

Statistical Parsing for Harmonic Analysis of Jazz Chord Sequences

Mark Granroth-Wilding and Mark Steedman

School of Informatics
University of Edinburgh

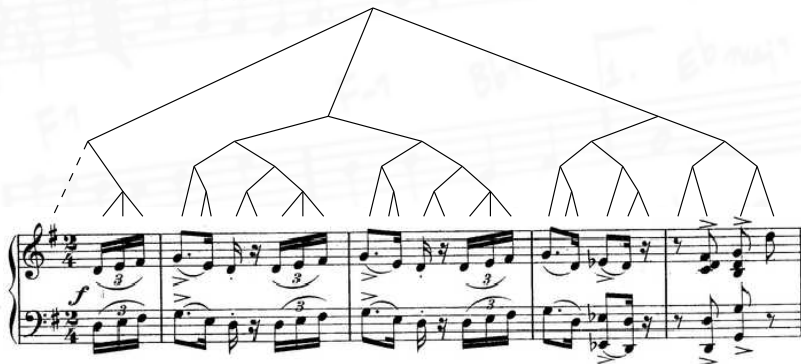
14th September 2012

Introduction

- Hierarchical structure in music
- Metrical structure
- Harmonic structure

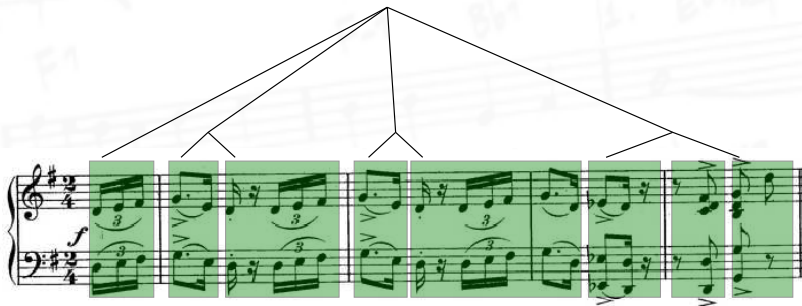
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Applications of Automatic Harmonic Analysis

- Automatic generation:
 - radio variations
 - arrangements
 - accompaniments
- MIR: e.g. identifying variations
- Transcription of scores

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Related Work

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- Winograd (1968)

Linguistics and the computer analysis of tonal harmony

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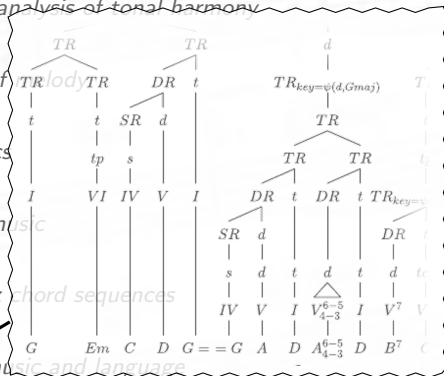
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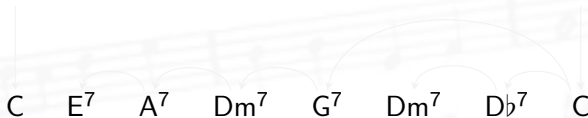


Harmonic Analysis

- Functional harmonic structure
 - Tension-resolution patterns between chords

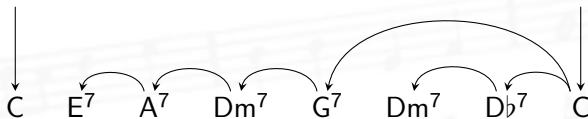
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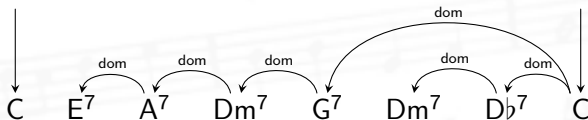
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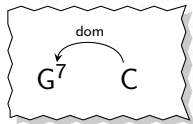


Harmonic Analysis

- Chords function as: **dominant**, **subdominant** or **tonic**
 - Dominant-tonic resolution
 - Subdominant-tonic resolution
 - Recursion
 - Substitution
 - Delayed resolution

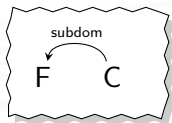
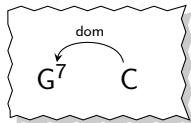
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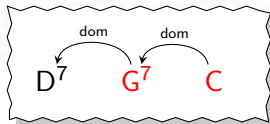
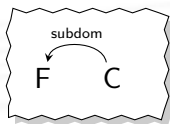
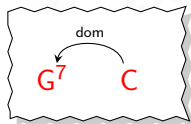
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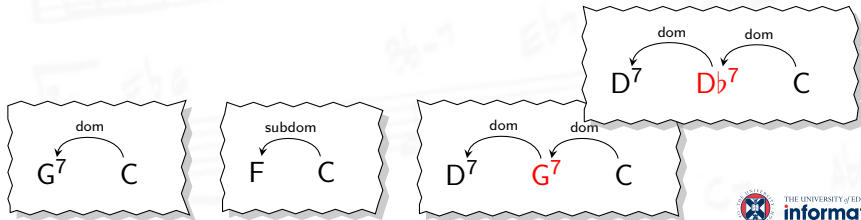
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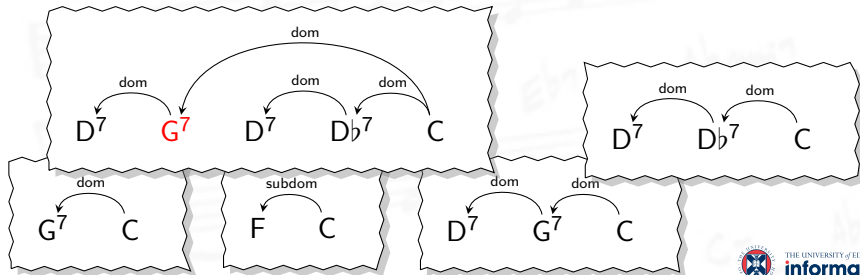
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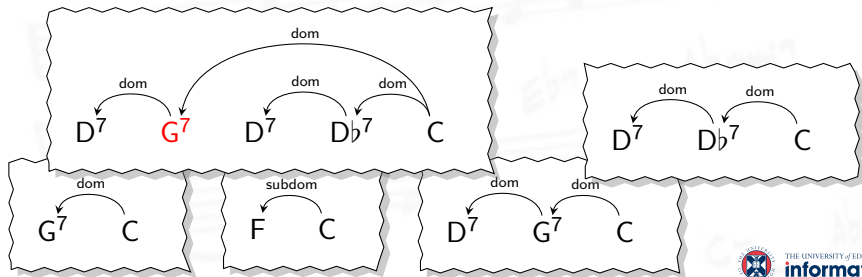
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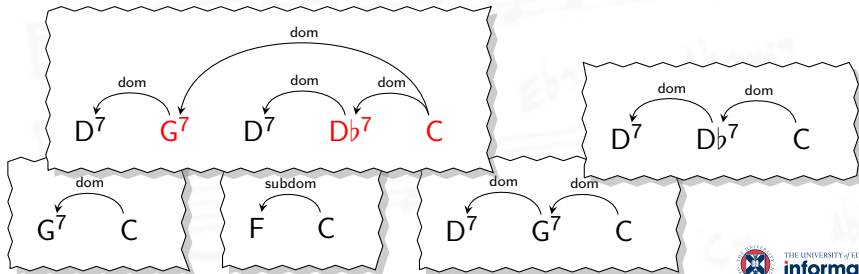
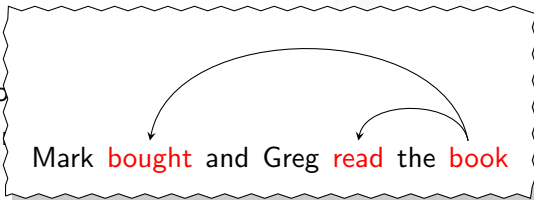
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Jazz Harmony

Jazz is interesting for harmonic analysis

- Large extended cadences
- Complex embedding
- Many substitutions
- Chord sequences

D $\flat$ o 7 Em 7 Am 7 E 7 B ϕ 7 E 7 $\flat$ 9 A 7 Dm 7 G 7 ... C 6

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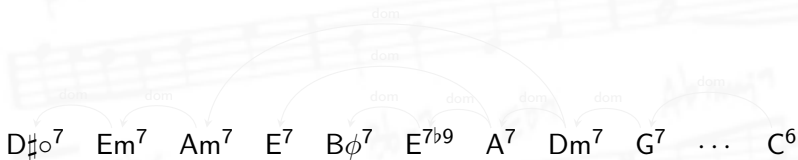
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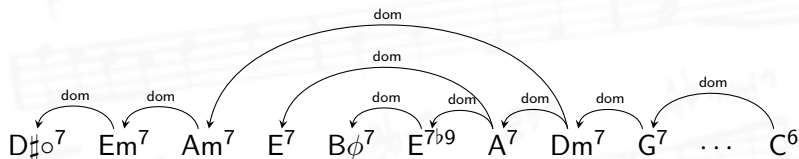


Call Me Irresponsible

Jazz Harmony

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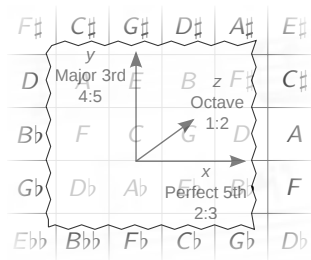
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Call Me Irresponsible

Tonal Space

- Longuet-Higgin's formalization of tonal theory
- Distinguishes tonal relations ambiguous in performance
- Partly distinguished on a score
- Harmonic analysis disambiguates tonal relations



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<i>F#</i>	<i>C#</i>	<i>G#</i>	<i>D#</i>	<i>A#</i>	<i>E#</i>
<i>D</i>	<i>A</i>	<i>E</i>	<i>B</i>	<i>F#</i>	<i>C#</i>
<i>Bb</i>	<i>F</i>	<i>C</i>	<i>G</i>	<i>D</i>	<i>A</i>
<i>Gb</i>	<i>Db</i>	<i>Ab</i>	<i>Eb</i>	<i>Bb</i>	<i>F</i>
<i>Ebb</i>	<i>Bbb</i>	<i>Fb</i>	<i>Cb</i>	<i>Gb</i>	<i>Db</i>

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<i>D</i>	<i>A</i>	<i>E</i>	<i>B</i>	<i>F#</i>	<i>C#</i>
<i>Bb</i>	<i>F</i>	<i>C</i>	<i>G</i>	<i>D</i>	<i>A</i>
<i>Gb</i>	<i>Db</i>	<i>Ab</i>	<i>Eb</i>	<i>Bb</i>	<i>F</i>
<i>Ebb</i>	<i>Bbb</i>	<i>Fb</i>	<i>Cb</i>	<i>Gb</i>	<i>Db</i>

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<i>F</i> ♯	<i>C</i> ♯	<i>G</i> ♯	<i>D</i> ♯	<i>A</i> ♯	<i>E</i> ♯
<i>D</i>	<i>A</i>	<i>E</i>	<i>B</i>	<i>F</i> ♯	<i>C</i> ♯
<i>B</i> ♭	<i>F</i>	<i>C</i>	<i>G</i>	<i>D</i>	<i>A</i>
<i>G</i> ♭	<i>D</i> ♭	<i>A</i> ♭	<i>E</i> ♭	<i>B</i> ♭	<i>F</i>
<i>E</i> ♭♭	<i>B</i> ♭♭	<i>F</i> ♭	<i>C</i> ♭	<i>G</i> ♭	<i>D</i> ♭

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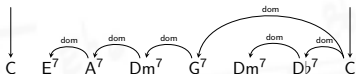
<i>F</i> ♯	<i>C</i> ♯	<i>G</i> ♯	<i>D</i> ♯	<i>A</i> ♯	<i>E</i> ♯
<i>D</i>	<i>A</i>	<i>E</i>	<i>B</i>	<i>F</i> ♯	<i>C</i> ♯
<i>B</i> ♭	<i>F</i>	<i>C</i>	<i>G</i>	<i>D</i>	<i>A</i>
<i>G</i> ♭	<i>D</i> ♭	<i>A</i> ♭	<i>E</i> ♭	<i>B</i> ♭	<i>F</i>
<i>E</i> ♭♭	A ⁷ Dm ⁷ G ⁷ C				<i>D</i> ♭

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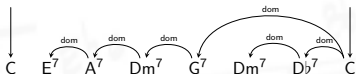
$F\sharp$	$C\sharp$	$G\sharp$	$D\sharp$	$A\sharp$	$E\sharp$
D	A	E	B	$F\sharp$	$C\sharp$
$B\flat$	F	C	G	D	A
$G\flat$	$D\flat$	$A\flat$	$E\flat$	$B\flat$	F
$E\flat\flat$	$A^7 Dm^7 G^7 C$				$D\flat$



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$G\flat$	$D\flat$	$A\flat$	$E\flat$	$B\flat$	F
$E\flat\flat$	$A^7 Dm^7 G^7 C$				$D\flat$

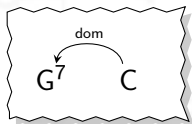


A	E	B	$F\sharp$	$C\sharp$	$G\sharp$	$D\sharp$
F	C	G	D	A	E	B
$D\flat$	$A\flat$	$E\flat$	$B\flat$	F	C	G
$B\flat\flat$	$F\flat$	$C\flat$	$G\flat$	$D\flat$	$A\flat$	$E\flat$

Tonal Space Harmonic Analysis

G⁷ ⇒ dominant, G

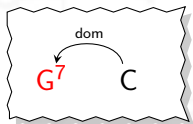
C ⇒ tonic, C



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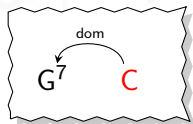
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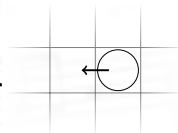
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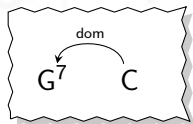


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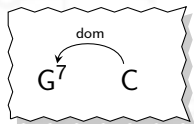
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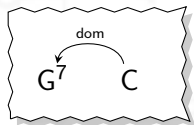


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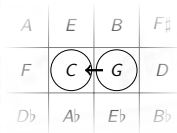
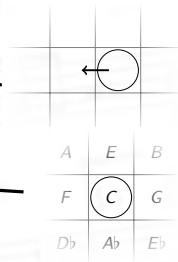
A	E	B
F	C	G
D ^b	A ^b	E ^b

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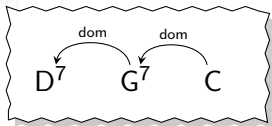


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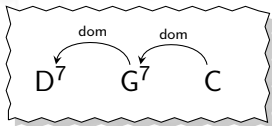


Harmonic Grammar

D⁷

G⁷

C

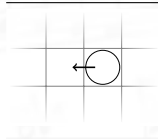
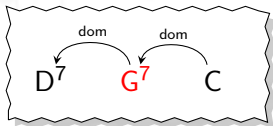


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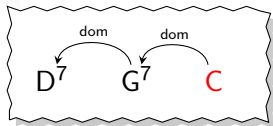
D⁷

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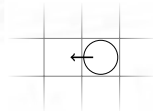
Harmonic Grammar



D⁷

G⁷

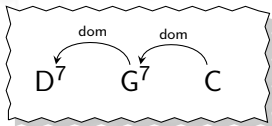
C



A	E	B
F	C	G
D ^b	A ^b	E ^b



Harmonic Grammar



D⁷

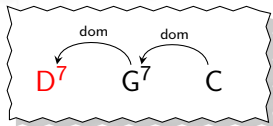
G⁷

C

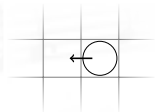
A	E	B
F	C	G
D ^b	A ^b	E ^b

A	E	B	F [♯]
F	C	G	D
D ^b	A ^b	E ^b	B ^b

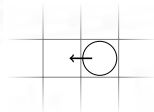
Harmonic Grammar



D⁷



G⁷

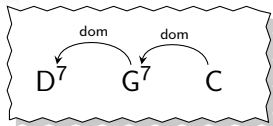
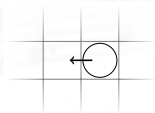
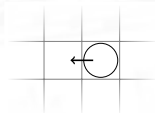


C

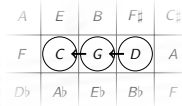
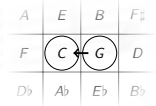
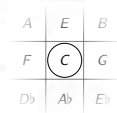
A	E	B
F	C	G
D ^b	A ^b	E ^b

A	E	B	F [♯]
F	C	G	D
D ^b	A ^b	E ^b	B ^b

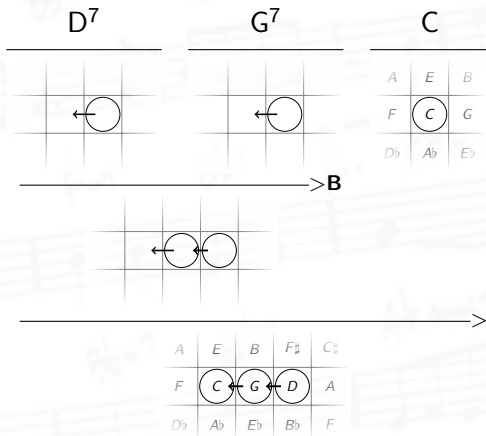
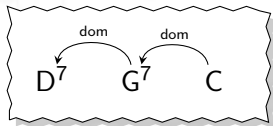
Harmonic Grammar

D⁷G⁷

C



Harmonic Grammar

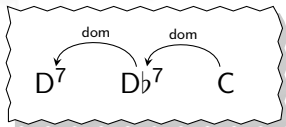


Harmonic Grammar

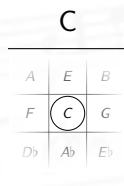
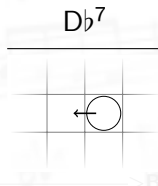
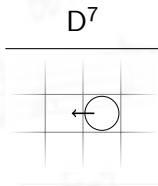
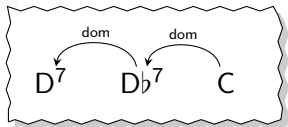
D⁷

D^{b7}

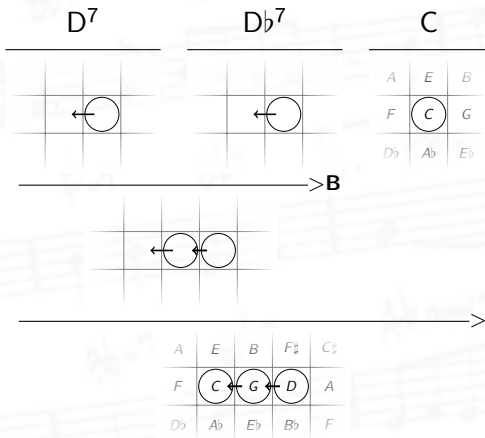
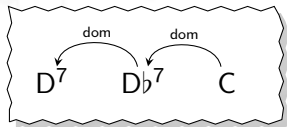
C



Harmonic Grammar



Harmonic Grammar



Harmonic Grammar

D⁷G⁷D⁷D^{b7}

C

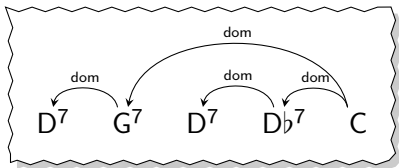
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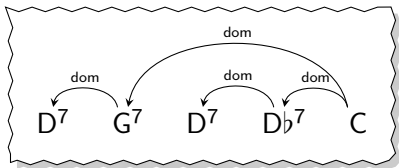
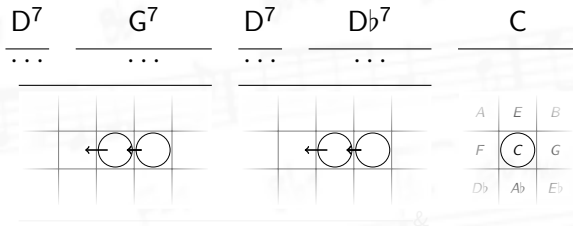
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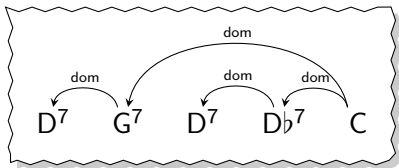
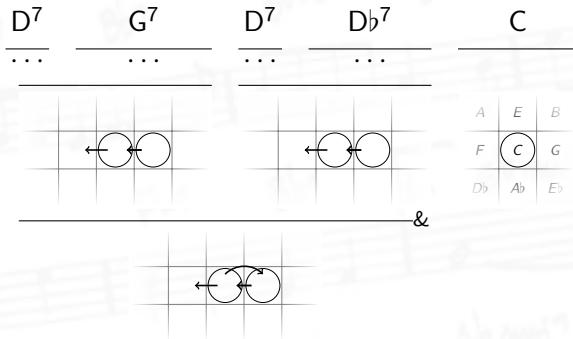
&



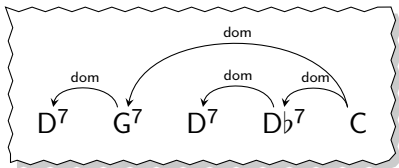
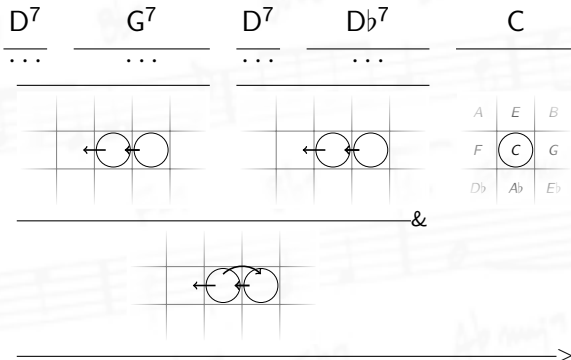
Harmonic Grammar



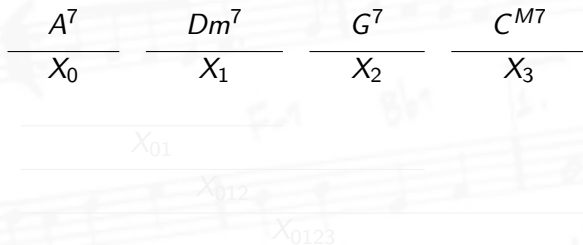
Harmonic Grammar



Harmonic Grammar

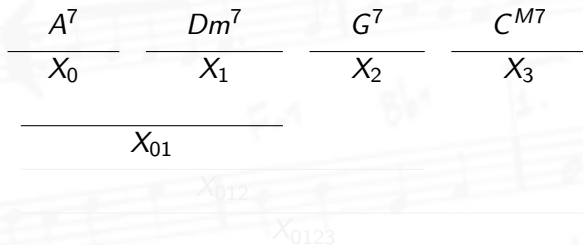


Parsing with Grammars



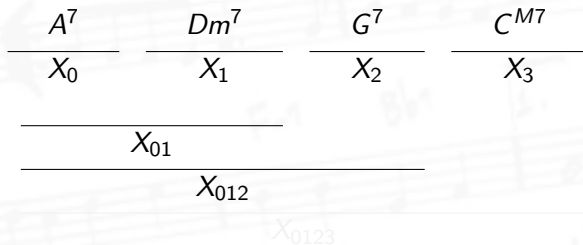
- Chart parsing

Parsing with Grammars



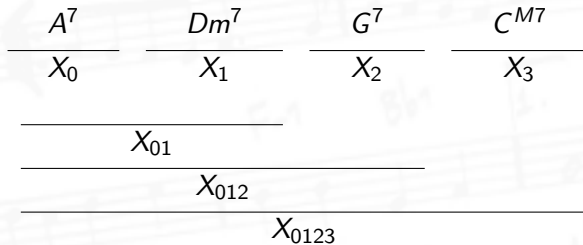
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Parsing with Grammars



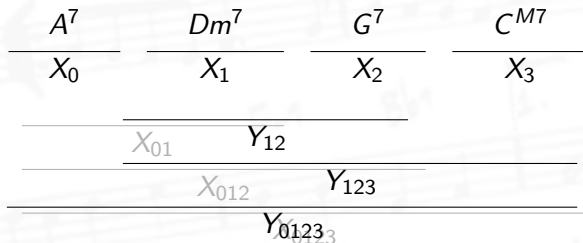
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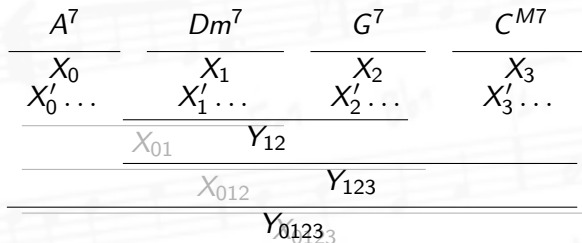
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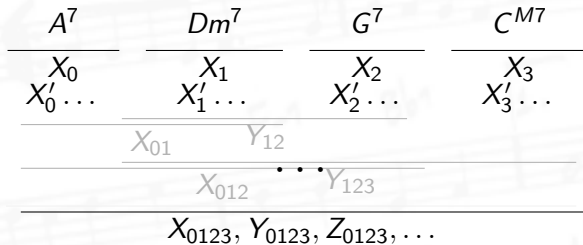
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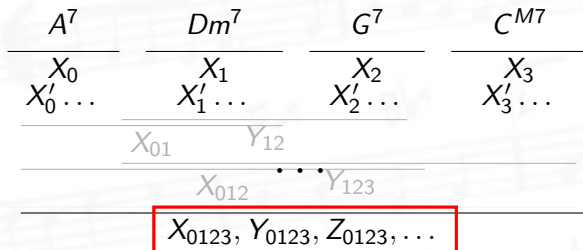
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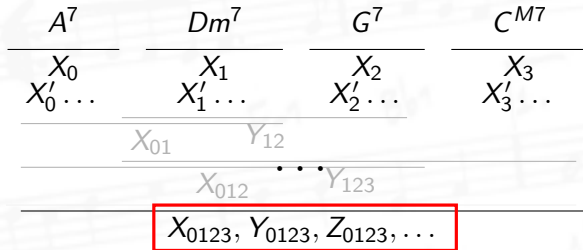
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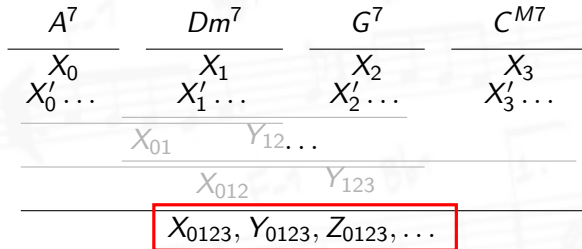
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Parsing with Grammars



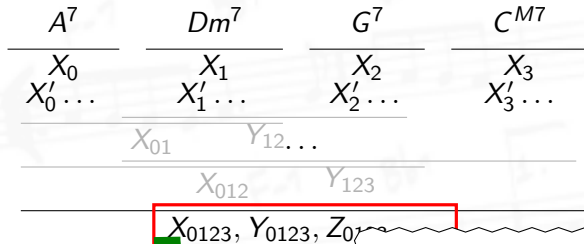
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Harmonic Analysis by Parsing



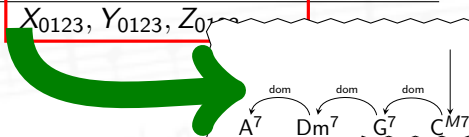
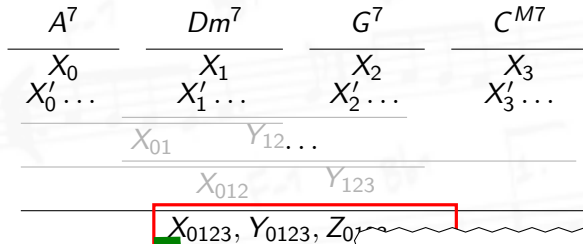
- Many analyses: parsing is slow
- Which are plausible?
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Harmonic Analysis by Parsing

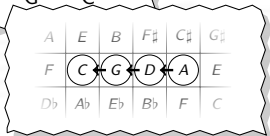


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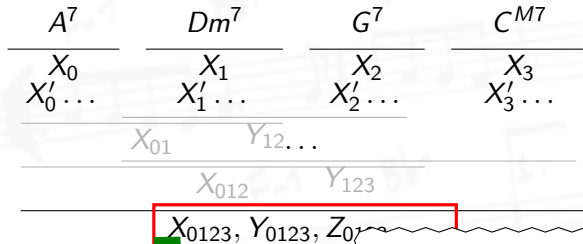
Harmonic Analysis by Parsing



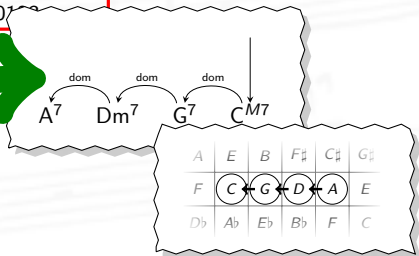
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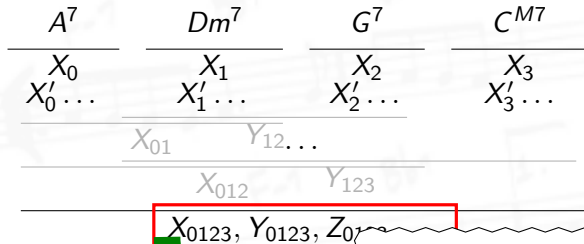
Harmonic Analysis by Parsing



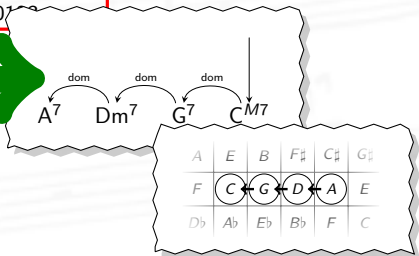
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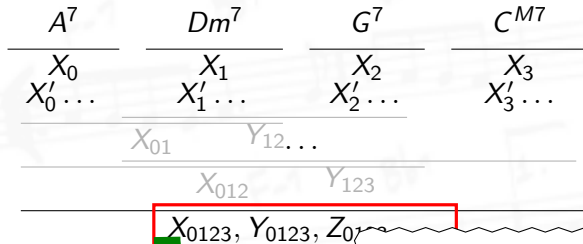
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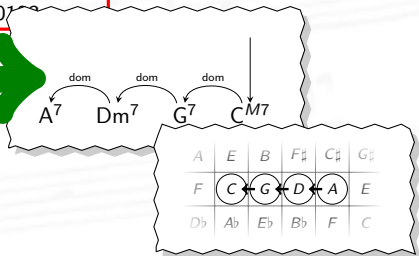
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Harmonic Analysis by Parsing

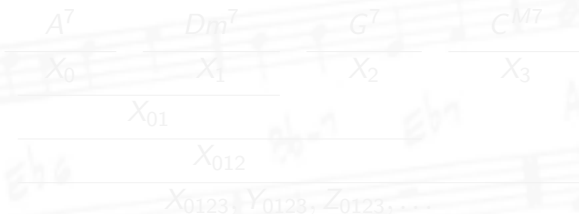


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Statistical Parsing

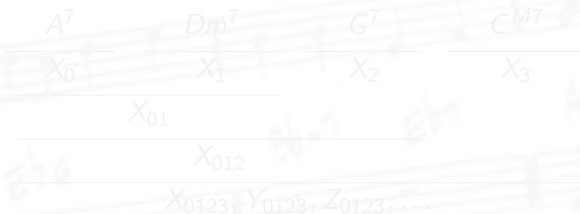
- Supervised statistical parsing models
- Guide parser and rank interpretations
- Parsing model: Hockenmaier & Steedman (2002)¹
- Model of CCG derivations, PCCG
- Supervised training



¹Generative models for statistical parsing with Combinatory Category Grammar, ACL

Statistical Parsing

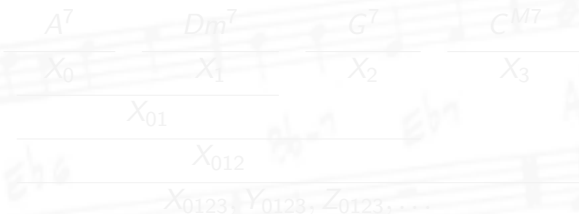
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$$\begin{array}{cccc}
 A^7 & Dm^7 & G^7 & C^{M7} \\
 \hline
 X_0 & X_1 & X_2 & X_3 \\
 \hline
 & X_{01} & & \\
 \hline
 & & X_{012} & \\
 \hline
 & & & X_{0123}, Y_{0123}, Z_{0123}, \dots
 \end{array}$$

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 \hline
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 \hline
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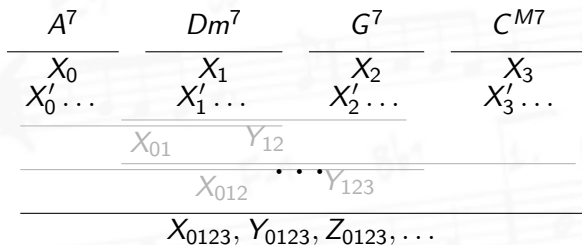
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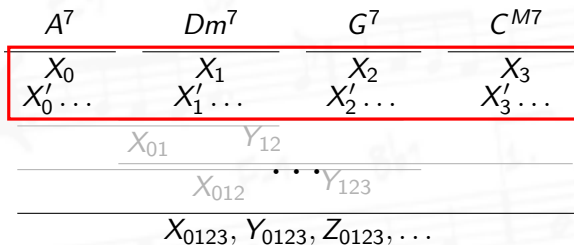
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Supertagging



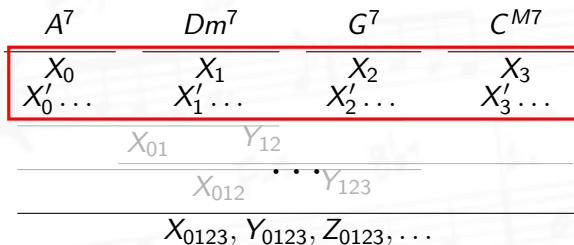
- Reduce choice of lexical categories
- Sequence model
- Here: HMM

Supertagging



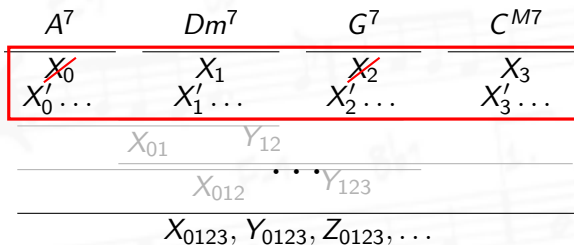
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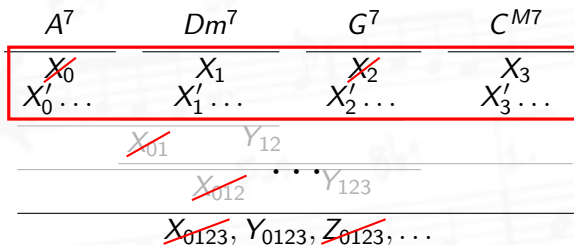
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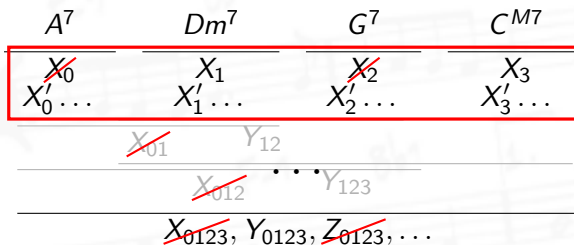
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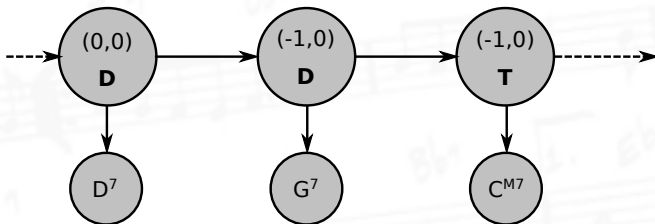
Baseline: HMMPATH

Construct path directly

VI	III	VII	♭IV	♯I
IV	I	♭V	II	♭VI
♭II	♭VI	♭III	♭VII	IV

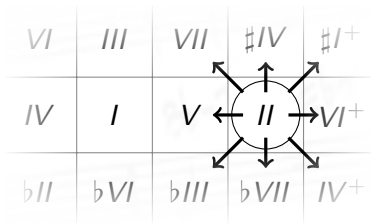
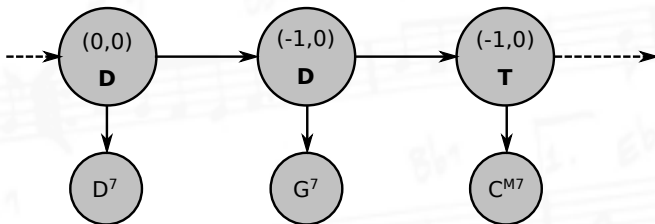
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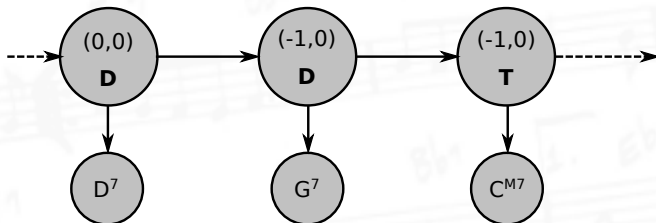
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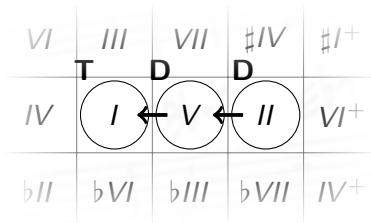
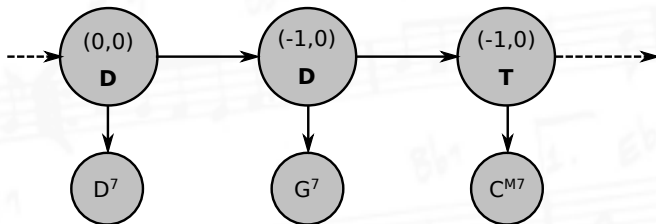
Construct path directly



<i>VI</i>	<i>III</i>	<i>VII</i>	<i>#IV</i>	<i>#I+</i>
		D	D	
<i>IV</i>	<i>I</i>	<i>V</i>	<i>II</i>	<i>VI+</i>
		←		
<i>bII</i>	<i>bVI</i>	<i>bIII</i>	<i>bVII</i>	<i>IV+</i>

Baseline: HMMPATH

Construct path directly



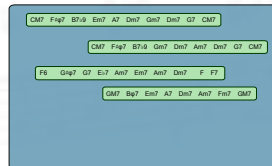
Jazz Corpus

- Annotated training corpus
 - Jazz chord sequences
 - Full grammatical derivation annotated
 - → full harmonic analysis
 - 74 sequences: ~3k chords
 - Cross-validation

Jazz Corpus

- Annotated training corpus

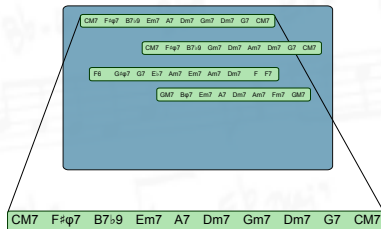
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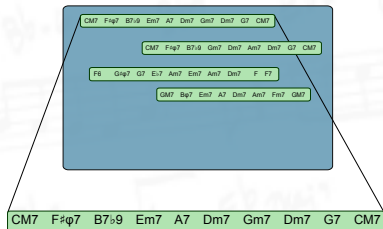
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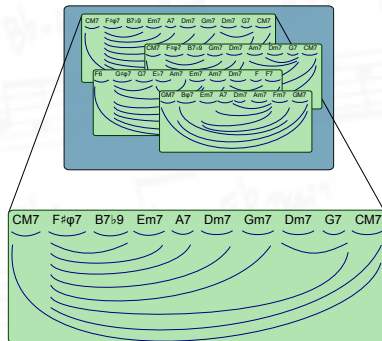
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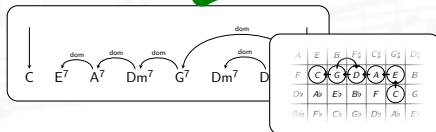
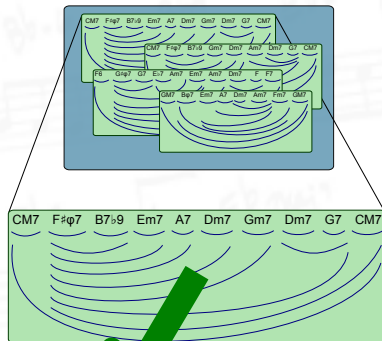
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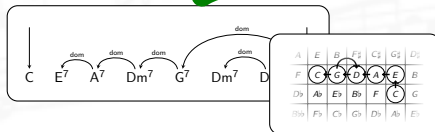
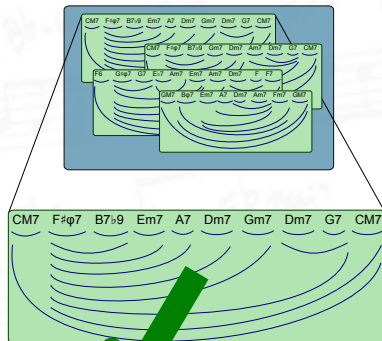
- → full harmonic analysis
- 74 sequences: ~3k chords
- Cross-validation



Jazz Corpus

- Annotated training corpus
- Jazz chord sequences
- Full grammatical derivation annotated
- → full harmonic analysis

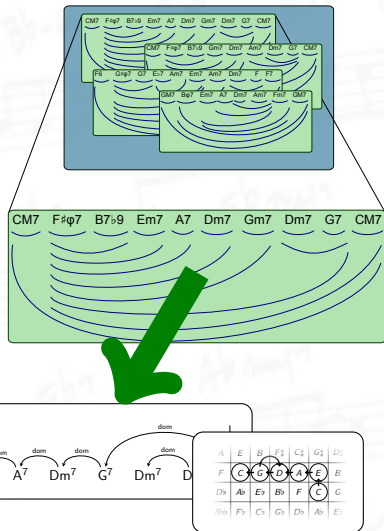
- 74 sequences: ~3k chords
- Cross-validation



A	E	B	F ⁷	C ⁷	G ⁷	D ⁷
F	C	G	D	A	E	B
D ⁷	A ^b	E ^b	B ^b	F	C	G
B ^b	F ^b	C ^b	G ^b	D ^b	A ^b	E ^b

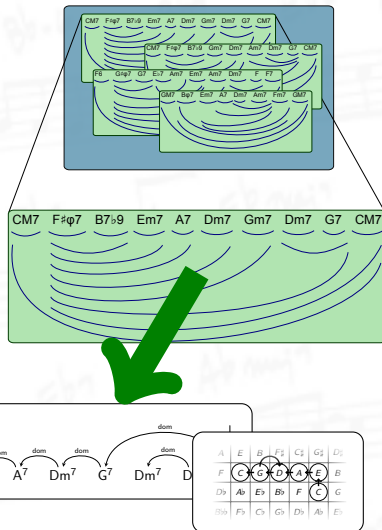
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Afternoon in Paris
Alice in Wonderland

Anthropology

Beauty and the Beast

Black Orpheus

Blackberry Winter

Blue in Green

Boplicity

Bud Powell

Byrd Like

Call Me Irresponsible

Can't Help Lovin' Dat Man

Chelsea Bridge

A Child is Born

Chippie

Chitlins Con Carne

Como En Vietnam

Confirmation

Crescent

Dear Old Stockholm

17/21

CM7

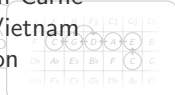
C

E⁷

A⁷

dom

dom



Evaluation Metric

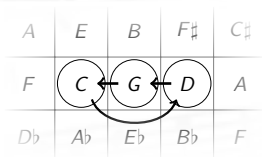
Tonal space edit distance



Precision, recall, f-score

Evaluation Metric

Tonal space edit distance



Precision, recall, f-score

Evaluation Metric

Tonal space edit distance

A	E	B	F $\sharp$	C $\sharp$
F	C	G	D	A
D $\flat$	A $\flat$	E $\flat$	B $\flat$	F

D	A	E	B
B $\flat$	F	C	G
G $\flat$	D $\flat$	A $\flat$	E $\flat$
E $\flat\flat$	B $\flat\flat$	F $\flat$	C $\flat$

Precision, recall, f-score

Evaluation Metric

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Precision, recall, f-score

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Precision, recall, f-score

Evaluation Metric

Tonal space edit distance

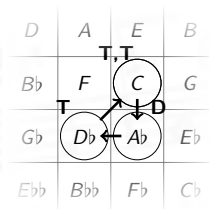
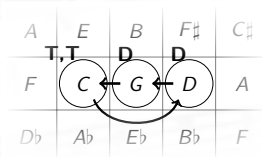
A	E	B	F $\sharp$	C $\sharp$
F	C	G	D	A
D $\flat$	A $\flat$	E $\flat$	B $\flat$	F

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Precision, recall, f-score

Evaluation Metric

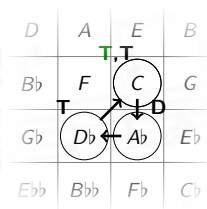
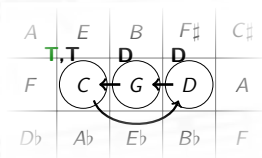
Tonal space edit distance



Precision, recall, f-score

Evaluation Metric

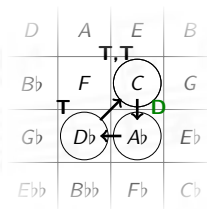
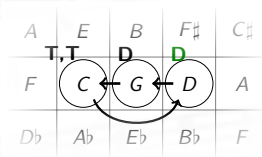
Tonal space edit distance



Precision, recall, f-score

Evaluation Metric

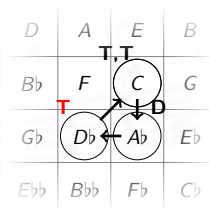
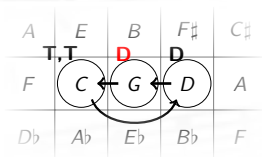
Tonal space edit distance



Precision, recall, f-score

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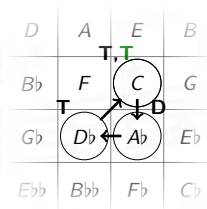
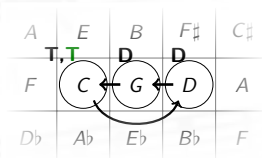
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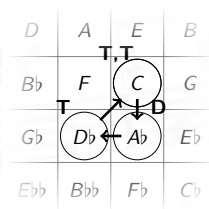
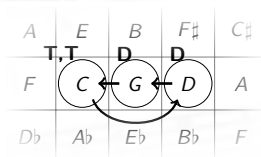
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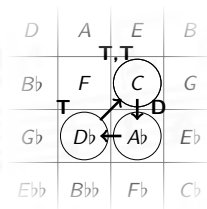
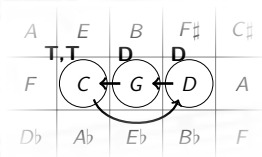
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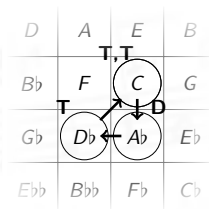
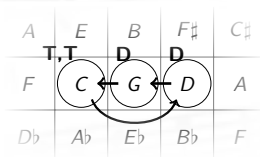
Tonal space edit distance



Precision, recall, f-score

Evaluation Metric

Tonal space edit distance



Precision, recall, f-score

Results

Tonal space edit distance (%)

	<i>Precision</i>	<i>Recall</i>	<i>F-score</i>	<i>Coverage</i>
HMMPATH	81.1	87.7	84.3	100
ST+PCCG	86.0	90.8	88.3	98.7

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Backoff

- Use HMMPATH where ST+PCCG fails
- HMMPATH always produces an analysis

Tonal space edit distance (%)

	<i>P</i>	<i>R</i>	<i>F</i>	<i>Coverage</i>
HMMPATH	81.1	87.7	84.3	100
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ST+PCCG+HMMPATH	85.7	92.0	88.7	100

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Conclusion

- Syntactic grammars for harmonic analysis of chord sequences
- Harmonic analysis in tonal space
- Jazz grammar
- Model of derivations, supertagging
- Jazz corpus
- Parsing with grammar helps recover harmonic structure

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The End

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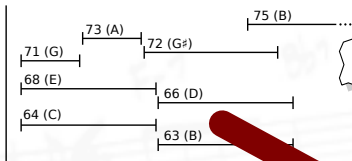
Tonal Space

<i>C♯</i>	<i>G♯</i>	<i>D♯</i>	<i>A♯</i>	<i>E♯</i>	<i>B♯</i>	<i>F♯♯</i>	<i>C♯♯</i>	<i>G♯♯</i>	<i>D♯♯</i>	<i>A♯♯</i>
<i>A</i>	<i>E</i>	<i>B</i>	<i>F♯</i>	<i>C♯</i>	<i>G♯</i>	<i>D♯</i>	<i>A♯</i>	<i>E♯</i>	<i>B♯</i>	<i>F♯♯</i>
<i>F</i>	<i>C</i>	<i>G</i>	<i>D</i>	<i>A</i>	<i>E</i>	<i>B</i>	<i>F♯</i>	<i>C♯</i>	<i>G♯</i>	<i>D♯</i>
<i>D♭</i>	<i>A♭</i>	<i>E♭</i>	<i>B♭</i>	<i>F</i>	<i>C</i>	<i>G</i>	<i>D</i>	<i>A</i>	<i>E</i>	<i>B</i>
<i>B♭♭</i>	<i>F♭</i>	<i>C♭</i>	<i>G♭</i>	<i>D♭</i>	<i>A♭</i>	<i>E♭</i>	<i>B♭</i>	<i>F</i>	<i>C</i>	<i>G</i>
<i>G♭♭</i>	<i>D♭♭</i>	<i>A♭♭</i>	<i>E♭♭</i>	<i>B♭♭</i>	<i>F♭</i>	<i>C♭</i>	<i>G♭</i>	<i>D♭</i>	<i>A♭</i>	<i>E♭</i>
<i>E♭♭♭</i>	<i>B♭♭♭</i>	<i>F♭♭</i>	<i>C♭♭</i>	<i>G♭♭</i>	<i>D♭♭</i>	<i>A♭♭</i>	<i>E♭♭</i>	<i>B♭♭</i>	<i>F♭</i>	<i>C♭</i>

Roman Numeral Tonal Space

$\sharp I^-$	$\sharp V^-$	$\sharp II^-$	$\sharp VI^-$	$\sharp III$	$\sharp VII$	$\sharp\sharp IV$	$\sharp\sharp I$	$\sharp\sharp V^+$	$\sharp\sharp II^+$	$\sharp\sharp VI^+$
VI^-	III^-	VII^-	$\sharp IV^-$	$\sharp I$	$\sharp V$	$\sharp II$	$\sharp VI$	$\sharp III^+$	$\sharp VII^+$	$\sharp\sharp IV^+$
IV^-	I^-	V^-	II^-	VI	III	VII	$\sharp IV$	$\sharp I^+$	$\sharp V^+$	$\sharp II^+$
$b II^-$	$b VI^-$	$b III^-$	$b VII^-$	IV	I	V	II	VI^+	III^+	VII^+
$bb VII^-$	$b IV^-$	$b I^-$	$b V^-$	$b II$	$b VI$	$b III$	$b VII$	IV^+	I^+	V^+
$bb V^-$	$bb II^-$	$bb VI^-$	$bb III^-$	$bb VII$	$b IV$	$b I$	$b V$	$b II^+$	$b VI^+$	$b III^+$
$bbb III^-$	$bbb VII^-$	$bb IV^-$	$bb I^-$	$bb V$	$bb II$	$bb VI$	$bb III$	$bb VII^+$	$b IV^+$	$b I^+$

MIDI Parsing

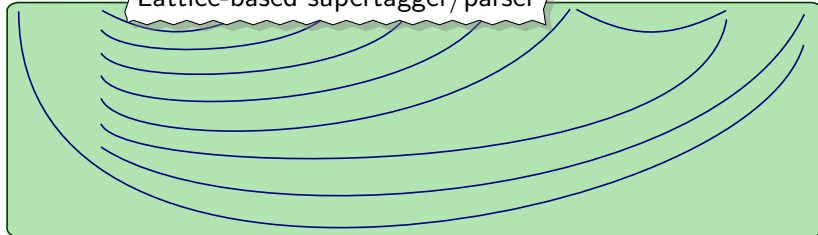


MIDI input

Chord recognizer: lattice

CM7	F# ϕ 7	B ^{7b9}	Em ⁷	F#m ⁷	Am	Do ⁷	F ⁶	B ϕ 7	Am ⁷
Em	Am	Co ⁷	G ⁷	F#m ⁷	Am	Do ⁷	F ⁶	B ϕ 7	Am ⁷
⋮	⋮	⋮	⋮	⋮	⋮	⋮	⋮	⋮	⋮

Lattice-based supertagger/parser



New Results

Tonal space edit distance (%)

	<i>P</i>	<i>R</i>	<i>F</i>	<i>Coverage</i>
HMMPATH	80.3	87.2	83.6	100
PCCG	92.0	90.4	91.2	97.4
ST+PCCG	90.3	92.1	91.2	100

Extra Slides

Tonal Space

Roman Tonal Space

MIDI Parsing

New Results