Universidade de São Paulo
Brasil

CHROMA INTERVAL CONTENT AS A KEY-INDEPENDENT HARMONIC PROGRESSION FEATURE

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June 28, 2019

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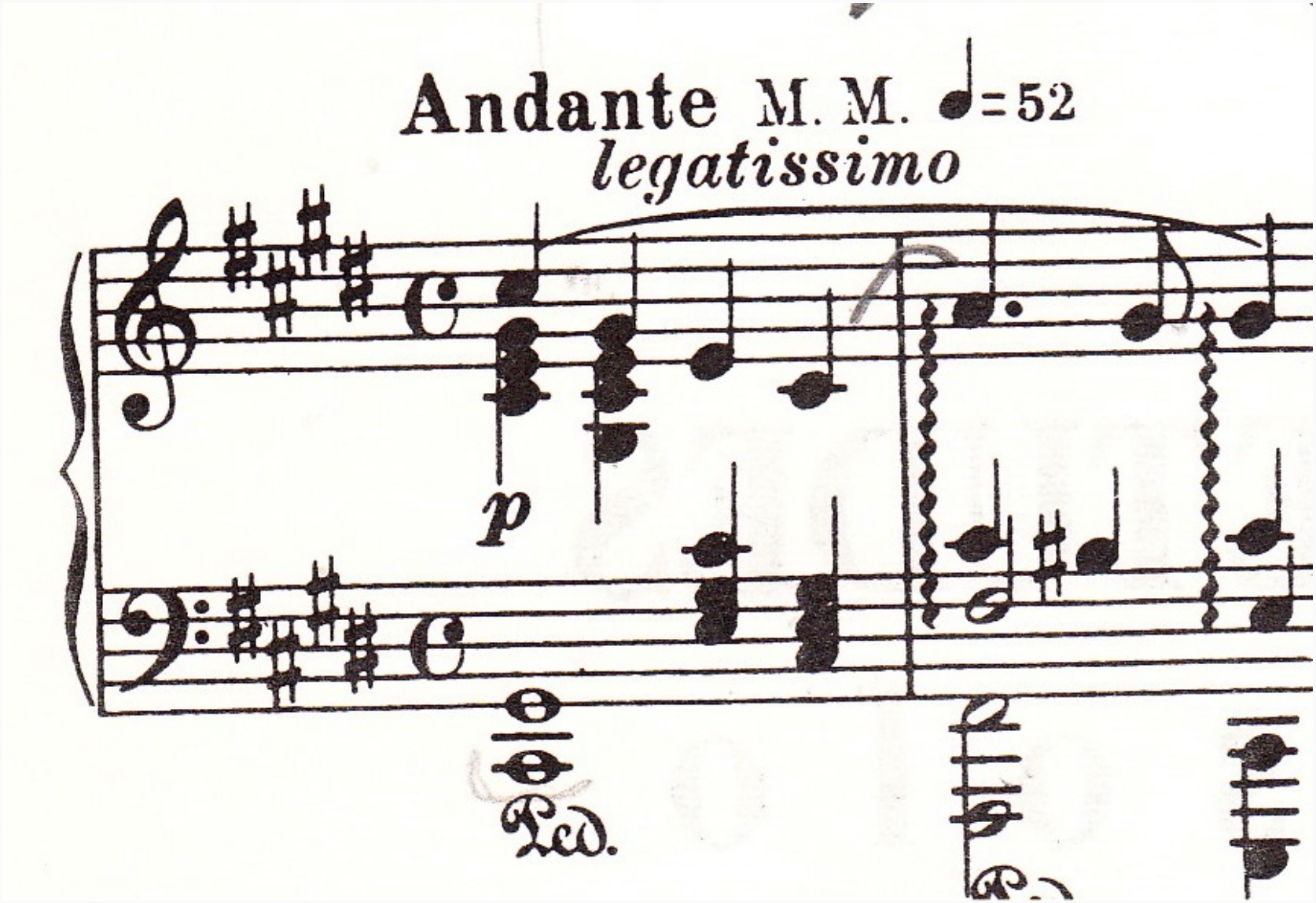
Motivation - characterize chord interval content changes from audio



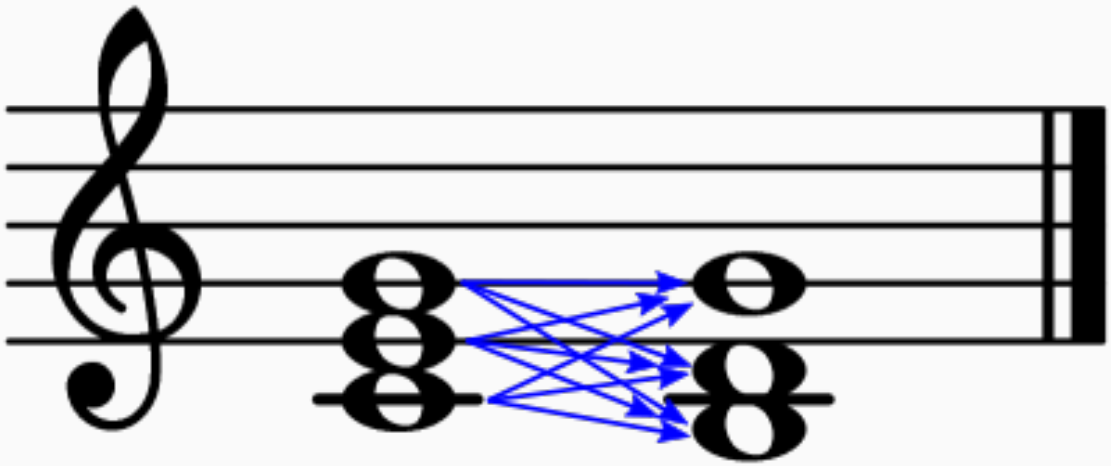
Presentation

Uses for a Key Independent Harmonic Progression Feature

- Musicological studies (e.g. harmonic idioms)
- Models for automatic harmonization
- Harmonic similarity and diversity
- Harmony-based MIR tasks
  (e.g. browsing and classification, version/cover song identification)

Directional Interval Content (DIC)

DIC vectors[1] count melodic displacement (in semitones) between **every pair of notes** from subsequent chords:



$$\text{DIC} = (1, 0, 1, 1, 1, 0, 0, 3, 0, 0, 1, 1)$$

In this chord progression there are 3 occurrences of an ascending perfect 5th and 1 occurrence of each of the following (ascending) intervals: unison, major 2nd, minor 3rd, major 3rd, minor 7th and major 7th.

[1] Cambouropoulos, *A directional interval class representation of chord transitions*, 2012.

Directional Interval Content (DIC)

Two (equivalent) mathematical models for DIC are:

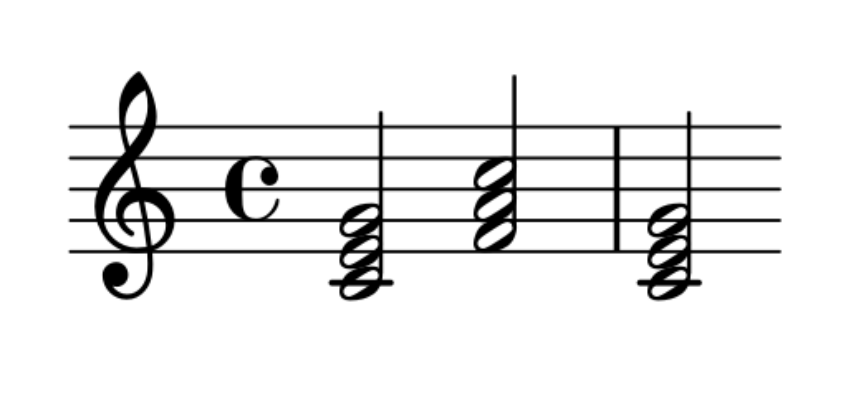
$$\mathrm{DIC}_{A\mapsto B}[n] = \sum_{a\in A}\sum_{b\in B}\delta_{n,(b-a)\%N}, \quad \delta_{i,j} = \begin{cases} 1 & \text{if } i = j, \\ 0 & \text{otherwise,} \end{cases} \tag{1}$$

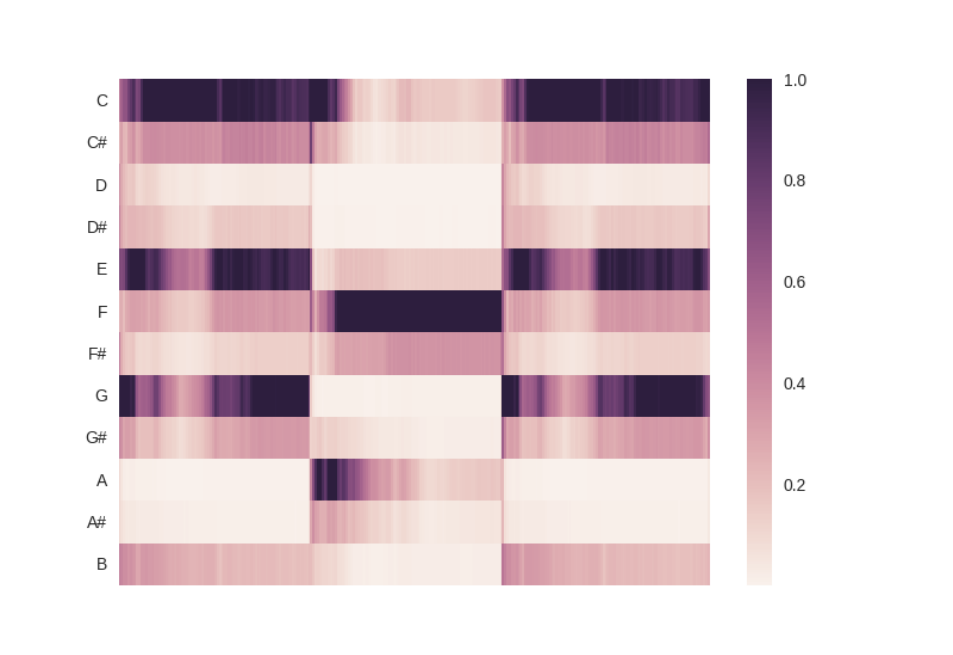
and

$$\mathrm{DIC}_{A\mapsto B}[n] = \sum_{m=0}^{N-1} I^A_m I^B_{(m+n)\%N}, \quad I^X_i = \begin{cases} 1 & \text{if } i \in X, \\ 0 & \text{otherwise.} \end{cases} \tag{2}$$

Chroma Feature

Chroma vectors indicate the **amount of energy** in a given audio segment **for each pitch class**.





Dynamic Chroma (DC)

Dynamic chroma[2] is an audio feature that expresses changes between two subsequent chroma vectors, by **considering all possible transpositions** of the 2nd chord.

Given two chroma vectors $X, Y \in \mathbb{R}_+^N$,

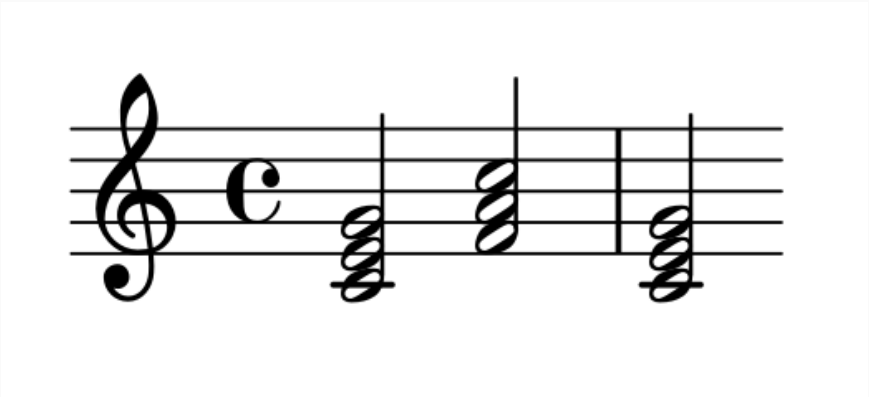
$$\mathrm{DC}_{X \mapsto Y}[n] = Z - \| Y^{(n)} - X \|, \;\; n = 0, 1, \ldots, N-1, \tag{3}$$

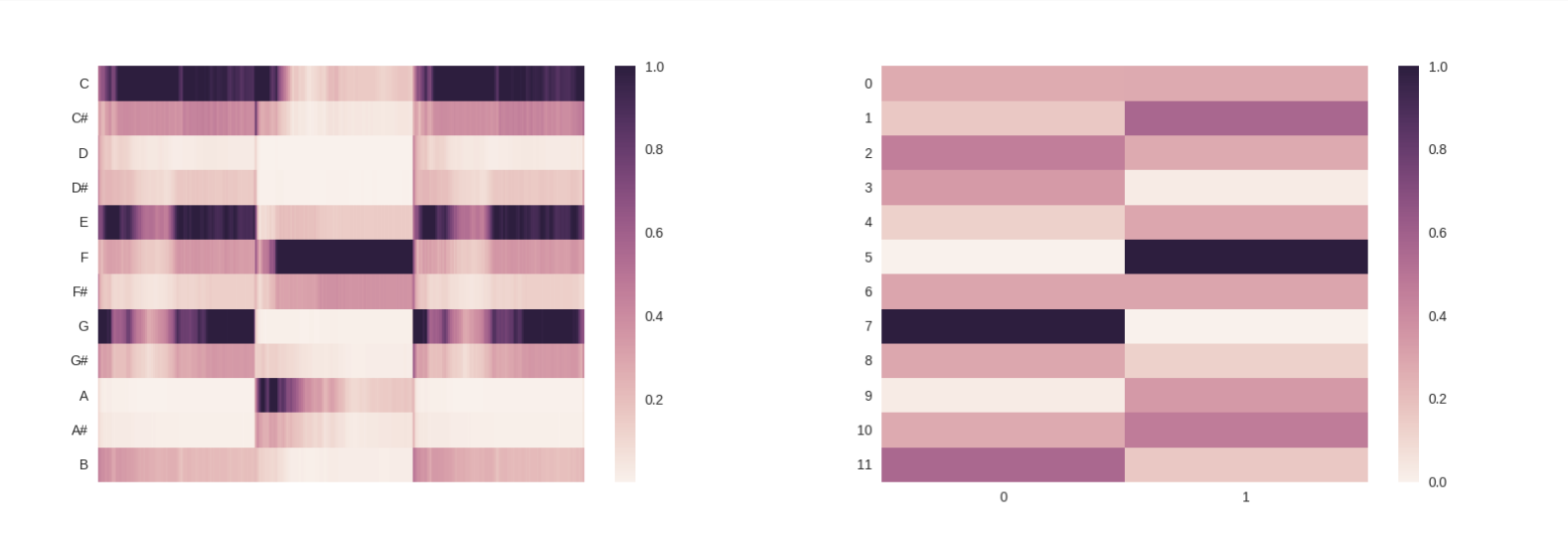
where $Y_k^{(n)} = Y_{(k-n)\%N}$ and $Z = \max_n \{ \| Y^{(n)} - X \| \}$.

[2] Kim and Narayanan, *Dynamic chroma feature vectors with applications to cover song identification*, 2008.

Dynamic Chroma (DC)

In this example, the 2nd chord transposed +7 semitones becomes identical do the 1st chord (and analogously for the 3rd chord transposed +5 semitones with respect to the 2nd chord).





Chroma Interval Content (CIC)

Chroma Interval Content vectors extend CIC vectors from the symbolic domain to chroma vectors: given $X, Y \in \mathbb{R}_+^N$,

$$\mathrm{CIC}_{X \mapsto Y}[n] = \sum_{m=0}^{N-1} X_m \, Y_{(m+n)\%N}. \tag{4}$$

This definition is mathematically equivalent to

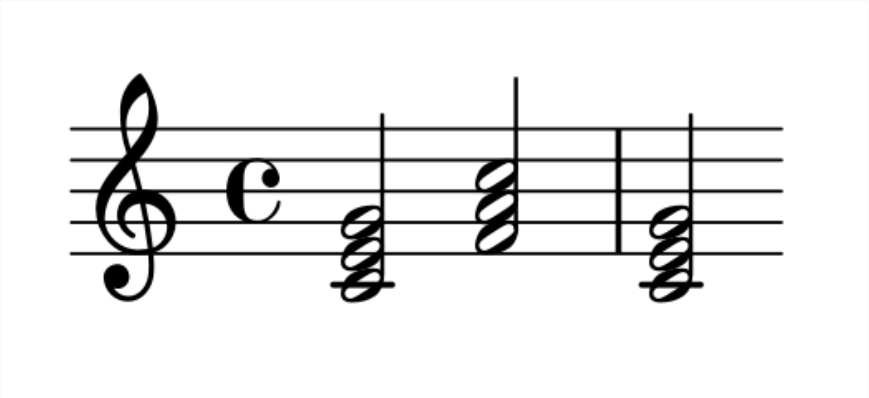
$$\mathrm{CIC}_{X \mapsto Y} = \overleftarrow{\mathcal{F}^{-1}\left(\mathcal{F}(X)\mathcal{F}\left(\overleftarrow{Y}\right)\right)} \tag{5}$$

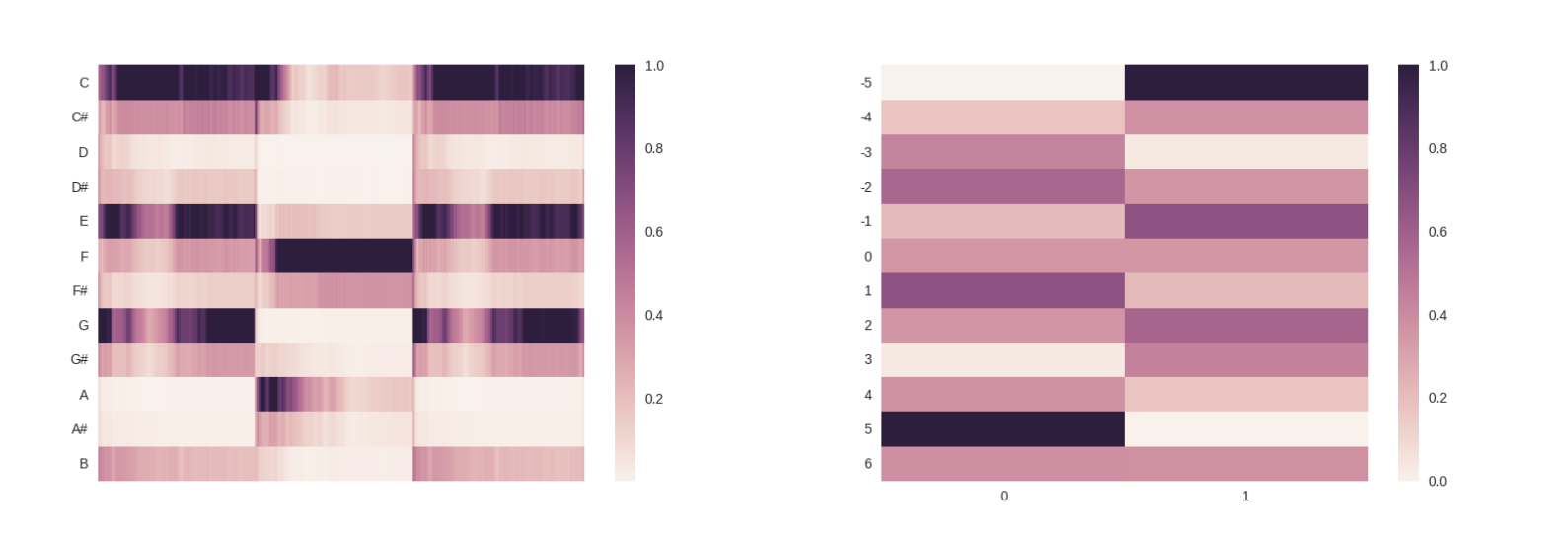
which allows the computation in time $\mathcal{O}(N \log N)$ (instead of $\mathcal{O}(N^2)$).

Chroma Interval Content (CIC)

Similarly to DIC, **CIC captures melodic/intervallic motions** between the chords.

Unlike DC, it **does not consider transpositions** of either chord.

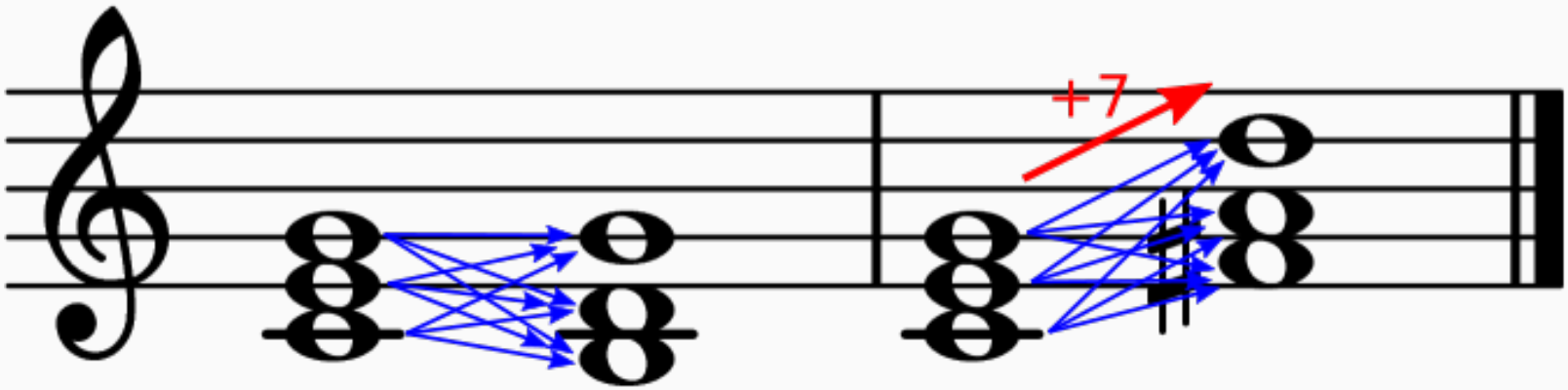




Mathematical and musical properties

Key Transposition

Transposing one of the chords produces a corresponding rotation of the CIC vector. This is also true for DIC. In the following examples we consider symbolic examples with binary chroma vectors, for which CIC = DIC.

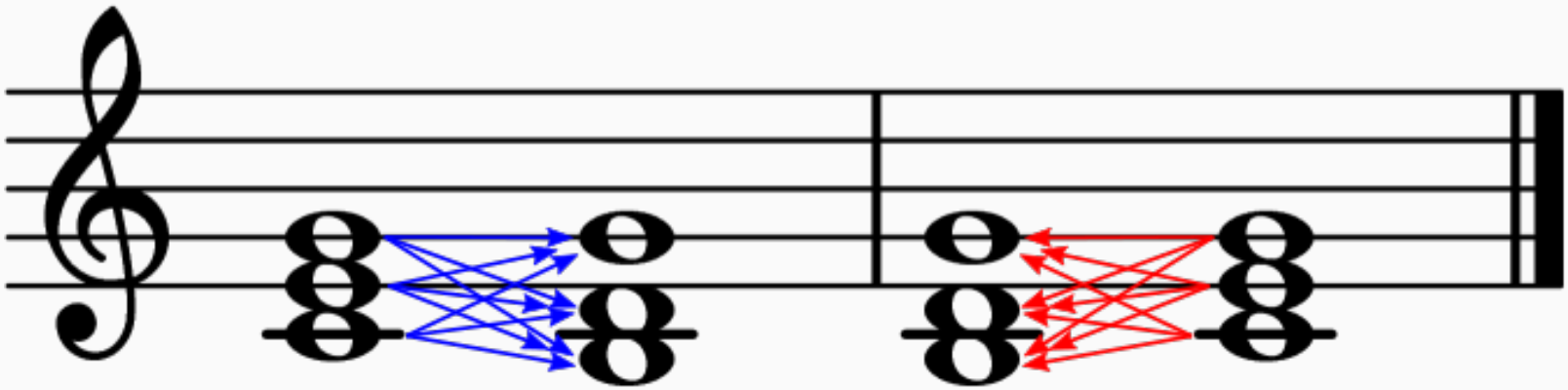


$$\mathrm{CIC}(\mathrm{A}) = (1, 0, 1, 1, 1, 0, 0, 3, 0, 0, 1, 1)$$

$$\mathrm{CIC}(\mathrm{B}) = (0, 0, 3, 0, 0, 1, 1, 1, 0, 1, 1, 1)$$

Commutativity

Changing the order of the chords changes the signs of the intervals between corresponding notes, flipping the CIC/DIC vectors:

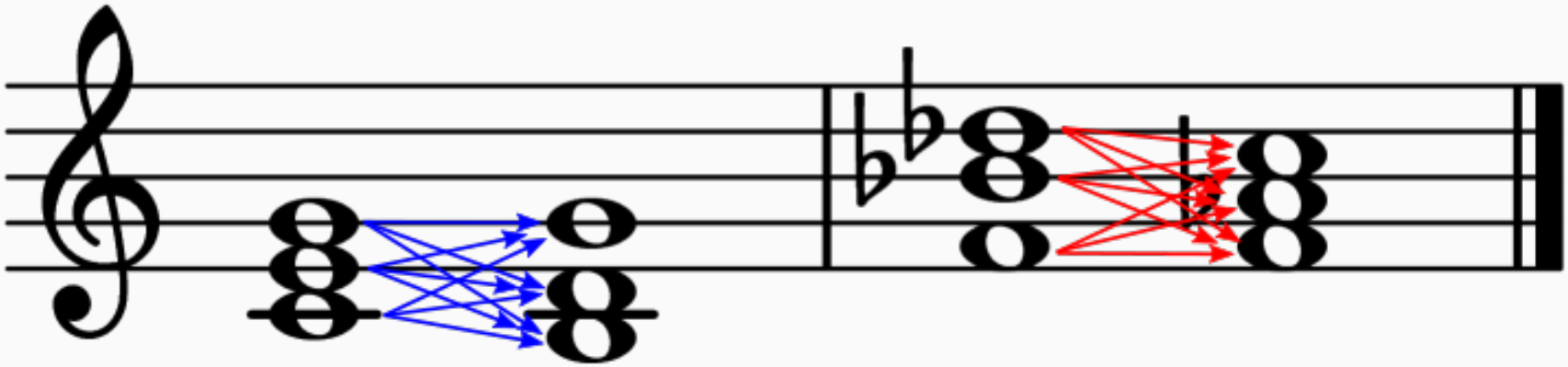


$$\mathrm{CIC}(A) = (1, 0, 1, 1, 1, 0, 0, 3, 0, 0, 1, 1)$$

$$\mathrm{CIC}(B) = (1, 1, 1, 0, 0, 3, 0, 0, 1, 1, 1, 0)$$

Pitch Class Inversion

Inverting the chords (mirroring with respect to C) and changing their sequence produces the exact same intervallic motions:



$$\mathrm{CIC}(A) = (1, 0, 1, 1, 1, 0, 0, 3, 0, 0, 1, 1)$$

$$\mathrm{CIC}(B) = (1, 0, 1, 1, 1, 0, 0, 3, 0, 0, 1, 1)$$

Experiments

Indexing Harmonic Progression

- a dataset $\mathcal{S}$ of all three-note chords that may be obtained from a given diatonic scale $\{0, 2, 4, 5, 7, 9, 11\}$;
- for every chord A in $\mathcal{S}$ a set of pseudo-chroma vectors $\mathcal{C}(A)$ was built based on geometric progressions of amplitudes $\varrho^k,\ k = 0, 1, \ldots, K-1$ with several amplitude decaying factors and number of harmonics
- for every chord progression $A \mapsto B \in \mathcal{S} \times \mathcal{S}$ a binary archetype $\mathrm{CIC}_{I_A \mapsto I_B}$ and $\mathrm{DC}_{I_A \mapsto I_B}$ were used as a search item within the set
- both methods did retrieve 100% of correct results for a large number of progressions in $\mathcal{S} \times \mathcal{S}$
- Taking all searches combined the overall scores were 96.9% for CIC and 97.3% for DC.

Genre Classification - “500 Greatest Songs of All Time” by Rolling Stone

#	ARTIST	TITLE	TIME	BPM	YEAR	GENRE	DISC-TRACK	DETAILS
1	Bob Dylan	Like a Rolling Stone	6:04	95.6	1965	Rock 1960s	POWERTRK_155-14	(details...)
2	The Rolling Stones	Satisfaction	3:43	134.7	1985	Rock 1980s	ESSENTLS_012-13	(details...)
3	John Lennon	Imagine	3:02	152.6	1971	Slow	POWERTRK_023-07	(details...)
4	Marvin Gaye	What's Going On	3:47	101.5	1971	Dance 1970s	POWERTRK_085-07	(details...)
5	Aretha Franklin	Respect	2:23	114.5	1967	Rock 1960s	POWERTRK_046-16	(details...)
6	The Beach Boys	Good Vibrations	3:36	148.8	1966	Rock 1960s	POWERTRK_032-08	(details...)
7	Chuck Berry	Johnny B. Goode	2:38	84.1	1958	Rock 1950s	POWERTRK_021-12	(details...)
8	The Beatles	Hey Jude	7:08	146.9	1969	Rock 1960s	BEATLES__BLA-13	(details...)
9	Nirvana	Smells Like Teen Spirit	5:01	117.5	1991	Rock 1990s	POWERTRK_022-01	(details...)
10	Ray Charles	What'd I Say (Parts 1 And 2)	5:06	89.6	1959	Rock 1950s	POWERTRK_071-16	(details...)
11	The Who	My Generation	3:17	97.2	1966	Rock 1960s	POWERTRK_043-14	(details...)
12	Sam Cooke	A Change Is Gonna Come	3:13	138.3	1960	TBD	DTRANDOM_005-16	(details...)
13	The Beatles	Yesterday	2:05	97.6	1966	Rock 1960s	BEATLES__RDA-13	(details...)
14	Bob Dylan	Blowin' in the Wind	2:46	93.8	1967	TBD	HOTSTUFF_026-19	(details...)
15	The Clash	London Calling	3:18	134.3	1979	Rock 1970s	POWERTRK_084-13	(details...)
16	The Beatles	I Want to Hold Your Hand	2:26	131.1	1966	Rock 1960s	BEATLES__RDA-05	(details...)
17	Jimi Hendrix	Purple Haze	2:50	110.2	1968	Rock 1960s	POWERTRK_042-13	(details...)
18	Chuck Berry	Maybellene	2:19	118.4	1955	Rock 1950s	POWERTRK_095-13	(details...)
19	Elvis Presley	Hound Dog	2:15	88.8	1956	Rock 1950s	POWERTRK_023-06	(details...)
20	The Beatles	Let It Be	3:52	137.5	1969	Rock 1960s	BEATLES__BLB-12	(details...)

(Clercq and Temperley, “A corpus analysis of rock harmony”, `http://rockcorpus.midside.com`)

Genre Classification

Genre	# of items
Rock	85
Slow	33
Dance	10

Average	CIC performance	DC performance
Macro	0.30 ($\pm$ 0.10)	0.24 ($\pm$ 0.04)
Weighted	0.54 ($\pm$ 0.10)	0.47 ($\pm$ 0.09)
Micro	0.59 ($\pm$ 0.09)	0.52 ($\pm$ 0.12)

Metric	CIC performance	DC performance
F-measure	0.74 ($\pm$ 0.02)	0.72($\pm$ 0.07)
Precision	0.68 ($\pm$ 0.06)	0.70 ($\pm$ 0.16)
Recall	0.81 ($\pm$ 0.05)	0.75 ($\pm$ 0.09)

(Chen et al., "Xgboost: A scalable tree boosting system", 2016)

Conclusion

- CIC extends Directional Interval Content (DIC) vectors to chroma features
- Dynamic Chroma considers differences between chromas of rotated chords and this reflects a musical model based on harmonic functions which are obtained by rotation
- Chroma Interval Content views chord progressionsas multi-layered displacements of chroma energy in many simultaneous directions, similarly to the harmonic flows in voice-leading
- Reduces thetheoretical complexity from $\mathcal{O}(N^2)$ to $\mathcal{O}(NlogN)$ for a chord progression between N-dimensional chroma vectors

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References

Thank you!