



University of HUDDERSFIELD

University of Huddersfield Repository

Jan, Steven

A Memetic Analysis of a Phrase by Beethoven: Calvinian Perspectives on Similarity and Lexicon-Abstraction

Original Citation

Jan, Steven (2015) A Memetic Analysis of a Phrase by Beethoven: Calvinian Perspectives on Similarity and Lexicon-Abstraction. *Psychology of Music*. ISSN 1741-3087

This version is available at <http://eprints.hud.ac.uk/id/eprint/23720/>

The University Repository is a digital collection of the research output of the University, available on Open Access. Copyright and Moral Rights for the items on this site are retained by the individual author and/or other copyright owners. Users may access full items free of charge; copies of full text items generally can be reproduced, displayed or performed and given to third parties in any format or medium for personal research or study, educational or not-for-profit purposes without prior permission or charge, provided:

- The authors, title and full bibliographic details is credited in any copy;
- A hyperlink and/or URL is included for the original metadata page; and
- The content is not changed in any way.

For more information, including our policy and submission procedure, please contact the Repository Team at: E.mailbox@hud.ac.uk.

<http://eprints.hud.ac.uk/>

A MEMETIC ANALYSIS OF A PHRASE BY BEETHOVEN: CALVINIAN PERSPECTIVES ON SIMILARITY AND LEXICON-ABSTRACTION

1. Similarity in the Light of Evolutionary Theory

This article explores certain similarity relationships in music (Cone, 1987; Wiggins, 2007) from a cultural-evolutionary perspective, specifically the memetics of Dawkins and others (Blackmore, 1999; Dawkins, 1989; Jan, 2007). Memetics is predicated on the idea that units of cultural information, memes, share certain properties with units of biological information, genes, such that both may be regarded as “replicators” involved in Darwinian processes. It regards the most significant similarity relationships as those which arise through meme transmission (homology), privileging these over relationships which arise through chance resemblance (analogy) (Dennett, 1995, p. 357). In addressing a specific case study, I argue that a memetic orientation has the capacity to integrate different perspectives on similarity – computational, music-theoretical/analytical, psychological, and neurobiological – under the “master-narrative” of Darwinian evolutionary thought.

I begin by discussing some general issues arising from the study of similarity in music, both human-conducted and computer-aided, and then consider similarity relationships between patterns in a phrase by Beethoven, from the first movement of the Piano Sonata in A \flat major op. 110 (1821), and various potential memetic precursors. The main purpose of this section is to illuminate certain theoretical hypotheses, more than to offer new analytical or aesthetic insights into an already extensively discussed composition (see, for instance, Ockelford, 2005). I then explore how the kinds of similarity identified in the Beethoven phrase might be understood in psychological/conceptual and neurobiological terms, the latter by means of William Calvin’s Hexagonal Cloning Theory. I conclude by attempting to map the various spaces within which memetic replication occurs.

2. Allusions, Musemes, and Listeners

Supplementing the manual labors of music theorists and analysts – specifically those who examine style from the perspective of “digital”/pattern recurrence as opposed to “analogue”/parametric similarity – considerable advances have been made recently in the development of pattern-finding software, some under the stimulus of the MIREX competition (Cambouropoulos, 1998; Conklin & Anagnostopoulou, 2006; Hawsett, 2013; Huron, 2002; Lartillot & Toiviainen, 2007; Lartillot, 2009; “MIREX,” 2014). Cope argues that “referential analysis [his own computer-aided process of identifying ‘allusions’ between works] might add context to standard analytical approaches” (2003, p. 27). This is on the grounds that the resulting “intertextual” (cross-work) listening is potentially richer than what might be termed “immured” (work-centric) listening; and it is arguably not in contradiction to the aesthetic contemplation most often associated with the latter mode (Dahlhaus, 1982, p. 5). In this sense, Cope is in alignment with those strands of musicological thought which maintain that seemingly autonomous movements and works are actually highly interconnected, and thus the borders which separate them are porous (Korsyn, 1991; Street, 1989).

A reorientation of perspective relates intertextual listening to the concerns of this article. Instead of an exclusive focus on listeners’ (varied, shifting) experiences of pattern similarity,

it also considers the attributes of the patterns themselves, and utilizes similarity-finding methodologies as a means of tracking their (re)appearance from work to work. Specifically, it adopts a Darwinian perspective and considers the allusions as memes (Jan, 2007), using the underlying philosophy and methodologies of pattern-finding software to track their transmission.

The *a priori* rationale for the memetic approach is that, as a number of “extended/universal-evolutionary” theorists argue (Dawkins, 1983b; Plotkin, 2010), any system which sustains discrete units whose attributes motivate their being copied will almost inevitably tend to boot up the evolutionary algorithm (Dennett, 1995, p. 343) and will thus become a “Darwin machine” (Calvin, 1996, p. 6) – whether the units are genes, elements of mammalian immune systems, or the gestalt-partitioned sound-segments hypothesized here to constitute memes in music (hereafter, “musemes”). That Darwinism is a valid way of looking at this aspect of music is because it is “not a theory; it is not even an observed fact: it is a tautology” (Dawkins, 1989, p. 86). Seen in this way,¹ a piece of music is a point of intersection for a number of museme lifecycles, connecting “antecedent” to “consequent” copies (or “coindexes”). Those who have the capacity to replicate musemes – in “classical” music this is the composer; in other musical cultures, the roles of listener, composer, and performer often overlap – assimilate them from their culture because certain properties of musemes motivate their copying. In Dawkins’ well known formulation, this phenomenon underpins replicators’ metaphorical “selfishness” (Dawkins, 1989; Jan, 2007, p. 9).

Most psychological accounts of similarity in music are concerned with listeners’ ability to detect relationships between musical entities, and this is clearly important for the perception and cognition of a piece or style. In Ockelford’s terms, such “zygonic” links create “a sense of *derivation* stemming from one musical element imitating another that is important in creating the sense of narrative in music” (2013, p. 16; his emphasis). From the “musemes’ eye view” (Blackmore, 2000), however, what matters is that there is a motivation to engender the transmission/replication which gives rise to similarities – in Ockelford’s terms (gestalt-demarcated) group-level zygonic links (2013, p. 136) – across works. This is primarily a function of perceptual-cognitive salience, and only secondarily of how (non-composer) listeners respond to similarities between patterns. The selfishness of musemes requires that consideration of similarity should balance that which interests listeners – those intra/intertextual relationships listeners (sometimes) perceive and (sometimes) find significant, perhaps partly for genetically motivated reasons – with the interests of musemes – those attributes which (sometimes) attract the attention of composers-as-listeners and which thereby motivate replication. Memetics arguably offers a forum for this exploration of the “nurtural” aspects of listening and their consideration in the same broad terms as those “natural” aspects encompassed by evolutionary theory and (evolutionary) psychology.

Evidencing all these assertions is beyond the scope of this article and so my objective here is the rather more limited one of arriving at a specifically evolutionary analysis of the selected phrase in order to explore its musemic structure and hypothetical replication history. If a similarity is detected one must consider whether it results from memetic transmission (homology), consciously or unconsciously by the composer; or whether it is a fortuitous

¹ See (Jan, 2010, pp. 5–8) for a more extended justification for a memetic orientation in music theory and music psychology.

recurrence of the same pattern (analogy). There is often no definitive answer to this question but, logically, the longer the replicated segment and the greater the number of shared pitches (and, to a lesser extent, rhythms), the greater the likelihood that the relationship is homological rather than analogical. Potential quantifications of such conceptual (and therefore potentially evolutionary) proximity include the “Earth-Mover’s Distance” metric (Jan, 2014) and Ockelford’s measure of “zygonicity,” the latter an index of derivation between two patterns and thus of the intentionality to imitate (2013, pp. 37, 256). When such “neutral-level” assessments are made with the support of “poietic” knowledge (Nattiez, 1990), our confidence in them is enhanced. Nevertheless, while central in cultural-evolutionary terms, the analogy/homology distinction may not necessarily impinge significantly upon listeners’ perception and cognition of similarity relationships, unless their responses are mediated by knowledge of a passage’s provenance, or by a belief (on the grounds of length and mapping) that the pattern in question must have had a specific antecedent.

In any such attempt to reconstruct the creative process, the analyst-as-listener inevitably brings to bear “esthetic” responses (Nattiez, 1990). These are colored by familiarity not only with music written before (in this case) Beethoven’s sonata, but also with music written after, which may contain musemes copied from those in the Beethoven passage. Whether hearing the music in 1821 or in 2015, every listener draws upon a unique musemic inheritance which mediates, in complex and sometimes ahistorical ways, the hearing of antecedent and (in modern listeners) consequent music. Nor is such hearing ever static in a given individual, changing over time as a result of rehearsals of a passage and of other music, related or unrelated musemically to it (Ockelford, 2013, p. 10). Even if possible, an “archaeological” mode of hearing (Byros, 2009) is further complicated by the wider conceptual framework – the “verbal-conceptual memes” – of an individual or a culture. In the case of the modern “academic” listener, this framework includes often conflicting theoretical models which have their own evolutionary history and which intersect with listening in myriad ways (Jan, 2011, sec. 4.3.1).

3. A Memetic Analysis of a Phrase from Beethoven’s Sonata op. 110

The kinds of affinities between works I regard as musemes are understood by Cope in terms of a continuum linking the five partially overlapping categories of “quotation,” “paraphrase,” “likeness,” “framework,” and “commonality” (2003, p. 11; Jan, 2014). These range from the direct reproduction of extended segments characterizing quotation to the anonymous examples of musical building blocks constituting commonalities (these being equivalent to Narmour’s “style shapes” (1990, p. 34)). For memetics, the most common type of replicated pattern folds this continuum back on itself, linking quotation with commonality. That is, a large proportion of musemes appear to be slightly longer and more salient than the 3–4 element commonalities which form the connective tissue of most styles, but they are shorter than the longest (7+-element) examples of quotations, with all the culturally proscribed implications of plagiarism these may carry. They tend to sit in the middle of the $<7\pm 2$ -element “Millerian” constraint-frame of short-term memory (Miller, 1956; Snyder, 2000).

Using these categories as a frame of reference, the closing phrase from the exposition of op. 110, I, Example 1, has been selected as the analytical object, on account of its motivic richness, its clearly demarcated texture, and the clarity of its figuration. As suggested in Section 2, undertaking such an analysis necessitates going beyond neutral-level evidence: it encourages an attempt to situate oneself at the poietic level in order to try to determine what music Beethoven might have known and to understand how he might have manipulated it in the passage under investigation. Nevertheless, while the posited antecedent coindexes seem

neutrally and poietically legitimate, the analogy/homology distinction means that other examples might have been the true sources. This proviso is arguably less important than the clear probability, on Darwinian grounds, that this music (and music generally) was not created *de novo* and that, accordingly, each meaningful element of its content had an antecedent (Ockelford, 2013, pp. 141–142). An exception to this principle is evolutionary “good tricks” (Dennett, 1995, p. 77) – obvious solutions (often commonalities), which composers tend repeatedly to alight upon independently.

Example 1 is divided into six segments or zones, on the basis of changes in texture, dynamics, figuration, and register. The component musemes are identified partly on the basis of gestalt-psychological segmentation criteria (Deutsch, 1999) and partly on the basis of “coindexation-determined segmentation” (Jan, 2011, sec. 4.1.2). That is, patterns are located in the literature which match the gestalt-demarcated segments in Beethoven’s phrase. This process is conducted by a combination of introspection, using the later version of the pattern as a “cue” to recalling earlier forms, and using the *Themefinder* website (Huron, Kornstädt, & Sapp, 2014), identifying potential matches according to the scale-degree sequence of the pattern in question. For reasons of space, and because they are considered in subsequent sections, only musemes in Zone 1 and one museme in Zone 4 are discussed in detail after Example 1. The relationship of the remainder to their hypothesized antecedents will be evident from the annotations on Example 1, which functions for these zones rather in the manner of a (inter- rather than intra-work) Kellerian wordless “Functional Analysis” (Keller, 2001).²

Example 1: Beethoven, Piano Sonata in A\flat major op. 110 (1821), I, mm. 23–40 and Hypothesized Antecedent Coindexes

Mx Z1/1A+1B: m. 23³–24¹

This musemeplex is understood as occupying m. 23³–24¹, being terminated by the closural force of the metrically strong event at m. 24¹ (Narmour, 1990, pp. 11, 219). It contains two motions from a I⁶₃ chord to a V⁴₂, the terminal return to the relatively stable I⁶₃ at m. 24¹ exerting a further closural force. An antecedent coindex might be read in Mozart’s Concerto K. 482, Example 1 ii, the middleground outer-voice line across mm. 51–4 tracing four iterations of the I⁶₃–V⁴₂ motion plus the terminal return to I⁶₃, from which Beethoven might be hypothesized to have selected a subset. If the Mozart passage is accepted as a valid antecedent coindex, then it demonstrates the capacity of musemes to migrate between structural levels, moving from being a framework (Mozart) to being a commonality (Beethoven).

² The hypothesized antecedent coindexes are placed on the smaller staves above and below the Beethoven extract. For simplicity, the passage will be taken to be in E \flat major and not the dominant of A \flat . Musemes (“M”) are numbered consecutively within each zone (Z1/1A, Z1/2, etc.), and variants are indicated by superscript (Z1/1¹, Z2/3B², etc.). Numbering of the latter is undertaken on the basis of hypothesized evolutionary sequence with respect to posited coindexes and also idiostructural ordering in op. 110, I. The constituent strata of “musemeplexes” (“Mx”) – complexes formed from two or more independently replicated musemes – are indicated alphabetically (e.g., Z1/1A (upper line), Z1/1B (middle of three or lower line of two), Z1/1C (lower line of three)). Their independence is symbolized by “//” on the linking bracket; strata whose bracket is not so marked are non-independent elements of a single indivisible museme.

Mx Z1/2A+1B¹: mm. 24¹–24³

Mx Z1/2A+1B¹ overlaps with Z1/1A+1B, in that the terminal element of the first is the initial element of the second (Jan, 2007, p. 74). Mx Z1/1A+1B is perhaps unusual in returning, at its third and fifth elements, to the disposition of its first and third. The more normal continuation is arguably represented by Mx Z1/2A+1B¹, wherein the melodic $\hat{2}$ proceeds to $\hat{5}$ over the I^6_3 in a strictly three-element structure. Mx Z1/2A+1B¹ has at least two coindexes in Beethoven's own music. The first, an antecedent coindex, underpins the theme of the slow movement of the Sonata op. 13, Example 1 iii a. The second, a consequent coindex, appears in the sketches for the Tenth Symphony, to whose Adagio melody (Cooper, 1985, p. 13) I have added an implied harmonization, after op. 13, II, in Example 1 iii b. The op. 13 and symphony forms may be evolutionarily prior to that of op. 110, on account of their arguably more stable $\hat{1}-\hat{4}-\hat{3}$ (Z1/2B) not $\hat{3}-\hat{4}-\hat{3}$ (Z1/1B¹) bass motion.³ While it is not always possible to account for the particular patterns of parataxis exhibited by musemes, Z1/2A+1B¹ may have been invoked to fill this particular locus by Z1/1A+1B because the two-fold reiteration of the $I^6_3-V^4_2$ motion of Z1/1A+1B creates a strong implication of a further iteration which is realized by Z1/2A+1B¹.

Mx Z1/3A+3B: mm. 24³–25²

Motion in parallel tenths around a sustained $\hat{4}$ tracing the progression $IV^6_3-V^7$ defines Mx Z1/3A+3B, which intersects with the rhythmic museme of Z1/1A+1B. The terminal node (final element) of Z1/3A+3B is arguably more ambiguous than is the case with Z1/1A+1B. This is because whereas the terminal node of Z1/1A+1B (m. 24¹) is a relatively stable I^6_3 approached by downward bass motion from the a_b of the preceding V^4_2 , the analogous point of Z1/3A+3B implies further continuation to V^7 by virtue of the preceding two-fold repetition of the falling bass progression g–f. Both Z1/1A+1B and Z1/3A+3B exemplify the effect of a “musico-operational/procedural” meme (that is, a replicated idea about how to manipulate musical material) which motivates the slowing down of a harmonic progression on its third statement. In view of this, the terminal node of Z1/3A+3B is either m. 25¹ (on accentual grounds) or (as is read here) m. 25² (on repetition-habituation grounds). If the latter reading is accepted, Beethoven's museme maps more closely onto its hypothesized antecedent coindex, the passage from *Le nozze di Figaro* in Example 1 iv, which also has three motions from $IV^6_3-V^7$. In Beethoven's passage the $b^2_2-a^2_2$ motion of m. 24³ migrates into the inner voice, as $b^1_1-a^1_1$, in m. 25¹⁻²; and the voice-leading of Z1/3A+3B is unparsimonious: whereas its Mozartean antecedent renders the progression smoothly in three voices, Beethoven's four parts necessitates either octave doubling of a line or, as here, disjunct inner parts.

³ A distinction must be drawn between chronological and evolutionary priority: a museme or musemplex *x* (e.g., Z1/2A+2B in Symphony no. 10) might occur in a work which was composed after a work containing museme *y* (e.g., Z1/2A+1B¹ in op. 110, I), but *x* might originally have arisen in (or certainly occurred in) a work composed before that containing *y* (e.g., Z1/2A+2B in op. 13, II).

M Z4/1: mm. 31¹–34¹

M Z4/1, appearing in mm. 8–17 of the Overture to *Die Zauberflöte*, Example 1 xi, consists of seven harmonic elements marked *a–g*. Their function is as follows: *a*: ii⁶₅; *b*: II⁶₅ (V⁶₅/V); *c*: V⁴₃/IV; *d*: IV⁶₃; *e*: vii⁷/V; *f*: V⁷; *g*: I. More fundamentally, the passage articulates a ii/IV–V–I progression, the “structural” dominant of which occurs at m. 15 (that at m. 13 is arguably a passing harmony within a IV⁶₃...vii⁷/V frame). Essentially the same progression appears in mm. 31¹–34¹ of Beethoven’s sonata, albeit in a more compressed form: a framework (a shallow-middleground level museme generated by foreground-orientated figuration) in Mozart becomes a more foreground-orientated museme in Beethoven.

Mozart’s element *a* is rendered in Beethoven at m. 31¹, the distinctive sound of the ii⁶₅ imparting to his passage the sacerdotal gravity of Sarastro’s temple. Element *b* follows immediately in Beethoven, whereas in Mozart it is deferred by contrapuntal prolongation of the ii⁶₅. Unlike Mozart’s passage, Beethoven’s element *b* proceeds to the stylistically more normative V of m. 31³ and thence to a resolution on the expected local tonic. This segment, mm. 31³–32³, constitutes an intercalated musemeplex, Z4/2A+2B, homologically separate to Z4/1. In Mozart, by contrast, there is no resolution on V here, the sidestepping V⁴₃/IV of m. 11⁴, element *c*, re-energising the subdominant/supertonic prolongation. As a result of the transposed repetition of the intercalation in mm. 32³–33¹, element *c* also occurs in Beethoven, on the last semiquaver of m. 32, reaching (in a mirror of Mozart’s rhythmic scheme) the target IV on the following strong beat.

A diminished seventh chord, element *e* in Mozart, is a functional analogue to his element *b*, whereas Beethoven’s element *e* is a simple reiteration of the II⁶₅ harmony of his element *b*. Beethoven essentially replays m. 31^{2–3} in m. 33^{2–3}, but slight differences between the two segments betray the influence of the Mozart passage. The disposition of the dominant seventh chord on the final semiquaver of Beethoven’s m. 33 – B_b, a_b, d¹, b_b¹ – is identical to that of the Mozart passage (m. 15³, string parts). On its resolution to element *g*, the upper b_b¹ is repeated over the bar line and the d¹ resolves, as expected, to e_b¹. This disposition might be understood to derive from the Overture’s main Allegro theme, Example 1 xiv, which is orientated to these two pitches in mm. 16–17. Thus, Beethoven presents vertically what in Mozart unfolds horizontally.

4. Aspects of the Perception and Conception of Musemes and Lexicons

Like all humans, Beethoven was able to memorize yet distinguish between the kinds of patterns hypothesized in Example 1, whose various similarities motivate Cope’s concept of the “lexicon”. This refers to supersets which encompass a family of similar patterns (2003, p. 20). It relates closely to the notion of museme “alleles” (Jan, 2010). Just as a gene allele is an “alternative form” of a gene (Dawkins, 1983a, p. 283), a museme allele is a substitute form of a museme, one which forms a member of a class related by certain structural or functional commonalities. Because of this, one member of the class is able to substitute for another in a particular context and still ensure musical coherence. Lexicons are most readily supported by Cope’s categories of paraphrase, likeness, and framework, in that these describe sets of patterns which are related by similarity of interval, contour, and underlying structure, respectively.

Discussing this idea using Example 1 as a point of reference, I attempt in this and the following section to integrate a memetic perspective, a structural-hierarchical account of similarity, and a neurobiological pattern- and lexicon-implementation based upon intersection at various hierarchic levels.

A lexicon draws together the features of a number of patterns which are perceived or conceived as equivalent in some way. Regarded as museme allele-classes, lexicons result from the common ancestry of a number of musemes. Two ostensibly separate lexicons may “overlap”, owing to similarities between certain of the musemes which instantiate them. It is difficult to determine whether this results only from analogical resemblance between particular musemes or whether it is the consequence of an earlier lexicon “bifurcation.”⁴ In the latter case, homological lexicon intersection occurs. Using Venn diagrams, Figure 1 i and ii represent these situations respectively.

Figure 1: Lexicon and Museme Intersection

Various complications cloud this determination:

- There may be differences between the hierarchic location of musemes, in that two musemes which are superficially similar may not in fact share an underlying structural framework, and would therefore arguably not belong in the same lexicon.
- A lexicon overlap might appear to result from pitch or rhythmic similarity between two musemes, but their rhythmic or pitch content, respectively, might be different, arguably placing them in separate lexicons.
- There may be partial overlaps between, on the one hand, contrapuntal musemeplexes consisting of stratified, evolutionarily separate melodic musemes and, on the other hand, single-stratum musemes or other musemeplexes. Such stratified complexes can logically support only partial overlaps between one or more of their component strata and other (single-stratum) musemes. They may also support partial overlaps with other musemeplexes, the other strata potentially remaining separate. In these various cases there may be either an analogical or homological relationship between the overlapping segments.

One contributory factor to the last of these is the difficulty of making a hard-and-fast distinction between harmonic and melodic musemes. When two or more parts move in rhythmic unison, have simultaneous initial and terminal museme nodes, and lack melodic salience in the lower part(s), it is perhaps more appropriate to speak only of a harmonic museme. Where there is more melodic individuality, one might identify two or more melodic musemes in contrapuntal combination, plus a resultant harmonic museme (Jan, 2011a). In the case of $Mx Z1/1A+1B$ and $Z1/2A+1B^1$, the bass, tenor, and soprano lines appear to have sufficient independence and salience to qualify as melodic musemes despite their rhythmic synchrony, but for the sake of clarity the middle parts are not labeled as separate musemes in

⁴ Bifurcation is the splitting of one museme-allele line into two branches. Its (perhaps rarer) opposite, hybridization, is the (re-)fusion of two formerly evolutionarily separate museme-lines.

Example 1. These attributes of independence and salience motivate the use of the “//” symbol which, as noted, indicates the hypothesis that the upper and lower strata of Z1/1A+1B and Z1/2A+1B¹ are evolutionarily separate musemes (which, at the risk of circular reasoning, is the precondition for describing the structure resulting from their association *as* a musemeplex).

A clear example of overlapping is seen between Z1/1A+1B and Z1/2A+1B¹ which, in addition to their temporal-sequential elision, manifest a “conceptual” overlap engendered by their shared I⁶₃–V⁴₂–I⁶₃ progression and the $\hat{3}$ – $\hat{4}$ – $\hat{3}$ bass motion of Z1/1B and Z1/1B¹, the latter motion metonymically representing the former progression.⁵ It might be argued, as represented in Figure 1 iii, that

- the $\hat{3}$ – $\hat{4}$ – $\hat{3}$ bass motion and I⁶₃–V⁴₂–I⁶₃ progression of Z1/1B and Z1/1B¹ belong to one lexicon, “Lexicon x”; that
- the $\hat{3}$ – $\hat{2}$ – $\hat{3}$ line of Z1/1A belongs to a second, “Lexicon y”; and that
- the $\hat{3}$ – $\hat{2}$ – $\hat{5}$ line of Z1/2A belongs to a third, “Lexicon z,” the latter two melodic musemes existing in association with a common bass-line/harmonic-progression museme.

It is nevertheless difficult to determine whether one may properly speak of three separate homological-lexical categories overlapping in op. 110 via these particular museme forms. There may instead be only two lexicons, Lexicon x/y (Z1/1A+1B) = $\hat{3}$ – $\hat{2}$ – $\hat{3}$ /I⁶₃–V⁴₂–I⁶₃/ $\hat{3}$ – $\hat{4}$ – $\hat{3}$, and Lexicon x/z (Z1/2A+1B¹) = $\hat{3}$ – $\hat{2}$ – $\hat{5}$ /I⁶₃–V⁴₂–I⁶₃/ $\hat{3}$ – $\hat{4}$ – $\hat{3}$. It may even be the case that there are simply three sub-lexicons within a single encompassing lexicon, Lexicon x/y/z = $\hat{3}$ – $\hat{2}$ – \hat{X} /I⁶₃–V⁴₂–I⁶₃/ $\hat{3}$ – $\hat{4}$ – $\hat{3}$, as indicated by the outer circle. This determination is complicated by the idiostructural context of direct juxtaposition (Z1/1A+1B → Z1/2A+1B¹) and the processive, mutational nature of such juxtapositions.

Showing more complex intersections and overlappings than those represented by Figure 1, the Euler diagram in Figure 2 represents the relationships between all the musemes of Example 1. The latter are given in schematic form in Example 2. Table 1 summarizes the defining attributes of each lexicon. Fourteen lexicons are posited here, but other groupings of musemes (and therefore different numbers and configurations of lexicons) are of course possible. The defining attributes of lexicons are understood as specific pattern content, expressed in terms of interval and scale-degree sequence or harmonic progression, and not more abstract, conceptual qualities, such as contour or uncontextualized pitches (e.g., “contains an A \sharp ”).

Example 2: Summary of Musemes and Musemeplexes in Example 1
--

Figure 2: Lexicon Intersection in Example 1
--

⁵ The additional iteration of the progression in Z1/1B as against Z1/1B¹ is discounted for the sake of argument. Of course, this difference in museme components may itself motivate a different reading of lexicon membership, indicating how fluid and nuanced such determinations are.

Table 1: Attributes of Lexicons in Figure 2⁶
--

5. Aspects of the Neurobiological Implementation of Musemes and Lexicons

I now turn to the issue of how musemes and lexicons are implemented in the brain in order to relate the spatial representations of Figure 1 and Figure 2 to what is currently known about the neural encoding of musical information. William Calvin's Hexagonal Cloning Theory ("HCT") (Calvin, 1996, 1998) offers a robust mechanism for the neocortical implementation of musemes and lexicons and thus may account for significant aspects of the perception, cognition, and generation of music. While a full account of the HCT is beyond the scope of this article, its claims support evidence concerning the perception and cognition of music, including similarity and lexical relationships (for a more detailed account, see Jan, 2011, from which some passages below are adapted). Calvin argues that "minicolumns" of neurons (1996, p. 205) responding to a particular input pitch will excite near-neighboring minicolumns such that monotonal triangular arrays will be formed over the surface of the auditory cortex (1996, p. 34). A museme consists of a series of such arrays in a "spatiotemporal firing pattern" ("SFP") (1996, p. 47). The most parsimonious geometric arrangement of these "interdigitating" (1996, pp. 118, 179), temporally coordinated arrays is the hexagon, virtual structures overlaid on real patterns of triangular-array excitation. The "cloning" of hexagons across the surface of cortex in response to an incoming stimulus or elicited memory motivates the emergence of the percept or memory into conscious awareness (1996, p. 45).

Hexagonal cloning drives Darwinian competition between rival hexagons, the "winning" configuration representing the closest fit between incoming data and extant encodings. The latter – our long-term memories of music and thus the most fundamental form of musemes – are preserved by durable patterns of neuronal connectivity related by Calvin to the "attractors" of chaos theory. Like a depression on an otherwise smooth surface, these draw the elements of an incoming pattern towards specific array vertices (1996, p. 68). Many configurations of attractors might be "burned" into the same region of cortex, forming virtual strata likened by Calvin to the thin, overlapping layers of fish in the Japanese delicacy sashimi (1996, p. 107).

More recent work in this area has concerned spatial representation using the "grid cells" of the entorhinal cortex (Burak & Fiete, 2009; Killian, Jutras, & Buffalo, 2012; Shrager, Kirwan, & Squire, 2008; Stensola et al., 2012). These are thought to be implicated in positional location in two-dimensional space and, like certain other brain systems, map incoming dimensional data systematically onto cortical neurons. While such studies tend not to make explicit reference to the HCT (but see Garliauskas & Šoliūnas, 2000), and while some even considerably predate Calvin's work (O'Keefe & Dostrovsky, 1971), the cells they describe also form triangular arrays which are similarly grouped into hexagonal plaques (Fuhs & Touretzky, 2006, p. 4269, Figure 2). The field of research these studies describe, in conjunction with Calvin's work, may be argued to theorize a broadly unified approach to the encoding of certain types of sensory data, one where the systematic mapping of real-world space to the geometry of the cortical

⁶ The falling fourth-progressions of L10 are bracketed in Example 2. Such subdivisions of longer pitch sequences require gestalt support to exist as viable musemes. As shown in Example 2, a third category of fourth-progression, ↓1–↓2–↓2, might be read in Z2/1B.

surface might also encompass the mapping of more abstract spaces including those engendered by pitch.

There are two aspects to the application of the HCT to musemes and lexicons. The first concerns the encoding of foreground-level musemes and the lexicons which encompass them; the second concerns the implementation of the higher-order abstractions which relate musemes within lexicons and lexicons to other lexicons. Before exploring these aspects, it is worth noting that what is discussed below is a relatively circumscribed area of a much wider network of relationships. That is, the account focuses upon the fundamental mechanics of musical information storage as hypothesized by the HCT. It does not, for reasons of space, go into detail on certain related issues, all of which appear readily accountable for by Calvin's theory. These include the motor actions motivated by musical patterns which underpin musical performance (Jan, 2011, sec. 2, Table 1; Leman, 2008), and the verbal-conceptual memes associated with purely musical information as part of the semiotic content of music (Jan, n.d.).

Figure 3 hypothesizes how the lexicon configurations in Figure 1 iii might be implemented in the cortex. Triangles colored red are active (firing) and those colored blue are "silent."⁷ H[exagon]1 represents Z1/1B and Z1/1B¹ ((Sub-)lexicon *x*), including inner voices/IMPLIED harmony. H2 and H3 represent, respectively, the melodic musemes Z1/1A ((Sub-)lexicon *y*) only and Z1/2A ((Sub-)lexicon *z*) only. H4 represents the lexicon encompassing H1–H3 (Lexicon *x/y/z*). It also represents – to identify other alleles – the opening motive of the Allegretto of Beethoven's "Moonlight" Sonata (Example 3 i), transposed to E_b major, provided the c² array (shown dotted red) is firing; and a figure from the first movement of Beethoven's Piano Concerto no. 4 (Example 3 ii), similarly transposed. In both perception and recollection, the cortical substrate of these musemes is hypothesized to consist of a sequential movement through specific patterns of array activation.

Figure 3: Calvinian Implementation of Figure 1 iii

Example 3: Musemes in Figure 3

- i) Beethoven: Piano Sonata in C# minor op. 27 no. 2 ("Moonlight") (1802), II, mm. 0³–2¹

- ii) Beethoven: Piano Concerto no. 4 in G major op. 58 (1805), I, mm. 157–8

⁷ The minicolumnar grid is taken from <http://williamcalvin.com/Demo2.htm> (accessed 27 November 2014). While not intended to represent the precise topographic organization of the auditory cortex, it assumes that its surface is systematically "tuned" to pitch, with sufficient receptor repetition and interdigitation to allow hexagons to encompass the same pitch class in different octaves and in different configurations.

The same sequence of pitch or the same pitch content might give rise to two separate musemes on account of rhythmic differences, as in the case of Z1/1B and Z1/1B¹. Calvin distinguishes between spatial-only (semantic memory) and spatiotemporal (episodic memory) patterns (1996, p. 65; Snyder, 2000, p. 108), implying that the primary parameter encoded by arrays is pitch, and that rhythm is an emergent property resulting from firing-order. Whereas the firing-order in perception and cognition is a response to incoming stimuli, in memory it is an artifact of the interaction between “initial conditions” and attractor embedding (1996, p. 66). A set of stimulus cues – perhaps the previously heard or recalled museme – may activate the arrays for a specific pitch museme to fire in a variety of patterns, defined by the progress of the activation down a range of possible sashimi-paths from attractor to attractor to the stasis of the lowest stratum. These paths constitute the memories of specific durational, accentual, or inter-onset-interval configurations defining a range of co-adapted rhythmic musemes.

Intersecting hexagons in Figure 3 represent overlaps between elements in certain parameters at various points of two or more musemes, implemented as shared triangular arrays straddling musemes. Ignoring rhythm, the pitch intersection set $H1/(S-)lx \cap H2/(S-)ly \cap H3/(S-)lz$ is the six-pitch melodic-harmonic sequence $\hat{2}-\hat{3}|\hat{5}/V^4_2-I^6_3/\hat{4}-\hat{3}$, boxed in Example 1 and Example 3.⁸ It links all alleles, and so the presence of this SFP (“S” here representing spatial, not spatiotemporal) constitutes the defining criterion for membership of the lexicon encompassed by H4. Two or more musemes within a lexicon may share one or more arrays which, unlike those at $H1 \cap H2 \cap H3$, are not common to all members of the lexicon, this being a candidate cortical analogue for the phenomenon of the sub-lexicon. This situation might occur in the context of alleles containing the pattern enclosed by the dotted box in Example 3 i, with its characteristic $\hat{6}/c^2$, a pitch absent in $H1 \cap H2 \cap H3$.

The layout of Figure 3, if replicated in cortex, suggests that numerous (sub-)lexicons may occupy the same region of cortex, being distinguished only by their particular SFPs. While Figure 1 and Figure 2 represent patterns as to some extent distinct and topographically separate, Figure 3 suggests that a variety of patterns are spatially coexistent in the connectivity, awaiting activation. Whether Z1/1A, Z1/2A, and Z1/1B and Z1/1B¹ are regarded as separate lexicons or as sub-lexicons depends in part on the size of the encompassing hexagon, on the number of “voices” it includes, and on the particular SFPs of the incorporated arrays. As with intersection *within* lexicons, that *between* lexicons (represented in Figure 1 ii and iii) arises through array interdigitation: elements constituting a museme or sub-lexicon in one lexicon might be common to a museme or sub-lexicon in another, in which case the two lexicons partially overlap as a result of hexagonal straddling. It appears likely that the majority of lexicons are connected via such partial intersections, and so the museme intersection within a lexicon creating sub-lexicons is replicated, at a recursively higher level, by intersection between lexicons.

This property arguably attenuates the conceptual and cortical distinctions between lexicons and sub-lexicons, and between lexicons and other lexicons. In cortex such distinctions – and thus the categories they represent – appear to be fuzzy. Moreover, the Calvinian implementation of a pattern does not appear contingent upon its provenance. The analogy-homology distinction does not appear to have a direct cortical equivalent, so whilst evolutionarily very significant, and while potentially relevant to listeners, it is not “written

⁸ The $\hat{5}$ (b_1^2) does not occur as a melodic pitch in every allele, but is nevertheless present (as b_1^1/b_1) in all.

into” the cortex at the level of topographical museme/lexicon implementation. The brain’s priority appears to be parsimonious pattern encoding, not with charting a particular individual’s necessarily limited impression of memetic-evolutionary history.

Cognition of similarity between musemes within a lexicon appears contingent upon abstraction of the underlying similarities between superficially different pattern-instantiations, which also appears to underpin a number of other music-psychological phenomena, including the features-schemata dualism (Gjerdingen, 1988, 2007; Leman, 1995) and, therefore, Cope’s notion of frameworks. This is implemented by the principle of “hashing,” where an abstracted “message digest” acts as a “unique short-form identifier ... of something more complicated” (Calvin, 1996, pp. 17, 207). Prominent and defining attributes which qualify a set of similar patterns for membership of a lexicon – the intersection set containing those elements common to all musemes within it, such as the pattern at $H1 \cap H2 \cap H3$ in Figure 3 – are copied to a “centrally-located category representation” (“CLR”) (Calvin, 1996, p. 135). Abstraction is accomplished by what Calvin terms “*faux-fax*” links connecting certain analogous arrays from hexagons in different regions of cortex to matching arrays of higher-level “index hexagons” (1996, pp. 125, 131).

Figure 4 (after Jan, 2011, Figure 14) hypothesizes a mechanism for this process. The NE, NW, and SE quadrants encompass representations of three lexicons, A, B, and C, within each of which are three musemes, A_x , A_y , and A_z , etc., each represented as a group of three hexagonal tiles. The arrays of each allele are shown in various different colors; the identical set of colors employed in each allele is not intended to suggest that each has exactly the same pitch-class content as its co-alleles. The SW quadrant encompasses the CLR(s), wherein those pitches of the musemes constituting each lexicon occupying all-member intersection sets (represented by a three-note subset of the arrays) are abstracted by the higher-order representations, each shown as a group of three hexagonal tiles.

Figure 4: Calvinian Implementation of Hierarchic Lexical Abstraction

This model is “vertical”/hierarchic, in that patterns stored in a CLR are not only a cognitive but also a musico-structural abstraction, however one theorizes this (Lerdahl & Jackendoff, 1983; Schenker, 1979). The pitches constituting lexicon-defining intersection sets and sub-lexicons tend to be the structural frameworks of their associated musemes: they are often important triadic and/or scalic pitches situated in strong metric positions and tightly connected by implication-realization forces (Narmour, 1990), and so are privileged acoustically and perceptually (Deliège, 2001). Such intersection sets intrinsically imply a degree of reduction, and the differences between intersecting and non-intersecting museme-elements represent if not a structural-hierarchic ladder then certainly an Einsteinian spatial curvature of the lexicon, which flags these privileged pitches for abstraction. Note that the “recursively higher level” referred to above in connection with Figure 3 and (sub-)lexicon intersection is defined by reference to “horizontal” expanse, not the pitch-structural selection characteristic of the higher levels of vertical abstraction.

The latter process appears multiply recursive: there may be several progressively more abstract levels of indexation, corresponding to increasingly remote musico-structural levels. At these higher levels there may be input from conceptual thought: while abstraction of lower-level patterns might be driven by bottom-up forces, that of higher-level features may involve the intercession of top-down verbal-conceptual memes. Recursivity is represented in Figure 4 by the *faux-fax* links converging on A_x , intended to suggest that quadrants A, B, and C (\approx “sub-

foreground”; level 3 \approx level $\boxed{3}$ in Example 1) themselves represent abstractions of patterning at a lower level (\approx foreground; level $2/\boxed{4}$); and also by those leaving from the CLR (\approx shallow-middleground; level 4 \approx level $\boxed{2}$ in Example 1) to connect to a still higher-level representation (\approx deeper middleground; level 5 \approx notional level $\boxed{1}$ in Example 1), perhaps one which abstracts structural aspects common to a number of CLR hexagons. The latter may themselves be organized into lexicons because similar higher-level structures might be abstracted from a variety of lower-level lexicon-sets. CLR lexicons might also intersect horizontally in the same ways as those at lower levels, as represented by the overlappings shown on Figure 4. The potentially large number of indexation levels implies there is a quasi-analogue progression in the vertical “plane” analogous to that linking lexicons in the horizontal.

Museme Z4/1 offers a concrete example of hierarchic abstraction. The Mozart and Beethoven passages, while very different in their foreground musemic content (the level $(2/\boxed{4})$ below that $(3/\boxed{3})$ of structures in quadrants A–C), are abstractable to the underlying $ii^6_5-II^6_5-V^4_{,3}/IV-IV^6_3-vii^7/V-V^7-I$ framework situated at level $3/\boxed{3}$. At the sub- $3/\boxed{3}$ level, several non-shared musemes might be identified, such as the rising fourth-progression $b^1_1-c^2-d^2-e^2/\hat{5}-\hat{6}-\hat{7}-\hat{1}$ (Mozart, mm. 53–4), the semiquaver triadic figures $e^1_1-c^2-a^1_1$ and $f^2-d^2-b^1_1$ (Mozart, m. 54), the falling fourth-progression $b^1_1-a^1_1-g^1-f^1/\hat{5}-\hat{4}-\hat{3}-\hat{2}$ (Beethoven, m. 33), and the dotted-rhythm perfect cadence (Beethoven, mm. 33–4), shown enclosed by dotted boxes in Example 1. While not a common pattern, other instantiations of the level- $3/\boxed{3}$ museme may exist, generated by different level- $2/\boxed{4}$ musemes. At the level $(4/\boxed{2})$ of the CLR, a linearly and harmonically coherent subset of the level- $3/\boxed{3}$ framework – perhaps $ii^6_5-II^6_5-V^7-I$, or even the diatonic $ii^6_5-V^7-I$ – might be indexed. This may conceivably occupy a lexicon consisting of patterns whose analogies may arise from different lower-level homologies.

6. Mapping Musemes in Cultural, Idiostructural, and Cortical Space

I have argued that the selfish m(us)eme is reducible to the hexagonal collection of triangular arrays constituting Calvin’s “cerebral code”. Once it has conquered sufficient cortical territory by Darwinian force, this cluster of synchronized neuronal minicolumns is able to motivate its host to produce “phenotypic” (extra-somatic) equivalents of the “memotypic” (brain-level) SFP, which facilitate its further transmission (Jan, 2007, p. 30, Table 2.1). Despite the relatively limited range of tonal materials in all musical systems, the “Humboldtian” richness of music (Merker, 2002) allows not only for a great diversity of patterning but also for miscopying, and with it a multitude of lexical relationships. These extend horizontally (via intersection) and vertically (via indexation), flooding musemic space with the differential similarity relationships which create coherence and comprehensibility in music.

Musemic propagation occurs within and between a number of spaces: the cultural (analogous to Meyer’s dialect (1996, p. 23)); the idiostructural (the sequences of musemes in works); and the cortical (the locus of the most fundamental memetic processes). These might be regarded as cultural equivalents to the intra-work foreground, middleground, and background levels, respectively. Figure 5 represents the relationships which obtain between each space. Musemes are represented by hexagons and lexicons by circles; solid arrows represent intra-brain or brain-work relationships between musemes and dotted arrows represent intra-work or work-work relationships.

Figure 5: Museme Flows across Cortical, Idiostructural, and Cultural Space

Arrow group 1(a–d) represents memetic transmission of a hexagon (memotype) from one cortex to another, via a musical work (phemotype). The third stage of this process (1c) need not be realized: a museme might be copied into a second cortex, but not be expressed phemotypically as part of an idiostructure – although without such expression it is difficult to verify, at a historical distance, whether transmission occurred. The dotted arrow (1d) represents the intertextual reappearance of a pattern from one work in another. Group 2(a–f) represents mechanisms underpinning lexical similarities between musemes within cortices and within works. These may derive from intra-cortical transmission/mutation (2a, 2b); from copying from other cortices (2d–f); or they may result from analogical similarities (2g). The intra-idiostructural dotted arrow here (2c) represents connections between musemes as they unfold in works but, as implied apropos 2d–f, these may actually arise externally. Group 3(a–f) represents the manifestation of relationships described by groups 1 and 2 within culture (i.e., the sum of all idiostructures). This level encompasses perceived lexical similarities between (as opposed to within) works (3d). Wrapping torus-like back to the cortical level, culture feeds back to the cortical level (3f), doing so via the idiostructural (3e): the wider m(us)eme-pool is manifested not abstractly but concretely, via specific cultural products.

How is this process initiated for an individual?⁹ While not necessarily in contradiction to an empiricist perspective on learning, an important facet of columnar theories of neocortical function is their contention that “humans start with some basic structure ... in the brain around the time of birth, giving rise to a huge repertoire of inherent spatial-temporal firing patterns” (Leng & Shaw, 1991, p. 252). This implies that the neonate brain has the neuronal foundation for all possible m(us)emes already provisionally laid out in its connectivity, and that enculturation reifies these inherent possibilities, initiating a lifelong process of assimilating, categorizing, and indexing musemes. With a normal complement of 10^{10} neurons linked by 10^{14} synapses this seems eminently feasible (Leng & Shaw, 1991, p. 241, Fig. 7). In this sense the neonate cortex is, in Borges’ terms, a potential “Library of Babel,” a “multimemetic hypervolume” (after Dawkins, 1991, p. 67), encompassing all possible m(us)emes in all possible lexical arrangements and awaiting the activation and attractor embedding induced by environmental stimulation (Jan, 2007, p. 196). To paraphrase Borges, “the cortex is total and its *gyri* and *sulci* register all the possible chunk-sized combinations of the twelve pitch classes and rhythmic patterns (a number which, though extremely vast, is not infinite): in other words, all that it is given to express in all musics” (1970, pp. 81–82).

One possible visualization of a minuscule region of such a hypervolume is shown in Figure 6. Three musemes from Example 1 are represented on the *y* axis (“right-handed” orientation). Their constituent loci (temporal-sequential slots) are shown on the *x* axis, and the specific values at each locus (here pitch class, represented by the integer scale) are indicated on the *z* axis. The elliptical circles represent lexical relationships between the musemes (lexicon labels correspond to those in Figure 2 and Table 1). Constraints of the two-dimensional page prevent the representation of a fully multidimensional hypervolume, in which more than one value at each locus could be indicated. Represented minimally, the SFP of a cortical hexagon appears as a series of interconnected points in multidimensional space; represented more richly, it

⁹ The question of how it began at the level of the human species has been addressed by several commentators (see, for instance, Blackmore, 2000, p. 31; Mithen, 2006; Wallin, Merker, & Brown, 2000).

would appear as a multi-angular lamella, multiply intersecting with other such lamellae within the hypervolume.

Figure 6: Three Musemes in a Multimusemic Hypervolume

To summarize the issues considered here, we might reimagine Dawkins' definition of the meme – “a unit of cultural transmission, or a unit of *imitation*” (1989, p. 192; his emphasis) – by integrating it with the HCT. At the memotypic level, a m(us)eme can be defined as

a replicator existing as a sound/image/concept-encoding SFP embedded as a series of attractors in the underlying minicolumnar connectivity of the cortex by recurrent excitation resulting from sensory or motor input and capable of colonizing large areas of cortex (and of other brains' cortices) according to Universal-Darwinian principles of replication, variation, and selection. It aligns partially with other SFPs in the 'Library of Aristoxenus' (Jan, 2007, p. 201), such that lexical associations relate and connect the discrete and particulate into a wider continuum of similarity, transmission, context, and meaning relationships across cortical, idiostructural, and cultural space.

7. References

- Blackmore, S. J. (1999). *The meme machine*. Oxford: Oxford University Press.
- Blackmore, S. J. (2000). The Memes' Eye View. In R. Aunger (Ed.), *Darwinizing culture: The status of memetics as a science* (pp. 25–42). Oxford: Oxford University Press.
- Borges, J. L. (1970). *Labyrinths: Selected stories and other writings*. (D. A. Yates & J. E. Irby, Eds.). London: Penguin.
- Burak, Y., & Fiete, I. R. (2009). Accurate Path Integration in Continuous Attractor Network Models of Grid Cells. *PLoS Computational Biology*, 5(2), e1000291.
doi:10.1371/journal.pcbi.1000291
- Byros, V. (2009). Towards an “Archaeology” of Hearing: Schemata and Eighteenth-Century Consciousness. *Musica Humana*, 1–2, 235–306.
- Calvin, W. H. (1996). *The cerebral code: Thinking a thought in the mosaics of the mind*. Cambridge, MA: MIT Press.
- Calvin, W. H. (1998). Competing for Consciousness: A Darwinian Mechanism at an Appropriate Level of Explanation. *Journal of Consciousness Studies*, 5(4), 389–404.
- Cambouropoulos, E. (1998). *Towards a general computational theory of musical structure*. University of Edinburgh, Edinburgh.
- Cone, E. T. (1987). On Derivation: Syntax and Rhetoric. *Music Analysis*, 6(3), 237–255.
- Conklin, D., & Anagnostopoulou, C. (2006). Segmental Pattern Discovery in Music. *INFORMS Journal on Computing*, 18, 285–293.
- Cooper, B. (1985). Newly Identified Sketches for Beethoven's Tenth Symphony. *Music and Letters*, 66(1), 9–18.

- Cope, D. (2003). Computer Analysis of Musical Allusions. *Computer Music Journal*, 27(1), 11–28.
- Dahlhaus, C. (1982). *Aesthetics of music*. (W. W. Austin, Trans.). Cambridge: Cambridge University Press.
- Dawkins, R. (1983a). *The extended phenotype: The long reach of the gene*. Oxford: Oxford University Press.
- Dawkins, R. (1983b). Universal Darwinism. In D. S. Bendall (Ed.), *Evolution from molecules to men* (pp. 403–425). Cambridge: Cambridge University Press.
- Dawkins, R. (1989). *The selfish gene* (2nd ed.). Oxford: Oxford University Press.
- Dawkins, R. (1991). *The blind watchmaker*. London: Penguin.
- Deliège, I. (2001). Introduction: Similarity Perception, Categorization, Cue Abstraction. *Music Perception*, 18, 233–243.
- Dennett, D. C. (1995). *Darwin's dangerous idea: Evolution and the meanings of life*. London: Penguin.
- Deutsch, D. (1999). Grouping Mechanisms in Music. In D. Deutsch (Ed.), *The psychology of music* (2nd ed., pp. 299–348). San Diego, CA: Academic Press.
- Fuhs, M. C., & Touretzky, D. S. (2006). A Spin Glass Model of Path Integration in Rat Medial Entorhinal Cortex. *The Journal of Neuroscience*, 26(16), 4266–4276.
- Garliauskas, A., & Šoliūnas, A. (2000). Hexagonal Approach and Modeling for the Visual Cortex. *Informatica*, 11(4), 397–410.
- Gjerdingen, R. O. (1988). *A classic turn of phrase: Music and the psychology of convention*. Philadelphia, PA: University of Pennsylvania Press.
- Gjerdingen, R. O. (2007). *Music in the galant style*. New York: Oxford University Press.
- Hawckett, A. (2013). *An empirical investigation into the concept of musical memes in western classical music using data mining techniques on MusicXML documents*. University of Huddersfield, Huddersfield.
- Huron, D. (2002). Music Information Processing Using the Humdrum Toolkit: Concepts, Examples, and Lessons. *Computer Music Journal*, 26(2), 11–26.
- Huron, D., Kornstädt, A., & Sapp, C. S. (2014, January 1). Themefinder. Retrieved from <http://www.themefinder.org/>
- Jan, S. B. (n.d.). From Holism to Compositionality: Memes and the Evolution of Segmentation, Syntax and Signification in Music and Language. *Language and Cognition*, accepted.

- Jan, S. B. (2007). *The memetics of music: A neo-Darwinian view of musical structure and culture*. Aldershot: Ashgate.
- Jan, S. B. (2010). Memesatz contra Ursatz: Memetic Perspectives on the Aetiology and Evolution of Musical Structure. *Musicae Scientiae*, 14(1), 3–50.
- Jan, S. B. (2011). Music, Memory, and Memes in the Light of Calvinian Neuroscience. *Music Theory Online*, 17/2. Retrieved from <http://www.mtosmt.org/issues/mto.11.17.2/mto.11.17.2.jan.html>
- Jan, S. B. (2014). Similarity Continua and Criteria in Memetic Theory and Analysis. *Journal of Music Theory Online*, 5.
- Keller, H. (2001). *Functional analysis: The unity of contrasting themes. complete edition of the analytical scores (Publikationen des Instituts für Musikanalytik, Wien)*. (G. W. Gruber, Ed.). Frankfurt am Main: Peter Lang.
- Killian, N. J., Jutras, M. J., & Buffalo, E. A. (2012). A Map of Visual Space in the Primate Entorhinal Cortex. *Nature*, 491, 761–764. Retrieved from <http://dx.doi.org/10.1038/nature11587>
- Korsyn, K. (1991). Towards a New Poetics of Musical Influence. *Music Analysis*, 10(1-2), 3–72.
- Lartillot, O. (2009). Taxonomic Categorisation of Motivic Patterns. *Musicae Scientiae Discussion Forum 4B: Musical Similarity*, 25–46.
- Lartillot, O., & Toiviainen, P. (2007). Motivic Matching Strategies for Automated Pattern Extraction. *Musicae Scientiae Discussion Forum 4A: Similarity Perception in Listening to Music*, 281–314.
- Leman, M. (1995). *Music and schema theory: Cognitive foundations of systematic musicology*. Berlin and Heidelberg: Springer.
- Leman, M. (2008). *Embodied music cognition and mediation technology*. Cambridge, MA and London: MIT Press.
- Leng, X., & Shaw, G. L. (1991). Toward a Neural Theory of Higher Brain Function Using Music as a Window. *Concepts in Neuroscience*, 2, 229–258.
- Lerdahl, F., & Jackendoff, R. (1983). *A generative theory of tonal music*. Cambridge, MA: MIT Press.
- Merker, B. (2002). Music: The Missing Humboldt System. *Musicae Scientiae*, 6, 3–21.
- Meyer, L. B. (1996). *Style and music: Theory, history, and ideology*. Chicago: University of Chicago Press.
- Miller, G. A. (1956). The Magical Number Seven, Plus or Minus Two: Some Limits on Our Capacity for Processing Information. *Psychological Review*, 63(2), 81–97.

- MIREX. (2014). Retrieved July 28, 2014, from http://www.music-ir.org/mirex/wiki/MIREX_HOME
- Mithen, S. (2006). *The singing neanderthals: The origins of music, language, mind and body*. London: Weidenfeld & Nicolson.
- Narmour, E. (1990). *The analysis and cognition of basic melodic structures: The implication-realization model*. Chicago: University of Chicago Press.
- Nattiez, J.-J. (1990). *Music and discourse: Toward a semiology of music*. (C. Abbate, Trans.). Princeton, NJ: Princeton University Press.
- O'Keefe, J., & Dostrovsky, J. (1971). The Hippocampus as a Spatial Map: Preliminary Evidence from Unit Activity in the Freely-Moving Rat. *Brain Research*, 34(1), 171–175. doi:10.1016/0006-8993(71)90358-1
- Ockelford, A. (2005). Relating Musical Structure and Content to Aesthetic Response: A Model and Analysis of Beethoven's Sonata Op. 110. *Journal of the Royal Musical Association*, 130(1), 74–118.
- Ockelford, A. (2013). *Applied musicology: Using zygonic theory to inform music education, therapy, and psychology research*. Oxford: Oxford University Press.
- Plotkin, H. C. (2010). *Evolutionary worlds without end*. Oxford: Oxford University Press.
- Schenker, H. (1979). *Free composition*. (E. Oster, Ed.). New York: Longman.
- Shrager, Y., Kirwan, C. B., & Squire, L. R. (2008). Neural Basis of the Cognitive Map: Path Integration Does Not Require Hippocampus or Entorhinal Cortex. *Proceedings of the National Academy of Sciences*, 105(33), 12034–12038. doi:10.1073/pnas.0805414105
- Snyder, B. (2000). *Music and memory: An introduction*. Cambridge, MA: MIT Press.
- Stensola, H., Stensola, T., Solstad, T., Frøland, K., Moser, M.-B., & Moser, E. I. (2012). The Entorhinal Grid Map is Discretized. *Nature*, 492, 72–78. Retrieved from <http://dx.doi.org/10.1038/nature11649>
- Street, A. (1989). Superior Myths, Dogmatic Allegories: The Resistance to Musical Unity. *Music Analysis*, 8, 77–123.
- Wallin, N. L., Merker, B., & Brown, S. (2000). *The origins of music*. Cambridge, MA: MIT Press.
- Wiggins, G. A. (2007). Models of Musical Similarity. *Musicae Scientiae Discussion Forum 4A: Similarity Perception in Listening to Music*, 11, 315–338.

