CONCEPTUAL BLENDING IN MUSIC CADENCES: A FORMAL MODEL AND SUBJECTIVE EVALUATION.

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ABSTRACT

Conceptual blending is a cognitive theory whereby elements from diverse, but structurally-related, mental spaces are ‘blended’ giving rise to new conceptual spaces. This study focuses on structural blending utilising an algorithmic formalisation for conceptual blending applied to harmonic concepts. More specifically, it investigates the ability of the system to produce meaningful blends between harmonic cadences, which arguably constitute the most fundamental harmonic concept. The system creates a variety of blends combining elements of the penultimate chords of two input cadences and it further estimates the expected relationships between the produced blends. Then, a preliminary subjective evaluation of the proposed blending system is presented. A pairwise dissimilarity listening test was conducted using original and blended cadences as stimuli. Subsequent multidimensional scaling analysis produced spatial configurations for both behavioural data and dissimilarity estimations by the algorithm. Comparison of the two configurations showed that the system is capable of making fair predictions of the perceived dissimilarities between the blended cadences. This implies that this conceptual blending approach is able to create perceptually meaningful blends based on self-evaluation of its outcome.

1. INTRODUCTION

Conceptual blending is a cognitive theory developed by Fauconier and Turner [8] 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. The general framework within which the current work is placed, comprises a formal model for conceptual blending [7] based on Goguen’s initial ideas of a Unified Concept Theory [9, 18]. This model incorporates important interdisciplinary research advances from cognitive science, artificial intelligence, formal methods and computational creativity. To substantiate its potential, a proof-of-concept autonomous computational creative system that performs melodic harmonisation is being developed.

Musical meaning is to a large extent self-referential; themes, motives, rhythmic patterns, harmonic progressions and so on emerge via self-reference rather than external reference to non-musical concepts. Since musical meaning largely relies on structure and since conceptual blending involves mapping between different conceptual structures, music seems to be an ideal domain for conceptual blending (musical cross-domain blending is discussed by Antović [1], Cook [6], Zbikowski [24]). Indeed, structural conceptual blending is omnipresent in music making: 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.

Suppose we have a basic tonal ontology where only diatonic notes are allowed and dissonances in chords are mostly forbidden (except possibly using minor 7th intervals as in the dominant seventh chord). We assume that some basic cadences have been established as salient harmonic functions around which the harmonic language of the idiom(s) has been developed, such as the authentic/perfect cadence, the half cadence, the plagal cadence and, even, older 15th century modal cadences such as the Phrygian cadence (Figure 1). The main question to be addressed is the following: Is it possible for a computational system to enrich its learned tonal ontology by inventing ‘new’ meaningful cadences based on blending between known cadences?

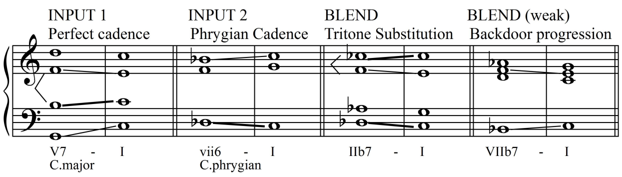


Figure 1: Conceptual blending between the basic perfect and Phrygian cadences gives rise to the Tritone Substitution progression/cadence. The Backdoor progression can also be derived as a weaker blend since less attributes of the two input spaces are retained leading to a lower rating by the system.

Figure 1 presents a conceptual blending example where the perfect and the 15th century modal Phrygian cadences are used as input spaces. These have been chosen in this example as they are both final cadences to the tonic and at the same time, they are very different (i.e. the Phrygian mode does not have an upward leading note to the tonic but rather a downward 'leading note' from the IIb to the I). Initially, these cadences are formally described as simply pitch classes with reference to a tonal centre (C tonality was adopted in this case). Assuming that the final chord is always a common tonic chord, blending takes place by combining pitches of the penultimate chords between different cadences. Rather than mere combination of pitches, other characteristic attributes of a cadence are also taken into account. Weights/priorities that reflect relative prominence (e.g., root, upwards or downwards leading note, dissonant note that requires resolution – see Figure 1 where lines of variable thickness illustrate relative strength of voice-leading connections in cadences) are assigned to each chord note according to a human expert. The 'blended' penultimate chord is also constrained to comply with a certain chord type such as the major or minor chord (in this instance the characteristic major chord with minor seventh was preferred).

Let us examine the particular blending example between the perfect and the Phrygian cadences more closely. Notes from the two input penultimate chords of the two cadence types create a large number of possible combinations. We start with combinations (at least 3 notes) of the highest priority/salience notes (notes connected with bold lines in Figure 1). Many of these combinations are not triadic chords and may be filtered out using a set of constraints (in this instance our constraint is to have a chord that is a standard characteristic tonal chord such as a dominant seventh), while also a note completion step might be required (adding notes to incomplete blending results) if the examined combination incorporates too few notes; more details regarding constraints will be given in subsection 2.1. Among the accepted blends, the most highly rated one based on priorities values is the tritone substitution progression (IIb7-I) of jazz harmony. This simple blending mechanism 'invents' a chord progression that embodies characteristics of the Phrygian cadence (root/bass downward motion by semitone) and the dominant seventh chord (resolution of tritone). Thus, it creates a new harmonic 'concept' that was actually introduced in jazz, centuries later than the original input cadences. The Backdoor Progression also appears in the potential blends albeit with much lower priority (i.e. a much weaker blend) – see Figure 1. A number of other applications and uses of harmonic blending [11] and, more specifically, chord blending are reported in [7].

Following the above, a challenging question that needs to be addressed concerns the evaluation of the outcome produced by such a creative system. The mere definition of creativity is problematic and not commonly accepted as many authors approach it from different perspectives (e.g., [3,5,17,21], for a comprehensive discussion see [10]). Applications of computational creativity to music pose the extra issue of aesthetic quality judgement since creativity may not always be accompanied by aesthetic value and vice versa. In terms of assessing a creative system, the two usual approaches are to either directly evaluate the final product or to evaluate the productive mechanism [16]. The present work is concluded by an empirical experiment that attempts to address the former by shedding some light on how the system's output is perceived leaving -for the moment- the issue of aesthetic value intact.

To this end, the output of the cadence blending system described in the following section is used to set up a preliminary subjective evaluation of the conceptual blending algorithm applied to cadence invention. As stated previously, the computational system is capable of creating a variety of blends combining elements of two input cadences and it further estimates the expected relationships between the produced blends. A number of blends between the perfect and the Phrygian cadence were produced in order to test the ability of the cadence blending system to accurately predict their perceived relations (i.e. the functionality of the blends) using an 'objective' distance metric (see subsection 2.2). To achieve this, a pairwise dissimilarity listening test for the nine cadences (two original, four blends and three miscellaneous) was designed and conducted. Subsequent multidimensional scaling (MDS) analysis was utilised to obtain geometric configurations for both behaviourally acquired pairwise distances and dissimilarity estimations by the algorithm. Comparison of the two configurations showed that the system can model the perceptual space quite accurately.

2. FORMAL CONCEPTUAL BLENDING MODEL

This section begins with a description of the conceptual blending mechanism utilised by the system for cadence construction. It then proceeds with a consideration of a naive distance metric for pairs of cadences based on representation of cadences according to the system.

2.1 Cadence generation through chord blending

A cadence is described as a progression of (at least) two chords that conclude a phrase, section or piece of music [2]. In our case we have examined the simplest case of two chords, a penultimate and a final chord. If the final – destination – chord is considered fixed, then blending between two cadences can occur by blending the penultimate chords of the cadences. The penultimate chords should therefore be described in a way that reflects the 'functional' role of their constitutive components. To this end, 'chord-type' properties of the penultimate chords (i.e. characteristics of type such as major, minor etc.) should be considered in combination with 'key-related' characteristics (i.e. their relations to the final chord). For instance, a 'chord-type' and distinctive characteristic of the penultimate chord in the perfect cadence (V7) is the fact that it includes a tritone (between the third and the minor seventh), while two 'key-related' important characteristics are a) the fact that it includes the leading tone to the tonic (expressed as the pitch class 11 relative to the local key) and b) that its root moves by a perfect fifth to the tonic. Additionally, the specification of cadences (penultimate chords) should incorporate priority values, taking into account the fact that not all characteristics ('chord-type' or 'key-related') are equally salient.

The blending framework employed in this paper for producing novel cadences through concept blending has been presented in [7]. This framework follows Goguen's proposal to model conceptual spaces as algebraic specifications, while the utilised specifications defined in a variant of *Common Algebraic Specification Language* (CASL) [14] are extended with priority values associated to axioms. These specifications incorporate symbols as basic building blocks, over which more refined specifications are constructed, beginning from the sort *'Note'* that is utilised to built the sort *'Chord'*. The sort *Chord* represents the penultimate chord of the cadence which is in fact the notion of the cadence as previously described. A *Note* can receive values between 0 and 11, indicating the 12 pitch classes. In addition, a '+' operator is considered for arithmetics of addition in a modulo 12. For example, $7 + 9 = 4$ denotes that a sixth plus a fifth is a major third.

A *Chord* specification incorporates two kinds of attributes that relate to the aforementioned 'chord-type' and 'key-related' attributes, respectively *'chordNote'* and *'keyNote'*. The *'chordNote'* property indicates semitone distances between the chord's root and the notes comprising the chord, e.g., a major chord with minor seventh has the following relative notes: $[0, 4, 7, 10]$. On the other hand, the *'keyNote'* property indicates semitone distance between the scale's root note and the notes comprising the chord, e.g., a major chord with minor seventh and with chord root on the fifth degree of the major scale (i.e. pitch class 7) has the following key-related notes: $[7, 11, 2, 5]$.

The salient characteristics of penultimate chords, and in extension of cadences, are defined for the two input spaces by employing human knowledge [1]. The salience of a penultimate chord property is input to the system as a *priority* value which is then directly linked to this property. The output of conceptual blending, i.e. a conceptual blend, should incorporate the most salient features of the two input spaces – reflected by higher priority values. Additional constraints that concern further knowledge about chords are imposed. For the system employed in this paper, presented in more detail in [7], the additional constraints concern the facts that a chord should not have a major and a minor third ('*chordNote* 3 and 4) at the same time, it should not have a minor second (*'chordNote'* 1) and it should not have both a perfect and a diminished fifth (*'chordNote'* 6 and 7) at the same time. When a new *blendoid* [2] emerges, these constraints are enforced in the form of a *consistency check* on the chord specification. Thereby, *inconsistent* blends are discarded.

The input cadences that have been selected to demonstrate blending of harmonic concepts were the *perfect* and the *Phrygian*, with their attributes and priorities depicted in Table 1. For both cadences, the highest priorities are assigned in such a way that the most musically salient aspects of the penultimate chords are highlighted. For the perfect cadence, the most highlighted features include the leading note (*keyNote*: 11) to the tonic and the fact that its type includes a tritone (*chordNote*: 4 and *chordNote*: 10). For the Phrygian cadence, the musically salient feature is the descending leading note (*keyNote*: 1) to the tonic.

perfect		Phrygian	
attribute	priority	attribute	priority
keyNote: 7	*p*: 2	*keyNote*: 10	*p*: 1
keyNote: 11	*p*: 3	*keyNote*: 1	*p*: 3
keyNote: $\boxed{5}$	*p*: 1	*keyNote*: $\boxed{5}$	*p*: 2
keyNote: $\boxed{5}$	*p*: 2		
chordNote: $\boxed{0}$	*p*: 1	*chordNote*: $\boxed{0}$	*p*: 1
chordNote: 4	*p*: 3	*chordNote*: 3	*p*: 1
chordNote: $\boxed{7}$	*p*: 1	*chordNote*: $\boxed{7}$	*p*: 1
chordNote: 10	*p*: 3		

Table 1: Attributes and priorities (higher values indicate higher priority) considered in the blending system for the input penultimate chords in the perfect and Phrygian cadences. Common attributes of both cadences (the generic space [7]) appear in boxes.

tritone		backdoor	
attribute	priority	attribute	priority
keyNote: 1	*p*: 3	*keyNote*: 10	*p*: 1
keyNote: 11	*p*: 3	*keyNote*: *2*	*p*: 1
keyNote: $\boxed{5}$	*p*: 2	*keyNote*: $\boxed{5}$	*p*: 2
keyNote: *8*	*p*: *1*	*keyNote*: *8*	*p*: *1*
chordNote: $\boxed{0}$	*p*: 1	*chordNote*: $\boxed{0}$	*p*: 1
chordNote: 4	*p*: 3	*chordNote*: 4	*p*: 3
chordNote: $\boxed{7}$	*p*: 1	*chordNote*: $\boxed{7}$	*p*: 1
chordNote: 10	*p*: 3	*chordNote*: 10	*p*: 3

Table 2: Attributes and priorities (higher values indicate higher priority) in the tritone substitution and backdoor cadences that result as blends from the perfect and Phrygian cadences. The completion step adds the *keyNote*: *8*.

The computational chord blending framework combines the *salience* of chord features and core ideas of the notion of *Amalgams* [15], resulting in a process that iteratively produces blendoids with descending salience in their characteristics. However, the produced blendoids potentially require completion, i.e. additional reasoning mechanisms that fill-in incomplete properties. Let us consider the example of the tritone substitution cadence blend to elucidate the completion step, as demonstrated in Table 2. The tritone substitution cadence is acquired by preserving the most salient *keyNote* attributes (with priority 3) from both input spaces: $[1, 5, 11]$, and all the *chordNote* attributes of the perfect cadence: $[0, 4, 7, 10]$. However,

[1] In this study, for convenience, they are determined manually by a music expert.

[2] The term *blendoid* refers to a possible result of blending, which, however, is not necessarily consistent or optimal. Additional criteria either validate or discard the consistency of a blendoid as well as evaluate it as optimal (based on 'blending optimality principles' or on domain-specific characteristics inherited to the blendoid).

the utilisation of the pitch classes $[1, 5, 11]$ does not satisfy the requirements for a full dominant seventh chord of type $[0, 4, 7, 10]$. The completions step for the pilot study presented in [7] is performed manually, although it is possible to develop an automatic completion algorithm based on the chord root provided by the utilisation of the General Chord Type (GCT) [4] algorithm. For instance, in the tritone substitution, pitch class 1 is assigned as a root note, a fact that leads to the completion of the pitch class (*keyNote*:) 8 as a perfect fifth (to match the *chordNote*: 7). The backdoor cadence preserves the *keyNote* attributes spaces: $[2, 5, 10]$, which are not the ones with the highest priorities, and again all the *chordNote* attributes of the perfect cadence: $[0, 4, 7, 10]$. Similarly, the completion step assigns the pitch class 10 as a root note, while the requirement for a minor seventh (*chordNote*: 10) leads to importing the pitch class (*keyNote*:) 8 into the blend. Since no background knowledge about the role of the attribute *keyNote*: 8 is given, the 'default' priority 1 is inserted, which will also be the case for all the examples in this paper: if attributes emerge through completion that have not been modelled in the input spaces, the default priority 1 is assigned.

2.2 Model-based distance metric

A naive method to compute the distances between pairs of cadences is by comparing their common features with the set of all their distinct features. In our case, since the final chord is always the same minor tonic, the comparison boils down to the features of their penultimate chords. Thereby, the more features these chords have in common, the more similar the cadences should be. For two cadences, C_i and C_j two sets are considered: the *intersection*, $\cap(C_i, C_j)$, and the *union*, $\cup(C_i, C_j)$ of their penultimate chord features. The intersection is the set of their common features and the union is the sum of all the features appearing in both cadences without repetitions. For instance, for the cadences indexed 1 and 3 in Table 3:

$$\cap(C_1, C_3) = [[5, 11], [0, 4, 7, 10]],$$

$$\cup(C_1, C_3) = [[1, 2, 5, 7, 8, 11], [0, 4, 7, 10]].$$

The considered distance based on the intersection and union of the features of penultimate chords is computed by dividing the number of elements in the intersection with the number of elements in the union. If $N(X)$ is the number of elements in a set X, then the distance between two cadences is computed as

$$d(C_i, C_j) = \frac{N(\cap(C_i, C_j))}{N(\cup(C_i, C_j))}.$$

In the aforementioned example, $d(C_1, C_3) = 6/10$.

3. EMPIRICAL EVALUATION

In order to investigate the functionality of the blended cadences (i.e. the perceived relationships between them) we conducted a pairwise dissimilarity rating listening experiment using as stimuli the nine selected cadences described below. This approach is widely adopted in psychoacoustics because it enables the construction of perceptual spaces by employing multidimensional scaling (MDS) analysis on the obtained dissimilarity matrices.

3.1 Stimuli

The stimulus set consisted of the two input cadences (perfect and Phrygian), four blends of the input spaces and three miscellaneous cadences (Figure 2). More specifically, seven selected blends were as follows: blend 3 was the tritone substitution progression, blends 4 and 5 were the backdoor progression (the latter without seventh), cadence 6 was a plagal cadence (it was input manually as a cadence instance that was not a blend and was rather different to the two input cadences), cadence 7 contained a minor dominant penultimate chord, cadence 8 was essentially a French-sixth chord-type (similar in principle to the tritone substitution) and cadence 9 was a manually constructed non-blend chromatic chord. Note that all the cadences were assumed to be in C minor and each cadence was preceeded by the notes C and F to reinforce perception of tonal context – the only chord that changed in each stimulus was the penultimate chord. Table 3 illustrates the cadences used in the subjective experiment with the *keyNote* and *chordNote* features grouped in two arrays. Therefore, since the system is able to produce blended cadences according to these features (*keyNote* and *chordNote*), the similarity between two cadences in terms of the system's modelling should depend merely on them.

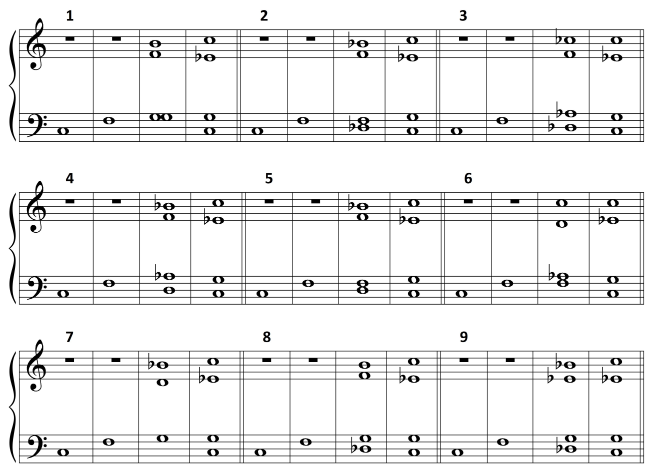


Figure 2: Score annotation of the two input cadences (1-2), 4 blends of the input spaces (3-6) and 3 miscellaneous cadences (7-9).

3.2 Participants

Fifteen listeners (aged 19-48, mean age: 26.5, 8 female) participated in the listening test. All reported normal hearing and long term music practice (years on average: 18.7, range: 6 to 43). Participants were students in the Department of Music Studies of the Aristotle University of Thessaloniki. All participants were naive about the purpose of the test.

	input		blends				miscellaneous		
index	1	2	3	4	5	6	7	8	9
keyNote	[7, 11, 2, 5]	[10, 1, 5]	[1, 5, 8, 11]	[10, 2, 5, 8]	[10, 2, 5]	[2, 5, 9, 0]	[7, 10, 2]	[1, 5, 7, 11]	[3, 7, 10, 1]
chordNote	[0, 4, 7, 10]	[0, 3, 7]	[0, 4, 7, 10]	[0, 4, 7, 10]	[0, 4, 7]	[0, 3, 7, 10]	[0, 3, 7]	[0, 4, 6, 10]	[0, 4, 7, 10]

Table 3: The penultimate cadence chords for the experiments along with their features and their respective indexes.

3.3 Procedure

In the pairwise dissimilarity listening test, participants were asked to compare all the pairs among the nine sound stimulus set using the free magnitude estimation method [23]. Therefore, they rated the perceptual distances of forty-five pairs (same pairs included) by freely typing in a number of their choice to represent dissimilarity of each pair (i.e., an unbounded scale) with 0 indicating a same pair.

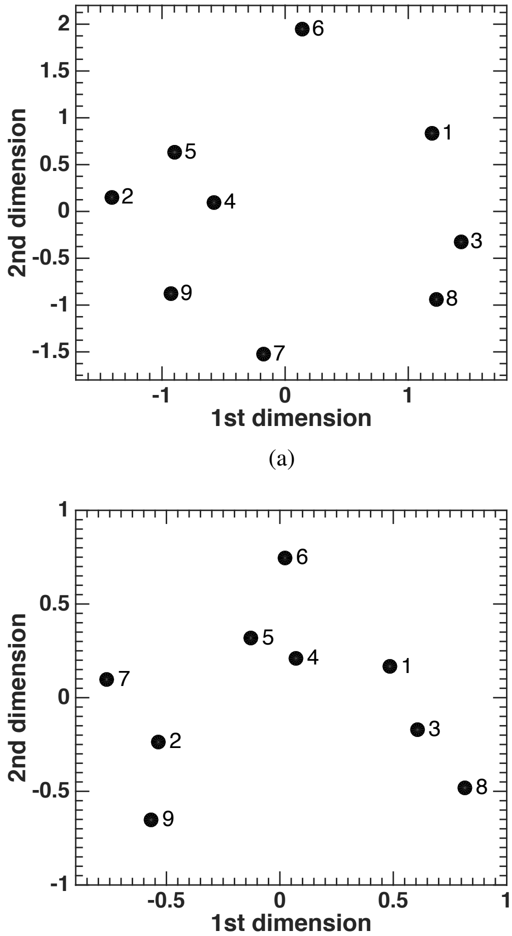
Listeners became familiar with the different cadences during an initial presentation of the stimulus set in random order. This was followed by a brief training stage where listeners rated four selected pairs of stimuli. For the main part of the experiment participants were allowed to listen to each pair of sounds as many times as needed prior to submitting their rating. The pairs were presented in random order and listeners were advised to retain a consistent rating strategy throughout the experiment. In total, the listening test sessions, including instructions and breaks, lasted around twenty minutes for most of the participants.

4. EXPERIMENTAL RESULTS

The proposed formal conceptual blending framework enables the generation of multiple cadences with different values of 'importance', as reflected by the priorities of the attributes preserved into the penultimate chords of the resulting cadences. For the purpose of this study, the system-wise 'objective' distance metric between cadences (see subsection 2.2) is merely based on the common features of the penultimate chords, not taking priority values into account. The aim of this study is to examine whether the pairwise distances between several cadences, as expressed by this 'objective distance' is aligned with the cognitive/perceptual distances that musically trained participants assign.

A non-metric, weighted individual differences scaling (INDSCAL) MDS analysis as offered by the SPSS PROXSCAL (proximity scaling) algorithm [13] was applied to the dissimilarity matrices. INDSCAL computes weights that represent the importance attributed to each perceptual dimension by each participant and then uses these weights to reconstruct a common perceptual space. Additionally, the 'ordinal' option applies a rank ordering transformation to the raw dissimilarities within each participant's responses. The non-metric approach was adopted since it has been proven robust to the presence of monotonic transformations or random error in the data [19, 22].

A two-dimensional solution of the behavioural data with the following goodness of fit measures: Stress-I: .228



(b)

Figure 3: The perceptual (a) and the algorithmic (b) spatial configurations for the nine selected cadences. The cadences are labelled according to the indexes of table 3.

and Dispersion Accounted for (DAF): .947 [3] was favoured. Considering the number of objects in combination with the number of dimensions, the achieved Stress-I value does not imply an adequate fit between the MDS model produced disparities and the actual distances reported by the participants. This fact can be attributed to the high level of uncertainty present in the subjective responses. However, the satisfactory interpretability of the two dimensional configuration (as will be shown below) supports the acceptance of this solution.

The dissimilarity matrix that was produced by the distance metrics of the cadence-blending-system was also analysed through non-metric MDS. The two-dimensional

[3] Stress-I is a measure of missfit where a lower value indicates a better fit (with a minimum of zero) and DAF is a measure of fit where a higher value indicates a better fit (with a maximum of one).

solution featured both acceptable Stress-I (.123) and DAF (.985). The configurations of both spaces are shown in Figure 3.

Visual inspection of the perceptual space reveals that prior expectations regarding cadence positioning are generally fulfilled. The perfect (no.1) and the Phrygian (no.2) input cadences are positioned far away from each other on the 1st dimension. This dimension could be interpreted as 'modal vs tonal' since negative values coincide with absence of the leading note $[11]$ while positive values signify presence of the leading note. Cadences no.4 (backdoor with seventh) and 5 (backdoor without seventh) are naturally closely related. The clustering of no.4 and no.5 with the Phrygian could be explained by their shared notes $[5, 10]$ and also by the absence of the leading note $[11]$ that moves them away from the perfect cadence territory. Also, the close positioning of cadences no.3 (tritone substitution) and no.8 is explained by the fact that the former is a German-sixth-type while the latter is a French-sixth-type both sharing three basic notes $[1, 5, 11]$. These two cadences are additionally positioned more closely to the perfect cadence (no.1) than to the Phrygian showing that although the tritone substitution is created by incorporating the most salient attributes of the two input cadences (see subsection 2.1), it is not perceived as being equidistant between them. This can be explained by the fact that both no.3 and no.8 take the leading note $[11]$ and the seventh $[5]$ (that needs to be resolved) from the perfect cadence but only take note $[1]$ (base of the Phrygian) from the Phrygian. Cadence no.6 -the plagal- is positioned in the middle between the perfect and Phrygian along dimension 1 but is expectedly an outlier along dimension 2.

The comparison between the perceptual and algorithmic configurations was performed using Tucker's congruence coefficient [20]. As a guideline, for the congruence coefficient, values larger than .92 are considered good/fair, and values larger than .95 practically show equality between configurations [12]. In our case, the congruence coefficient between the perceptual and the algorithmic space was computed to be .944 indicating that the system can make a very good estimation of the relationships between cadences.

5. CONCLUSIONS

According to the theory of conceptual blending developed by Fauconier and Turner, novel conceptual spaces can be created by blending elements from diverse input conceptual spaces. Based on this theory and its category-theoretic interpretation proposed by Goguen this study presented initial developments of a system for blending between harmonic structures, using cadence blending as a proof of concept. To this end, two input spaces with simple formalisations of the perfect and the Phrygian cadences were used to produce several blended cadences.

The two input spaces along with the produced blends, and other cadences, were subjected to a pairwise dissimilarity rating listening test and subsequent MDS analysis in order to evaluate the output produced by the cadence blending system. The basic aim of the study was to examine whether perceptual distances between pairs of cadences, as rated by the participants, were actually reflected by an objective distance metric that related to the formalisation of cadences in the blending system. Indeed, the comparative results showed that the system is capable of making fair predictions of the perceived dissimilarities between the blended cadences. Given the uncertainty introduced by both the demanding nature of the behavioural task and the MDS analyses for the two sets of data, this result is deemed rather satisfactory and leads to the following implications:

1. The presented cadence description framework is *meaningful*. Although the representation of knowledge in cadences is very elementary (just describing the penultimate chords with their absolute and relative notes), the derived results align with human perception/cognition.

2. The utilised blending methodology produces *consistent* results in the sense that resulting blends do indeed match the perceptual/cognitive attributes of the input spaces.

The utilisation of more sophisticated system-oriented metrics is expected to increase the accuracy of the self-evaluation process within the system so as to produce meaningful results for a wider combination of input cadences (also ending in different final chords) or even for more complex harmonic structures. As an obvious next step, the parameters of the system distance metric can be refined to optimise the fit between the algorithm's prediction and the actual perception of cadence dissimilarities.

Cadence blending is a proof-of-concept example of the computational framework for conceptual blending that is being developed in the context of the COINVENT project [18]. Overall, the results of the subjective experiment, even with this elementary representation of cadences, indicate the effectiveness of this framework towards creating meaningful output. The long term objective is the application of the computational blending approach for developing melodic harmonisation methodologies that facilitate structural blending between harmonies of diverse music idioms. This will require the development of ontologies capable of describing significantly more complex harmonic concepts compared to a simple harmonic cadence. At the same time, the employed subjective evaluation will need to be enriched by more elaborate experiments that will not only be able to assess the aesthetic value and functionality of the blends but to also address the challenge of rating longer stimuli.

6. ACKNOWLEDGEMENTS

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7. REFERENCES

[1] M. Antović. Musical metaphor revisited: Primitives, universals and conceptual blending. *Universals and Conceptual Blending*, 2011.

[2] B. Benward and M. N. Saker. *Music in theory and practice*, volume I, page 359. McGraw-Hill, 7th edition, 2003.

[3] M. A. Boden. *The creative mind: Myths and mechanisms*. Psychology Press, 2004.

[4] E. Cambouropoulos, M. Kaliakatsos-Papakostas, and C. Tsougras. An idiom-independent representation of chords for computational music analysis and generation. In *Proceeding of the joint 11th Sound and Music Computing Conference (SMC) and 40th International Computer Music Conference (ICMC)*, ICMC–SMC 2014, 2014.

[5] T. Collins, R. Laney, A. Willis, and P. H. Garthwaite. Developing and evaluating computational models of musical style. *Artificial Intelligence for Engineering Design, Analysis and Manufacturing*, available on CJO2015:1–28, 2015.

[6] N. Cook. Theorizing musical meaning. *Music Theory Spectrum*, 23(2):170–195, 2001.

[7] M. Eppe, R. Confalonier, E. Maclean, M. Kaliakatsos-Papakostas, E. Cambouropoulos, M. Schorlemmer, M. Codescu, and K.U. Kühnberger. Computational invention of cadences and chord progressions by conceptual chord-blending. In *International Joint Conference on Artificial Intelligence (IJCAI) 2015, accepted for publication*, 2015.

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

[9] J. Goguen. Mathematical Models of Cognitive Space and Time. In Daniel Andler, Yoshinori Ogawa, Mitsuhiro Okada, and Shigeru Watanabe, editors, *Reasoning and Cognition*, volume 2 of *Interdisciplinary Conference Series on Reasoning Studies*. Keio University Press, 2006.

[10] A. K. Jordanous. *Evaluating computational creativity: a standardised procedure for evaluating creative systems and its application*. PhD thesis, University of Sussex, 2012.

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

[12] U. Lorenzo-Seva and J. M. F. Ten Berge. Tucker's congruence coefficient as a meaningful index of factor similarity. *Methodology: European Journal of Research Methods for the Behavioral and Social Sciences*, 2(2):57–64, 2006.

[13] J. J. Meulman and W. J. Heiser. *PASW Categories 18, Chapter 3*. SPSS Inc., Chicago, 2008.

[14] P. D. Mosses. *CASL Reference Manual – The Complete Documentation of the Common Algebraic Specification Language*, volume 2960. Springer, 2004.

[15] S. Ontañón and E. Plaza. Amalgams: A Formal Approach for Combining Multiple Case Solutions. In *Proceedings of the 18th International Conference on Case-Based Reasoning Research and Development*, ICCBR'10, pages 257–271, Berlin, Heidelberg, 2010. Springer-Verlag.

[16] M. Pearce and G. Wiggins. 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*, pages 22–32, 2001.

[17] M. Pearce and G. Wiggins. Evaluating cognitive models of musical composition. In *Proceedings of the 4th international joint workshop on computational creativity*, pages 73–80. Goldsmiths, University of London, 2007.

[18] M. Schorlemmer, A. Smaill, K.U. Kühnberger, O. Kutz, S. Colton, E. Cambouropoulos, and A. Pease. Coinvent: Towards a computational concept invention theory. In *5th International Conference on Computational Creativity (ICCC) 2014*, June 2014.

[19] R. N. Shepard. Metric structures in ordinal data. *Journal of Mathematical Psychology*, 3:287–315, 1966.

[20] L. R. Tucker. A method for synthesis of factor analysis studies. Technical report, Washington, DC: Department of the Army., 1951.

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

[22] F. W. Young. Nonmetric multidimensional scaling: Recovery of metric information. *Psychometrica*, 35:455–473, 1970.

[23] A. Zacharakis, K. Pastiadis, and J. D. Reiss. An interlanguage unification of musical timbre: bridging semantic, perceptual and acoustic dimensions. *Music Perception*, 32(4), 2015.

[24] L. M. Zbikowski. *Conceptualizing Music: Cognitive Structure, Theory, and Analysis*. Oxford University Press, 2002.