

# IDIOM-INDEPENDENT HARMONIC PATTERN RECOGNITION BASED ON A NOVEL CHORD TRANSITION REPRESENTATION

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## ABSTRACT

In this paper, a novel chord transition representation (Cambouropoulos 2012), that draws on the interval function between two collections of notes proposed by Lewin (1959), is explored in a harmonic recognition task. This representation allows the encoding of chord transitions at a level higher than individual notes that is transposition-invariant and idiom-independent (analogous to pitch intervals that represent transitions between notes). A harmonic transition between two chords is represented by a *Directed Interval Class (DIC) vector*. The proposed 12-dimensional vector encodes the number of occurrence of all directional interval classes (from 0 to 6 including +/- for direction) between all the pairs of notes of two successive chords. Apart from octave equivalence and interval inversion equivalence, this representation preserves directionality of intervals (up or down).

A small database is constructed comprising of chord sequences derived from diverse music idioms/styles (tonal music, different traditional harmonic idioms, 20<sup>th</sup> century non-tonal harmonic idioms). The proposed DIC representation is evaluated on a harmonic recognition task, i.e. we examine the accuracy of recognition of harmonic queries in this database. The results of the algorithm are judged by human music analysis experts.

It is suggested that the proposed idiom-independent chord transition representation is adequate for representing harmonic relations in music from diverse musical idioms (in equal temperament) and, therefore, may provide a most appropriate framework for harmonic processing in the domain of computational ethnomusicology.

## 1. INTRODUCTION

In recent years an increasing number of studies propose computational models that attempt to determine an appropriate representation and similarity measure for the harmonic comparison of two excerpts/pieces of music, primarily for music information retrieval tasks (Allali 2007, 2010; de Haas, 2008, 2011; Hanna et al., 2009; Paiement 2005; Pickens et al. 2002). Such models assume a certain representation of chords and, then, define a similarity metric to measure the distance between chord sequences. Chords usually are represented either as collections of pitch-related values (e.g., note names, MIDI pitch numbers, pitch class sets, chroma vectors, etc.), or as chord root transitions within a given tonality following sophisticated harmonic analysis (e.g. roman numeral analysis, guitar chords, etc.).

In the case of an absolute pitch representation (such as chroma vectors) transpositions are not accounted for (e.g., twelve transpositions of a given query are necessary to find all possible occurrences of the query in a dataset).

On the other hand, if harmonic analytic models are used to derive a harmonic description of pieces (e.g., chords as degrees within keys or tonal functions), more sophisticated processing is possible; in this case, however, models rely on complicated harmonic analytic systems, and, additionally, are limited to the tonal idiom.

All the above models rely on some representation of individual chords. There are very few attempts, however, to represent chord *transitions*. For instance, de Haas et al. (2008, 2011) represent chord transitions as chord distance values adapting a distance metric from Lerdahl's *Tonal Pitch Space* (2001); however, a chord transition being represented by a single integer value seems to be an excessive abstraction that potentially misses out important information.

This paper explores a richer chord transition representation that can be extracted directly from the chord surface and that is idiom-independent (Cambouropoulos 2012). This representation is essentially a re-ordering of the elements of Lewin's interval function (Lewin 1959). In the proposed chord transition representation, a harmonic transition between two chords can be represented as a *Directional Interval Class (DIC) vector*. The proposed 12-dimensional vector encodes the number of occurrence of all directional interval classes (from 0 to 6 including +/- sign for direction) between all the pairs of notes of two successive chords. As melodic intervals represent a melodic sequence in an idiom-independent manner, so does the DIC vector represent chord transitions in an idiom-independent manner. This means that, given a dataset comprising music pieces represented as sequences of chords, a given chord sequence query can be searched for directly in the chord progressions without any need for harmonic analysis.

In this study, a small database is constructed comprising of chord sequences (i.e. the main chord notes that form the underlying harmonic progression of any piece without root/key knowledge) derived from diverse music idioms/styles. More specifically, we include standard chord progressions from Bach chorales and along with harmonic progressions from modal Greek rebetiko songs, polyphonic songs from Epirus, Beatle songs and non-tonal pieces by B. Bartók, O. Messiaen, C. Debussy, E. Satie.

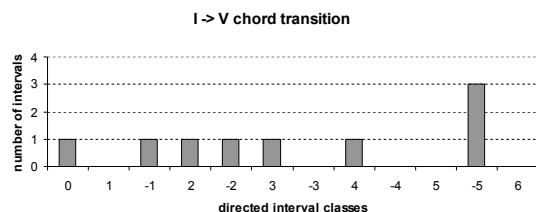
The proposed DIC representation is evaluated on a harmonic recognition task, i.e. we examine the accuracy of recognition of harmonic queries in the above database. Both the query sequence and the chord progressions in the dataset are converted to DIC vectors and exact matching for recognition is employed (approximate matching is also considered). The results of the algorithm are judged by human music analysis experts.

In the first section below the new Directed Interval Class (DIC) representation is introduced and some of its potentially useful properties are highlighted. Then, the DIC representation will be used as the basis for a preliminary test on a harmonic recognition task for different musical idioms. Finally, a brief discussion will summarise the importance of the proposed representation along with problems and shortcomings, and will suggest interesting new avenues for further exploration.

## 2. THE DIRECTED INTERVAL CLASS (DIC) CHORD TRANSITION REPRESENTATION

A novel chord transition representation is proposed. A harmonic transition between two chords can be represented as a Directional Interval Class (DIC) vector. The proposed 12-dimensional vector encodes the number of occurrence of all directional interval classes (from 0 to 6 including +/- sign for direction) between all the pairs of notes of two successive chords. That is, from each note of the first chord all intervals to all the notes of the second chord are calculated. Direction of intervals is preserved (+,-), except for the unison (0) and the tritone (6) that are undirected. Interval size takes values from 0-6 (interval class). If an interval  $X$  is greater than 6, then its complement  $12-X$  in the opposite direction is retained (e.g. ascending minor seventh '+10' is replaced by its equivalent complement descending major second '-2').

The 12-dimensional DIC vector features the following directed interval classes in its twelve positions: 0 (unison), +1, -1, +2, -2, +3, -3, +4, -4, +5, -5, 6 (tritone). For instance, the transition vector for the progression  $I \rightarrow V$  is given by the DIC vector:  $Q = \langle 1, 0, 1, 1, 1, 1, 0, 1, 0, 0, 3, 0 \rangle$  (which means: 1 unison, 0 ascending minor seconds, 1 descending minor second, 1 ascending major second, etc.) – see Figure 1, and further examples in Figure 2.

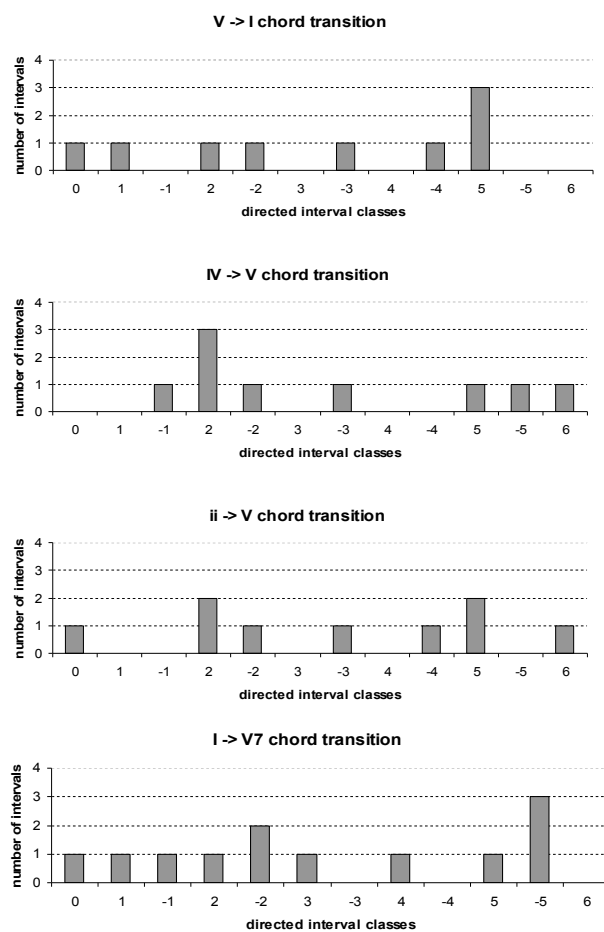


**Figure 1** The DIC vector:  $\langle 1, 0, 1, 1, 1, 1, 0, 1, 0, 0, 3, 0 \rangle$  for the chord transition  $I \rightarrow V$  depicted as a bar graph.

The DIC vector is unique for many tonal chord transitions. However, there are a number of cases where different tonal transitions have the same vector. For instance,

the transitions  $I \rightarrow V$  and  $IV \rightarrow I$  share the same DIC vector as their directed interval content is the same; it should be noted, that, heard in isolation (without a tonal centre reference), a human listener cannot tell the difference between these two transitions.

The proposed DIC representation preserves directionality of intervals (up or down), and, therefore, it incorporates properties of voice leading. For instance, the DIC vector naturally accommodates chord transition asymmetry. If the two chords in a chord transition are reversed, the absolute values of intervals are retained; however, the directions of intervals are reversed. This way, the vectors, for instance, for the  $I \rightarrow V$  transition and the  $V \rightarrow I$  transition, are different (compare, DIC vectors of Figure 1 and Figure 2a-top).



**Figure 2** DIC vectors for four standard tonal chord transitions:  $V \rightarrow I$ ,  $IV \rightarrow V$ ,  $ii \rightarrow V$ ,  $I \rightarrow V7$ .

It was initially hypothesised that the DIC vector (Cambouropoulos, 2012) uniquely determines the two chords that comprise the transition (except for cases when one of the two chords is symmetric, such as augmented chord, or diminished seventh chord). This is actually not true. Any specific chord transition has the same DIC vector with its retrograde inversion. This is an inherent problem in the DIC representation that introduces certain limitations in specific contexts. See next section for further discussion.

### 3. HARMONIC RECOGNITION

In this study the proposed DIC representation is tested on a harmonic recognition task, i.e. we examine the accuracy of recognition of harmonic queries in a small diverse-style harmonic database. The results of the algorithm are judged qualitatively by human music analysis experts. The music database, the DIC-vector-based harmonic recognition prototype and results will be presented in the sections below.

#### 3.1 Test Dataset

A small database is constructed comprising of chord sequences (i.e. the main chord notes that form the underlying harmonic progression of any piece without root/key information) derived from diverse music idioms/styles. More specifically, this purpose-made collection comprises of 31 chord reductions of music pieces reaching an overall number of 957 chords (4 Greek modal rebetiko songs, 3 polyphonic songs from Epirus, non-tonal pieces by B. Bartók, O. Messiaen, C. Debussy, E. Satie, 11 Beatle songs, and 5 chorales by J.S.Bach). Below is a brief description of the main harmonic features of each style. Examples of chordal reductions are illustrated in Figure 3. The dataset comprises of the following chord sequences:

- *Five chorales* by J. S. Bach, after their rhythmical reduction to a quarter-note harmonic rhythm and the removal of non-harmonic tones. The following chorales were used (the numbers correspond to the Breitkopf Edition): 20, 80, 101, 138, 345. Two different harmonizations (80 & 345) of "O Haupt..." were used, one in D major and the other in A minor. This material typically represents tonal harmonic progressions of the Baroque period.
- Erik Satie's *Gymnopédie no 1*, reduced to chordal progressions (one chord per bar). This material represents diatonic modal harmony of the early 20th century and the modal interchange/modulation procedure, where different diatonic modes are used, either with the same or with different pitch centers. One characteristic difference of this idiom from the tonal harmonic idiom is that the chord progressions are more unrestricted and do not adhere to standard functional relations and progressional formulae (for further discussion and analyses see Tsougras 2003).
- Excerpts of music by Claude Debussy, reduced to chord progressions: selected chordal sequences (b. 1-5, b. 13-16, b. 17-21, b. 42-43) from *Nuages* (1st movement of *Nocturnes* for orchestra) and the opening bars (b. 1-14) from *Claire de Lune* (nr. 3 from *Suite Bergamasque* for solo piano). This material represents the fluent "impressionistic" harmony of the early 20th century, with its relatively free dissonances and frequent planning procedure (parallel harmony, either diatonic or real/chromatic).
- Olivier Messiaen's chordal sequence from the piano part of *Liturgie du Cristal* (1st movement of the *Quartet for the End of Time*). This 17-chord sequence corresponds to the 17-part isorhythmic pattern of the piece (*talea*), and is part of the full 29-chord pattern that is in constant repetition (*color*). This material represents Messiaen's idiomatic modal harmony, based on his system of seven symmetrical chromatic modes of limited transposition.

- Béla Bartók's *Romanian Folk Dances* for piano nr. 4 (*Mountain Horn Song*) and nr. 6 (*Little One*, b. 1-16). These pieces are essentially harmonizations of original Romanian folk tunes from Transylvania, recorded and transcribed by Bartók himself. The original tunes are modal, either diatonic or chromatic, but the harmonizations create more complex sonorities and involve mixing of modes and symmetrical pitch structures. This material represents the initial stage of Bartók's "polymodal chromaticism" (a term used by the composer to describe modal mixing). For further discussion and analyses see Tsougras 2009.
- Three *Polyphonic Songs from Epirus* (Epirus is a region of northwestern Greece), reduced to vertical sonorities, and without the idiomatic glissandi or other embellishment types featured in the idiom. The reductions were produced from transcriptions made by K. Lolis (2006). This very old 2-voice to 5-voice polyphonic singing tradition is based on the anhemitonic pentatonic pitch collection - described as pc set (0,2,4,7,9) - that functions as source for both the melodic and harmonic content of the music. The songs chosen for the analysis are: *Την άμμο-άμμο πήγαινα* (4-voice, scale: G-Bb-C-D-F), *Έπιασα μια πέρδικα* (3-voice, scale: D-F-G-Bb-C), *Πέρασα 'πο 'να γιοφύρι* (4-voice, scale: G#-B-C#-E-F#).
- Four Greek *rebetiko* songs, reduced only to chord progressions. Each song's melody is based on a particular mode, called "dromos" (Greek "laikoi dromoi" have affinities with Turkish makams and frequently bear similar names, but they are quite different in their intervallic structure, since they are adapted to the equally-tempered scale and do not incorporate microtones). The songs chosen for testing were: *Με παράσυρε το ρέμα* by Vassilis Tsitsanis (D Ussak), *Απόψε φίλα με* by Manolis Chiotis (D hicaz), *Καϊζής* by Apostolos Chatzichristos (D natural minor) and *Πασατέμπος* by Manolis Chiotis (D hicaz/hicazkar). This material represents some cases of the idiomatic modal harmony of Greek "rebetiko". This modal harmony roughly results from the formation of tertian chords above structural pitches of the current mode and the use of certain cadence formulae for each mode.
- Eleven Beatles songs, reduced to chord sequences (expressed in conventional chord symbols, e.g. Cm, C<sup>M7</sup>, etc). The harmony of these popular songs incorporates a number of diverse influences (which range from blues and rock n' roll to pop ballad and classical songs), together with Lennon & McCartney's original progressions and harmonic style. The chosen material, which attempts to represent most of these influences and originalities, comprises the following songs: *All my loving*, *From me to you*, *She loves you*, *A hard day's night*, *Help*, *Michelle*, *Misery*, *Because*, *Yesterday*, *Penny Lane*, *Strawberry fields forever*.

The musical style that is more likely to have unique harmonic progressions is Messiaen's: the highly chromatic 5-note to 7-note sonorities (see Figure 3) constitute a highly individual harmonic idiom, and no common elements can be found among the other styles in the present data. Another quite unique style is the Polyphonic Epirus singing, with its purely pentatonic harmonic content and unresolved dissonances. The other styles are mainly based on tertian harmony, with Debussy's and Bartók's styles containing extensions or deviations. Only Bach's style is explicitly tonal, i.e. it is based on standard harmonic functions (mainly of the type S-D-T, especially on cadences), while the other tertian harmonic styles are idiomatically modal.

Reduction of Bach's chorale nr. 345 *O Haupt...*

Reduction of Erik Satie's *Gymnopédie no 1*, b. 32-39 and 71-78 (for further details see Tsougras 2003)

Claude Debussy, *Nuages* chord progressions (b. 13-16 and b. 42-43):

---- real planing with minor chords ----

WT chord    --- real planing ---    WT chord    octatonic chords

Reduction of Claude Debussy's *Clair de Lune*: (b. 1-14):

Olivier Messiaen's chordal sequence from piano part of *Liturgie du Cristal* (1st mov, *Quartet for the End of Time*)

*pp legato (très enveloppé de pédale)*

Béla Bartók's *Romanian Folk Dance nr. 4* reduction (b. 3-16) (for further details see Tsougras 2009)

Reduction of Polyphonic Song from Epirus *Tin ammo-ammo pigena*

Chord sequence of rebetiko song *Pasatempos* by Manolis Chiotis (D hicaz/hicaskar):

$Cm-Cm^6-Gm-D-Gm-Gdim-D-Cm-D-A-D-Gm-Cm-D^7-Gm-Cm-Eb-D$

Chord sequence of song *A hard day's night* by the Beatles:

$C-F-C-Bb-C-F-C-Bb-C-F-G7-C-F7-C-Em-Am-Em-C-Am-F7-G7-C-F-C-F7-C-F-C-F7-Bb-C$

Figure 3 Examples of chord sequences from diverse harmonic idoms contained in the test dataset.

### 3.2 Harmonic Recognition Model

In order to test the potential of the DIC representation a simple computer application (in Java) was devised. The user inputs a harmonic query (sequence of chords) and the system finds exact matches in a given database of chord reductions. Both the query sequence and the chord progressions in the dataset are converted to DIC vectors and, then, exact matching for recognition is employed. Approximate matching is currently available by use of wild cards (i.e. DIC vector entries can be replaced by wild cards);  $\delta$  &  $\gamma$  approximate matching is also possible but not explored in current study. The user interface is depicted in Figure 4; the exact positions of each match are listed in a side window (not depicted in Figure 4).

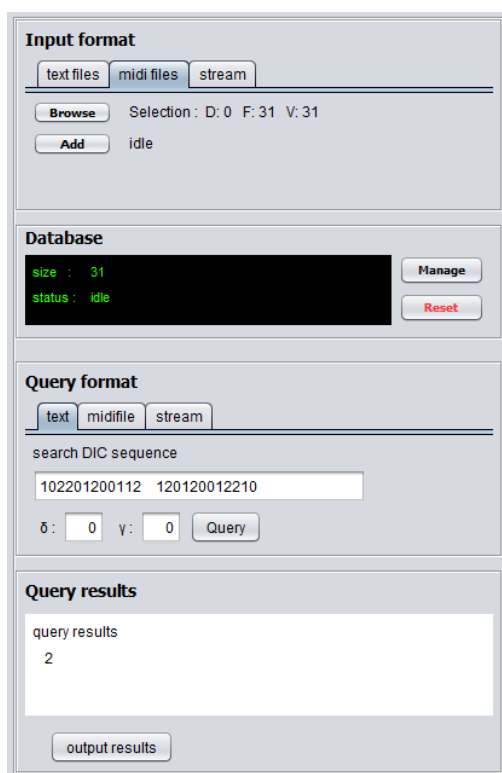


Figure 4 User interface of DIC-vector-based harmonic matching prototype

### 3.3 Results & Discussion

The harmonic recognition model can reveal individual harmonic elements that characterize the styles in our purpose-made database as well as common elements among them. We tested a large number of queries on the given dataset.

For this small dataset, relatively longer sequences comprising of four or more chords were uniquely identified in the correct position of the music piece from which they originated. For instance, we examined exhaustively Bach chorale 20 in terms of the longest repeating subsequence; the longest sequence found in at least one other piece was a 4-chord sequence (first four chords identified in position 26 of Strawberry Fields). Of course if the dataset is significantly extended we expect to find more occurrences of relatively longer harmonic sequences.

Below is a selection of specific harmonic progressions that were investigated and our comments on the results obtained:

- chorale style tonal cadence in major tonality:  $ii_5^6-V-I$ : found 5 times, only in Bach chorales (this is a characteristic cadence type of the chorale idiom)
- chorale style tonal cadence in minor tonality:  $ii_5^6-V-i$ : found 3 times, only in Bach chorales (this is a characteristic cadence type of the chorale idiom)
- major triad progressing to minor triad one perfect 5th down: found 21 times in Bach chorales, one Beatles song (Michelle) and three Rebetika songs (Απόψε φίλα με, Πασατέμπος, Με παρέσυρε το ρέμα)
- major triad progressing to major triad one perfect 5th down: found 100 times in Bach chorales, certain Beatles songs, Satie and certain Rebetika songs. This pattern is very common in styles based on the circle of fifths harmonic progression, namely tonal music and diatonic modal styles, or in other idiomatic styles (Debussy, Bartok, Messiaen, Epirus songs). See further extended comments below.
- major triad progressing to major triad one major second higher: found 23 times in Beatles songs, rebetiko songs, chorales, Satie (and once in Debussy).
- major triad seventh progressing to major triad a perfect fifth lower (perfect cadence): found 45 times only in Bach and Beatles songs (and once in Debussy). Not encountered in the other non-tonal idioms.
- major triad with major 7th progressing to major triad with major 7th one perfect 5th down: found 8 times, only in Satie's *Gymnopédies*
- major triad progressing to minor triad one major 2nd down: found 1 time, in one Rebetiko song (Πασατέμπος). This progression is expected to be found more often if rebetiko dataset is enlarged especially for hicaz mode.
- minor triad progressing to major triad one major 2nd up: found 4 times, in one Beatles song (Michelle) and two Rebetika songs both in hicaz mode (Απόψε φίλα με, Πασατέμπος).
- minor triad progressing to minor triad one minor 3rd down: found 4 times, only in Debussy's Nuages (as part of real planing with parallel minor chords). Most chord sequences tested on Nuages were unique to this idiomatic harmonic language.
- the third chord transition Debussy's Clair de Lune is identified three times in this piece (positions 3, 11, 16 in Figure 3). Many transitions are unique in this piece.
- The vast majority of chord transitions in the polyphonic songs from Epirus are identified only in this music style. For instance, the second chord transition in the reduction of Polyphonic Song from Epirus "Tin ammo-ammo pigena" (G-Bb-D → G-Bb-F-C) is identified twice in this song (position 2 and 9)
- Most chord transitions in the pieces by Satie, Debussy, Bartók and Messiaen are uniquely identified in the respective pieces and are characteristic of the specific

harmonic styles (always in the context of this small database).

Overall, the harmonic recognition model behaves as expected, and has sufficient distinctive power to discern the harmonic individualities of these different harmonic languages. Almost all of the harmonic queries were correctly detected (see one problem below) and all queries of at least three-chords length were identified without mistakes.

It is worth mentioning that the model is capable of finding repeating harmonic patterns even though pieces are in different keys (transposition invariance). Additionally, it is reminded that the system has no knowledge of the different kinds of harmonic systems (tonal, modal, chromatic, atonal, etc.), and is therefore interesting that it detects correctly any kind of harmonic query in diverse harmonic idioms.

A very interesting observation is the following: *the harmonic recognition model is equally successful/accurate when only the first five vector components are used*. We tested all the above queries using only the first five vector entries [0, 1, -1, 2, -2] (out of the 12) which correspond to *Unison* (i.e. common pitches between two chords) and *Steps* (i.e. ascending and descending semitones and tones); the resulting matches were the same in every case.

These small intervals may be thought as being mostly related to voice-leading as it is standard practice to try to connect chords avoiding larger intervals (using common notes and small step movements). The reduction of the DIC vector to a 5-component subvector, increases cognitive plausibility of the proposed representation. Although no cognitive claims are made in this paper, we just mention that representing the transition between two chords as the small intervals that link adjacent pitches (being potentially part of individual harmonic voices) affords this representation potential cognitive validity. This has to be explored further in future research. In any case, this reduced vector results in better computational efficiency.

As we were testing the DIC vector representation on the specific dataset, an important problem arised. There were certain special cases in which different chord successions were matched to the same vector. The most unsettling such occasion was the finding of 100 instances of *major triad* progressing to *major triad* one perfect 5th down. A number of the matched instances were *minor triad* progressing to *minor triad* one perfect 5<sup>th</sup> down. How was this possible?

After further investigation we realised that a chord sequence shares the exactly same DIC vector with its retrograde inversion! For the above instance, the retrograde inversion of a *major triad* progressing to *major triad* by an interval X is a *minor triad* progressing to *minor triad* by the same interval X. This is an inherent property of the DIC vector which reduces its descriptive power, and may have serious ramifications for certain tasks.

In the case of harmonic matching, this is not a serious problem if the sequences sought for are longer than 3 chords. The reason is that the additional context of neighboring chords disambiguates the overall sequence. For

instance, in the above example (finding 100 instances), if our sequence of major chords is preceded by a major chord one tone lower than the first chord, then we find only 12 instances of the sequence (most likely constrained to IV-V-I). Longer sequences will be even more unambiguous. In another example (fifth bullet above) the transition found in 23 instances will correspond most likely to a IV-V chord progression (even though it may correspond to a ii-iii transition between minor chords). If the first chord is preceded by a diminished chord a semitone lower, then the whole sequence of three chords is found only once in Bach chorale 20 (the sequence is vii<sub>o</sub>-I-V/V). The specific context restrains the search drastically.

There exist ways to address this problem by refining the DIC representation (introducing new concepts) but the DIC representation would lose its simplicity. We conjecture that such refinement might be necessary especially if the DIC representation is to be extended for use in the audio domain. Such options are open for further investigation.

Finally, an important issue not explored sufficiently in this study is chord progression similarity, i.e. how similar two chord sequences are. As it stands a V-I transition and a V7-I transition are different (not matched) because their DIC vectors are not identical. Or a V-I transition is not matched to another V-I transition if, a note is missing such as the fifth of the first or second chords. Such relations can be captured if certain tolerances are allowed. For instance, if all entries of one vector are smaller than the corresponding entries of the other vector, and the sum of the differences is three or less, then sequences such as V-I and V7-I would be matched. The similarity relations between vectors is an open issue for further research.

In the current implementation wild cards can be inserted allowing certain tolerance in the matching. Disabling entries 6-12 in the vector, i.e. using only the first five components, did not seem to make a difference as mentioned earlier in this section. Trying out a more radical example, we queried the system with the vector 0\*\*\*\*\*2; this means we are looking for a chord succession that contains no common notes and there exist two distinct tritone relations between different notes of the chords. The system returned 7 instances: 4 in the rebetiko songs and one in *Michelle* by the Beatles that correspond to the transition of major chord to minor chord a tone lower (or the reverse), 1 in Bartok's *Romanian Folk Dance nr. 4* that corresponds to the transition of minor chord 7<sup>th</sup> to major chord a tone higher, and 1 in Debussy's first measures of *Nuage* that corresponds to the transition of a perfect fourth harmonic interval to a perfect fifth a semitone lower. Such experiments allow the investigation of certain similarity relations.  $\delta$  &  $\gamma$  approximate matching is also possible but not explored in current study. More extended studies are necessary to determine 'meaningful' similarities between different transitions.

#### 4. CONCLUSIONS

In this paper the Directed Interval Class representation for chord transitions has been used in a

harmonic recognition task. A small database was constructed comprising of chord sequences derived from diverse music idioms/styles (tonal music, different traditional harmonic idioms, 20<sup>th</sup> century non-tonal harmonic idioms). A harmonic recognition application based on the DIC representation was developed and tested on the above dataset. As expected harmonic recognition accuracy was high especially for relatively longer chord sequence queries (longer than three chords). One of the most useful properties of the DIC representation is that it is transposition-invariant (independent of key). Some inherent limitations of the DIC vector were also presented and potential future improvements suggested.

It is suggested that the proposed idiom-independent chord transition representation is adequate for representing harmonic relations in music from diverse musical idioms (i.e., it is not confined to tonal music) and, therefore, may provide a most appropriate framework for harmonic processing in the domain of computational ethnomusicology.

## 5. REFERENCES

- Allali, J., Ferraro, P., Hanna, P., & Iliopoulos, C. (2007). Local transpositions in alignment of polyphonic musical sequences. *Lecture Notes in Computer Science*, Volume 4726, pp. 26–38, Springer.
- Allali, J., Ferraro P., Hanna P., & Robine M. (2010). Polyphonic Alignment Algorithms for Symbolic Music Retrieval. *Lecture Notes in Computer Science*, 2010, Volume 5954, pp. 466-482, Springer.
- Cambouropoulos, E. (2012) A Directional Interval Class Representation of Chord Transitions. In *Proceedings of the Joint Conference ICMP-ESCOM 2012*, Thessaloniki, Greece.
- de Haas, W. B., Wiering, F. and Veltkamp, R. C. (2011). A Geometrical Distance Measure for Determining the Similarity of Musical Harmony. Technical Report UU-CS-2011-015, Department of Information and Computing Sciences, Utrecht University, Utrecht, The Netherlands.
- de Haas, W. B., Veltkamp, R. C., and Wiering, F. (2008). Tonal pitch step distance: A similarity measure for chord progressions. In *Proceedings of the 9th International Conference on Music Information Retrieval (ISMIR)*, pp. 51-56.
- Hanna, P., Robine, M., and Rocher, T. (2009). An alignment based system for chord sequence retrieval. In *Proceedings of the 2009 Joint International Conference on Digital Libraries*, pages 101-104. ACM, New York.
- Kuusi, T. (2005) Chord span and other chordal characteristics affecting connections between perceived closeness and set-class similarity. *Journal of New Music Research*, 34(3), 257-271.
- Lerdahl, F. (2001). *Tonal Pitch Space*. Oxford University Press, Oxford.
- Lewin, D. (1959). Re: Intervallic relations between two collections of notes. *Journal of Music Theory*, 3(2), 298-301.
- Lolis, K. (2006) *Polyphonic Song from Epirus (Hπειρώτικο Πολυφωνικό Τραγούδι)*. Ioannina. (In Greek)
- Paiement, J.-F., Eck, D., and Bengio, S. (2005). A probabilistic model for chord progressions. In *Proceedings of the 6th International Conference on Music Information Retrieval (ISMIR)*, pp. 312-319, London.
- Pickens, J. and Crawford, T. (2002). Harmonic models for polyphonic music retrieval. In *Proceedings of the 11th International Conference on Information and Knowledge Management*, pp. 430-437. ACM, New York.
- Tsougras, C. (2003). "Modal Pitch Space - A Theoretical and Analytical Study". *Musicae Scientiae* 7/1, p. 57-86.
- Tsougras, C. (2009). Analysis of Early 20<sup>th</sup>-century Chromatic Modal Music with the use of the Generative Theory of Tonal Music - Pitch Space and Prolongational issues in selected Modal Idioms. *Proceedings of the 7th Triennial Conference of the European Society for the Cognitive Sciences of Music*, (12-16 August 2009, Jyväskylä, Finland), J. Louhivuori, T. Eerola, S. Saarikallio, T. Himberg, P. Eerola (eds), p. 531-539.