Structural Blending of Harmonic Spaces: a Computational Approach

Emilios Cambouropoulos, Maximos Kaliakatsos-Papakostas, Costas Tsougras

School of Music Studies, Aristotle University of Thessaloniki, Greece
`emilios@mus.auth.gr, maxk@mus.auth.gr, tsougras@mus.auth.gr`

ABSTRACT

This research focuses on concept invention processes and suggests that structural blending is a powerful mechanism that gives rise to novel musical concepts. Structural blending is omnipresent across several formal musical levels, from individual pieces harmoniously combining music characteristics of different pieces/styles, to entire musical styles having emerged as a result of blending between diverse music idioms. In this paper, we focus on conceptual blending in the domain of musical harmony and present primarily computational examples in the following harmonic domains: chord-level blending, chord sequence blending, scale blending, harmonic structure level blending, melody-harmony level blending. Structural blending can be used not only for music analysis and music understanding, but more so it may form the basis for creative / generative music systems; processes of conceptual blending can be incorporated in computational compositional systems, facilitating the creation of original music structures/pieces/styles and contributing to a richer comprehension / experience of music.

I. INTRODUCTION

New concepts may be invented by 'exploring' previously unexplored regions of a given conceptual space (exploratory creativity) or transforming in novel ways established concepts (transformational creativity) or by making associations between different conceptual spaces that are not directly linked (combinational creativity). Boden maintains that the latter, i.e., combinational creativity, has proved to be the hardest to describe formally (Boden 2009).

Conceptual blending is a cognitive theory developed by Fauconnier and Turner (2003; 2006) whereby elements from diverse, but structurally-related, mental spaces are 'blended' giving rise to new conceptual spaces that often possess new powerful interpretative properties allowing better understanding of known concepts or the emergence of novel concepts altogether. Conceptual blending is a process that allows the construction of meaning by correlating elements and structures of diverse conceptual spaces. It relates directly to Boden's notion of combinational creativity.

With regards to music, conceptual blending has been predominantly theorised as the cross-domain integration of musical & extra-musical domains such as text or image (e.g. Zbikowski 2002 & 2008; Cook 2001; Moore 2012), and primarily discussed from a musico-analytical perspective focusing on structural and semantic integration. Blending as a phenomenon involving 'intra-musical' elements (Spitzer 2003, Antovic 2011) is less straightforward. In principle, one of the main differences of blending theory from the theory of Conceptual Metaphor (CMT) is that it may involve mappings between incongruous spaces *within* a domain (e.g. conflicting tonalities in a musical composition). In this case,

'intra-musical' conceptual blending in music is often conflated with the notion of structural blending (Goguen & Harrell, 2012), and Fauconnier and Turner's theory is primarily applied to the integration of different or conflicting structural elements, such as chords, harmonic spaces, or even melodic-harmonic material from different idioms (e.g. Kaliakatsos-Papakostas et al. 2014; Ox 2012). A more extended discussion and critical examination of conceptual blending processes in music is presented in (Stefanou and Cambouropoulos, 2015).

In this paper it is maintained that the creative potential of conceptual blending (i.e., invention of new blends) in the domain of music is, probably, most powerfully manifest in processes that enable structural blending This study focuses on structural musical blending processes that are omnipresent across several formal musical levels, from individual pieces harmoniously combining music characteristics of different pieces/styles, to entire musical styles having emerged as a result of blending between diverse music idioms.

In the next section a succinct description of the core computational blending model is given, and, then, in section III, examples are given that illustrate the application of the theory of conceptual blending in the domain of music harmony.

II. FORMAL MODEL & HARMONY

In the context of the COINVENT project (Schorlemmer et al., 2014) a model is being developed that is based on Goguen's proposal of a Unified Concept Theory (Goguen, 2006), inspired by the category-theoretical formalisation of blending (Goguen, 1999) that employs the category-theoretical colimit operation to compute blends. This methodological framework incorporates important interdisciplinary research advances from cognitive science, artificial intelligence, formal methods and computational creativity. As an illustration of the model's potentialities, a proof-of-concept autonomous computational creative system that performs melodic harmonization is developed.

Different musical styles/idioms establish independent harmonic spaces that involve a network of inter-related constituent concepts such as chord, root, scale hierarchy, tonality, harmonic rhythm, harmonic progression, voice-leading, implied harmony, reduction, prolongation and so on. Conceptual blending is facilitated when a rich background of concepts is available and when these concepts are structured in such ways that creative mappings are supported. Thereby, the existence of a rich background that includes formal descriptions of diverse harmonic elements is required, which fosters the selection and combination of concepts that inject novelty and creativity to the melodic harmonization process. A rich idiom-independent representation of harmonic concepts is proposed: from the

'primitive' chord events (see General Chord Type representation – Cambouropoulos et al 2014) to a hierarchical multiple-viewpoint representation of harmonic structure that allows 'meaningful' blends at various hierarchic levels of harmony. Knowledge extracted from a large dataset of more than 400 harmonically annotated pieces from various diverse musical pieces (mainly in a statistical formalization) comprise the rich background required for interesting and creative blends.

A core-model for conceptual blending has been developed that is schematized in Figure 1. According to this model, conceptual blending is employed between two input spaces, I1 and I2, while it is based on generalizing some concepts that pertain either to I1 or I2, leading to the respective 'weakened' input spaces, I1' and I2', where I1'and I2' are more general than I1 and I2 respectively (Ontañón and Plaza 2012). The concepts that are common in both input spaces are preserved in the 'generic' space (denoted by G in Figure 1). It is expected that two conceptual spaces, I1 and I2, will most likely include concepts that are incompatible and/or contradicting. To this end, the generalisation operation is successively employed for the weakening the input spaces for as long as there are contradicting concepts between them. This process leads to the resolution of all incompatibilities and contradictions, allowing the compatible and non-contradicting parts of the input spaces to be combined/blended ('blend' denoted by B in Figure 1).
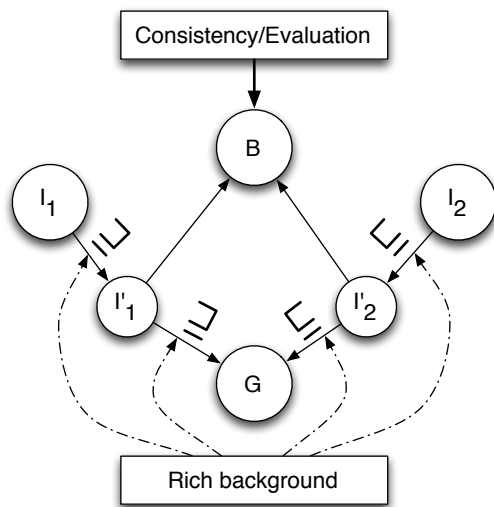

Figure 1. The COINVENT core model for conceptual blending between two input spaces (I1 and I2).

When considering, however, conceptual blending for input spaces that are grounded on rich knowledge repositories, there are numerous possibilities for generalisation, leading to questions about which generalisation scenario would yield a 'useful' or 'interesting' blend. Thereby, the utilisation of background knowledge is required for setting some domain-specific limitations to the generalisation possibilities that would potentially make sense, as well as a mechanism for consistency/evaluation check of the resulting-blended conceptual space.

An important part of a creative blending process is the evaluation of its output. Evaluating creativity - either human or computational - is a non-trivial task, especially when the assessment of aesthetic quality is also involved - a comprehensive discussion on aesthetic appreciation and aesthetic judgments is presented by Leder et al. (2004). The mere definition of creativity is problematic and not commonly accepted as many authors approach it from different perspectives (e.g. Boden, 2004; Wiggins, 2006; for a comprehensive discussion see Jordanous, 2012). Creativity is often approached by breaking it down into smaller constituent dimensions (e.g. novelty, value, surprise, problem solving ability, originality, divergence etc.). In terms of assessing a creative system, the two usual approaches are either to evaluate directly the product of the system or to evaluate the productive mechanism (Pearce, 2001). A preliminary empirical evaluation of the output of the chord blending module of the melodic harmonisation system is given in section III-A.

Aim of this paper is to provide an overview of the wide spectrum of creative applications that the development of the COINVENT blending model introduces in the context of a melodic harmoniser, and to present examples of conceptual blending in musical harmony, in the following harmonic domains:

- Chord-level blending: Individual chords that share common properties are blended giving rise to novel instances of chord functions (e.g., cadence blending)
- Chord sequence blending: sequences of chords from different idioms are blended creating sequences of different degrees of originality (sequence concatenation and sequence chord-to-chord bending
- Scale-blending: Scales are combined to create novel artificial scales.
- Melody-harmony level: a given melody with specific properties and implied harmonic space(s) is blended with features of a different harmonic space allowing the generation of novel melodic harmonisations.
- Harmonic structure level: different levels of harmonic structure from diverse harmonic spaces are combined generating 'coherent' new blended harmonies.

The presented examples aim to demonstrate the effectiveness of the computational model in 'inventing' novel concepts (like the 'invention' of the tritone substitution progression in the next section). Some of these examples are generated computationally, others are described theoretically in a systematic manner with the view to implementing them in the COINVENT melodic harmonisation system.

III. HARMONIC BLENDING EXAMPLES

A. Chord Level Blending

Chords can be seen not only as simple collections of co-sounding notes, but as richer concepts that embody several properties/relations: from roots, types and degrees of dissonance to voice leading characteristics and chord functionality. Is it possible to blend different chordal input spaces? As a first experiment, an attempt has been made to blend musical cadences (Eppe et al., 2015), and, more specifically, the pre-final chords of cadences that have well-established functional characteristics. For instance, conceptual blending may be applied to the input spaces of a perfect cadence and a phrygian cadence (Figure 2), these

being represented as collections of notes in a tonal context with weights attached to each note based on functional properties (e.g. salience of leading note or tritone in the prefinal chord of the perfect cadence – see bold lines in Figure 2). This blending process gives rise to the Tritone Substitution progression (a cadential type that emerged in jazz, centuries after the main tonal/modal input cadences! – see Figure 2); many other blends are possible (e.g. backdoor progression/cadence – see Figure 2) some of which have been examined further in an empirical listening test (see below).
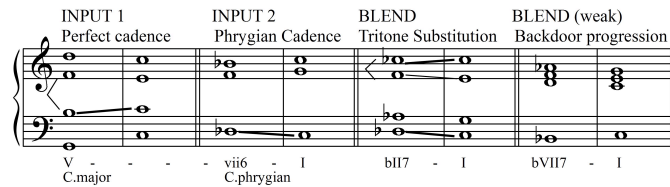

Figure 2. Conceptual blending between the basic perfect and phrygian cadences gives rise to the Tritone Substitution progression / cadence (the Backdoor progression can also be derived as a blend, even though a weaker blend).

A preliminary subjective evaluation of the proposed blending system has been conducted (Zacharakis et al., 2015). A pairwise dissimilarity listening test using as stimuli original and blended cadences (in total nine cadences) produced by the system was conducted. Multidimensional Scaling analysis provided spatial configurations for both behavioural data and the dissimilarity estimations by the algorithm. The aim of the study was to examine whether perceptual distances between pairs of cadences, as rated by the participants, were actually reflected by distance metrics that relate to the formalisation of cadences in the blending system. The comparative results show that the system is capable of making fair predictions of the perceived dissimilarities between the blended cadences and that the system can model the perceptual space quite accurately.

B. Chord Sequence Level Blending

Chord level blending can be employed for chord sequence concatenation (i.e. connecting sequences that cannot be 'naturally' connected within a certain idiom) or for original sequence blendings (e.g., blending of chord with similar functions in two sequences, or, even, full bending of every corresponding chord in two sequences).

Suppose we have trained a harmonic system on the basic major-minor harmonic idiom (without chromatic alterations). The system has learned basic chords (e.g., major, major seventh, minor, diminished, diminished seventh) and chord progressions (e.g. first-order transition matrices) for the major and minor scales separately, and, can use these to generate new chord sequences (Kaliakatsos-Papakostas et al., 2014). Such a system works fine within a certain key, but may reach an impasse if a transition to a new distant key is required. For instance, let us suppose that a chord sequence starts in C major and at some point it is forced to proceed into a chord progression starting with chords G#7-C# (remote modulation from C major to C# major). The system will not find any transition from the available diatonic chords in C major to the G#7 chord and will terminate or give an arbitrary continuation. Could chord blending give a solution to overcome this impasse creating an acceptable transition to bridge these two remote key areas?

Let us assume that the system has generated a sequence of chords in C major such as C-Dm-G7-C-(F) and then encounters the G#7-C# modulation chords. The C major chord can be followed by a number of chords (e.g. F, Fm, G etc.) but not G#7. Is it possible to blend, for instance, F with G#7 to create a new transitional chord that bridges the two key regions? F is [5,9,0] and G#7 is [8,0,3,6] in pitch class (pc) notation. If we blend these two chords and constrain the resulting chord to belong to one of the basic chord types (e.g., 4-note tertian chords such as major seventh, diminished seventh), we get [0,3,6,9] which contains two notes from the first chord and three from the second; this resultant chord is the diminished seventh chord that is well-known to be very versatile and useful for modulations to various keys. The blending mechanism 'invents' a new chord state that bridges the two key regions. This chord can then be used as an ending constraint to the C major (first) tonality and, at the same time, as a beginning constraint to the C# major (second) tonality, allowing the chord sequence generator of the melodic harmoniser (Kaliakatsos-Papakostas et al., 2014) to construct a chord sequence that covers both tonality areas.

Chord blending may be employed not only to connect different chord sequences, but to blend in a chord-to-chord fashion two different sequences. Such experiments are currently performed and are part of ongoing research.

C. Scale Blending

Using a similar strategy as the one employed for chord blending, it is possible to create new scales. Especially in jazz a variety of non-diatonic scales are used, many of which can be seen as blends between standard established scales. Aspects of the scale ontologies that may enter the blending process are individual scale degrees, whole tetrachords, and/or tonic degrees. The examples presented in Figure 3 are some interesting cases – these have been assembled manually for the scope of this paper and are part of ongoing research in computational music blending.
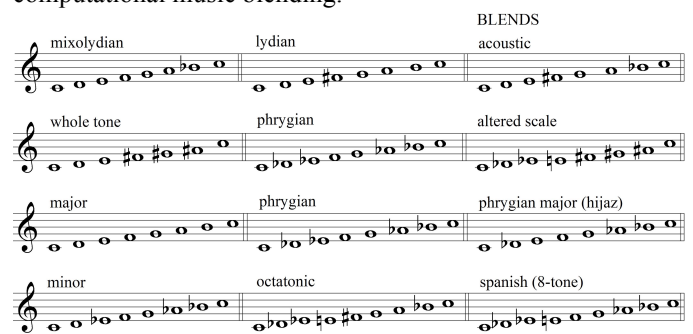

Figure 3. Scale blending - the last scale in each staff may be seen as a blend between degrees of the two previous scales.

Scale blending may be used in the context of the proposed harmoniser as a means to alleviate inconsistencies between the scale upon which a given melody is built and the scale(s) associated with a proposed harmonic space.

D. Melody – Harmony Level Blending

The friction between musical styles and potential incompatibilities can prompt creative processes that allow

new concepts to emerge. Musical creativity often arises when radically different musical idioms/styles intersect. Attempting to harmonise given melodies in foreign harmonic styles is a domain which allows different musical concepts to meet, or even clash, making it an appropriate field to explore musical blending and concept invention (for instance, in the context of the movement of musical nationalism that emerged in the 19th century, composers *blended* local musical elements such as folk melodies with aspects of established western musical idioms such as classical tonality or post-tonal harmony, giving rise to new harmonic musical styles).

A melody embodies a rich set of musical concepts that relate to scales, tonal centres, motives, cadential patterns, phrase structure, rhythmic characteristics, implied harmony, and so on. Harmonising a given melody within its implied 'natural' harmonic space involves primarily exploratory creative processes, whereas a foreign harmonic language triggers the need to combine different musical spaces leading to novel harmonic concepts (combinational creativity). A number of different harmonisations of a single melody are given in Figures 4 & 5; the harmonisations are created automatically by the COINVENT melodic harmoniser (see next subsection; at this stage, chord types are computer-generated - voice leading is added manually). The creative system is expected to be able to adapt/adjust existing harmonic systems to foreign (possibly incompatible) melodic structures by means of transformation and/or invention of new harmonic concepts; in this phase, however, the alignment of two distinct musical spaces is assisted by the user (e.g. which notes should be harmonised, harmonic rhythm, selection of 'appropriate' harmonic idiom for selected melody).

a. Michelle (Beatles) harmonised in Bach chorale style

b. Michelle (Beatles) harmonised in traditional jazz style

Figure 4. Two different harmonisations of *Michelle* by The Beatles (chord types generated by melodic harmoniser).

a. Bach Chorale melody harmonised in medieval Fauxbourdon style

b. Bach Chorale melody harmonised in Renaissance modal style

Figure 5. Two different harmonisations of a Bach Chorale melody (chord types generated by melodic harmoniser).

E. Harmonic Structure Level Blending

Conceptual invention and blending is facilitated when a rich background of diverse concepts is available and when these concepts are structured in such ways that creative mappings are supported. When concept invention takes place, the rich structural networks that often lie dormant under 'seemingly' simple concepts, get activated enabling meaningful mappings and productive blends. A computational system of (musical) creativity must have access to such rich underlying structural representations on various hierarchic levels.

It is maintained that a melodic harmonisation assistant that facilitates conceptual blending should allow a modular highly structured representation of harmonic concepts in an explicit manner at various hierarchic levels and parametric viewpoints. In this study, five constituent structural components of harmony are explicitly represented:

- Harmonic pitch space: scales, pitch hierarchies in scales, consonance/dissonance, chord types.
- Chord transitions: Learning of chord transitions from corpus data in one or more idioms/styles (e.g. dominant is followed most commonly by tonic chord).
- Cadences: Learning of chord transitions that end phrases at various hierarchic levels (e.g. for tonal music, perfect cadence for the highest level cadence, other types of cadences at various lower level structural boundaries).
- Modulations: Changes of harmonic pitch spaces that characterise a certain style (e.g. neighbouring/distant tonalities, density of modulations, etc.).
- Voice leading: general characteristics of the way chords are realised and connected in a given idiom (e.g. parallel/similar/oblique/contrary motion, drone tones, repetition or 'compulsory' motion of certain pitches, preparation/resolution of dissonance, etc.).

In the current study, at the lowest level the General Chord Type (GCT) representation (Cambouropoulos et al 2014) has been utilised for automatically encoding chords in the context of a given pitch space and consonance/dissonance ordering of intervals. Then this extracted encoding is used for harmonic learning at various levels. Kaliakatsos-Papakostas et al. (2014) introduce a constrained HMM (cHMM) that combines a well–studied probabilistic methodology, namely, the hidden Markov model (HMM), with constraints that incorporate fixed beginning and/or ending chords and/or intermediate anchor chords. Beginning or ending chords (cadences) and intermediate chords (e.g. relating to tonicisations/modulations/phrase endings) are represented using simple probabilistic grammars that capture harmonic dependencies among distant events. The application of efficient voice leading is also tackled through a statistical learning technique, which encapsulates statistical information about pitch height contour relations between the constituent pitches of successive chords. The phrase structure and the voice-leading statistical learning methodology are parts of ongoing research.

Once structural characteristics of diverse harmonic idioms are induced in an explicit modular fashion, then blends can be

created that combine different harmonic aspects from different harmonic spaces. For instance, modal chord transitions may be combined with tonal cadences (see example in Figure 6), or, more 'adventurous' arbitrary blends may be generated that combine, say, atonal chord transitions with tonal voice leading and jazz cadences. Such harmonic blending can be found in music by composers of different periods (most notably in the 20th century).

Figure 6.   Bach Chorale melody harmonised in medieval Fauxbourdon style with inserted tonal cadences (cf. Figure 5a).

IV. CONCLUSION

Structural conceptual blending in music is a powerful mechanism that gives rise to novel musical concepts. In this study, a number of computational examples have been presented in the domain of harmony; these examples highlight the potential of the proposed formal conceptual blending strategy. More specifically, examples were presented in harmonic blending at the level of chords (cadences), chord sequences, scales, harmonic structure modules, and melodic harmonisation. Structural blending can be used for understanding musical structures, but, additionally, it may form the basis for creative / generative music systems. It is suggested that formal blending processes can be incorporated in computational compositional systems, in order to invent new harmonic concepts and to create original music structures/styles. It is suggested that conceptual blending may contribute to a richer comprehension/experience of music and to the development of more creative compositional systems.

ACKNOWLEDGMENTS

REFERENCES

Antovíc, M. (2011). Musical metaphor revisited: Primitives, universals and conceptual blending. *Universals and Conceptual Blending*, February 2011.

Boden, M. A. (2009). Computer Models of Creativity. *AI Magazine*, 30(3):23.

Boden, M. A. (2004). *The creative mind: Myths and mechanisms* (2nd edition). Routledge, London, UK.

Cambouropoulos, E. , Kalliakatsos-Papakostas, M, Kühnberger, K-U., Kutz, O., Smaill, A. (2014). Concept Invention and Music: Creating Novel Harmonies via Conceptual Blending. In *Proceedings of the 9th Conference on Interdisciplinary Musicology (CIM2014),* Berlin, Germany.

Cambouropoulos, E., Kaliakatsos-Papakostas, M., Tsougras, C., (2014). An Idiom-independent Representation of Chords for Computational Music Analysis and Generation. In *Proceeding of ICMC-SMC 2015,* Athens, Greece.

Cook, Nicholas. (2001). Theorizing musical meaning. *Music Theory Spectrum* 23/2: 170-195.

Eppe, M., Confalonieri, R., Maclean, E., Kaliakatsos-Papakostas, M., Cambouropoulos, E., Schorlemmer, M. and Kühnberger, K.-U. (2015). Computational invention of cadences and chord progressions by conceptual chord-blending. *Proceedings of the 24th International Joint Conference on Artificial Intelligence (IJCAI)* 2015.

Fauconnier, G. and Turner, M. (2003). *The Way We Think: Conceptual Blending And The Mind's Hidden Complexities*. Basic Books, New York, reprint edition.

Goguen, J. (1999). *An introduction to algebraic semiotics, with application to user interface design*. In C. L. Nehaniv, editor, Computation for Metaphors, Analogy, and Agents, volume 1562 of Lecture Notes in Computer Science, pages 242–291.

Goguen, J. (2006). Mathematical Models of Cognitive Space and Time. In D. Andler, Y. Ogawa, M. Okada, and S. Watanabe (eds.), *Reasoning and Cognition, Interdisciplinary Conference Series on Reasoning Studies*, volume 2. Keio University Press.

Goguen, J. and Harrell, D. H. (2010). Style: A Computational and Conceptual Blending-Based Approach. In S. Argamon and S. Dubnov (eds.), *The Structure of Style: Algorithmic Approaches to Understanding Manner and Meaning*, pp. 147–170. Springer.

Jordanous, A. K. (2012). *Evaluating computational creativity: a standardised procedure for evaluating creative systems and its application* (Doctoral dissertation, University of Sussex).

Kaliakatsos-Papakostas, M. & Cambouropoulos, E. (2014). Probabilistic harmonisation with fixed intermediate chord constraints. *Proceeding of the ICMC-SMC 2015*, Athens, Greece.

Leder, H., Belke, B., Oeberst, A., & Augustin, D. (2004). A model of aesthetic appreciation and aesthetic judgments. *British Journal of Psychology*, *95*(4), 489–508.

Moore, Allan F. (2012). *Song means: Analysing and interpreting recorded popular song.* Ashgate, Aldershot.

Ontañón, S., and E. Plaza. 2012. *On Knowledge Transfer in Case-Based Inference*. In D. Agudo, Belén, and I. Watson, (editors) Case-Based Reasoning Research and Development, *Lecture Notes in Computer Science, volume 7466.* Springer Berlin Heidelberg, pp. 312–326.

Ox, J. (2014). Analogy and Conceptual Blending are Part of a Visualization Toolkit for Artists and Scientists: Introducing the Cognitive Space Transfer. *Proceedings of the IEEE VIS2014 Arts Program VISAP'14: Art + Interpretation.* Paris, France.

Pearce, M., & Wiggins, G. (2001). Towards a framework for the evaluation of machine compositions. In *Proceedings of the AISB'01 Symposium on Artificial Intelligence and Creativity in the Arts and Sciences* (pp. 22–32).

Schorlemmer, M., Smaill, A., Kühnberger, K.-U., Kutz, O., Colton, S., Cambouropoulos, E. and Pease, A. (2014). COINVENT: Towards a Computational Concept Invention Theory, *5th International Conference on Computational Creativity (ICCC),* 10-13 June 2014, Lubljana, Slovenia.

Spitzer, M. (2003). The metaphor of musical space. *Musicae Scientiae*, 7(1):101-120.

Stefanou, D. and Cambouropoulos, E. (2015). Enriching the Blend: Creative Extensions to Conceptual Blending in Music. *Proceedings of the 9th Triennial Conference of the European Society for the Cognitive Science of Music (ESCOM)* Manchester.

Turner, M. (2014) *The Origin of Ideas: Blending, Creativity, and the Human Spark.* Oxford University Press, 2014.

Wiggins, G. A. (2006). A preliminary framework for description, analysis and comparison of creative systems. *Knowledge-Based Systems* 19(7):449–458.

Zacharakis, A., Kaliakatsos-Papakostas, M. and Cambouropoulos, E. (2015) Conceptual Blending in Music Cadences: A Formal Model and Subjective Evaluation. (submitted).

Zbikowski, L. M. (2002) *Conceptualizing Music: Cognitive Structure, Theory, and Analysis.* Oxford University Press.

Zbikowski, L. M. (2008) Metaphor and music. *The Cambridge handbook of metaphor and thought,* pp. 502-524.