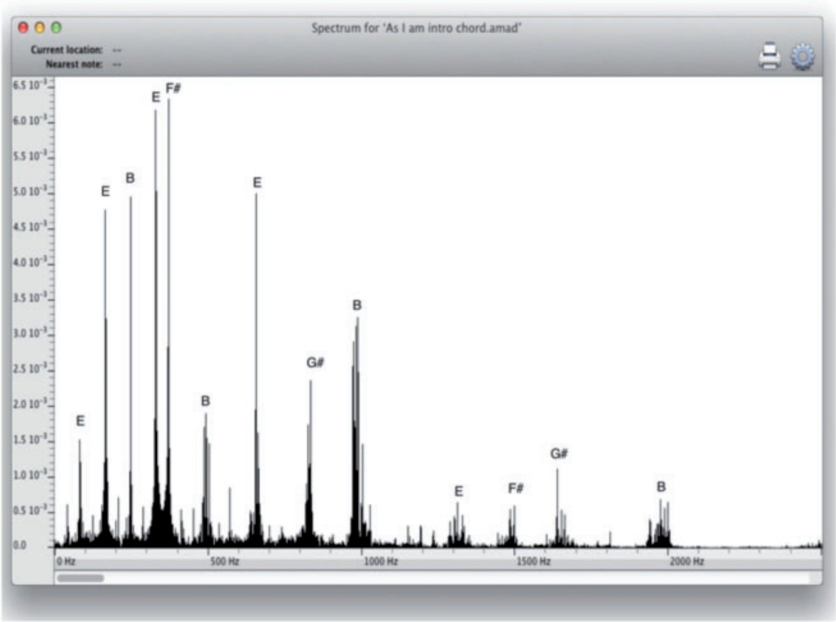
36 The published score only includes the interval of a fifth, and videos of live performances of "As I Am" show Jordan Rudess, the synthesizer player, only holding the interval of a fifth with his left hand.

37 If the synthesizer player were sustaining the notes E, G♯, and B, the frequency spectrum would prominently include harmonics of the fundamental G♯ that would not be harmonics of the notes E and B, such as the fifth harmonic of G♯, B♯, and the fifteenth harmonic, G. Moreover, the spectrum in Example 17(a) follows the harmonic series of the lower note of the fifth interval, E, with the harmonics of the upper note, B, overlaid on the harmonic series of the E. The chord sounds higher in register than the E_2/B_2 fifth because the increase in amplitude increases the prominence of the upper harmonics and partially masks the lower notes. Including the third as a played note would create high levels of intermodulation distortion, which would make the notes of the chords indistinct. Guitar players mostly use overdrive sounds for triads to avoid the intermodulation distortion phenomenon. The Barber Small Fry (Barber Electronics) medium gain (i.e., overdrive) pedal is designed to reduce intermodulation distortion for playing triads, ninth, and thirteenth chords.

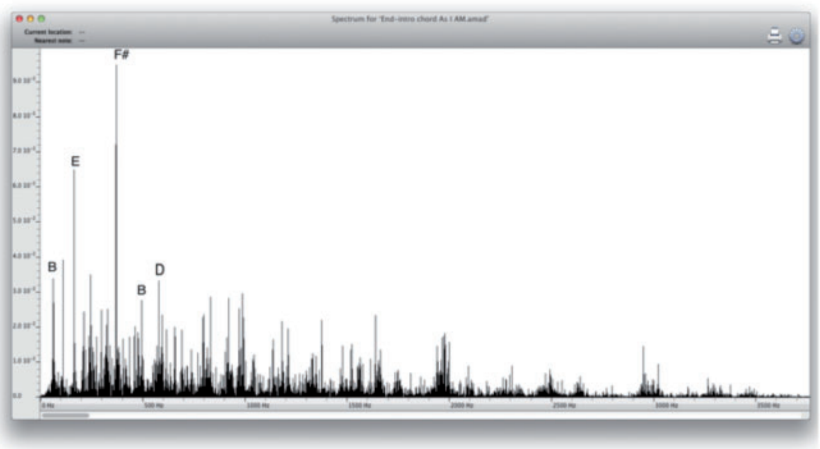
38 Interested readers may request colored sonograms by writing to me at scotto@ohio.edu.

39 Covach (2005, 71).

40 Osborn (2013, 39).



example 17(a). *Spectral analysis of the beginning of the synthesizer intro chord*

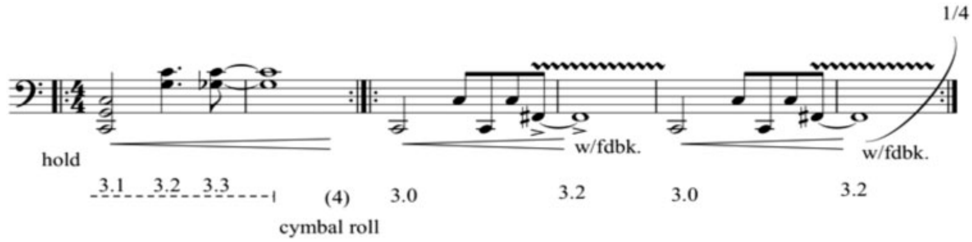


example 17(b). *Spectral analysis of the end of the synthesizer intro chord*

An archetypal example of song with a modular-binary-cyclic form is "I've Been Tired" from the album *Come on Pilgrim* (1987) by the Pixies.[41] Obviously, dist-space analyses of modular-binary-cyclic forms are not very informative because they simply show the formal divisions of the work repeatedly cycling between two dist-space c-pitches. Many works, however, alter the structure of the modular-binary-cyclic form by, for example, progressively filling in the gap created by the shift from dist-space c-pitch 0 (clean) to c-pitch 3 (distortion) with a sequence of c-pitches. Other works might break the cycle of alternating verse and chorus as well as undermine the dominance of the chorus by creating progressions through dist-space that shifts the focal point to a new formal division. In fact, progressions through dist-space can transform a modular-binary-cyclic form into an integrated and teleological or progressive directional form where choruses and verses become points in a directional progression leading to a climax. The full range of dist-space, outlined in Example 12, facilitates analyzing the structure of progressive directional form works.

The nu metal band Korn is known for their heavily distorted sound produced, in part, by their use of seven-string guitars, five-string bass, and down-tuning. "Freak on a Leash"

41 The Pixies essentially established the format of alternating clean guitars in the verse with distorted guitars in the chorus, and their foundational role in establishing the paradigm is reflected in the title of the 2006 film documenting their career, *loudQUIETloud: A Film about the Pixies*.

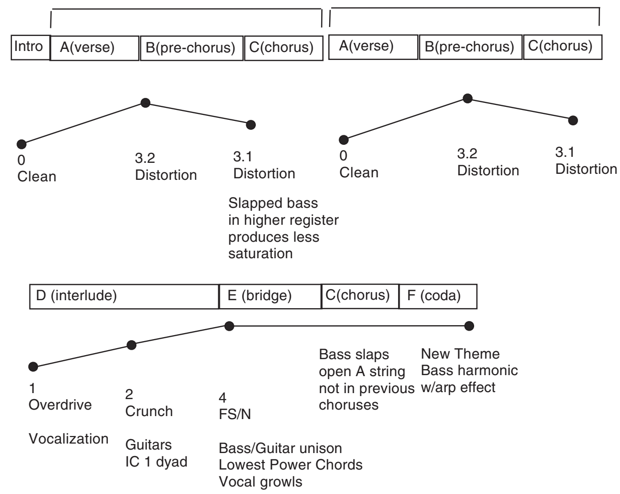


EXAMPLE 18. *Intro-distortion crescendo realized by the guitar entrance*

from their 1998 CD, *Follow the Leader*, is a complex example of a distortion progression transforming the modular and binary clean/verse-distorted/chorus format into an integrated directional three-part form. For "Freak on a Leash," the guitars and bass tune down a whole-step: for guitar A–D–G–C–F–A–D, which is simply D-standard, and for bass A–D–G–C–F. The distortion progression divides the work into three large parts (Ex. 21). The first and second parts have essentially the same structure consisting of verse/pre-chorus/chorus with an introduction added to the first part. The third part contains an interlude, bridge, chorus, and coda. The dist-space analysis below the form in Example 21 follows the standard format of clean verse and distorted chorus. However, as the analysis indicates, the chorus is actually slightly less distorted than the pre-chorus due in part to the bass guitar, which plays picked style on the lowest string adding to the saturation of the overall ensemble sound. The bass changes in the chorus to a higher register and the light slapped technique attenuates the transient creating a less saturated ensemble sound.

Rather than the quick rise and slight decrease found in parts 1 and 2, the distortion progression in part 3 builds on the earlier momentum and achieves the highest level in dist-space in the bridge, which is maintained till the end of the song. The interlude begins with slightly growling vocalizations by Jonathan Davis that move the voice into the dist-space c-pitch 1 range (overdrive) in contrast to dist-space c-pitch 0 (clean) singing of the previous verse and chorus. The guitars enter midway through the interlude antiphonally trading pitches that produce an interval-class 1. The combination of intermodulation distortion and waveform deformation moves the guitar sound into the range of dist-space c-pitch 2 (crunch). Davis maintains the intensity of his vocalizations until he shouts the word "go," which moves his vocals into the range of dist-space c-pitch 3 (distortion). The move to a higher region of dist-space prepares and signals the beginning of the next section.

The bridge following the interlude achieves the highest level of distortion/saturation in the composition. The power chords played by both guitars in their lowest register produce increased levels of intermodulation distortion and saturation of the frequency spectrum, while the bass contributes to the frequency saturation by doubling the lowest notes of the power chords. Davis simultaneously moves his voice into the highest region of the distortion range of dist-space by growling



EXAMPLE 21. *"Freak on a Leash" from* Follow the Leader *by Korn: distortion contours and form*

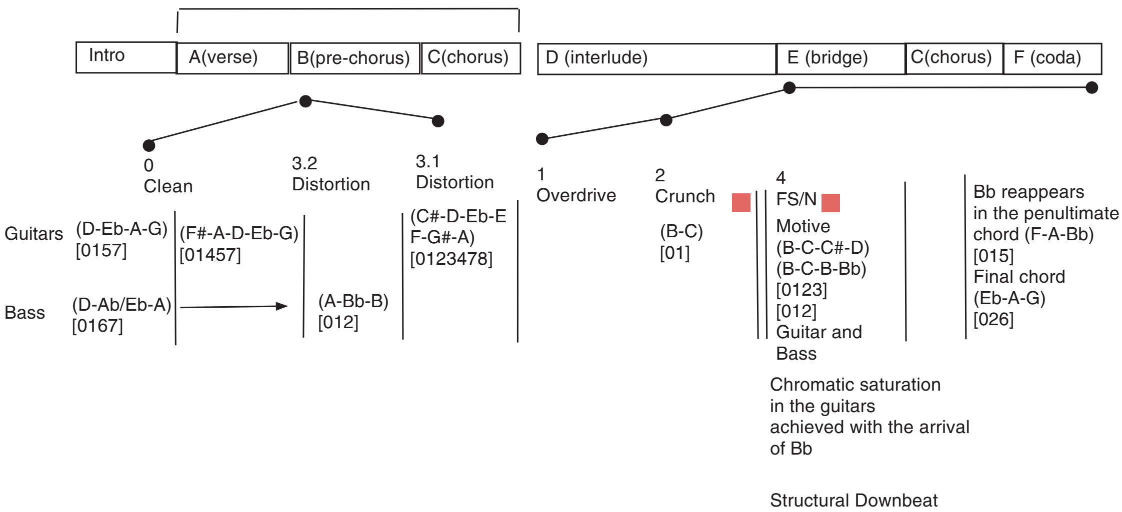
through the entire bridge. The chorus following the bridge achieves a higher level of distortion than previous choruses. The guitars play dense chords that increase the level of intermodulation distortion.[42] Rather than playing in a higher register, the bass player slaps the open A string (lowest note on the bass) with much more force adding noise bursts and amplitude that further saturate the sound. The coda maintains the distortion intensity of the bridge and chorus while the bass introduces a new theme by arpeggiating harmonics.[43]

The two large sections (consisting of verse/pre-chorus/chorus) preceding the point of maximum distortion build up to the focal point of the song, the bridge. The unfolding of the pitch material reinforces the focal point function of the bridge (Ex. 22). "Freak on a Leash" is essentially a pitch-class composition that contains several three- and four-note set classes whose common interval is a tritone or ic 6.[44] The main guitar

42 Essentially, the guitars are playing first-inversion triads minus the functionality of first-inversion chords.

43 Harmonics are another structural feature of distortion since the frequencies that distortion adds to a waveform facilitates the production of harmonics by the guitars.

44 The pitch structures in "Freak on a Leash" actually extend beyond Everett's category 6b: "chromatically related scale degrees with little dependence upon pentatonic basis . . . common-practice harmonic and



example 22. *"Freak on a Leash" from* Follow the Leader *by Korn: distortion, form, and chromatic saturation*

motive in the introduction is D–A–E♭, a member of sc 3-5[016], while the bass plays half-step related ic 6s (D–A♭/E♭–A) that form a member of sc 4-9[0167]. The piece ends with a member of sc 3-8[026] (E♭-G-A), where the final G decays, leaving ic 6 (E♭–A) as the final sound. The verse, pre-chorus, and chorus each add new pitch classes to the opening collection. For example, the pitch-class collection in the verse forms sc 5-Z18[01457] by adding F♯ to the (D–E♭–G–A) collection; the bass adds B♭ to the pitch-class (A, B) to form a member of sc 3-1[012] in the pre-chorus; and the guitars add pitch-classes C♯, E, and F to the collection (D–E♭–A♭–A) to form a member of sc 7-6[0123478] in the chorus.

With the addition of pitch-classes B and C, the only pitch classes in the interlude, the seven-string guitars have played every pitch class except one, B♭, which arrives in the bridge. The main motive, performed by the seven-string and bass guitars in the bridge, has two parts: the rising chromatic segment B–C–C♯–D, which is performed three times, followed by the B–C–B–B♭ cadential figure. This four-measure pattern repeats three times. The verse/pre-chorus/chorus sections build up to the bridge—the focal point in the overall form where the seven-string guitars achieve both pitch-class space and dist-space saturation. To borrow Edward T. Cone's term, the bridge is essentially a structural downbeat: "It is one of those important points of simultaneous harmonic and rhythmic arrival that I call a structural downbeat, for it is so powerful that retrospectively it turns what precedes it into its own upbeat."[45]

The song's lyrics, the physical actions of the performers, and the audience's participation in a live performance all support the perception of the sections preceding the bridge as an upbeat. The line of text "feeling like I have no release" only appears in the third verse immediately preceding the bridge. The lyrics subtly and somewhat ironically foreshadow and prepare the bridge where the somewhat constrained aggression of the previous two parts is unleashed and exemplified by Davis's growls and the dist-space c-pitch 3.3 (heavy distortion) of the guitars. In the video accompanying the song, the band members display intense physical motion during the bridge, such as head banging, extreme physical playing, and Davis's nearly out-of-control jumping. Moreover, in live concert, the audience would mosh during the bridge.[46]

Finally, comparing contour graphs of the opening guitar motive to the distortion progression contour graphs of composition's form reveals an interesting correspondence. The antiphonal guitar motive generates members of scs 3-5[016] and 3-4[015], and both scs are subsets of sc 4-16[0157]. The pitch realization of the motives creates the c-segs <021> and <012>, respectively. The dist-space contour of the verse/pre-chorus/chorus sections is also, by translation, <021>, while the dist-space contour of the interlude/bridge section is, by translation, <012>.[47] Membership in contour-segment classes <021> and <012> are the only possibilities for three-element

voice-leading behaviors are often irrelevant at deeper levels as well as the surface" (Everett, 2006). Compositions such as "Freak on a Leash" probably belong to seventh category in which pitch classes relate to each other with no dependence on scale-degree relationships.

45 Cone (1968, 24–25).

46 Moshing is a style of dance where the participants exhibit aggressive physical motion. An extreme form of moshing occurs when the dancers collectively start a circular motion usually moving counterclockwise. The extreme form of moshing usually begins in the bridge section of "Freak on a Leash," and Davis's shouting of the word "go" may be intended as a signal to start the extreme moshing.

47 Translation in contour theory "is an operation through which a csubseg of n distinct c-pitches, not numbered in register from 0 to (n-1), is renumbered from 0 for the lowest c-pitch to (n-) for the highest c-pitch in the csubset." Marvin and Laprade (1987, 228). In Example 23, to translate the dist-c-seg <124>, dist-c-pitch 1 becomes 0, and with n equals the cardinality of the c-seg, so the highest dist-c-pitch is (3-1) or 2. By translation, cset <124> becomes <012>. The translation process is similar for

collections under translation, inversion, retrogression, and retrograde inversion, so any three element collection is either a member of contour class <012> or <021>.[48] While the correspondence may not be particularly remarkable, Korn's minimal approach to composing pitch and timbre motives along with the limited number of three element contour classes does produce a high level of coherence within and across musical dimensions that would be opaque to more traditional harmonic and voice-leading analyses. The correspondence across musical dimensions adds to the structural richness of the composition.

Korn's live performances of "Freak on a Leash" replicates the formal distortion structure of recorded tracks outlined in Example 21 remarkably well.[49] Even though the contrast between dist-space c-pitches that creates the progressive directional form is much more pronounced on the studio track, live versions of the song essentially maintain the progression of dist-space c-pitches that define the song's formal structure. The difference between the studio track and live versions is analogous to seeing the same picture in and out of focus. Maintaining the distortion sound of the guitars on the studio track in live performances accounts in part for the effectiveness of replicating the formal aspects of the work. First, the guitarists use exactly the same amplifiers in the studio and in live performances. Second, the change from analog to digital production of recordings has reduced the differences between studio tracks and live performances because the studio has become mobile with the rise of digital audio workstations (DAWs), portable computers, and modern live sound systems. For example, live performances replicate the studio placement of the microphones on amplifiers, and the output of the microphones goes into a soundboard that essentially performs the same functions as the mixing console in the studio. From the mixing console, the signal is sent to the house sound system and speakers. The venue's sound engineer can add processing, such as equalization and compression, at the live performance mixing console. Consequently, the audience is hearing the distortion of the guitar amplifiers live in essentially the same way they hear the sound on a studio track, processed through a mixing console.[50]

Korn prepared an acoustic arrangement of "Freak on a Leash" for their appearance on the television show *MTV-Unplugged* (2006). The show's fundamental goal to present an intimate performance experience for audience and band is analogous to a traditional chamber music concert. Besides the small TV studio setting, bands substitute acoustic instruments for their electric guitars and amplifiers. Of course, "unplugged" is a bit of a misnomer because the audience does not hear the sound of the acoustic instruments and vocals directly. Each instrument plays into a microphone as they do in the studio and live performances attached to a mixing console that sends the signal to studio sound system (amplifier) and speakers. In fact, the acoustic guitars used by Korn for their unplugged appearance had electric pickups that were plugged into small guitar amplifiers, and microphones transmitted the amplifier sound to the mixing console. Needless to say, since the studio sound system amplifies sound, it can replicate the timbral processing of guitar amplifiers to a lesser degree. For example, if the amplitude of signal received by a microphone is too high, then the sound distorts.

Three aspects of "Freak on a Leash's" acoustic arrangement are dependent on the particulars of the studio track: dynamics, texture, and orchestration. These particulars help the acoustic arrangement re-create the distortion structure of the studio track. As demonstrated earlier, dist-space and dyn-space are essentially identical in structure, and distortion is a function of amplitude, so the c-pitches in dist-space can be reinterpreted as c-pitches in dyn-space (with 0 equaling the softest and 4 equaling the loudest dynamic levels). Therefore, the increasing dynamic level of a sound or the ensemble is analogous to a sound becoming more distorted. Texture and dynamics are coupled because ensemble texture establishes dynamic level as well as the amplitude of the instruments. Moreover, ensemble texture helps re-create the effect of distortion because adding more instruments to the ensemble fills in the frequency spectrum from low to high the same way distortion progressively saturates the frequency spectrum of a sound. Orchestration is perhaps the most significant musical element used to re-create the sound of distortion. Besides adding piano and an additional vocalist (Amy Lee, lead singer from the band Evanescence), three cellos and three double basses augment the traditional rock quartet. The sawtooth waveform of bowed string instruments produces a sound similar to the asymmetrical distortion produced by guitar amplifiers because it contains both odd and even harmonics.[51] Bowed cellos and basses can sound very similar to guitars in the 3 range of dist-space, especially when they are bowed aggressively.

The overall form of the acoustic arrangement maintains the progressive directional form of the studio track, but with slight variations, such as the chorus achieving the highest "distorted" state rather than the pre-chorus in the two sections preceding the bridge (see Ex. 23 and compare with Ex. 21). Moreover, a guitar and cello interlude precede the verse in the second large section substituting for the "clean" verse at the start of the

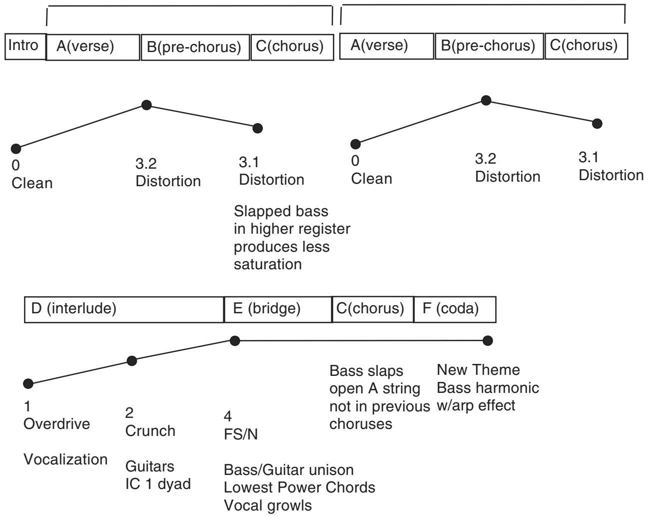
the dist-c-seg <0, 3.2, 3.1>. However, simply pruning the region designation 3 from the dist-c-seg produces the translated dist-c-seg <021>.

48 For a complete discussion of C-space segment classes along with a table listing all C-space segment classes, see Marvin and Laprade (1987).

49 See, for example, Korn, "Freak on a Leash," live performance in Boston 2012.

50 In fact, the digital mobile studio allows engineers to produce studio quality recordings of live performances, which has created a new method for bands to distribute their music. Metallica and Pearl Jam, for example, sell downloadable recordings of every live performance on their websites.

51 Fletcher and Rossing (1991, 45).



EXAMPLE 23. *Acoustic version of "Freak on a Leash" from* MTV-Unplugged: *distortion contours and form*

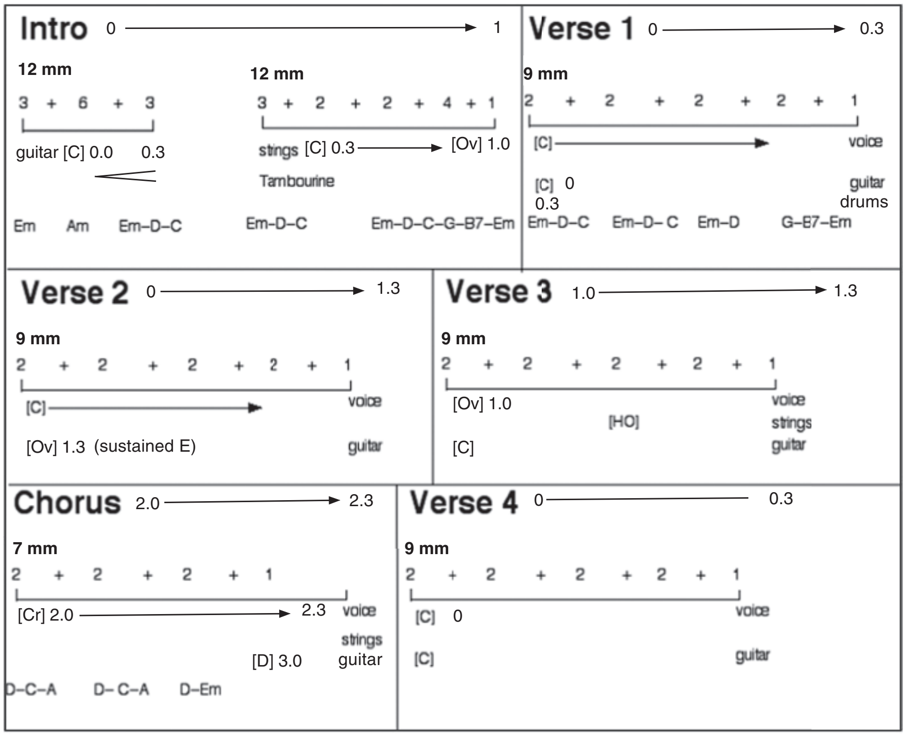
section. The progression to the first chorus increases both dynamics and texture progressively as the solo piano begins the arrangement and accompanies the first verse where the vocalists engage in an antiphonal exchange. The dynamic level and the density of the texture increase with the entrance of the guitar in the pre-chorus and the vocal duet. The bowed string instruments that substitute for the sound of the distorted guitars first appear in the chorus at the end of the first large section basically following the structure of the studio track. The texture of the chorus saturates with the addition of the drums and slapped bass guitar to the ensemble. Jonathan Davis's growling vocals completes the association with the studio track's distorted chorus.

The progression to the chorus in the second large section is more nuanced as the bowed strings appear in each section that fill in the c-pitch gaps of the first section. As in the studio track, the bridge section achieves the highest "distortion" level, and the beginning of the bridge is marked by a large structural downbeat at the 2'53" mark. Dynamically and texturally, the bridge is the loudest and most densely scored section of the work. Combining the cymbals with Amy Lee's vocalization in the high register of her voice adds to the "saturated" character of the bridge, as does the aggressive bowing of the string instruments. The ensemble maintains the "distortion" level of the bridge through the final chorus and coda following the structure of the studio track. Although electric guitars and amplifiers are absent from the acoustic arrangement of "Freak on a Leash," the recorded features of the arrangement reinforce the structural importance of distortion in the architecture of the composition.

Rather than creating a multipart unidirectional form by alternating clean and distorted guitars in the verse and chorus, the distortion progression in Metallica's song "Nothing Else Matters" from *Metallica* (1990–93) follows a more variegated and intricate trajectory; it produces an asymmetrical arch form that traverses the entire range of dist-space. The composition is firmly rooted in the power ballad tradition of songs in slow tempo that crescendo to an emotive and loud chorus at the climax.[52] However, Metallica alters the format by replacing the climactic chorus with a guitar solo. Moreover, asymmetric groupings of verses and chorus replace the binary alternation of verse and chorus.[53] The composition's overall dist-space progression, however, is similar structurally to the previous example because clean verses lead to more distorted choruses, and coupling clean verses to distorted choruses divides the piece into three large sections.

The composition's lengthy introduction, a feature typical of many Metallica works, contains several structural features that shape the overall form. The pitch-class organization of works composed prior to 1991, such as "Blackened," is a "riff"-based pitch-class set composition that extends Everett's tonal system 6, so the fairly conventional harmonic foundation of "Nothing Else Matters" is not typical of their works.[54] The guitar and bass unfold the triadic progression i–iv–VI–♭VII–i in the key of E minor in the first of the introduction's two main twelve-measure sections (Ex. 24). The progression is essentially repeated, expanded, and divided into two parts in the second section. The first part repeats the i–♭VII–VI from the end of the first section while the second part expands the progression with III and V^7 before returning to the tonic.[55] The expanded progression functions similarly to a chaconne because it is repeated in the verses verbatim for the remainder of the composition. Since the progression repeats without further expansion or development, the trajectory and build up to the climax must occur in a dimension or dimensions other than the harmonic. The slight increase in the distortion level of the guitar and the ensemble structure (adding instruments to saturate the ensemble and mix) in the introduction suggest the trajectory to the climax will take place in dist-space.

52 Frith (2001, 100–01).
53 Metallica lyrics for "Nothing Else Matters."
54 Nearly every text on popular music defines a "riff" slightly differently, but most definitions characterize it as a short melodic, rhythmic, and/or harmonic idea. One of the problems with providing a complete definition of the term is it is often defined relative to a style, such as rock or jazz. For example, in most heavy metal compositions, in particular Metallica's compositions, a riff is a short melodic idea that may be based on the structure of a scale. A riff can even be based on an interval or interval pattern. Riffs, particularly in heavy metal are equivalent to motivic ideas, especially motivic ideas in pitch-class compositions. Moreover, riffs are often developed independently of any harmonic foundation, such as common-practice harmonic progressions. Consequently, riff-based composition is similar to Schoenberg's idea of composing with the tones of a motive.
55 Everett's system 4 (blues-based rock: minor-pentatonic-inflected major-mode systems) perhaps best explains the structure of the passage.



EXAMPLE 24. *Distortion and formal structure through verse 4 in "Nothing Else Matters"*

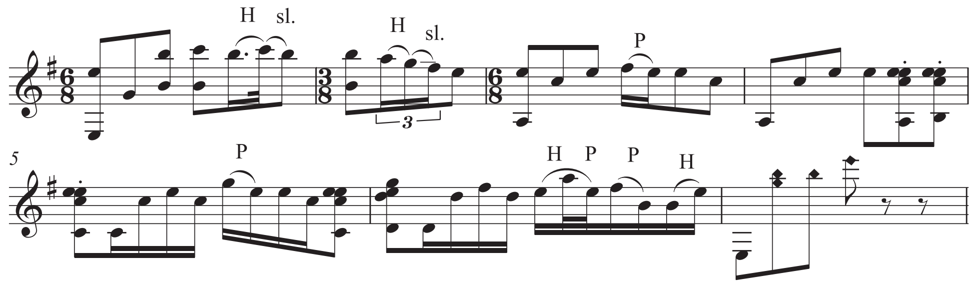
The introduction's first section features a very clean guitar sound (dist-space c-pitch 0) with perhaps a very light chorus effect similar to the sound of a twelve-string guitar (Ex. 24). A dist-space c-pitch 0 (clean) bass accompanies the guitar. After six measures of arpeggiating the E-minor tonic chord in compound duple meter, the guitarist begins rhythmically elaborating the arpeggiations by progressively replacing the eight notes with sixteenths (Ex. 25). The process essentially produces a rhythmic accelerando that reaches its apex on the ♭VII chord (D) preceding the return of the tonic and the start of the second section. The guitarist simultaneously begins a crescendo from *piano* to *mezzo forte*, and the increased amplitude of the electric guitar signal introduces a little distortion (especially if the position of the amplifier's gain control is close to the border between the clean and overdrive regions of dist-space). The guitarist's crescendo does take the signal right to the edge of the range of dist-space c-pitch 0, so the overall motion of the guitar timbre is from dist-space c-pitch 0 to 0.3 (Ex. 24).

The guitar crescendo repeats in the second section of the introduction. However, additions to the ensemble increase the distortion level, and the saturation level of the mix raises the overall distortion level. For example, the sawtooth waveform of the gently bowed violins accompanying the guitar during the "chaconne" progression produces a sound similar to a guitar in the c-pitch 1 region of dist-space (overdrive). The soft tambourine struck every two measures also increases the overall distortion level since the "jangle" of the tambourine can, depending on its volume, suggest a range of dist-space c-pitch from 1 to 4 (CS/N). The approach to the cadence increases the distortion level as the volume of the ensemble increases and moves the section's overall sound into the dist-space c-pitch 1 region (overdrive). The guitar enters immediately following the cadence, playing a distorted harmonic glissando with a volume swell, creating an elision to the next large section that recalls the crescendos of the previous two sections and anticipates the progression to the climax.[56]

The section following the introduction (consisting of verses 1, 2, and 3 plus the first chorus) traverses dist-space from c-pitch 0 (clean) to the edge of c-pitch 3 (distortion). The progression is gradual with each verse increasing the distortion level, which reaches an apex at the end of the chorus achieving c-pitch 2.3. The change in vocal timbre in each verse and chorus guides the gradual transformation. Hetfield is known for his deep, often nasal, chest resonant vocal style. However, his vocal timbre in verses 1 and 2 is very "clean" because he sings softly with precise intonation using a head resonant voice. The

56 To perform a volume swell, the guitarist strikes the strings with the volume potentiometer at 0, and then raises the volume to produce the crescendo effect. Often a volume pedal placed between the guitar and amplifier substitutes for the volume potentiometer. It should be noted that the swell technique is also used to imitate the sound of a bowed string instrument on the guitar. Striking the string(s) with the volume set to 0 then raising it removes the transient portion of the guitar sound and produces a sound very similar to a bowed violin. Distortion is often added to the guitar sound to help duplicate the sustain quality of a bowed violin.

Standard guitar notation



example 25. *Guitar rhythmic accelerando in first section of the introduction (9–28 seconds) of "Nothing Else Matters"*

c-pitch of the voice in verses 1 and 2 is 0. In the third verse, his voice takes on a more mouth resonant nasal timbre, the dynamic level increases, and the voice is double tracked in the mix to produce a fuller sound. Consequently, the vocal timbre moves to dist-space c-pitch 1.[57] The vocal timbre in the chorus gradually becomes even more growling and chest resonant, so the voice moves from c-pitch 2.0 to c-pitch 2.3 at the end of the chorus.

The guitar retains the clean tone of the introduction while accompanying the vocals in verse 1. Although the drums enter for the first time, they play relatively softly, which keeps the overall distortion level at dist-space c-pitch 0. The distortion level of verse 1 moves from dist-space c-pitch 0 to 0.3 as the dynamic level of the ensemble increases. While the second verse retains many of the timbre structures of the first verse, eventually a second guitar enters playing a sustained E_4/G_4 dyad (sounding pitch) whose c-pitch is 1.3 (heavy overdrive). The distortion level of the second verse progresses from c-pitch 0 at its beginning to 1.3 at its end. Hetfield's doubled vocals shift to c-pitch 1.0 in verse 3, as if he is trying to match the distortion of the guitar. Although the c-pitch 1 (overdrive) guitar does not appear and the c-pitch 0 (clean) guitar is still a feature of verse 3, the c-pitch 1 sound of the second verse appears halfway through the verse with the return of the strings. The dynamic level once again increases as the cadence approaches. The combination of ensemble saturation and dynamic level raises the distortion level in verse 3 from c-pitch 1.0 to 1.3 at its end.

The distortion level of the voice at the start of the chorus begins where verse 3 left off with dist-space c-pitch 2. Although the second guitar returns halfway through the chorus, it adds a new element, c-pitch 3 (distorted) power chords. Nevertheless, the volume of the guitar is not very loud in the mix, so the overall distortion shows a modest increase.[58] The chorus also contains a crescendo, and with the addition of the distorted guitar track, so the dist-space progression moves from c-pitch 2.0 to 2.3. Example 27 contains a dist-space contour graph of the entire song, and the first bracket above the dist-space c-pitches shows the progression from dist-space c-pitch 0 to 2.3 in the first large section consisting of verses 1, 2, and 3 plus chorus.

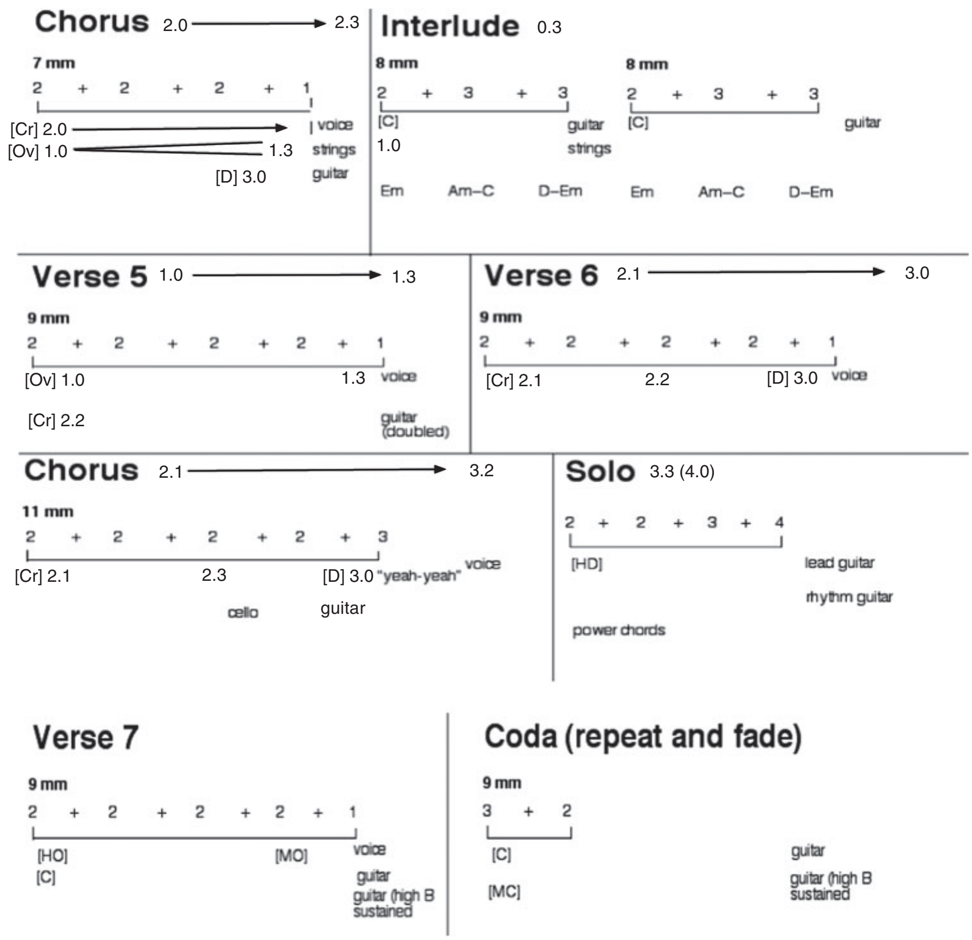
The second section consisting of verse 4 plus a chorus temporally contracts the first section, but it repeats the same dist-space progression from c-pitch 0 to 2.3 (Exx. 24 and 26). The interlude following the second chorus recalls the introduction by bringing back the finger picked solo guitar melodically elaborating the opening "chaconne" progression. Recalling the introduction in the interlude has the effect of temporarily halting the dist-space progression to the climax, but overall the interlude does not return to dist-space c-pitch 0. The violins, drums, and a second guitar accompany the solo and raise the overall distortion level of the interlude to c-pitch 1.

The final section begins with verse 5, where Hetfield's voice moves to dist-space c-pitch 1 (overdrive) as if prolonging the c-pitch of the interlude and continuing where the previous chorus ended (Ex. 26). The sustained distorted E played by the guitar and the ubiquitous crescendo return in verse 5, so the dist-space progression moves from c-pitch 1 to 1.3. The timbre of the voice at the beginning of verse 6 produces c-pitch 2.1 (crunch) and gradually shifts to c-pitch 3.0 (distortion). The chorus repeats the dist-space progression of verse 6 but takes it a little further. The guitars are now doubled, they play c-pitch 3 (distortion) power chords, and they are more prominent in the mix. Moreover, the largest crescendo of the piece occurs in the chorus following verse 6, creating a progression from c-pitch 2.1 to 3.2. The crescendo reaches its climax when Hetfield literally growls/screams the words "yeah-yeah."

The guitar re-creates the growled "yeah-yeah" text at the beginning of the solo with dist-space c-pitch 3.0 and an added bend that raises the lower note of the A/D dyad a whole step

57 Double tracking is simply the recording technique whereby a single recording of a guitar or voice, for example, is duplicated and assigned to an additional recording lane, essentially doubling the instrument, to create a fuller sound. See White (1997).

58 Keeping the distorted guitar low in the mix is perhaps a way of foreshadowing or setting up the climax, where it moves from its background position to the foreground to solo with the highest level of distortion in the work. By anticipating the distortion of the guitar solo in the choruses, the appearance of the distorted guitar solo perhaps sounds inevitable.

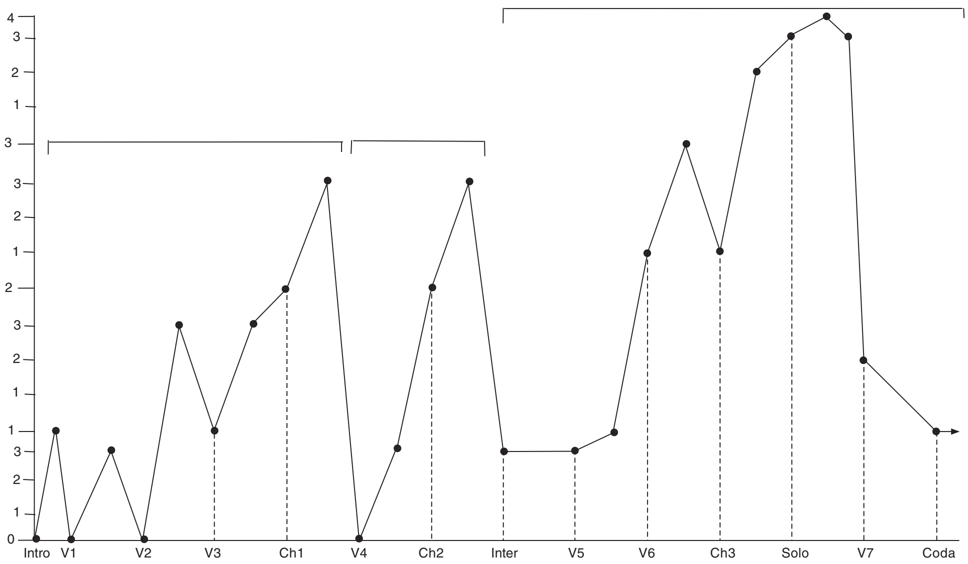


EXAMPLE 26. *Distortion and formal structure of the final section of "Nothing Else Matters"*

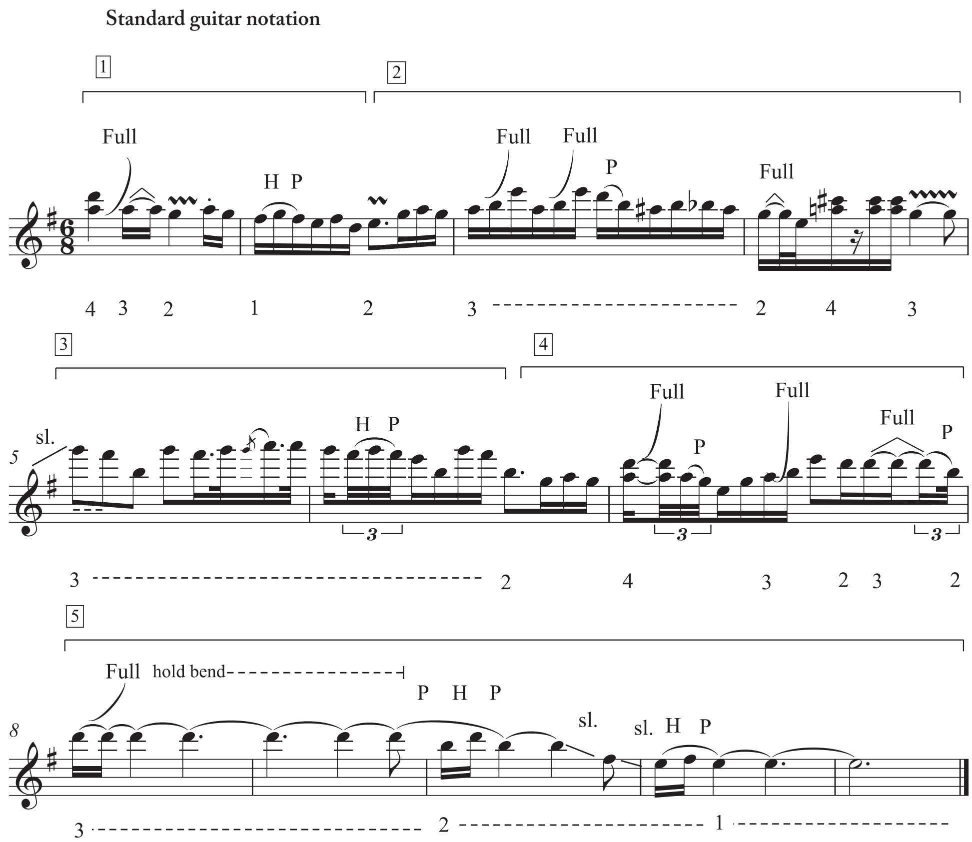
(Ex. 28 and Sound Ex. 29). The dyad creates intermodulation distortion, and bending the lower note up a whole step creates higher levels of intermodulation distortion taking the initial sound of the solo right to the edge of dist-space to c-pitch 4 (CS/N). The solo contains five phrases that move through the entire range of dist-space, as if summarizing and elaborating the dist-space progression that structures the entire work. The dist-space contour graphs of the five phrases in Example 30 reveal an overall symmetrical distortion structure to the guitar solo. The sustained single notes of the fifth phrase recall the sustained guitar notes of the verses, create a transition back to the verse, and begin the descending part of the distortion arch that returns to dist-space c-pitch 0 (clean).

In verse 7, the final verse of the work, the vocal timbre returns to dist-space c-pitch 0 (clean). However, the distorted high E sustained by the guitar remains and is more prominent in the mix than in previous verses, so the dist-space c-pitch of verse 7 remains at 1.2 (medium overdrive). The coda recalls the introduction because the ensemble returns to the guitar plus bass accompaniment format; here the guitar recalls the opening motive, and the timbre of the guitar returns to dist-space c-pitch 0 (clean). Recalling the introduction in the coda creates a symmetrical endpoint for the entire form. However, the symmetry is not exact because a sustained B played by a second distorted guitar sounds throughout the coda (albeit low in the mix) keeping the coda hovering on the border between dist-space c-pitch 0 and 1. The contour graph in Example 27 shows the three large sections of the work created by the dist-space progression, and it reveals the asymmetry of the arch form, which lends the entire form of the work an almost reverse sawtooth or ramp wave shape.

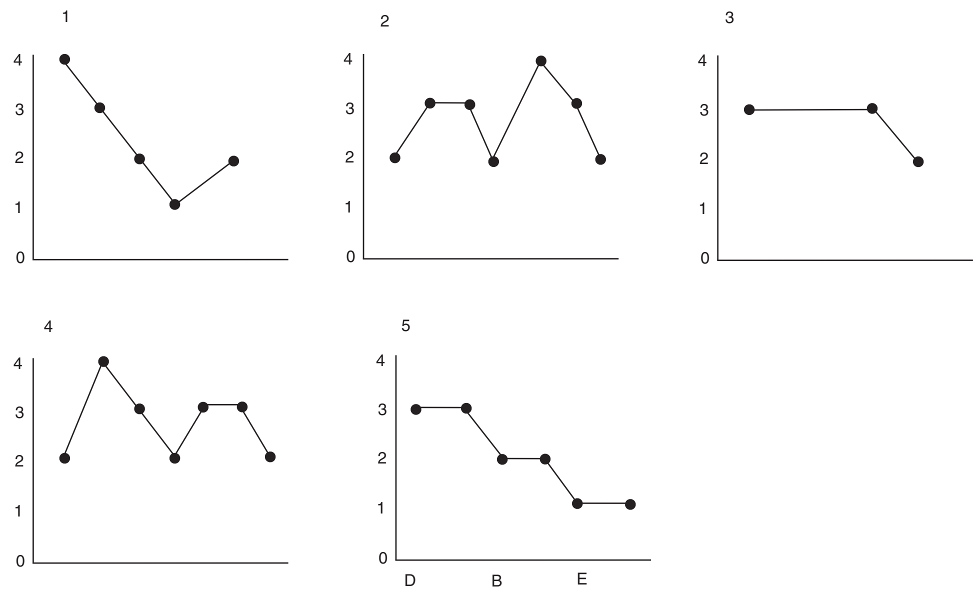
For the last ten years, Metallica has performed an abridged version of "Nothing Else Matters" in live concerts. Essentially, the song functions as an introduction to their most well-known song, "Enter Sandman," another track from the *Black Album*. "Enter Sandman" also begins with a solo guitar in the clean region of dist-space, so the end of the solo in "Nothing Else Matters" leads directly to the beginning of "Enter Sandman." In this way, the beginning of one song functions as the end of the other and vice versa. Nevertheless, Metallica's live performance of "Nothing Else Matters" replicates the formal distortion structure of the recorded track up to the solo very well. Of course, the contrasts between dist-space c-pitches that create the progressive directional form are much more



example 27. *Distortion contour graph and formal structure*



example 28. *Distortion contour pitches in the guitar solo*



EXAMPLE 30. *Distortion contour graph of the guitar solo*

pronounced on the studio track, but the live version maintains the progression of dist-space c-pitches that define the song's formal structure. For example, Hetfield re-creates his vocal progression through dist-space in live performances. Moreover, the live guitars' dist-space c-pitches are very close to the sound of the studio track, and Hetfield replicates the guitar solo note for note in live performances.[59] Again, the difference between the studio track and live versions is analogous to seeing the same picture in and out of focus.

CONCLUSION

The dist-space analytical tool facilitates greater intersubjective agreement between theorists, analysts, and performers because it models a continuum as a discrete set of values and creates a standardized measure that enables categorizing, comparing, and graphing the changes in a composition's distortion structure. The analytical examples demonstrate distortion's structural role in developing motivic and formal features of several heavy metal compositions. They illustrate a level of timbral complexity and a perspective on compositional structure that are not accessible with conventional analytical tools. For example, reexamined through the lens of distortion structure, the traditional verse-chorus format becomes a progressive directional form. Future research may reveal even more innovative formal structures determined by distortion. Moreover, the dist-space analyses suggest reexamining tonal voice leading and harmony's role in determining the pitch-class structures in some rock compositions. Distortion structures might determine some aspects of pitch structure rather than the reverse relationship, an implication suggested by many of the analyses above. Needless to say, the analytical approach presented here is not limited to the genre of heavy metal. Analyzing the structural function of distortion can be an important part of any rock music analysis. For example, distortion is an essential component of the sound of many blues guitarists, such as Stevie Ray Vaughan, or rock guitarists influenced by the blues, such as Robin Trower. Graphing and analyzing their use of distortion may offer another analytical perspective on their music. The analyses in this article focus on distortion as a phenomenon abstracted from the larger timbral context of a composition. A future investigation may study the interaction of distortion with other structural aspects of timbre. The dist-space tool, for example, can easily be adapted to graphing the five vowel sounds and motivic structures produced by the wah-wah pedal.[60] Heavily distorted guitars often use a wah-wah pedal, so the interaction of motivic structures in each dimension could open a new multidimensional analytical space. The sound of rock is perhaps its most important and identifiable feature, so understanding how its timbre structures a composition should be the highest priority of the analytical enterprise.

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59 Metallica rarely alters the pitch structure of their works in live performances. They essentially strive to perform their works as close to the studio versions as possible.

60 Scotto (1999).

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