

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

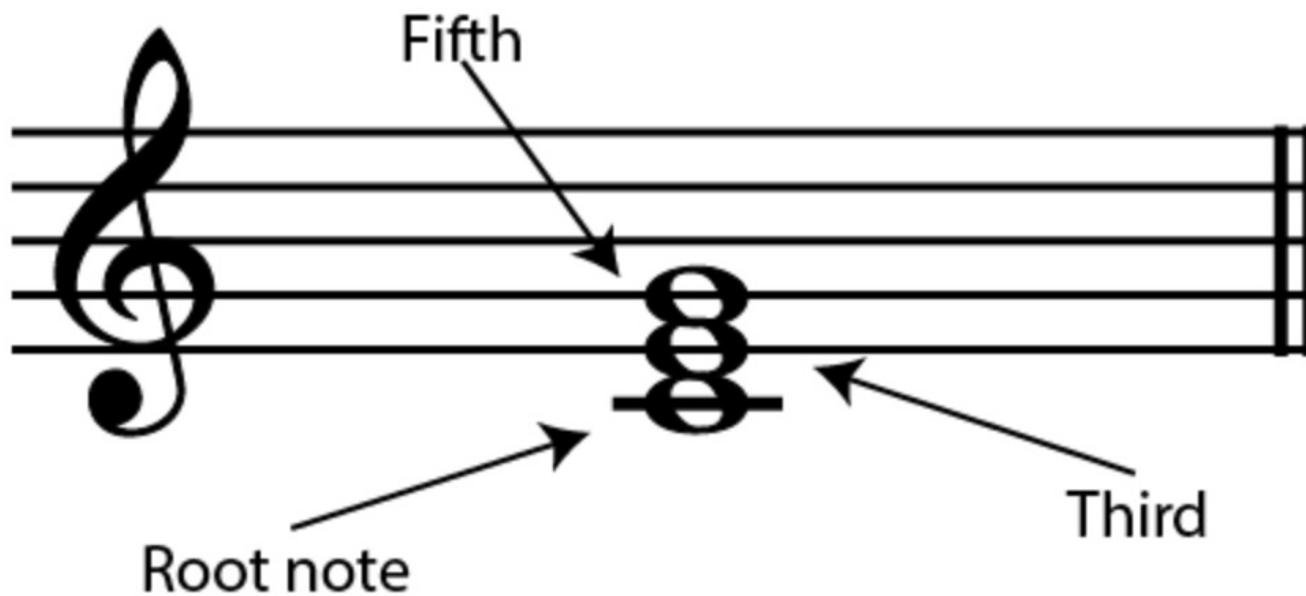
- ▶ **(Chord) Root – Lowest note in the chord's most compact position**
- ▶ **Scale degree – Position of a note relative to a musical scale**
- ▶ **Chord tones – Notes that are part of the current chord**
- ▶ **Non-chord tones – Notes that are not part of the current chord**
- ▶ **(Chord) Quality – Describes the intervals within a chord**
 - **Triad qualities: Major, Minor, Augmented, Diminished**
- ▶ **Triads – Chords with three notes**
- ▶ **Seventh chords – Chords with four notes**
- ▶ **Added Notes/Extensions – Additional chord notes beyond a 7th from the root**

Chord Basics

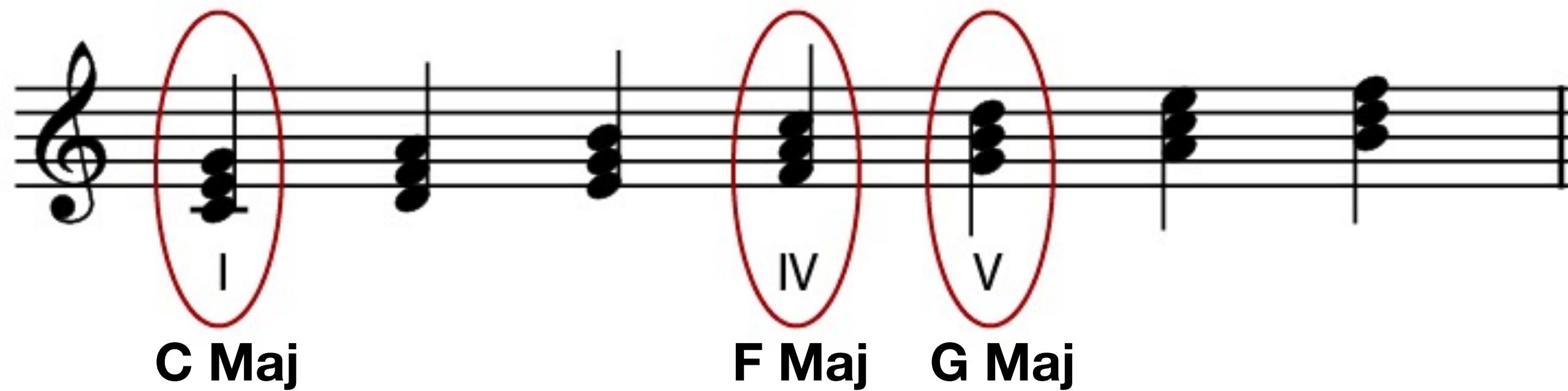
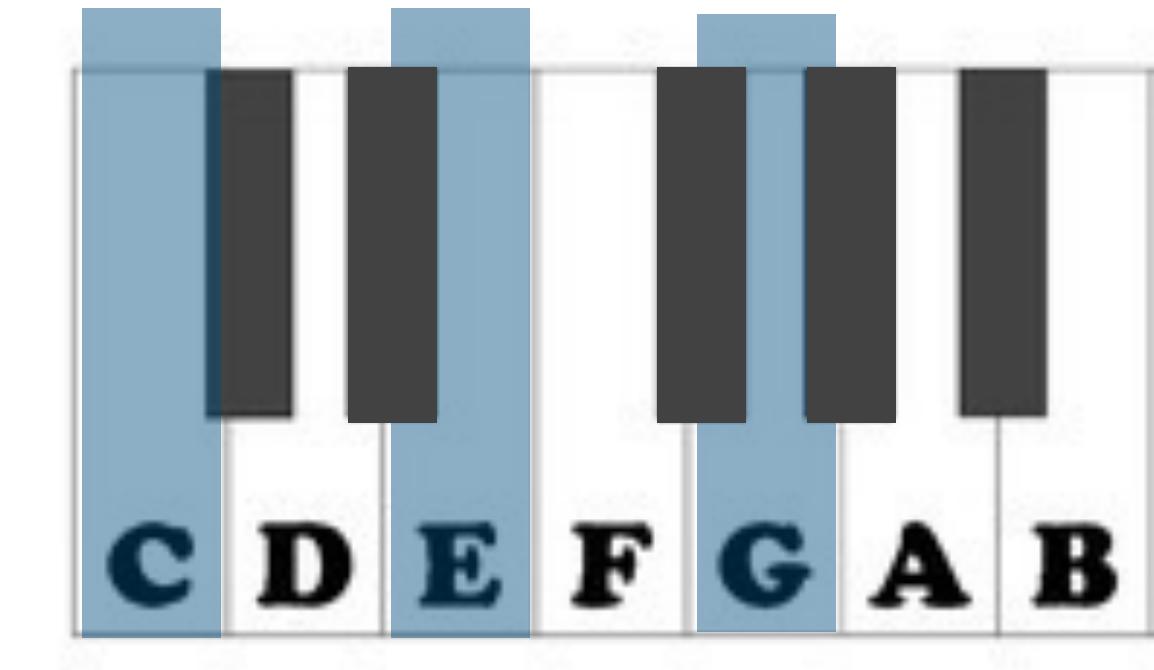
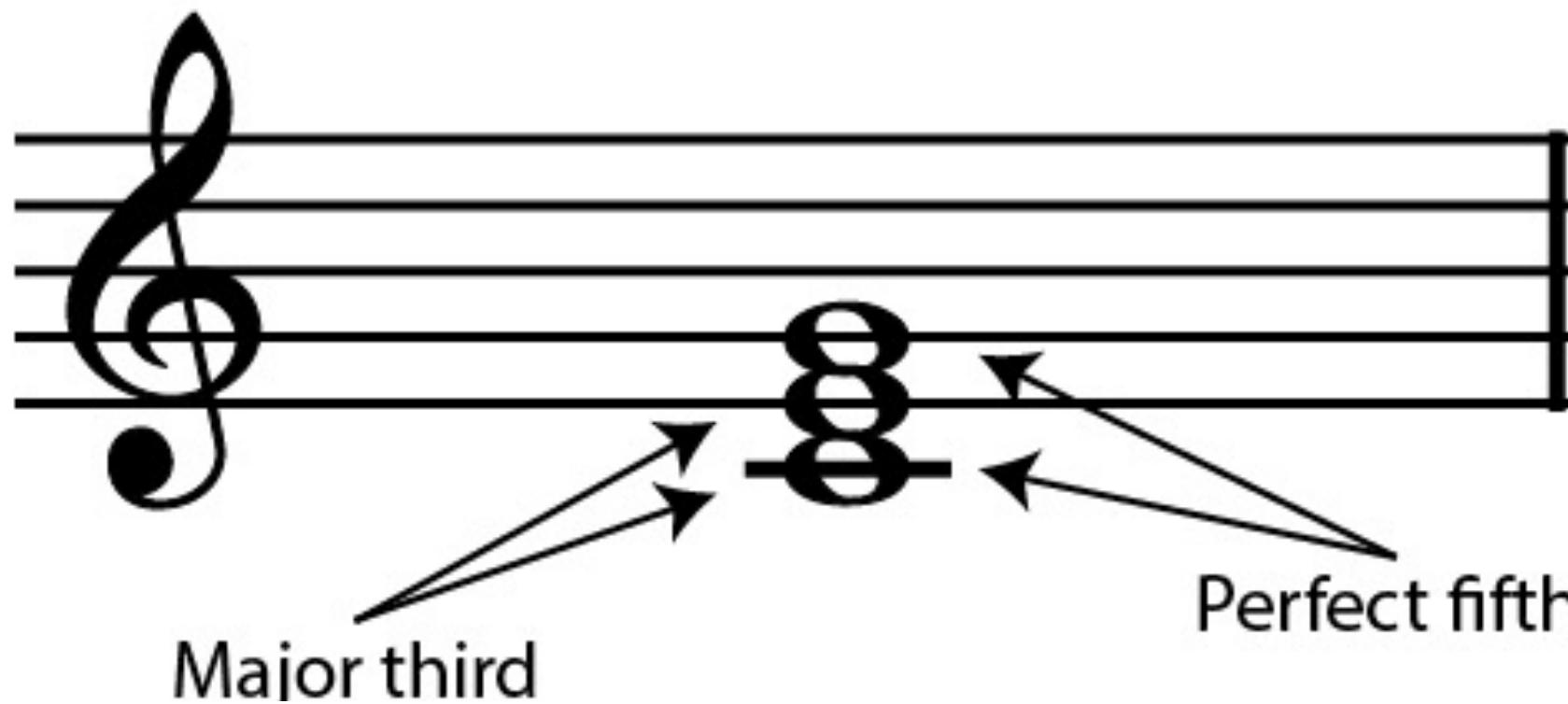
Chords



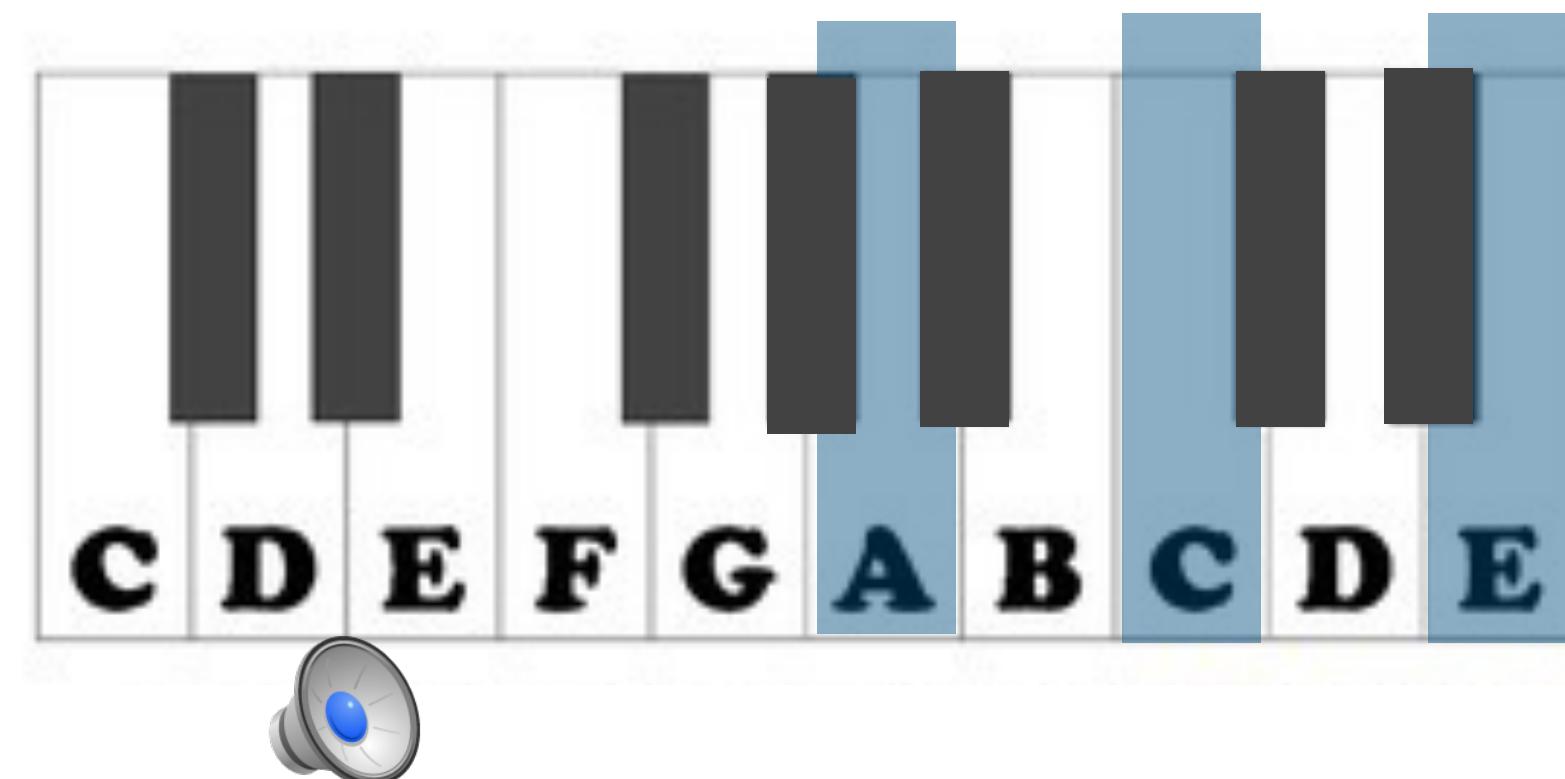
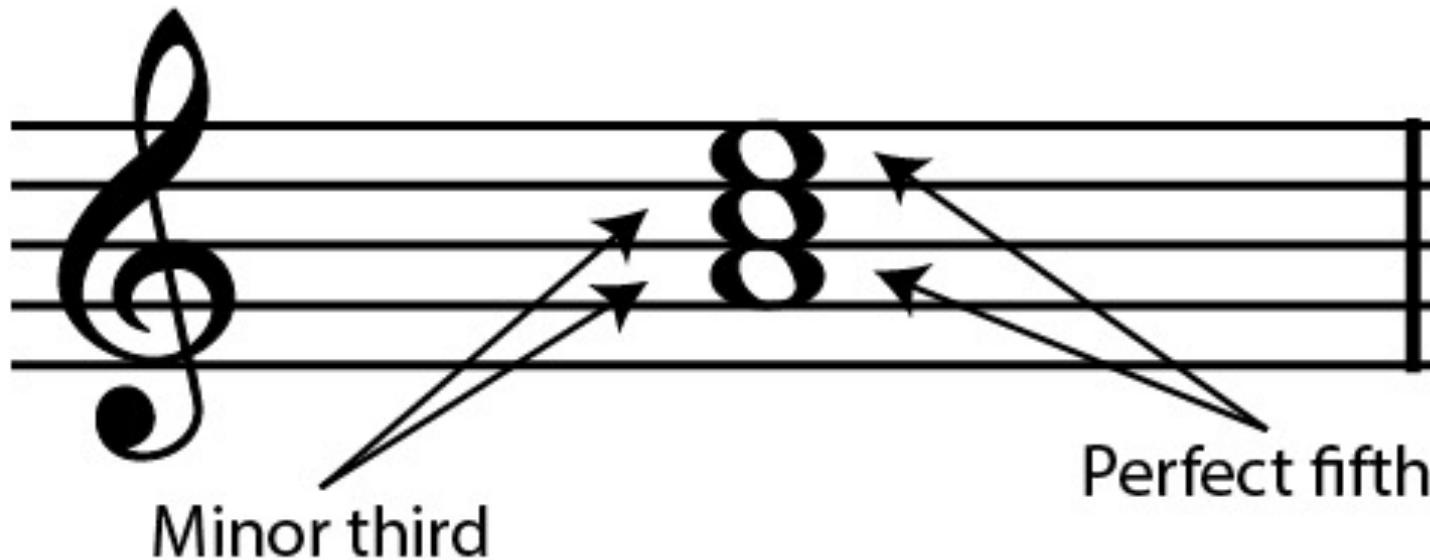
I	ii	iii	IV	V	vi	vii ^o
Cmaj	Dmin	Emin	Fmaj	Gmaj	Amin	Bdim



Quality: Major Triads

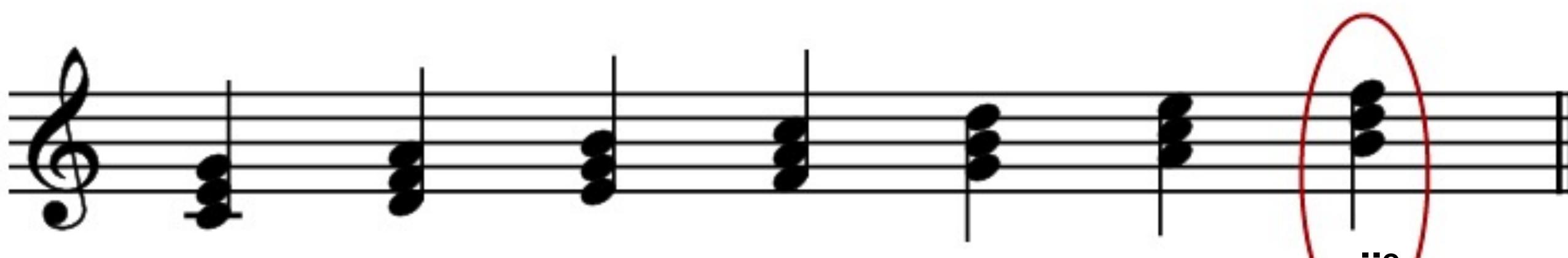
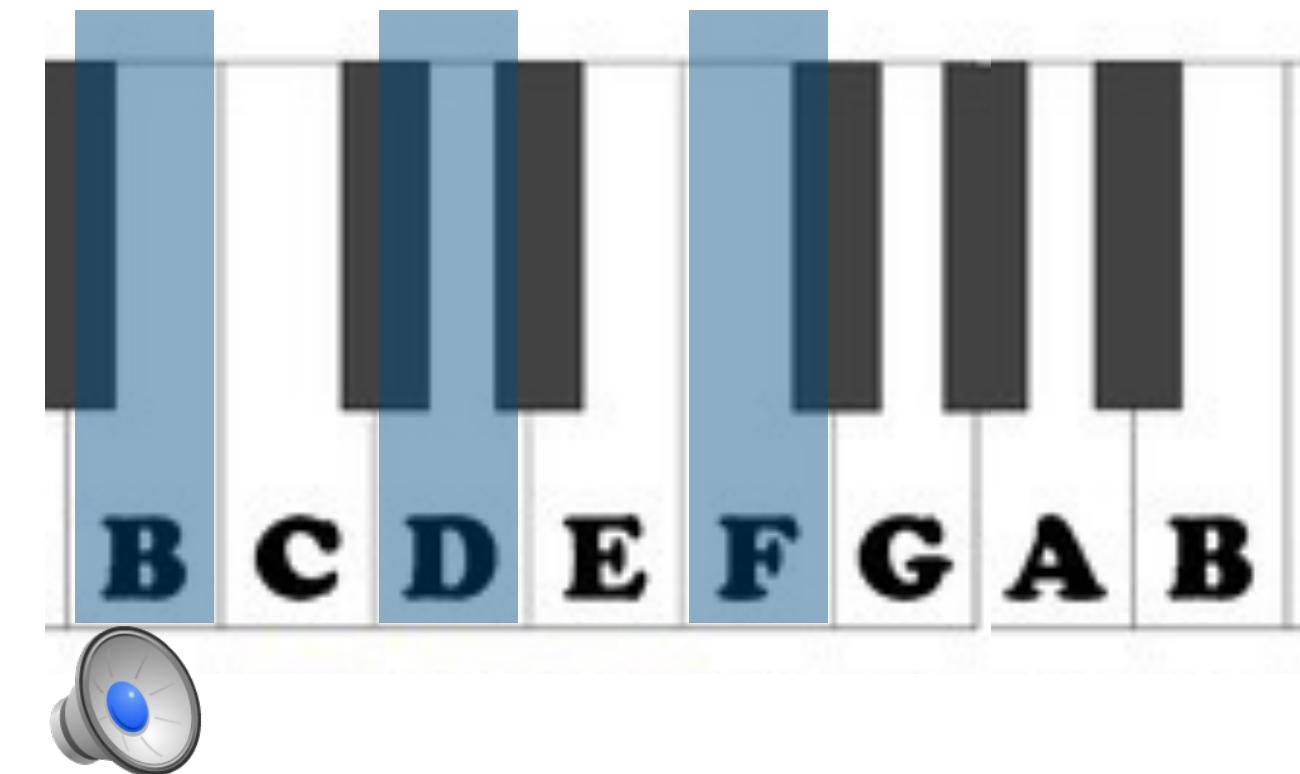
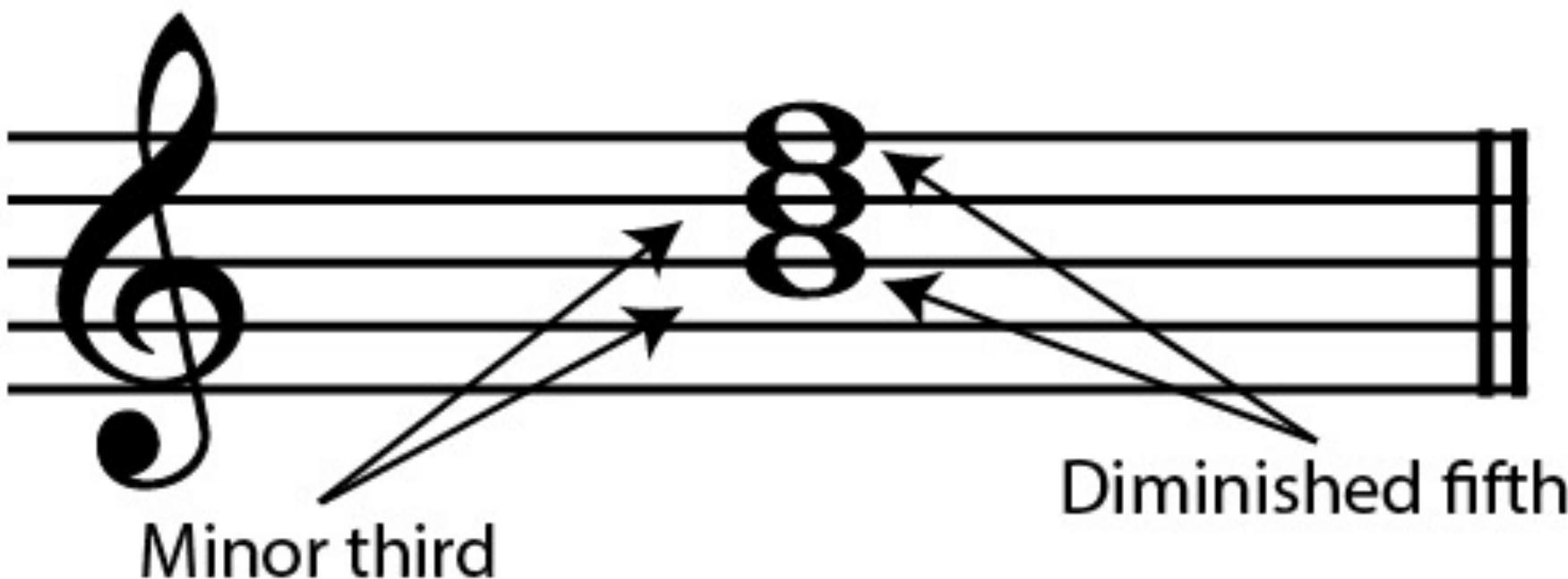


Quality: Minor Triads



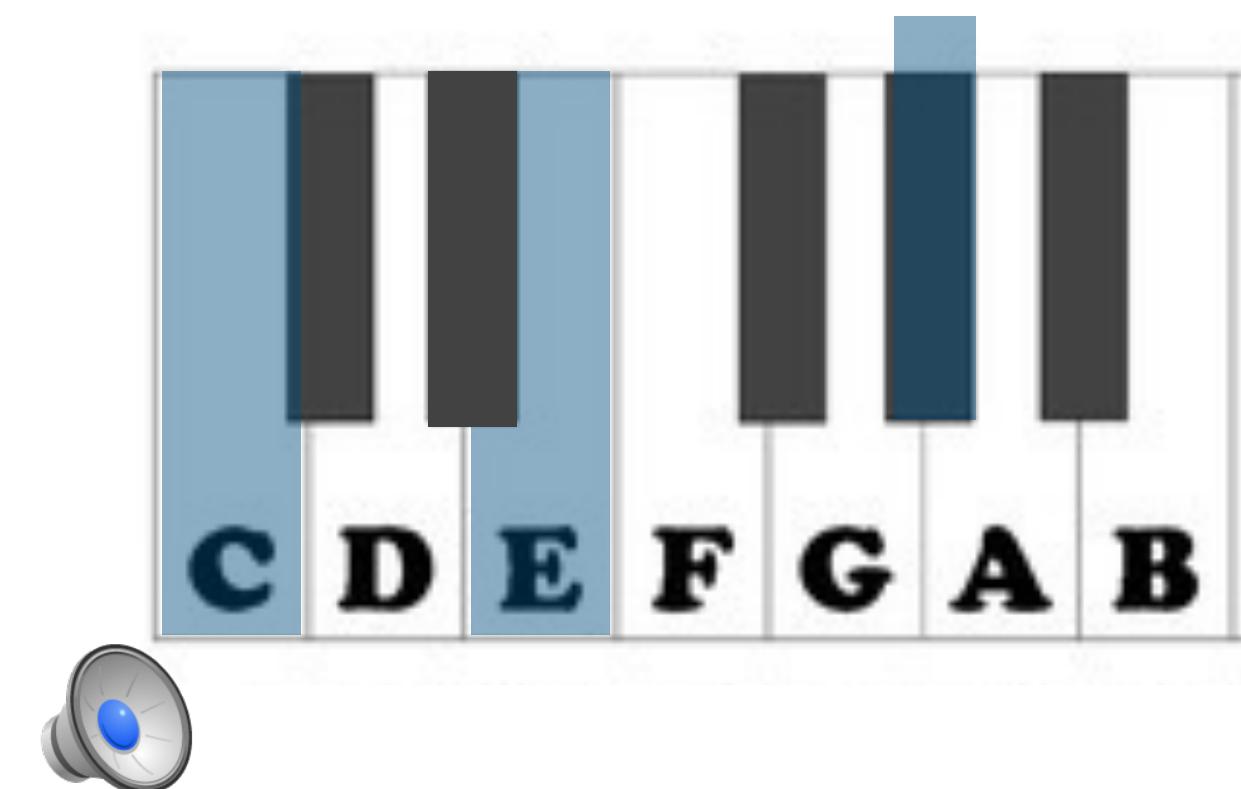
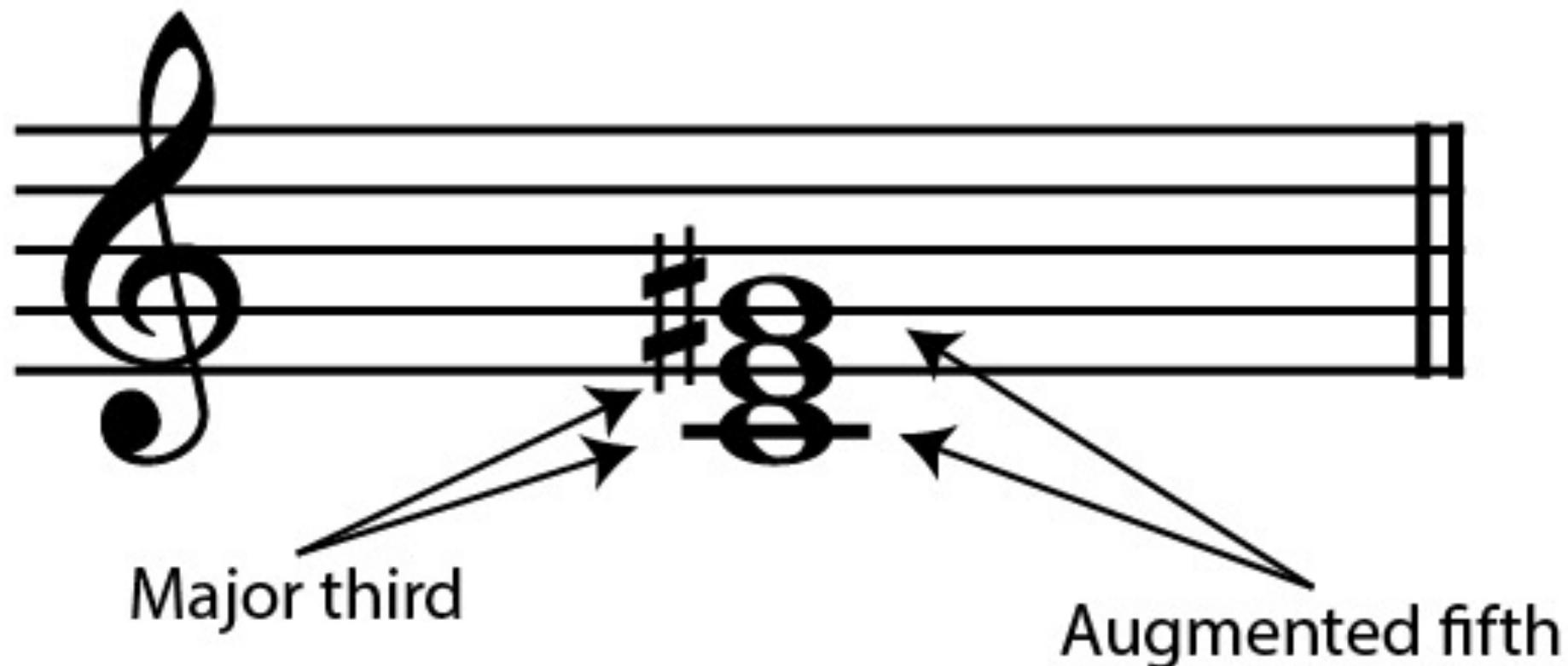
A musical staff with a treble clef. It shows three chords: d min (two black notes), e min (three black notes), and a min (three black notes). Red ovals highlight the second and third chords. Below the staff, Roman numerals indicate the chords: II, III, and VI. Below these, lowercase Roman numerals identify the specific chords: ii, iii, and vi.

Quality: Diminished Triads



b dim

Quality: Augmented Triads



A musical staff with a treble clef. The notes C, E, and G are shown. The note E is circled in red, and below it is the label "III⁺". The label "Caug" is at the bottom of the staff.

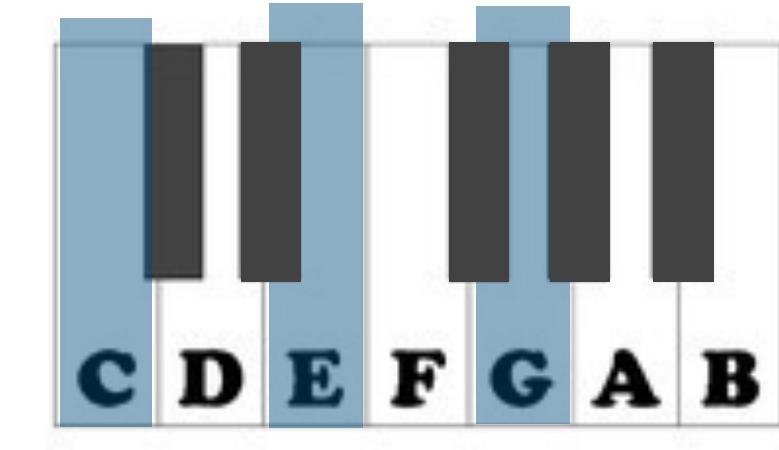
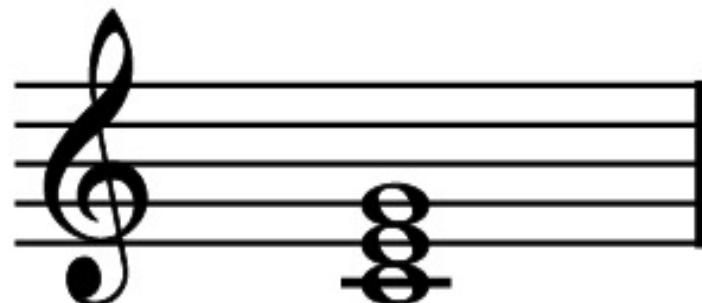
III⁺

Caug

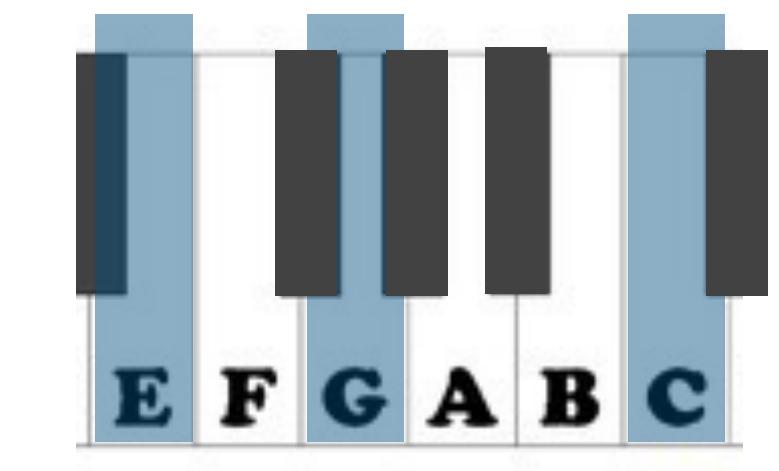
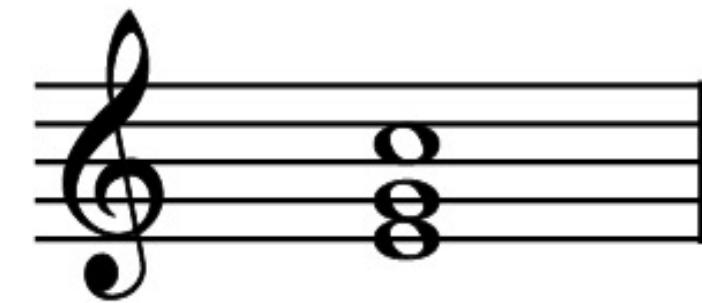
Triadic Inversions



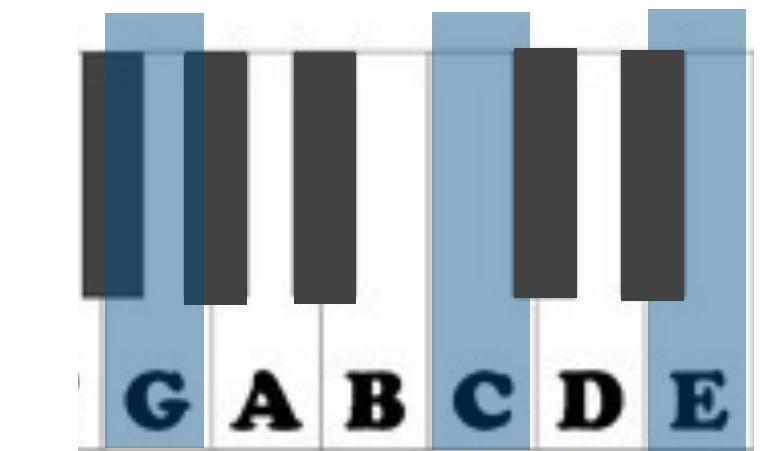
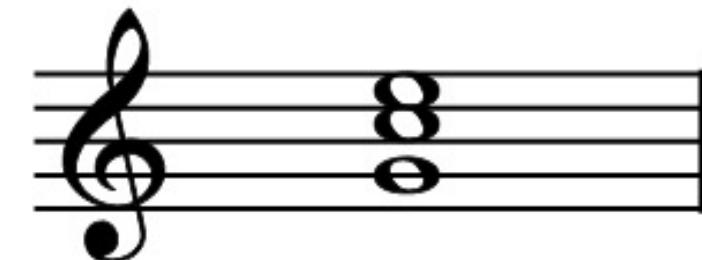
Root position



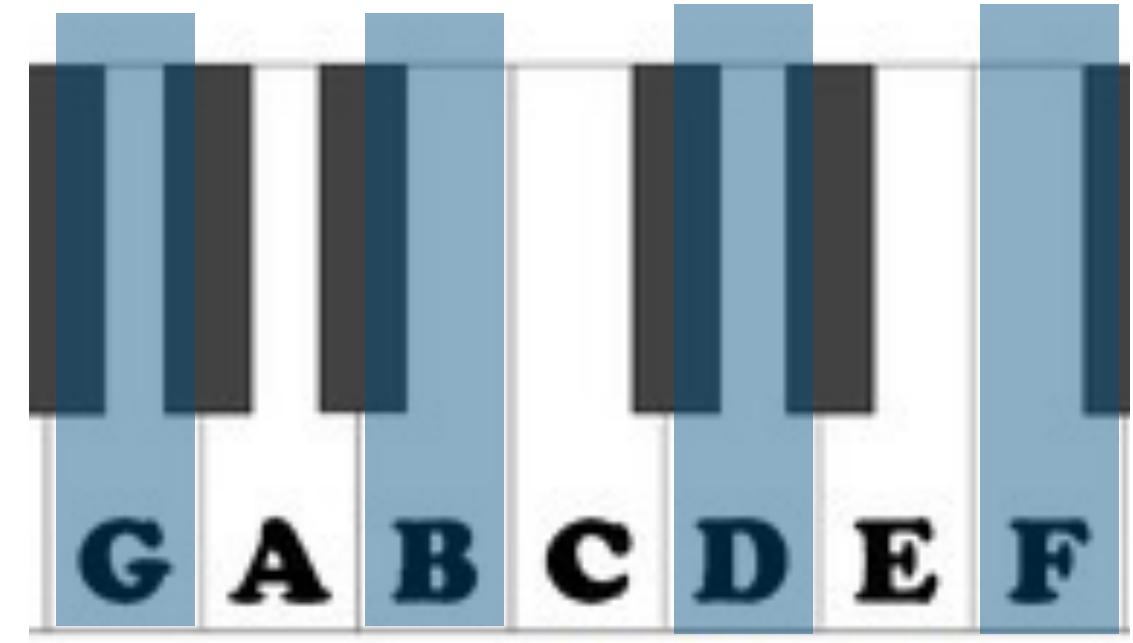
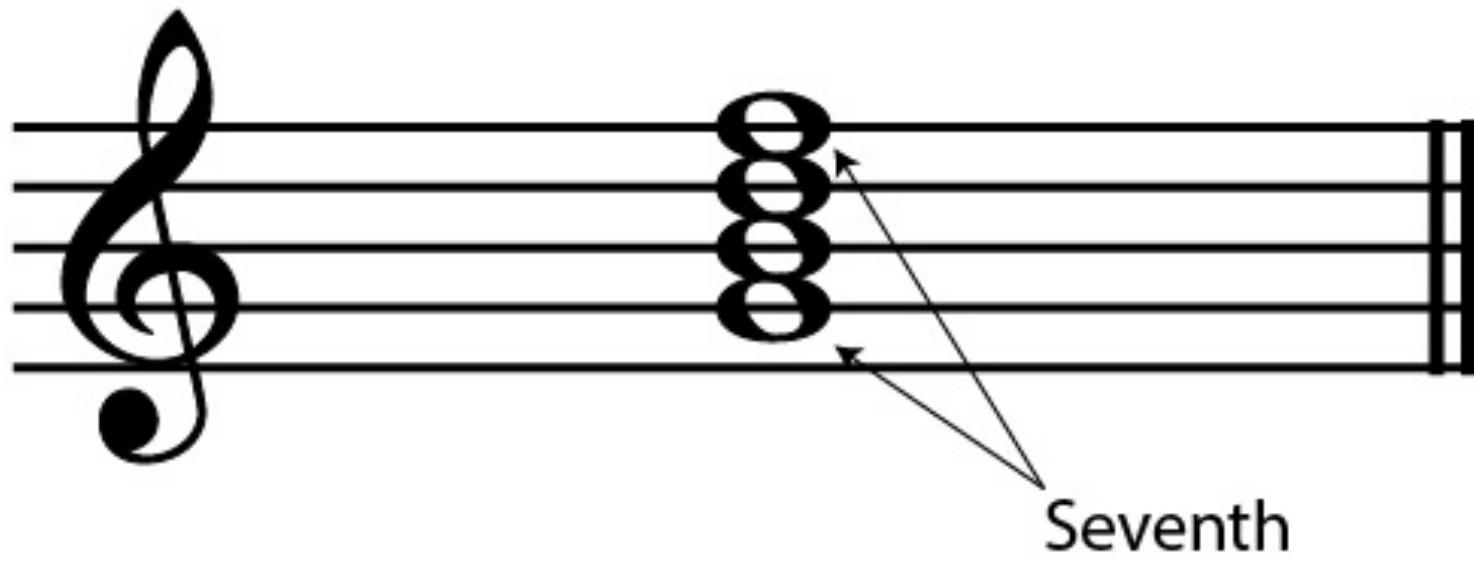
First Inversions



Second Inversions



Seventh Chords



Dominant Seventh Chords

A musical staff with a treble clef. Above the staff, the label "G7" is shown. Below the staff, two arrows point to the notes of a G7 chord: one arrow points to the top note of a stack of three black circles (labeled "Major triad"), and another arrow points to the bottom note of the same stack (labeled "Minor seventh"). The staff itself shows a sequence of eighth notes.

G⁷

Major triad Minor seventh

G⁷

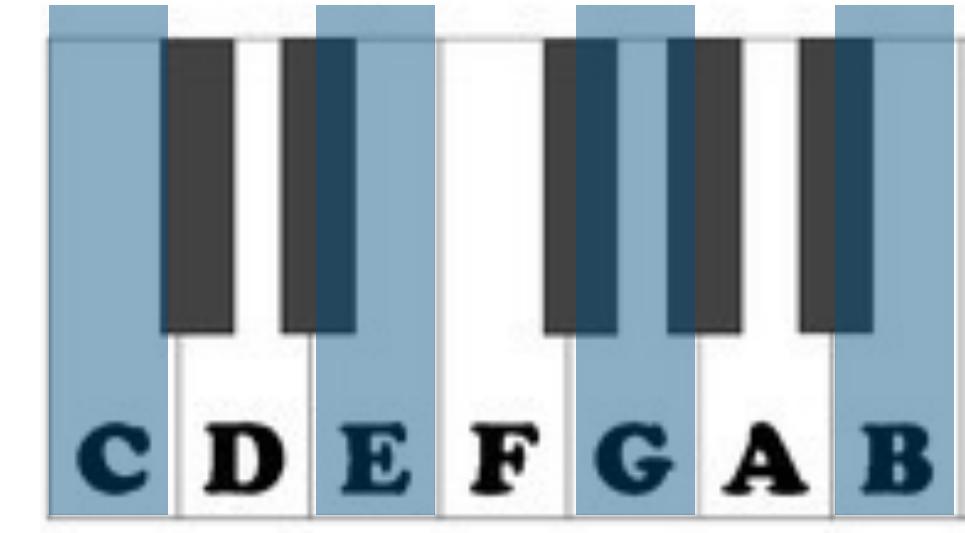
v⁷

Seventh Chords



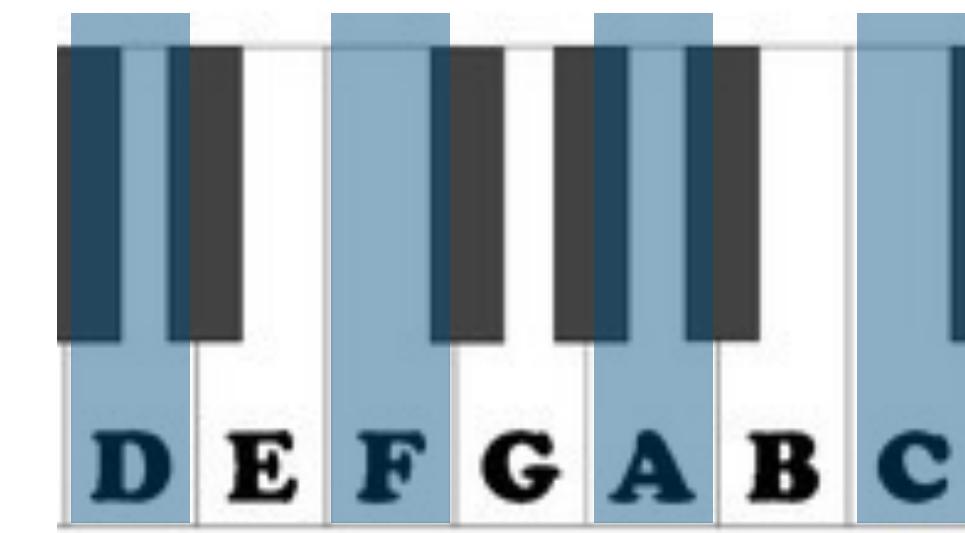
Major Seventh Chord

A musical staff in G clef shows three chords: CMaj⁷, CMaj⁷, and FMaj⁷. The first CMaj⁷ chord is analyzed with arrows pointing from the text "Major triad" to the bottom three notes (C, E, G) and from "Major seventh" to the top note (B). The second CMaj⁷ chord is labeled I⁷. The third FMaj⁷ chord is labeled IV⁷.

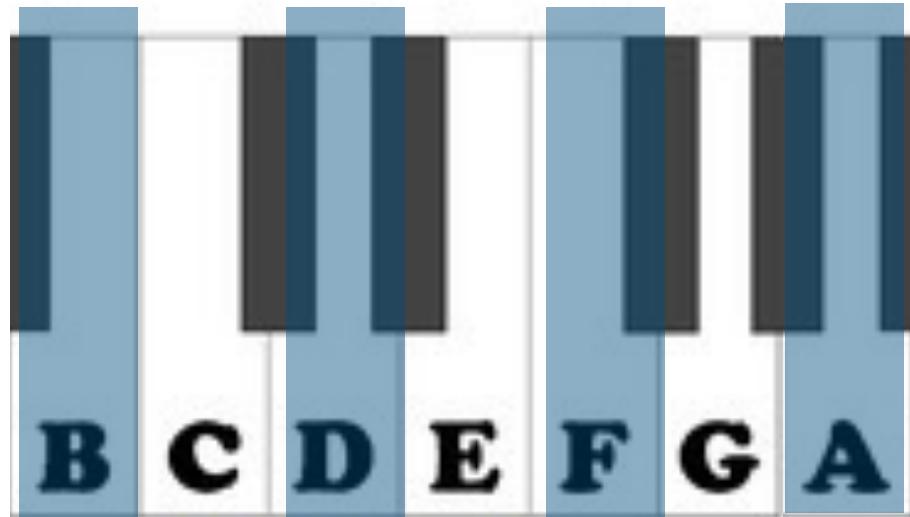


Minor Seventh Chord

A musical staff in G clef shows three chords: Dm⁷, Em⁷, and Am⁷. The first Dm⁷ chord is analyzed with arrows pointing from the text "Minor triad" to the bottom three notes (D, F, A) and from "Minor seventh" to the top note (C). The second Em⁷ chord is labeled ii⁷. The third Am⁷ chord is labeled vi⁷.



Seventh Chords



Half-diminished Seventh Chord

Bm^{7(b5)}

Diminished triad Minor seventh

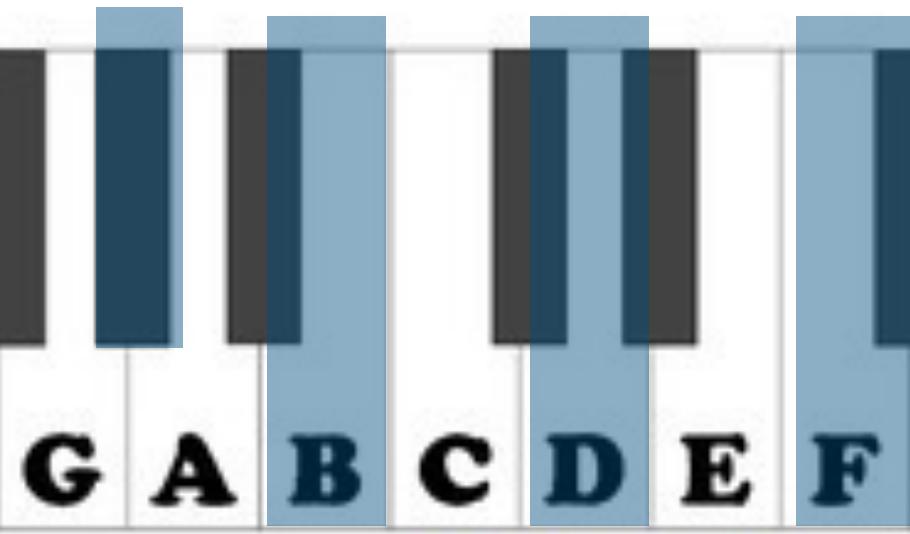
vii[°]

Diminished Seventh Chord

G[#]dim⁷

Diminished triad Diminished seventh

vii[°]



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 ^ø	
Diminished seventh	Diminished	Diminished seventh	Cdim7	C ^{ø7}	



G⁷

Major triad Minor seventh



CMaj⁷

Major triad Major seventh



Dm⁷

Minor triad Minor seventh

Bm7(b5)

Diminished triad Minor seventh

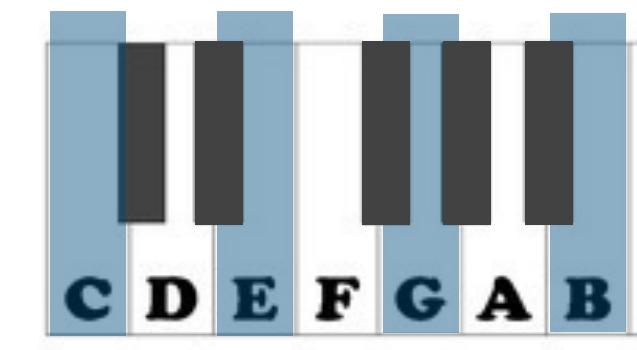
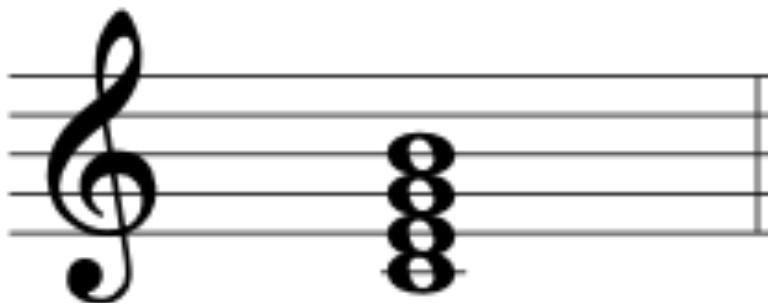


G#dim⁷

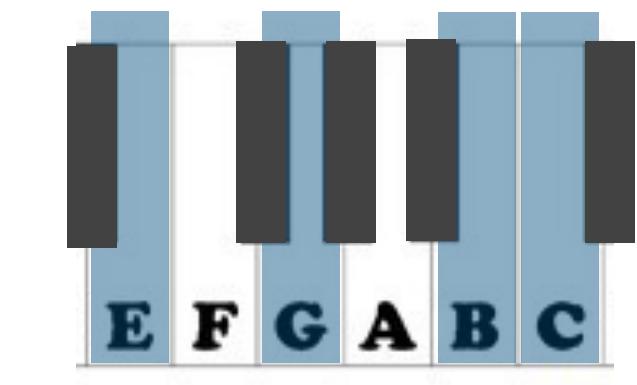
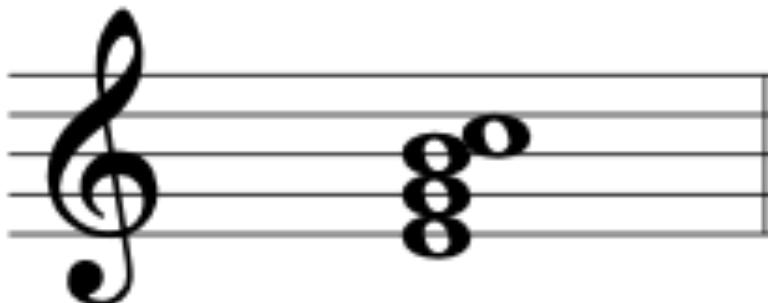
Diminished triad Diminished seventh

Seventh Inversions

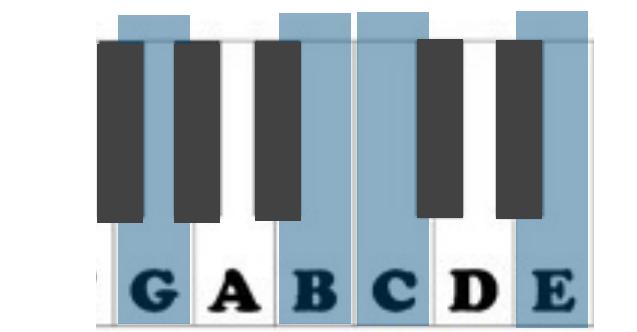
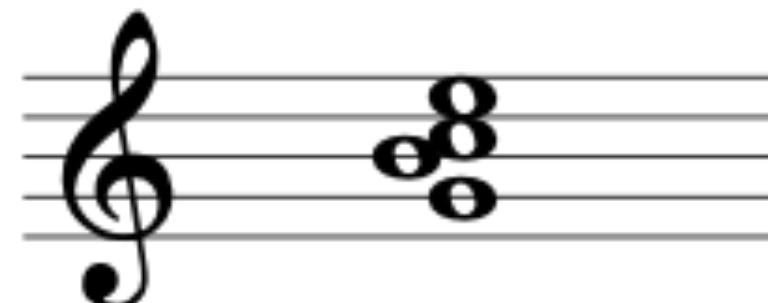
Root position



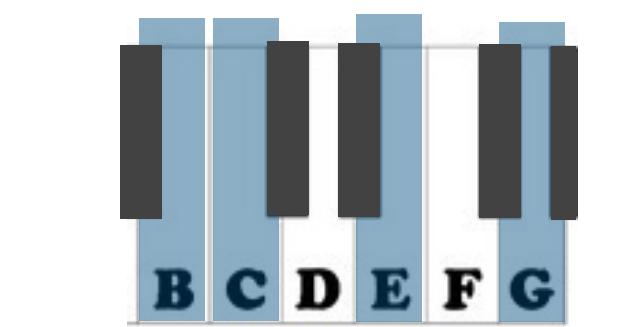
First Inversion



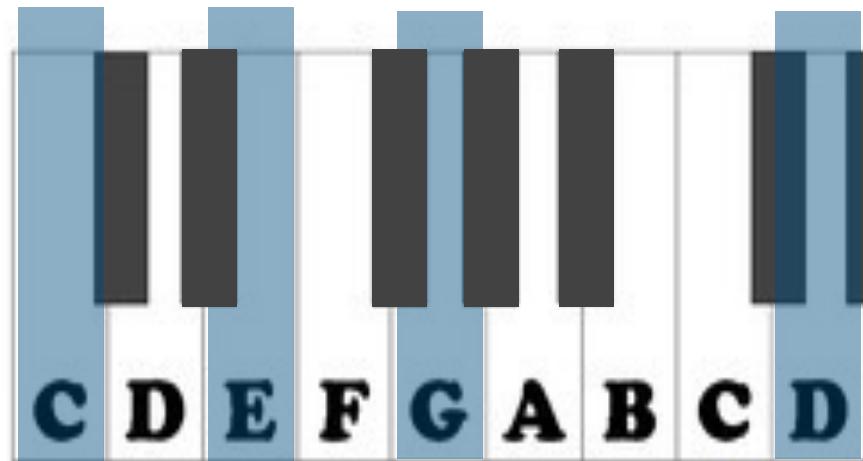
Second Inversion



Third Inversion

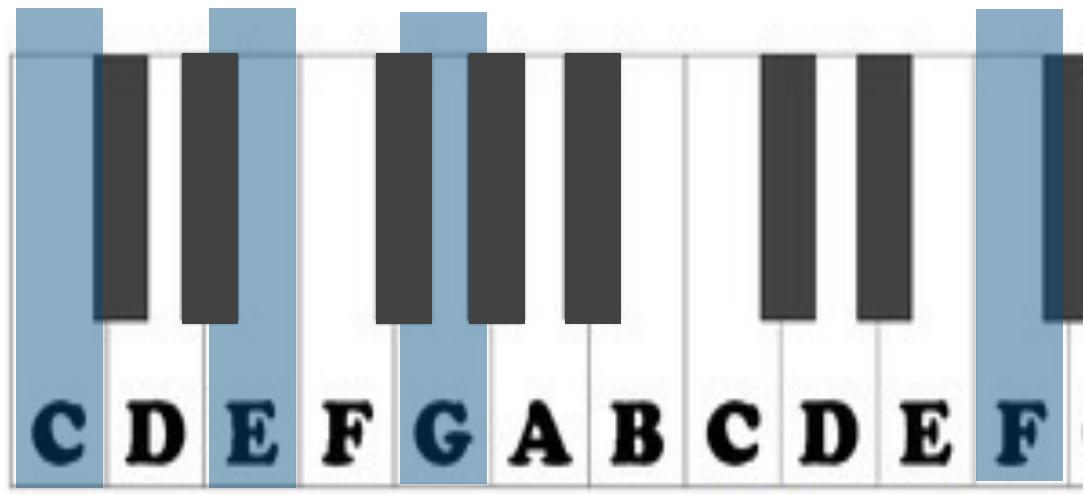


Other Added Notes/Extensions



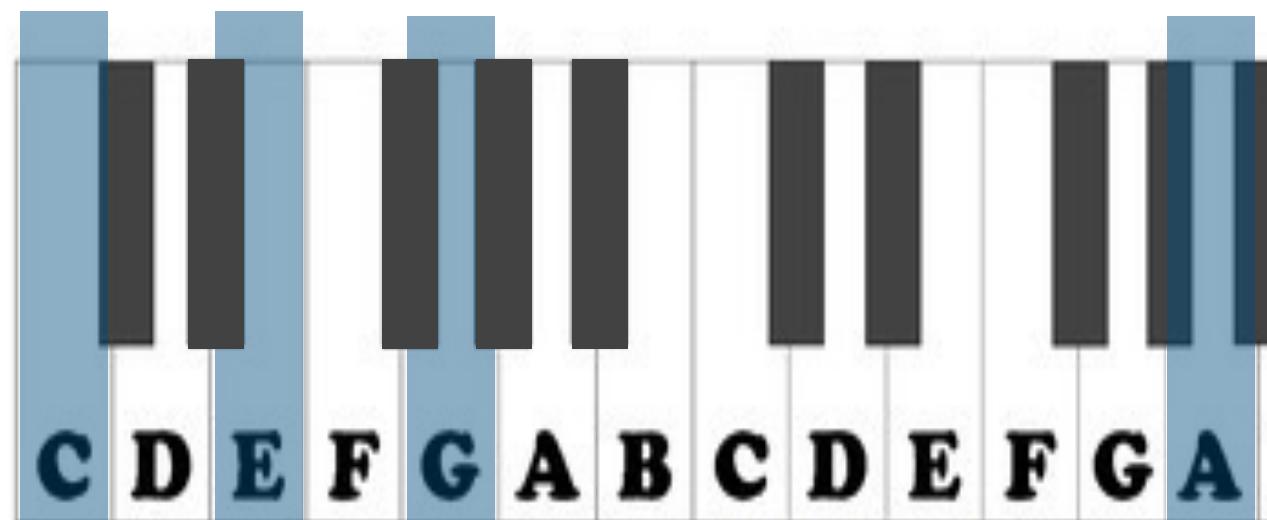
add9

Musical staff diagram for an add9 chord. It shows a treble clef, a bass note (G), and an added 9th note (A). Two speaker icons indicate audio examples.



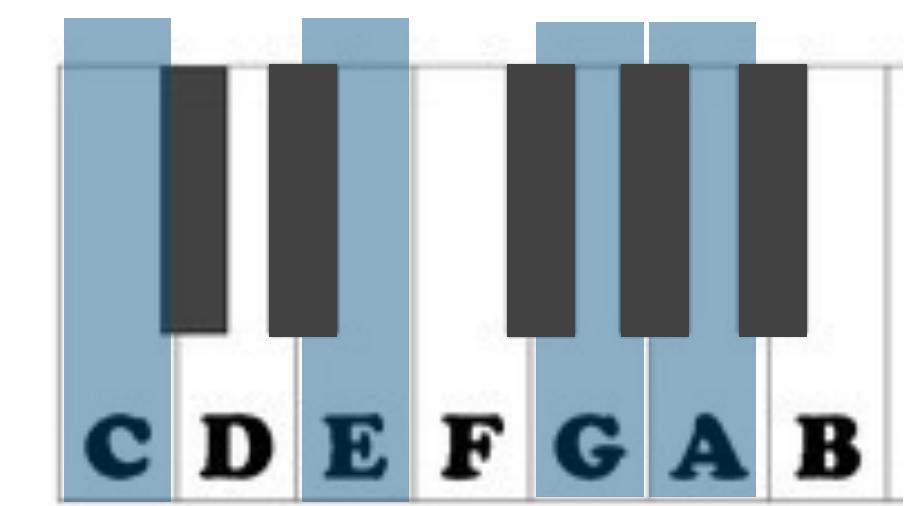
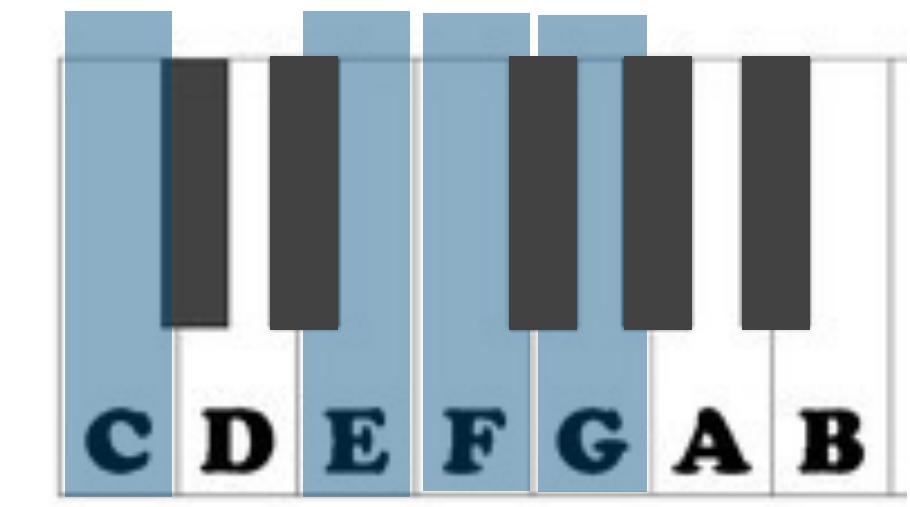
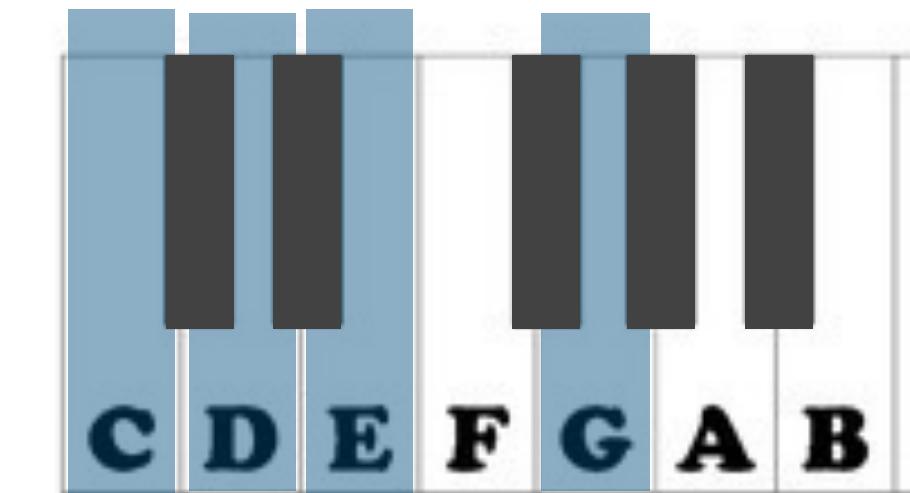
add11

Musical staff diagram for an add11 chord. It shows a treble clef, a bass note (G), and an added 11th note (C). Two speaker icons indicate audio examples.



add13

Musical staff diagram for an add13 chord. It shows a treble clef, a bass note (G), and an added 13th note (A). Two speaker icons indicate audio examples.



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

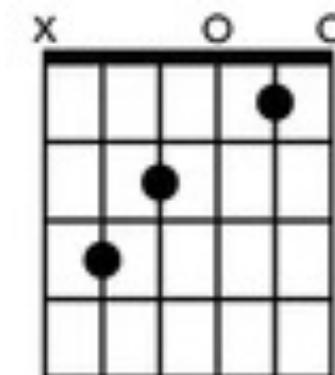
- ▶ **Chord Symbols**

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

C
or
Cmaj

- ▶ **Tabulature**

- 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

D: I I V⁷ I

Dmaj Dmaj A⁷ Dmaj

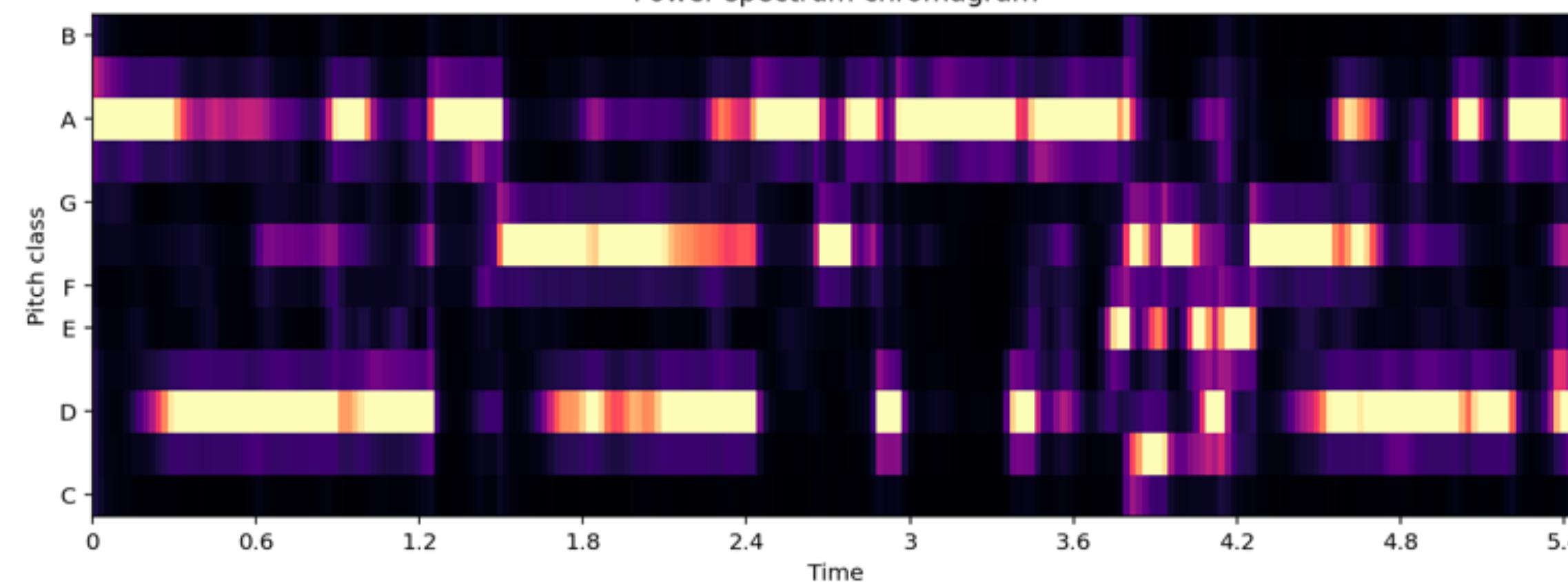
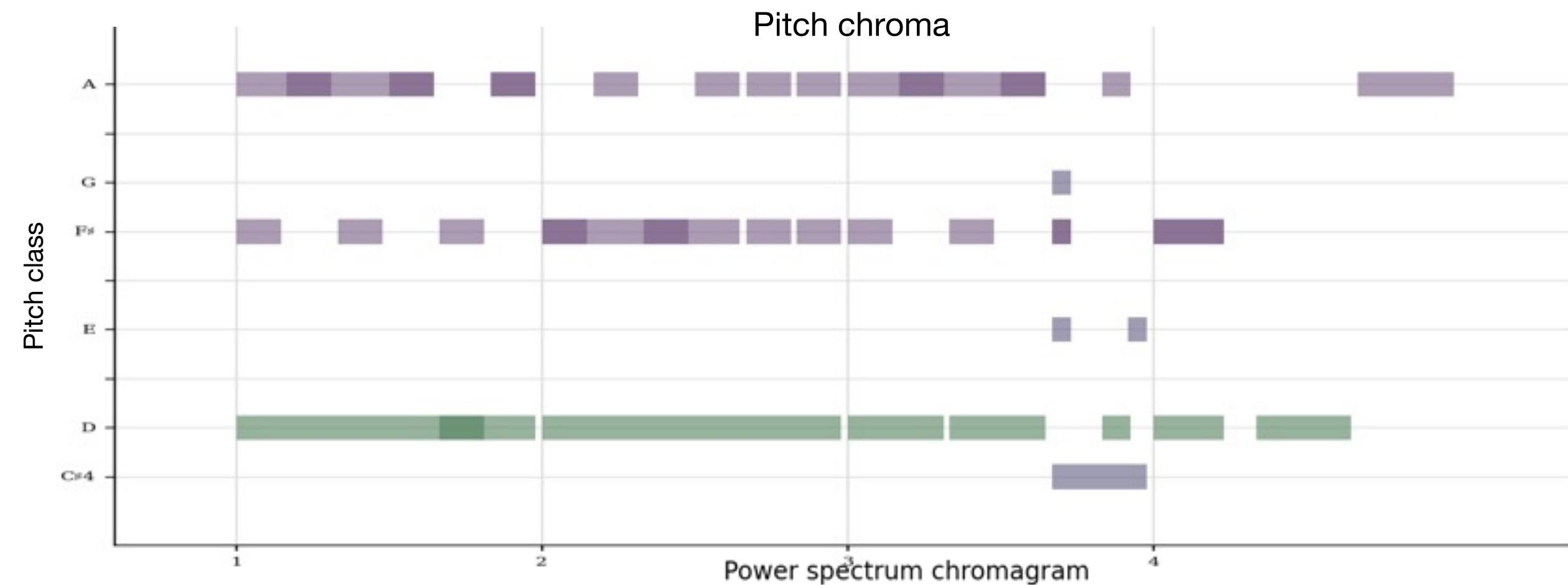
Information Different Labels Contain

9 Variationen über ein Minuett von Duport

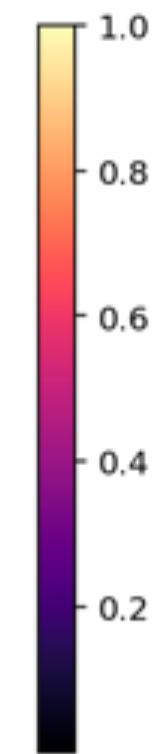
Mozart

Non-chord tone

D:	I	I	I ⁶⁴	V ⁷	I
	I	I	V ⁷	I	
Dmaj	Dmaj	A⁷		Dmaj	



D: I I V⁷ I
 Dmaj Dmaj A⁷ Dmaj



Pitch Class Content in Chords

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

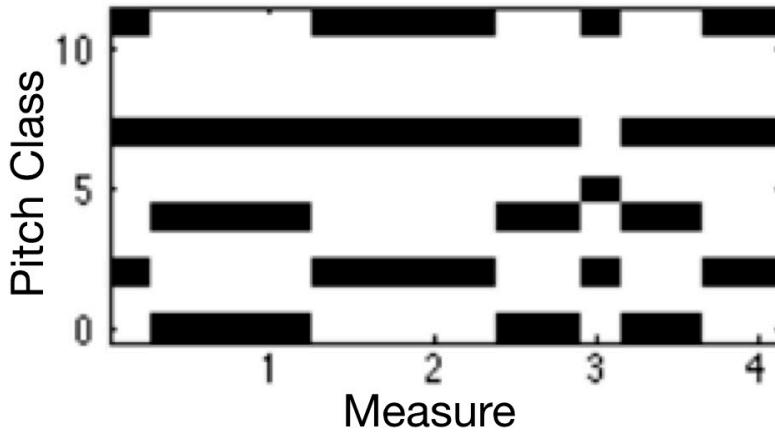
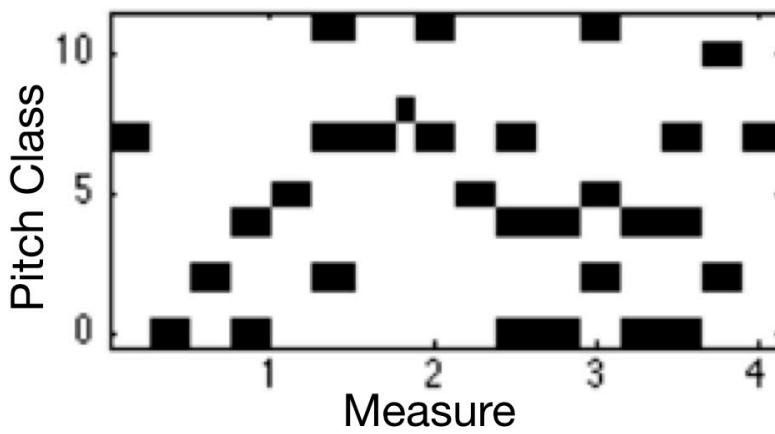
Theme

T

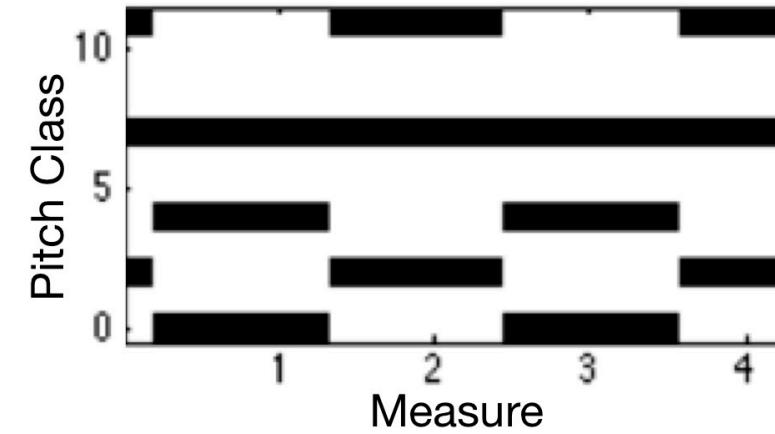
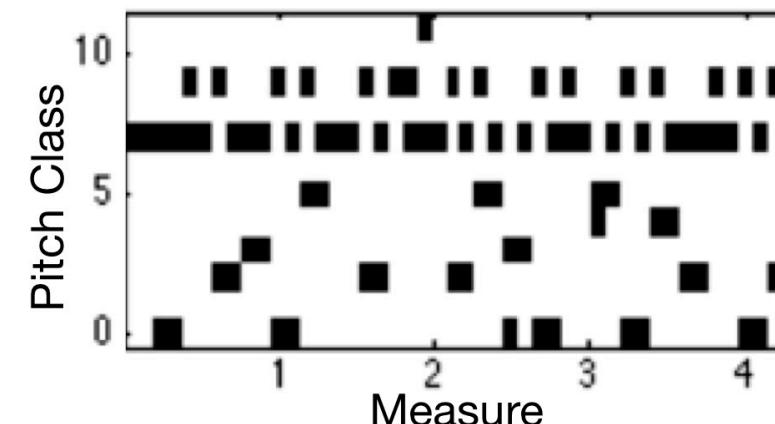
V I V6 I I6 viio6 I V64 V

D

Theme (Symbolic)



Variation (Symbolic)



Variation

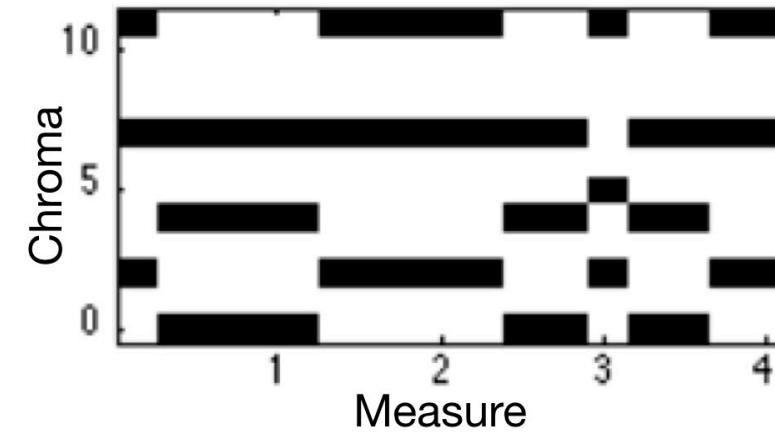
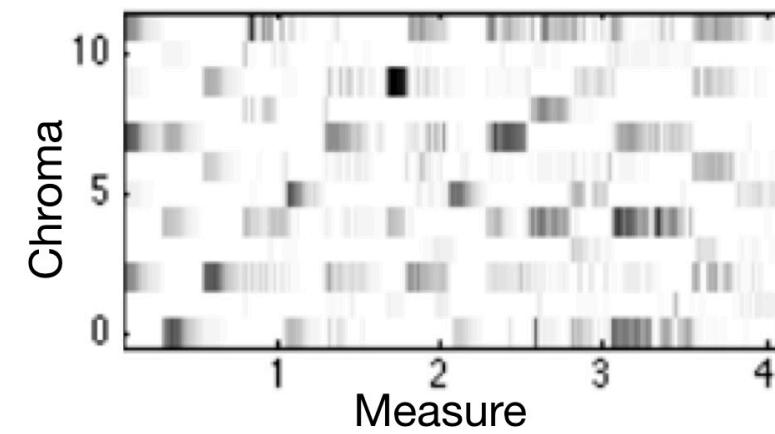
Beethoven

T

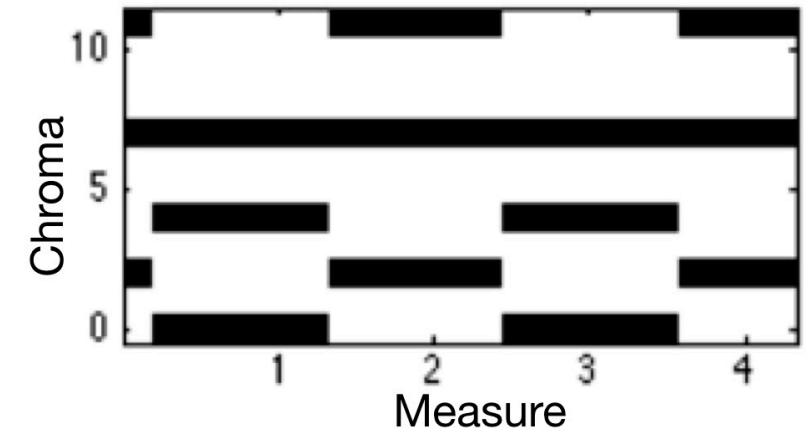
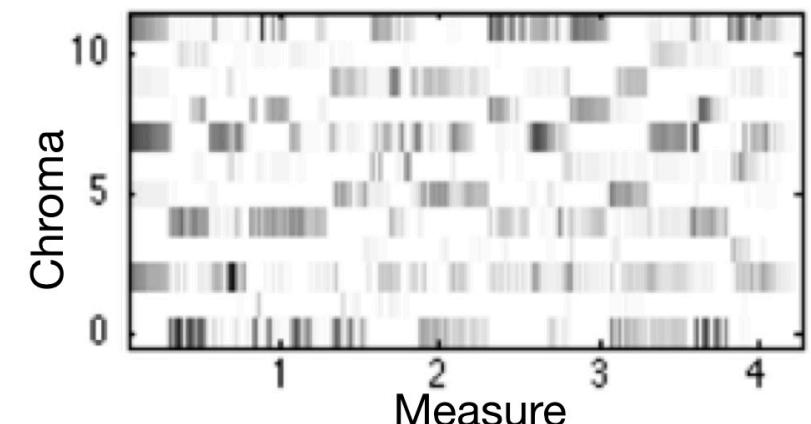
V I V I V I V

D

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)

(ii)

(iii)

(iv)

(v)

```

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

```

```

!!!OTL: Embraceable You
!!!COM: Gershwin, George
!!!ODT: 1928
**jazz
*>[A,B,A2,C]
*>A
*M4/4
*G:
1G:maj7
=
1B-o7
=
1A:min7

```

```

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

```

```

% 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 |

```

```

# 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 Roman Numeral Encoding (TAVERN)	Roman numerals Functions
(ii)	Annotated Beethoven Corpus (ABC)	Chord symbols
(iii)	Beethoven Piano Sonatas with Functional Harmony (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
(iii)	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 FALSE V43 2 1.5 3.5 2/4 127 12 1 1.5 Eb V 43 FALSE I 3 1 5 2/4 127 12 1 2.5 Eb I FALSE V2 4 1.5 7.5 2/4 127 12 1 1.5 Eb V 2 FALSE I6 5 1 9 2/4 127 12 1 1 Eb I 6 FALSE vi 5 2 10 2/4 127 12 1 1 Eb vi FALSE IV\\ \\ 6 1 11 2/4 127 12 1 2 Eb IV TRUE IV 7 1 13 3/4 127 12 1 1 Eb IV FALSE ii6 7 2 14 3/4 127 12 1 1 Eb ii 6 FALSE V2 7 3 15 3/4 127 12 1 1 Eb V 2 FALSE I6 8 1 16 3/4 127 12 1 2 Eb I 6 FALSE vi64 8 3 18 3/4 127 12 1 1 Eb vi 64 FALSE ii7 9 1 19 3/4 127 12 1 2 Eb ii 7 FALSE V43 9 3 21 3/4 127 12 1 1 Eb V 43 FALSE I6(7) 10 1 22 3/4 127 12 1 1 Eb I 6 7 FALSE		

Higher-Level Organization of Harmonic Material

Some Standard Pop Music Chord Progressions

Blues

C - F - G
I - IV - V



A musical staff with a treble clef and a bass clef. It shows three chords: C (two eighth notes on the A and C strings), F (two eighth notes on the A and D strings), and G (two eighth notes on the A and E strings).

50's
Doo wop

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



A musical staff with a treble clef and a bass clef. It shows four chords: C (two eighth notes on the A and C strings), a (one eighth note on the A string), F (two eighth notes on the A and D strings), and G (two eighth notes on the A and E strings).

Axis

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



A musical staff with a treble clef and a bass clef. It shows four chords: C (two eighth notes on the A and C strings), G (two eighth notes on the A and E strings), a (one eighth note on the A string), and F (two eighth notes on the A and D strings).

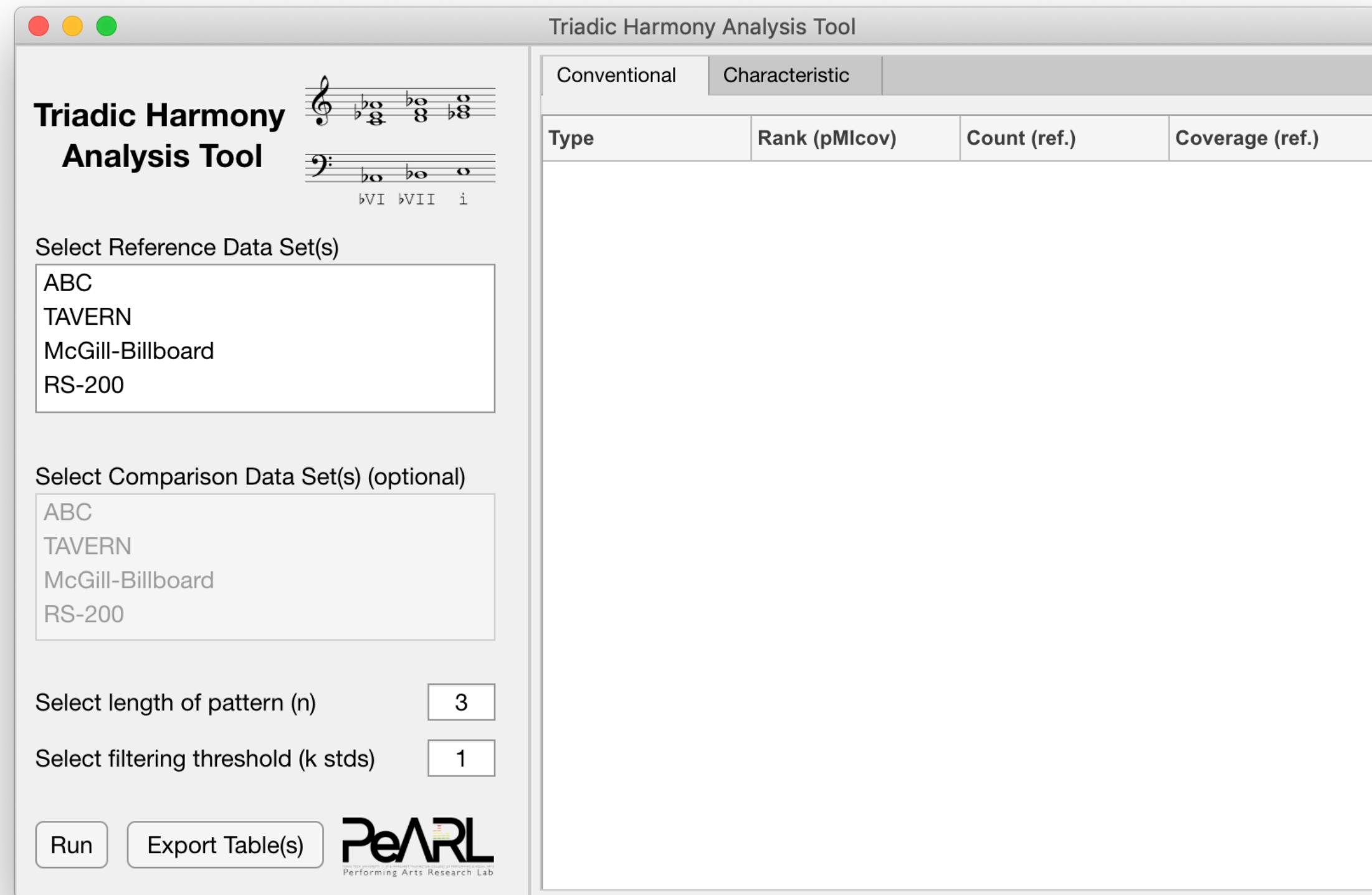


4 Chords
(2011)



Chord Progressions in Corpora

Sears and Forrest (2001)





Triadic Harmony Analysis Tool



Select Reference Data Set(s)

ABC
TAVERN
McGill-Billboard
RS-200

Select Comparison Data Set(s) (optional)

ABC
McGill-Billboard
RS-200

Select length of pattern (n)

3

Select filtering threshold (k stds)

1

Run

Export Table(s)

Conventional Characteristic

Type			Rank (pMIcov)	Count (ref.)	Coverage (ref.)
V(64)	V7	I	2.0508	187	0.8889
I6	V43	I	1.8239	27	0.4815
V	V42	I6	1.6407	32	0.3333
II(64)	II ^d 7	V	1.4882	29	0.2222
VII(64)	VII ^d 7	iii	1.4356	2	0.0741
I64	V42	I6	1.2315	9	0.2222
ii6	V7	I	1.2010	83	0.5926
I	I ^d 42	IV6	1.1707	5	0.1481
II	II ^d 42	V6	1.0086	5	0.0741
vii ^d 43	I6	i6	1.0008	2	0.0741
vi6	I ^d 7	V	0.9884	6	0.1481
V65	I ^d 42	IV6	0.9641	3	0.0741
I6	vii ^d 6	I	0.9286	13	0.2222
i	V42	i6	0.9136	4	0.1111
V	V(64)	V7	0.9118	9	0.2222
i6	V43	i	0.8912	4	0.1111
iii6	ii6	I6	0.8554	2	0.0741
II ^d 7	#vo7	vi	0.8362	2	0.0741
ii6	V	I	0.8355	32	0.5556
ii ^d 6	V(64)	V7	0.8353	3	0.1111
II(64)	II	V	0.8223	9	0.1111
vii ^d 6	I6	IV	0.8159	4	0.0741
#IV6	#IV	VII	0.8136	1	0.0370
#ivo7	V	i	0.7963	5	0.1481

Triadic Harmony Analysis Tool



Select Reference Data Set(s)

ABC

TAVERN

McGill-Billboard

RS-200

Select Comparison Data Set(s) (optional)

ABC

McGill-Billboard

RS-200

Select length of pattern (n)

3

Select filtering threshold (k stds)

1

Run

Export Table(s)



Conventional Characteristic

Type			Rank (r)	Count (ref.)	Count (comp.)
II(64)	IId7	V	5.2038	29	1
vi65	IId7	V	4.1532	14	1
V6	IId7	V	3.8053	11	1
I	IId7	V	3.6678	10	1
II(64)	II	V	3.5158	9	1
II	V6	I	2.9308	6	1
IV	I6	I	2.9308	6	1
vi6	IId7	V	2.9308	6	1
V(64)	V	I	2.8198	50	9
I64	IId7	V	2.8053	11	2
#ivo7	V	i	2.6678	5	1
II	IId42	V6	2.6678	5	1
ii	viiio	I	2.6678	5	1
iih65	V	i	2.6678	5	1
#ivo7	V7	I	2.3459	4	1
I	IV	I6	2.3459	4	1
I64	IV	I6	2.3459	4	1
Id7	IV64	I	2.3459	4	1
V	Id7	IV	2.3459	4	1
V	VId65	ii	2.3459	4	1
i	V42	i6	2.3459	4	1
ii	V(64)	V	2.3459	4	1
viiio6	I6	IV	2.3459	4	1

Triadic Harmony Analysis Tool



Select Reference Data Set(s)

ABC
TAVERN
McGill-Billboard
RS-200

Select Comparison Data Set(s) (optional)

ABC
McGill-Billboard
RS-200

Select length of pattern (n)

3

Select filtering threshold (k stds)

1

Run

Export Table(s)

Conventional			Characteristic			
Type			Rank (r)	Count (ref.)	Count (comp.)	
ii6	V7	I	7.8946	83	1	
V(64)	V	I	7.1634	50	1	
V(64)	V7	I	6.7445	187	5	
V	V42	I6	6.5196	32	1	
ii6	V	I	6.5196	32	1	
II(64)	IIId7	V	6.3775	29	1	
I6	V43	I	6.2744	27	1	
I	V42	I6	5.8415	20	1	
I6	V65	I	5.8415	20	1	
ii	V65	I	5.4264	15	1	
vi65	IIId7	V	5.3269	14	1	
I6	V	I	5.2200	13	1	
I6	viiio6	I	5.2200	13	1	
V6	V	I	5.1045	12	1	
V	V7	I	5.0431	23	2	
I64	IIId7	V	4.9790	11	1	
V6	IIId7	V	4.9790	11	1	
V7	V42	I6	4.9790	11	1	
I	IIId7	V	4.8415	10	1	
V43	V7	I	4.8415	10	1	
I64	V42	I6	4.6895	9	1	
II(64)	II	V	4.6895	9	1	
IV6	V65	I	4.6895	9	1	
V	V(64)	V7	4.6895	9	1	

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)

TAVERN (gettavern.org)

Quiz: Matching a variation to a theme

A musical staff in G clef, 3/4 time, and A-flat key signature. The staff consists of two systems of music. The first system starts with a measure of three eighth-note chords (G, C, E) circled in orange. The second system starts with a measure of eighth-note pairs (A-flat, C) circled in orange. Below the staff, labels are placed under specific measures: "I/T" under the first measure of the first system, "V7/D" under the first measure of the second system, and "I/D" under the second measure of the second system. A large orange box encloses the second system of the staff.

I/T V⁷/D I/D

I/T



Four variations of musical themes are shown in boxes:

- The first variation (bottom left) is in 6/8 time, featuring eighth-note pairs (G, C, E) circled in orange. It is labeled "I/T" at the bottom.
- The second variation (bottom center) is in 2/4 time, featuring eighth-note chords (G, C, E) circled in orange. It is labeled "V⁶⁵/T" at the bottom.
- The third variation (bottom right) is in 2/4 time, featuring eighth-note pairs (A-flat, C) circled in orange. It is labeled "V⁷/T" at the bottom.
- The fourth variation (bottom far right) is in 2/4 time, featuring eighth-note chords (A-flat, C, E) circled in orange. It is labeled "I/T" at the bottom.

Below these variations, another set of four boxes shows different musical patterns:

- The first (bottom left) is labeled "V⁷/D" at the bottom.
- The second (bottom center) is labeled "I/T" at the bottom.
- The third (bottom right) is labeled "V⁷/D" at the bottom.
- The fourth (bottom far right) is labeled "I/D" at the bottom.

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

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

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**