

Scales, Chords, and Cadences: Practical Music Theory for MIR Researchers

Chords

Main Topics

- **Chord Basics**
- **Chord Labels**
- **Evaluation for Automatic Chord Recognition**
- **Higher-Level Organization of Harmonic Material**

Terminology

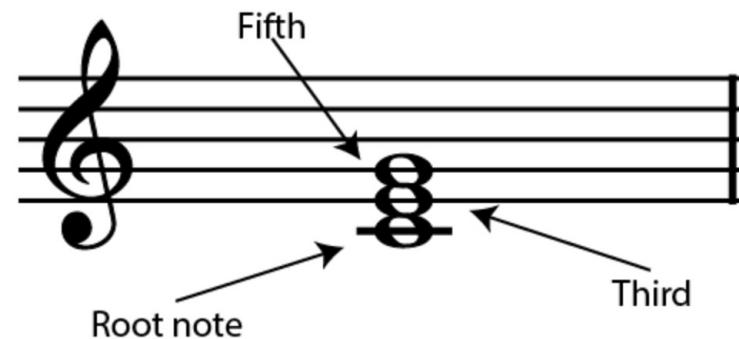
- **Root**
- **Scale degree**
- **Chord tones**
- **Non-chord tones**
- **Quality**
 - **Major, Minor, Augmented, Diminished**
- **Triads**
- **Seventh chords**
- **Added Notes/Extensions**

Chord Basics

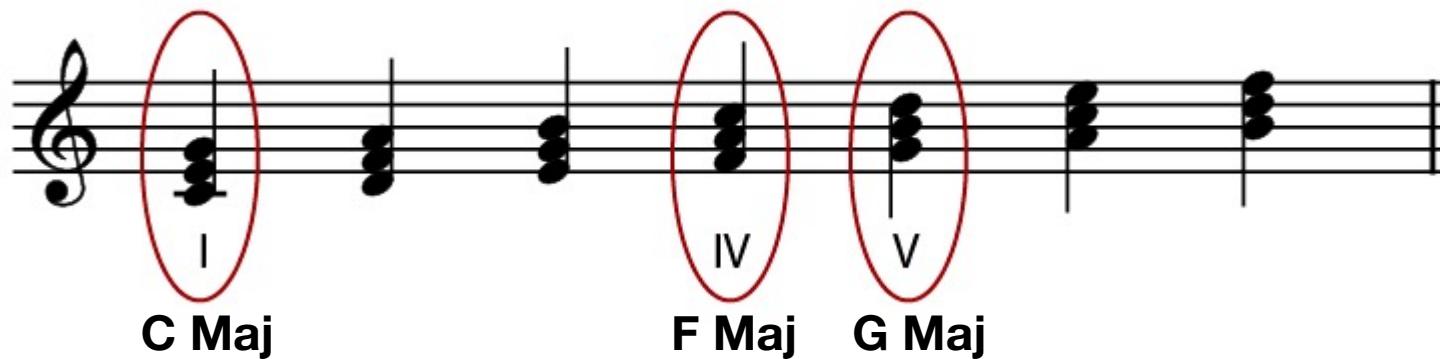
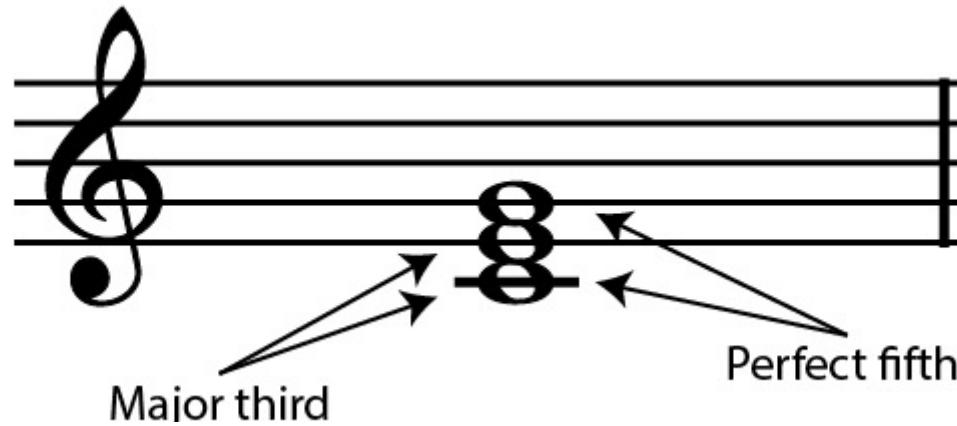
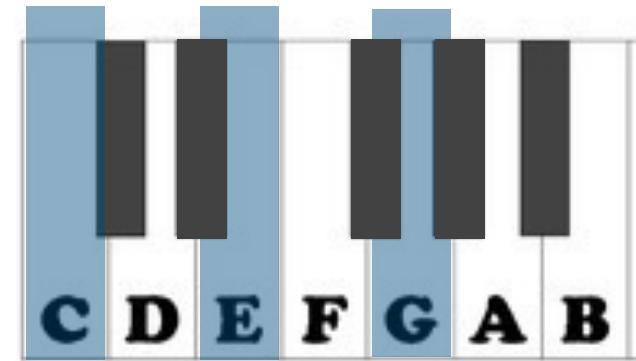
Chords



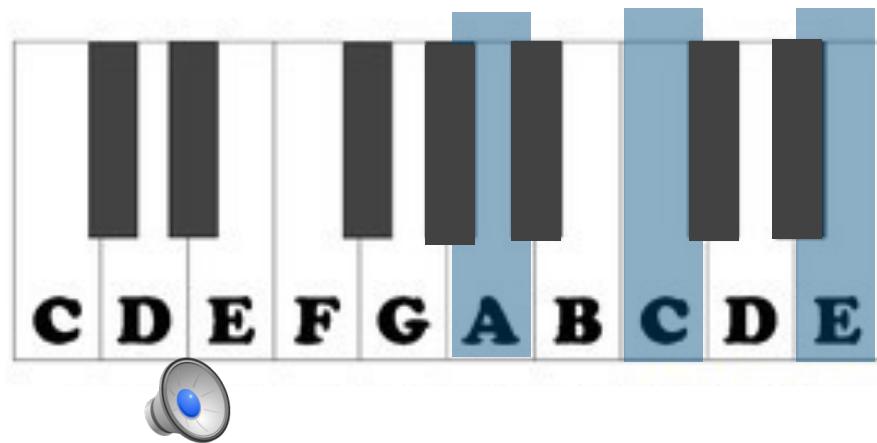
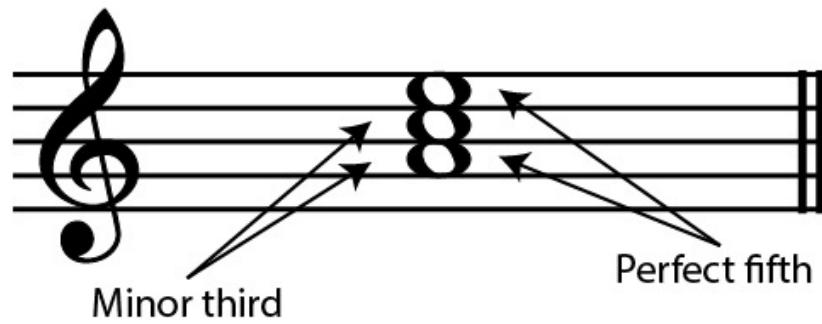
I	ii	iii	IV	V	vi	vii°
Cmaj	Dmin	Emin	Fmaj	Gmaj	Amin	Bdim



Quality: Major Triads



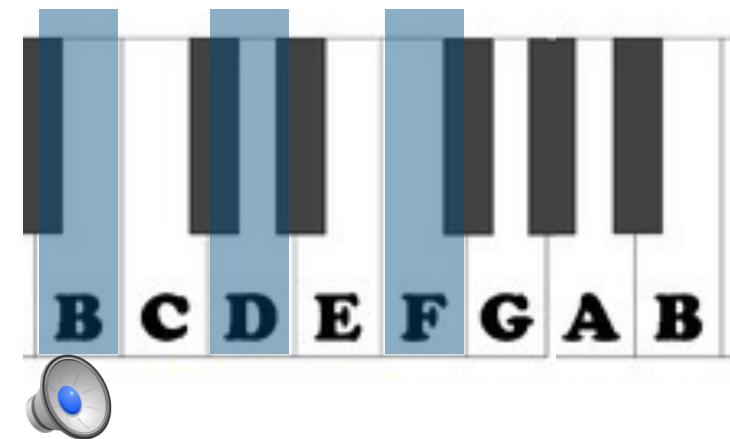
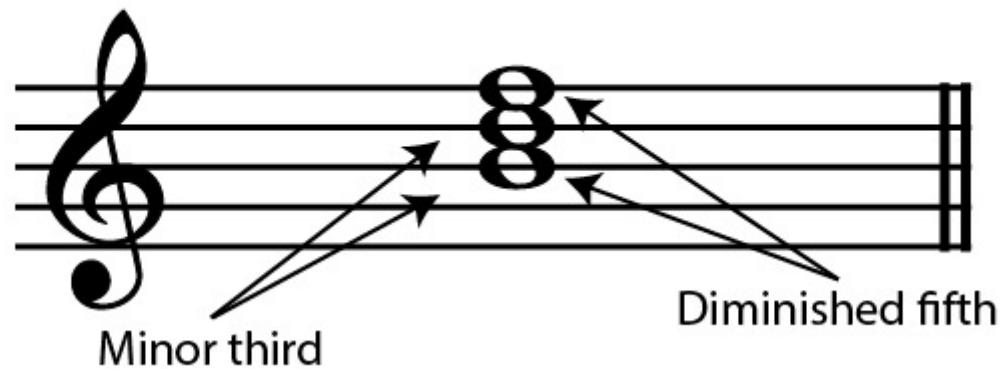
Quality: Minor Triads



A musical staff with a treble clef. Four chords are shown: ii (D minor), iii (E minor), VI (A major), and vi (A minor). The ii and iii chords are circled in red. The vi chord is circled in red and labeled "vi".

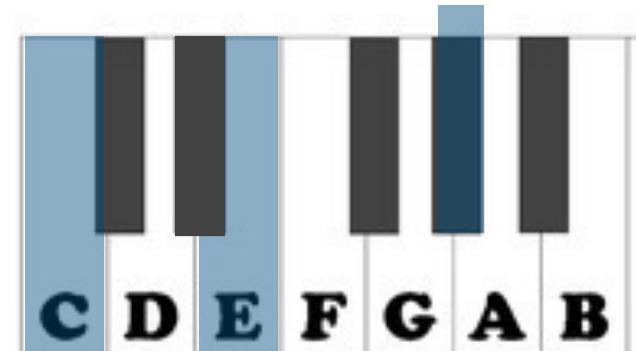
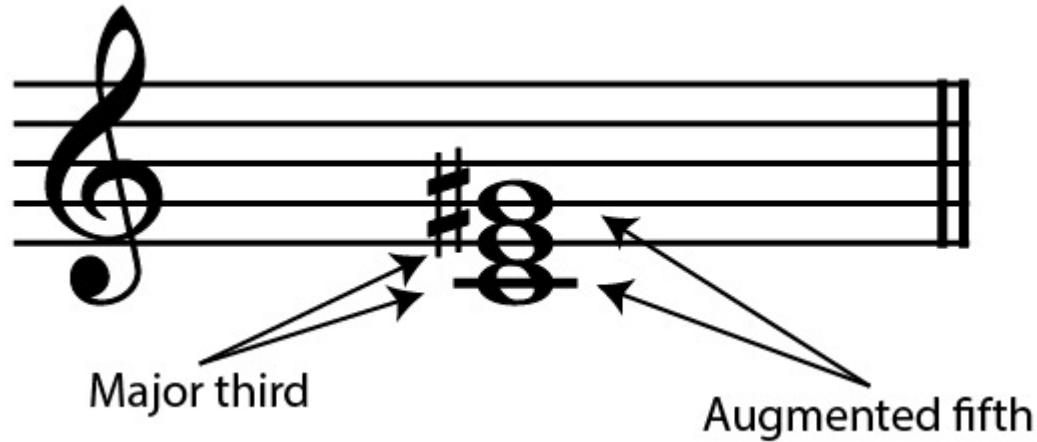
ii iii VI
d min e min a min

Quality: Diminished Triads



A musical staff showing a sequence of chords. The chords are represented by vertical stacks of three notes. A red circle highlights the seventh chord, which is a diminished triad. Below the staff, the label "vii^o" is written, followed by the label "b dim" in bold.

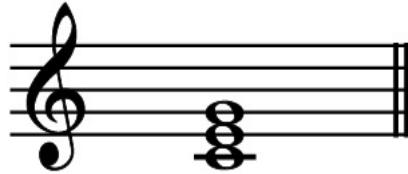
Quality: Augmented Triads



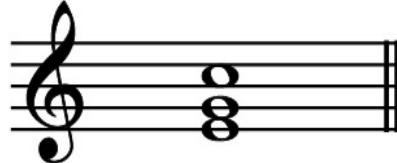
A musical staff showing a sequence of chords. The third chord, which is an augmented triad (Caug), is circled in red. Below the staff, the label "Caug" is written. The Roman numeral "III⁺" is placed directly beneath the circled chord.

Triadic Inversions

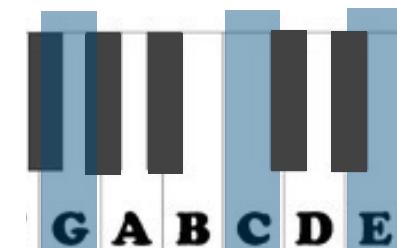
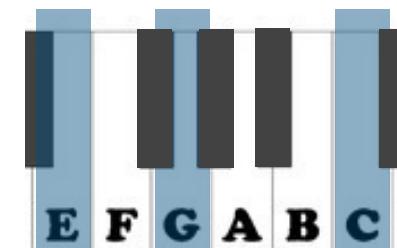
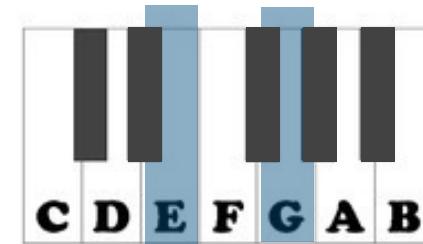
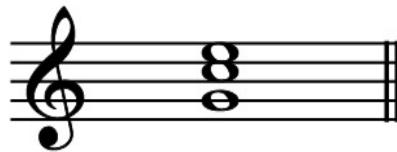
Root position



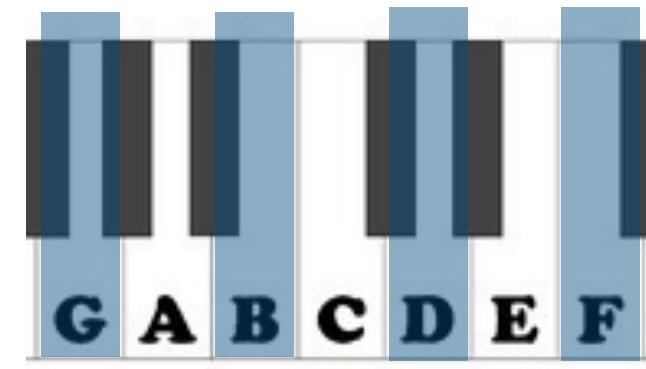
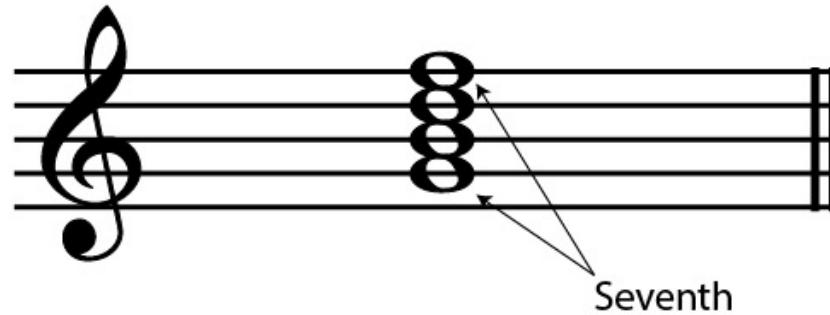
First Inversions



Second Inversions



Seventh Chords



Dominant Seventh Chords

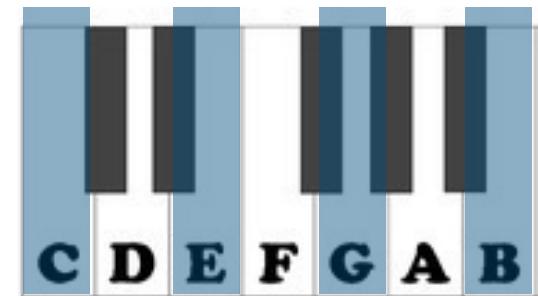
A musical staff with a treble clef. A vertical stack of four notes is labeled 'G⁷'. Below the staff, two arrows point to the bottom note: one labeled 'Major triad' and another labeled 'Minor seventh'.

The staff continues with several notes. To the right, another vertical stack of four notes is labeled 'V⁷'.

Seventh Chords

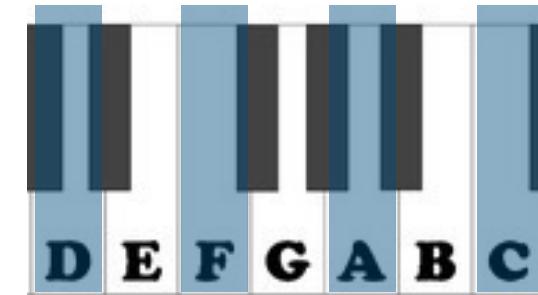
Major Seventh Chord

A musical staff in G clef. The first note is labeled **CMaj⁷**. Two arrows point from the bottom to the top note, which is labeled **Major triad** and **Major seventh**. The second note is labeled **CMaj⁷** with a Roman numeral **I⁷** below it. The third note is labeled **FMaj⁷** with a Roman numeral **IV⁷** below it. The fourth note is a short note.

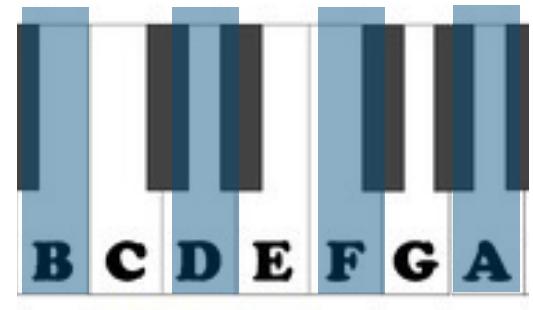


Minor Seventh Chord

A musical staff in G clef. The first note is labeled **Dm⁷**. Two arrows point from the bottom to the top note, which is labeled **Minor triad** and **Minor seventh**. The second note is labeled **Dm⁷** with a Roman numeral **ii⁷** below it. The third note is labeled **Em⁷** with a Roman numeral **iii⁷** below it. The fourth note is labeled **Am⁷** with a Roman numeral **vi⁷** below it.



Seventh Chords

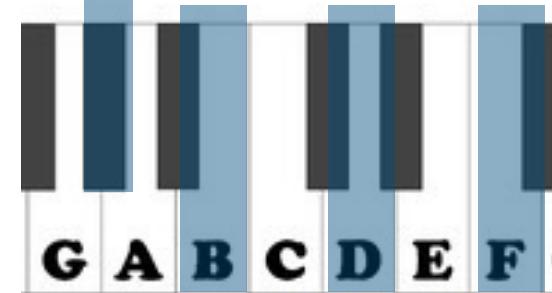


Half-diminished Seventh Chord

Musical staff showing the notes of a half-diminished seventh chord, labeled $Bm7(b5)$. The notes are: Diminished triad (B, D, F) and Minor seventh (B, D, F, A). The chord is shown in two inversions.

Diminished Seventh Chord

Musical staff showing the notes of a diminished seventh chord, labeled $G^\#dim^7$. The notes are: Diminished triad (G, B, D) and Diminished seventh (G, B, D, F). The chord is shown in two inversions.



Seventh Chords - Summary

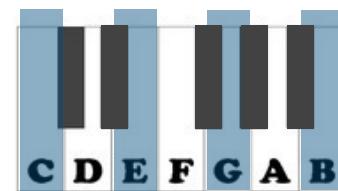
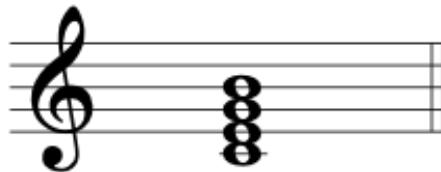
Chord	Triad type	Seventh interval	Chord symbol		
Dominant seventh	Major	Minor seventh	C^7		
Major seventh	Major	Major seventh	$CMaj^7$	CMa^7	C^Δ
Minor seventh	Minor	Minor seventh	Cm^7	C^-7	$Cmin^7$
Half-diminished seventh	Diminished	Minor seventh	$Cm7^{(b5)}$	C^0	
Diminished seventh	Diminished	Diminished seventh	$Cdim7$	C^o7	

The diagram illustrates five common seventh chords with their component triads and seventh intervals:

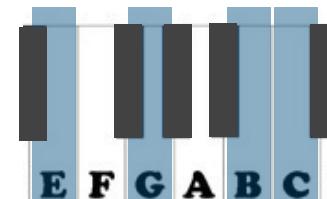
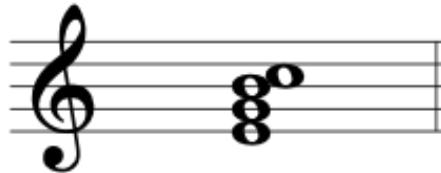
- G⁷**: Major triad (G, B, D) and Minor seventh (G, B, D, E).
- CMaj⁷**: Major triad (C, E, G) and Major seventh (C, E, G, B).
- Dm⁷**: Minor triad (D, F, A) and Minor seventh (D, F, A, C).
- Bm^{7(b5)}**: Diminished triad (B, D, F#) and Minor seventh (B, D, F#, A).
- G^{#dim7}**: Diminished triad (G, B, D) and Diminished seventh (G, B, D, F).

Seventh Inversions

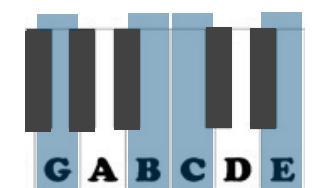
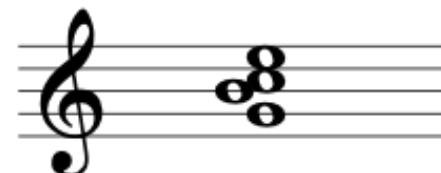
Root position



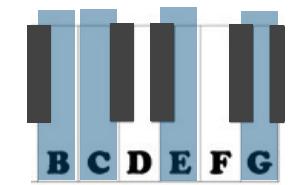
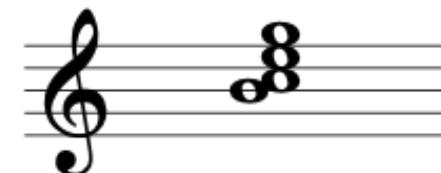
First Inversion



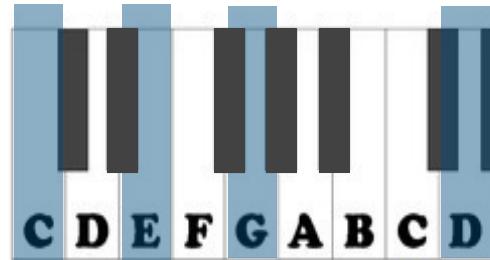
Second Inversion



Third Inversion

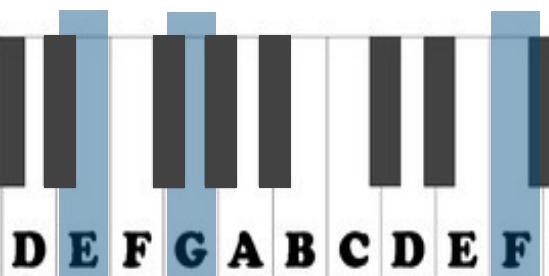


Other Added Notes/Extensions



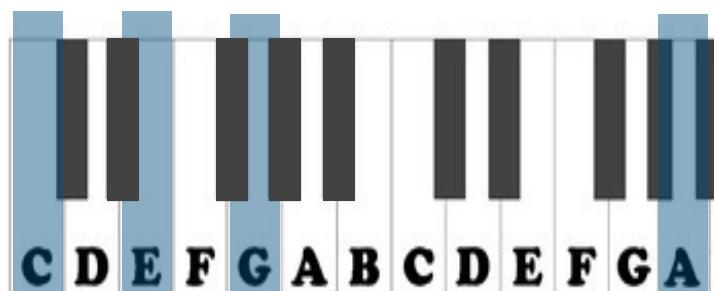
add9

Musical staff for an add9 chord. It shows a treble clef, an open circle (root note), a bass clef, an open circle (root note), and a solid circle (third note). Two speaker icons are shown at the ends of the staff.



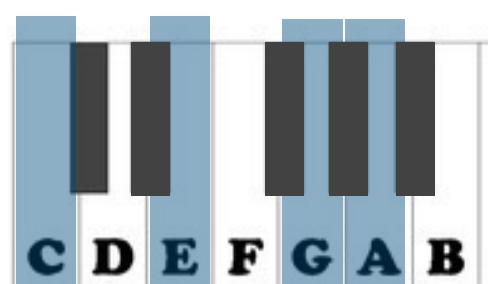
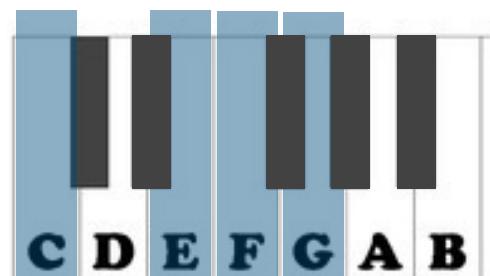
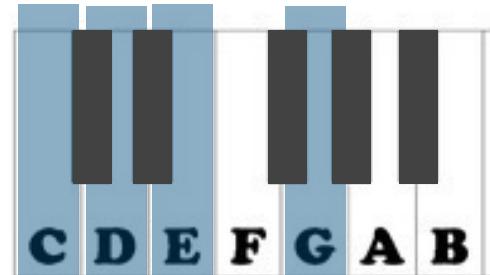
add11

Musical staff for an add11 chord. It shows a treble clef, an open circle (root note), a bass clef, an open circle (root note), and a solid circle (third note). Two speaker icons are shown at the ends of the staff.



add13

Musical staff for an add13 chord. It shows a treble clef, an open circle (root note), a bass clef, an open circle (root note), and a solid circle (third note). Two speaker icons are shown at the ends of the staff.



Chord Labels

What Information Different Labels Contain

▶ Roman numerals

- Scale degree + quality (major, minor, diminished, etc.)
- Indicate if any notes are added (7, 9, etc.)
- *Explicitly linked to key*

I
in C major

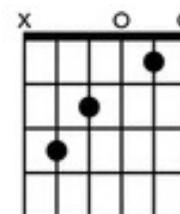
▶ Chord Symbols

- Root + quality (major, minor, diminished, etc.)
- Indicate if any notes are added (7, 9, etc.)
- *Independent of key*

C
or
Cmaj

▶ Tablature

- Denotes fingering on guitar fretboard
- *Independent of root and key*



Information Different Labels Contain



9 Variationen über ein Minuett von Duport

Mozart

D: I Dmaj I Dmaj V⁷ A⁷ I Dmaj

Chords can be expressed vertically, horizontally,
or a combination of the both

Information Different Labels Contain

9 Variationen über ein Minuett von Duport

Mozart

Non-chord tones

The musical score consists of two staves. The top staff shows a melody line with various note heads and stems. Three specific notes are circled in blue: one on the fourth beat of the first measure, one on the second beat of the third measure, and one on the first beat of the fourth measure. The bottom staff shows a harmonic bass line with sustained notes and rhythmic patterns.

D: I I V⁷ I

Dmaj Dmaj A⁷ Dmaj

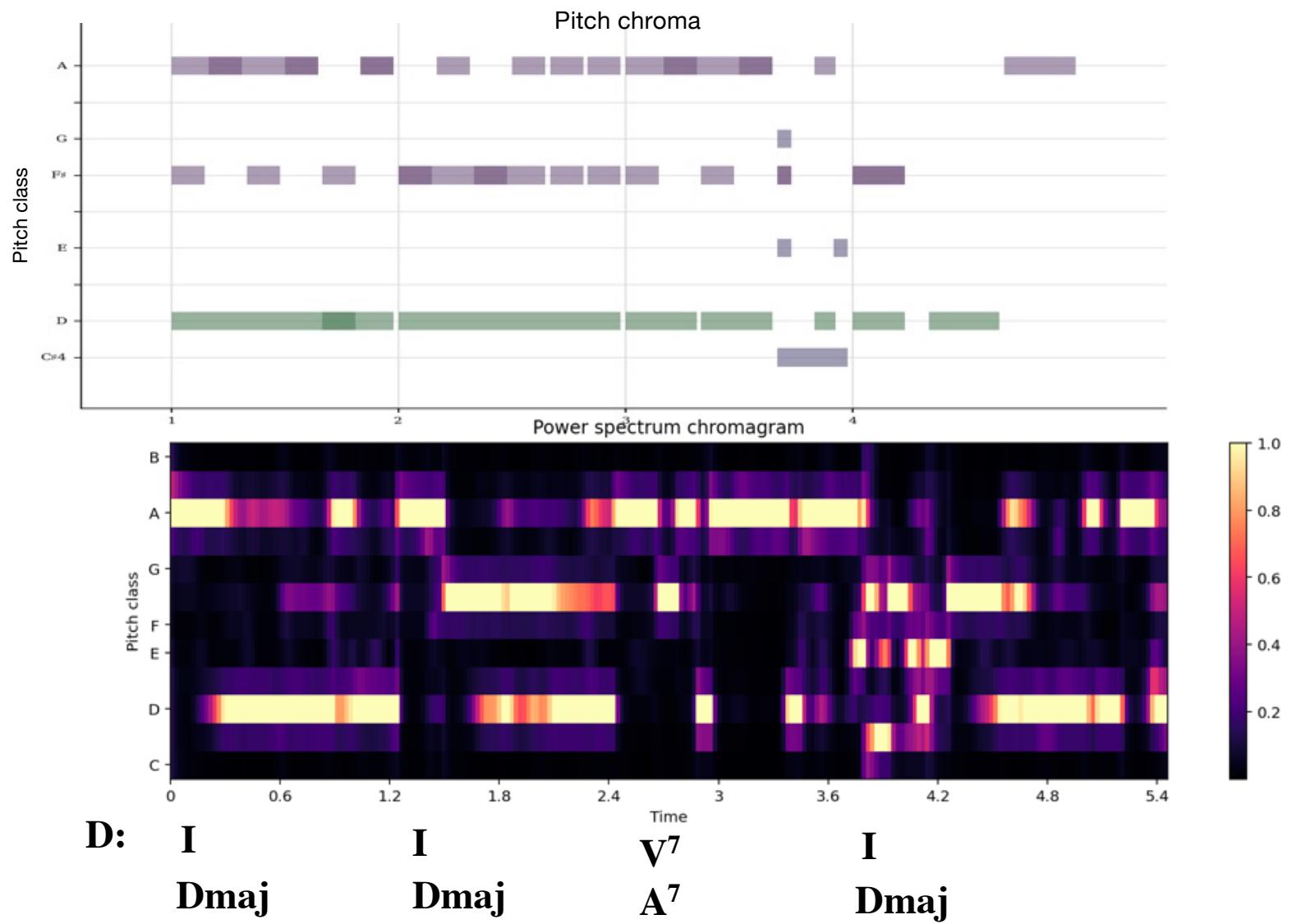
Information Different Labels Contain

9 Variationen über ein Minuett von Duport

Mozart

Non-chord tone

D: I I I⁶⁴ V⁷ I
I I V⁷ I
Dmaj Dmaj A⁷ Dmaj



Pitch Class Content in Chords

Variations on 'Es war einmal ein alter Mann', WoO 66

Theme

v I V6 16 viio6 I V64 v

T D

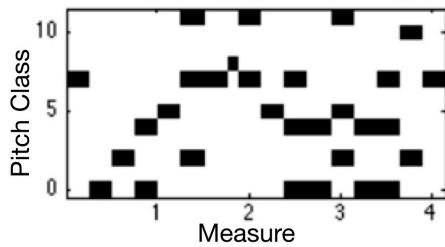
Variation

Beethoven

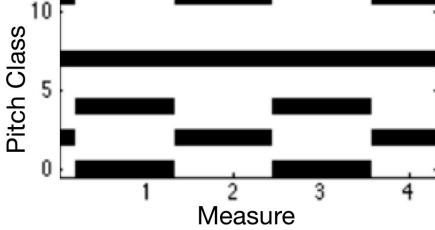
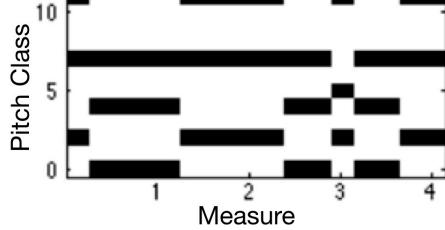
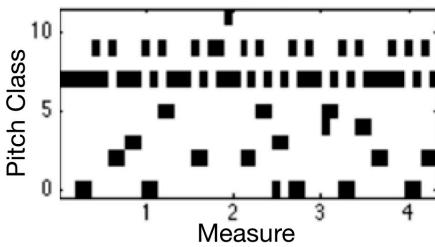
v I v I v

T D

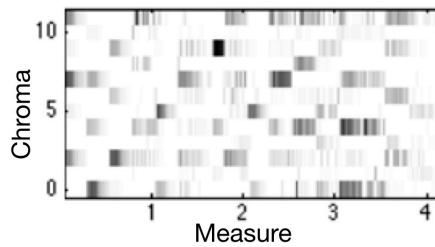
Theme (Symbolic)



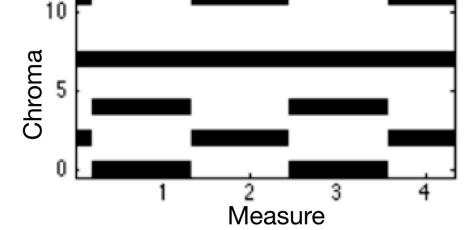
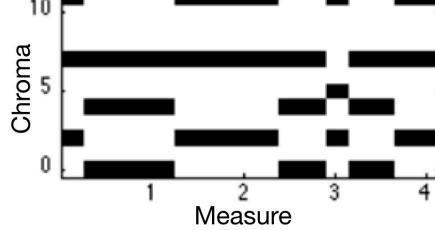
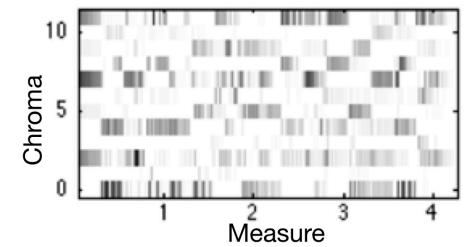
Variation (Symbolic)



Theme (Audio)



Variation (Audio)



Corpora

Some Corpora

	Name	Label Type
(i)	Kostka-Payne	Chord tones
(ii)	iRealB	Chord symbols
(iii)	Beatles	Chord symbols
(iv)	Real World Computing (RWC)	Roman numerals
(v)	Billboard	Chord symbols

(i) Key 0 18333 3 1
Key 17499 26666 1 0
Key 24999 37499 0 0
Key 35833 46666 3 1
Chord 0 416 3
Chord 416 833 8
Chord 833 1666 3
Chord 1666 2499 4
Chord 2499 3333 3
Chord 3333 4166 8
Chord 4166 4999 3

(ii) !!!OTL: Embraceable You
!!!COM: Gershwin, George
!!!ODT: 1928
**jazz
*>[A,B,A2,C]
*>A
*M4/4
*G:
1G:maj7
= 1B-07
= 1A:min7

(iii) 0.000000 0.414094 N
0.414094 1.329503 D
1.329503 1.770682 D:maj6
1.770682 2.258301 D
2.258301 3.117439 E/b7
3.117439 3.593448 E:maj6/b7
3.593448 3.999798 E/b7
3.999798 4.893766 G/5
4.893766 5.323335 G:maj6/5
5.323335 5.764514 G/5
5.764514 6.623653 D

(iv) % RWC-MDB-C-2001 No.2
% Mozart: Symphony No.40 in g minor, 1st Movement
@K=g @M=2/2 % key=g-minor, meter=2/2
% bars 1- (theme I)
g:
||: i | i | i | i | ii-7''' | ii-7''' | V7' |
V7 | i | !V9''' | i' | !V9''' | i' | {v: ii-7 |
!V-9'' | I! 1/2!V9'''' 1/2!V9''''/I |
I 1/2!V9'''' 1/2!V9'''' | I 1/2!V9'''' 1/2!V9'''' |
I !V9''''/I I !V9''''/I | I} V3?7'' | i V' |
i | i | iv7' | iv7={III: ii7 | V7 | V7 |

(v) # title: I Don't mind
artist: James Brown
metre: 6/8
tonic: C

0.0 silence
7.3469387e-2 A, intro, | A:min | A:min | C:maj | C:maj |
8.714013605 | A:min | A:min | C:maj | C:maj |
15.611995464 | A:min | A:min | C:maj | C:maj |
22.346394557 B, verse, | A:min | A:min | C:maj | C:maj |
29.219433106 | A:min | A:min | C:maj | C:maj |
36.279501133 | F:maj | F:maj | D:maj | D:maj |
43.053922902 | G:maj | G:maj | C:maj | C:maj |

Some Datasets

	Name	Label Type
(i)	Theme and Variations with Romand Numeral Encoding (TAVERN)	Roman numerals
(ii)	(ABC)	Chord symbols
(iii)	(BPH-FS)	Chord symbols

```
(i) !!!COM: Mozart
!!!OTL: 12 Variations on "Ah Vous dirais-je, Maman"
!!!Variation: Theme a
**function **harm **kern **kern
* * *clefF4 *clefG2
* * *k[] *k[]
*M4/4 *M4/4 *M2/4 *M2/4
*C: *C: *C: *C:
```

```
=1 =1 =1 =1
4T 4I 4C 4cc
4T 4I 4c 4cc
=2 =2 =2 =2
4T 4Ib 4e 4gg
4T 4Ib 4c 4gg
=3 =3 =3 =3
4T 4IV 4f 4aa
4T 4IV 4c 4aa
=4 =4 =4 =4
4T 4Ib 4e 4gg
4T 4Ib 4c 4gg
=5 =5 =5 =5
4T 4ii 4d 4ff
4T 4viio 4B 4ff
=6 =6 =6 =6
4T 4I 4c 4ee
4T 4vi 4A 4ee
=7 =7 =7 =7
4P 4iib 4F 4dd
4D 4V 4G (8.ddL
. . . 16eeJk
=8 =8 =8 =8
2T 2I 2C 2cc)
*- *- *- *-
```

```
(ii) -1 8 f 1 m 0 i
      8 16 f 5 D7 1 V65
      16 20 f 1 m 0 i
      20 24 f 5 D7 2 V43
      24 26 f 1 m 1 i6
      26 28 f 2 d 1 ii-6
      28 31 f 5 D7 0 V
      31 40 A- 3 m 0 iii
      4B 4ff
      =6 =6 =6
      4T 4I 4c 4ee
      4T 4vi 4A 4ee
      =7 =7 =7 =7
      4P 4iib 4F 4dd
      4D 4V 4G (8.ddL
      . . . 16eeJk
      =8 =8 =8 =8
      2T 2I 2C 2cc)
      *- *- *- *-
```

chord	measure	beat	totbeat	timesig	op	no	mov	length	global_key	local_key	numeral	figbass	changes	phraseend
.Eb.I	1	1	1	2/4	127	12	1	2.5	Eb	I	I			FALSE
V43	2	1.5	3.5	2/4	127	12	1	1.5	Eb	I	V	43		FALSE
I	3	1	5	2/4	127	12	1	2.5	Eb	I	I			FALSE
V2	4	1.5	7.5	2/4	127	12	1	1.5	Eb	I	V	2		FALSE
I6	5	1	9	2/4	127	12	1	1	Eb	I	I	6		FALSE
IV\\\\\\	6	1	11	2/4	127	12	1	2	Eb	I	IV			TRUE
IV	7	1	13	3/4	127	12	1	1	Eb	I	IV			FALSE
ii6	7	2	14	3/4	127	12	1	1	Eb	I	ii	6		FALSE
V2	7	3	15	3/4	127	12	1	1	Eb	I	V	2		FALSE
I6	8	1	16	3/4	127	12	1	2	Eb	I	I	6		FALSE
vi64	8	3	18	3/4	127	12	1	1	Eb	I	vi	64		FALSE
ii7	9	1	19	3/4	127	12	1	2	Eb	I	ii	7		FALSE
V43	9	3	21	3/4	127	12	1	1	Eb	I	V	43		FALSE
I6(7)	10	1	22	3/4	127	12	1	1	Eb	I	I	6	7	FALSE

Higher-Level Organization of Harmonic Material

Some Standard Pop Music Chord Progressions

Blues C - F - G I - IV - V

Axis C - G - a - F
I - V - vi - IV

**50's
Doo wop** C - a - F - G
I - vi - IV - V



4 Chords
(2011)

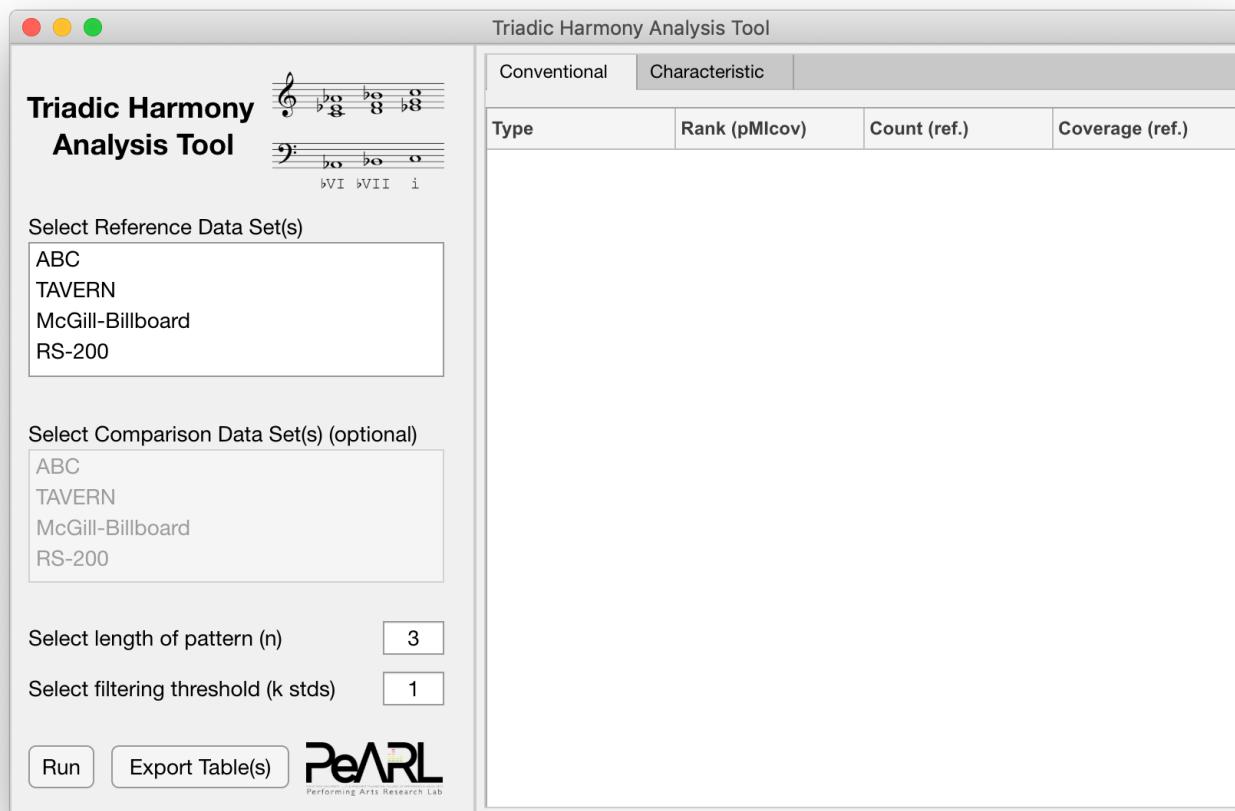
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<https://www.youtube.com/watch?v=oOlDewpCfZQ>

Chord Progressions in Corpora

Sears and Forrest (2001)



<https://osf.io/kdzm3/>

Function

- **Casual: Certain chords tend to lead to other chords**
 - V-I can give a sense of closure in certain musical styles
 - will get into more details about this later
- **Formal: Hierarchical model to capture how chords work together to build phrases**
 - Tonic (I) – Pre-dominant (ii or IV) – Dominant (V)

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Mozarts Werke.

12 VARIATIONEN über „Ah vous dirais-je, Maman“

für das Pianoforte
von

Serie 21. N° 6.

W. A. M O Z A R T.

Köch. Verz. N° 265.

TEMA.

The musical score for W.A. Mozart's 12 Variations on "Ah vous dirais-je, Maman" is presented in two staves. The top staff (treble clef) starts with a forte dynamic (ff) and contains 12 measures. The bottom staff (bass clef) starts with a forte dynamic (f) and also contains 12 measures. Both staves conclude with a half note followed by a colon. A vertical orange bar is positioned at the end of the first staff, marking the transition to the variations.

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Quiz: Matching a variation to a theme

Top staff of a musical score in G clef, 3/4 time, and B-flat key signature. The staff consists of two measures. Notes in the first measure are circled in orange. Labels below the staff identify them: "I/T" under the first note, "V⁷/D" under the second note, and "I/D" under the third note. The second measure also contains circled notes, which are enclosed in a large orange box.

?

?

Three variations of a musical theme, each consisting of two measures. The first variation (left) has circled notes and labels: "I/T", "V⁶⁵/T", "V⁷/T", and "I/T". The second variation (middle) has circled notes and a label: "V⁷/D". The third variation (right) has circled notes and labels: "I/T", "V⁷/D", "I/D", "V⁷/D", and "I/T". Arrows from the question marks point to the "V⁷/D" label in the middle variation and the "V⁷/D" label in the right variation.

Evaluation of Automatic Chord Estimation Algorithms

MIREX Evaluation Metrics

1. Chord root note only
2. Major and minor: N, maj, min
3. Seventh chords: N, maj, min, maj7, min7, 7
4. Major and minor with inversions: N, maj, min, maj/3, min/b3, maj/5, min/5
5. Seventh chords with inversions: N, maj, min, maj7, min7, 7, maj/3, min/b3, maj7/3, min7/b3, 7/3, maj/5, min/5, maj7/5, min7/5, 7/5, maj7/7, min7/b7, 7/b7

Labels not independent due to
overlapping content between labels

BEYOND CHORD VOCABULARIES: EXPLOITING PITCH-RELATIONSHIPS IN A CHORD ESTIMATION METRIC

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note name	C	C#	D	D#	E	F	F#	G	G#	A	A#	B
pitch class	0	1	2	3	4	5	6	7	8	9	10	11
C (I)	o	-	-	-	o	-	-	o	-	-	-	-
d (ii)	-	-	o	-	-	o	-	-	-	o	-	-
e (iii)	-	-	-	-	o	-	-	o	-	-	-	o
F (IV)	o	-	-	-	-	o	-	-	-	o	-	-
G(V)	-	-	o	-	-	-	-	o	-	-	-	o
a (vi)	o	-	-	-	o	-	-	-	-	o	-	-
b ^o (vii ^o)	-	-	o	-	-	o	-	-	-	-	-	o

Let C be the number of predicted notes \hat{y} in the ground truth correctly identified y

$$C = |\hat{y} \cap y| \quad (1)$$

Let I be the number of insertions (extra predicted notes) in the estimated chord that are not present in the ground truth.

$$I = |\hat{y} \setminus y| \quad (2)$$

Let A be the accuracy measurement for each chord estimate, calculated from C and I scaled between 0 and 1.

$$A = \frac{C - I + |y|}{2|y|} \quad (3)$$

Main Takeaways

- **Chord Labels**
 - Different types of chord labels (roman numerals, pop chord labels, tablature) contain different types of information with respect to key and chord root
 - Chord labels represent which notes or chroma are chord tones versus non-chord tones
- **Higher-Level Organization of Harmonic Material**
 - Chords do not occur in isolation
- **Evaluation for Automatic Chord Recognition**
 - Chord labels are not independent of one another