

Harmonic Analysis of Music Using Combinatory Categorical Grammar

Draft Dissertation Defence

Mark Granroth-Wilding

School of Informatics
Edinburgh

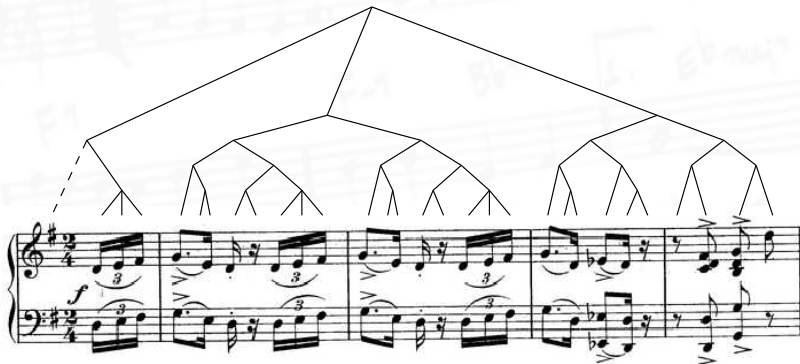
20th Aug 2012

Introduction

- Hierarchical structure in music
 - Metrical structure
 - Harmonic structure

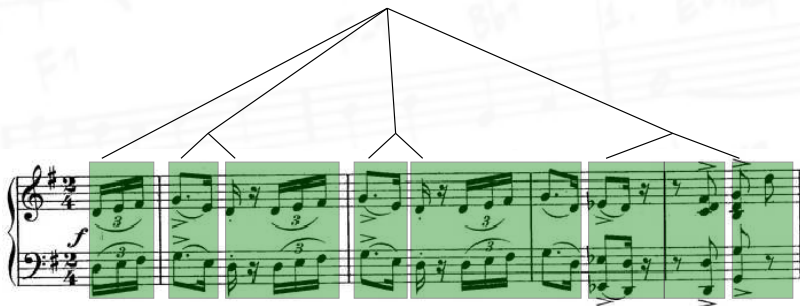
Introduction

- Hierarchical structure in music
- Metrical structure
- Harmonic structure



Introduction

- Hierarchical structure in music
- Metrical structure
- Harmonic structure



Applications

- Automatic generation:

- Song identification
- Language modeling
- Transcription of scores

Applications

- Automatic generation:
 - melodic variations
 - arrangements
 - accompaniments
- Song identification
- Language modeling
- Transcription of scores

Applications

- Automatic generation:
 - melodic variations
 - arrangements
 - accompaniments
- Song identification
- Language modeling
- Transcription of scores

Applications

- Automatic generation:
 - melodic variations
 - arrangements
 - accompaniments
- Song identification
- Language modeling
- Transcription of scores

Applications

- Automatic generation:
 - melodic variations
 - arrangements
 - accompaniments
- Song identification
- Language modeling
- Transcription of scores

Applications

- Automatic generation:
 - melodic variations
 - arrangements
 - accompaniments
- Song identification
 - Language modeling
 - Transcription of scores

Applications

- Automatic generation:
 - melodic variations
 - arrangements
 - accompaniments
- Song identification
- Language modeling
- Transcription of scores

Applications

- Automatic generation:
 - melodic variations
 - arrangements
 - accompaniments
- Song identification
- Language modeling
- Transcription of scores

Thesis Contributions

Thesis:

- Music has a syntax like that of language
- Parsing can be used to recover structures important to musical understanding

Contributions:

- Formal grammars for syntax of harmony
- Harmonic analysis by parsing
- Practical statistical parsing of chord sequences
- Extension to analysis of performance data

Thesis Contributions

Thesis:

- Music has a syntax like that of language
- Parsing can be used to recover structures important to musical understanding

Contributions:

- Formal grammars for syntax of harmony
- Harmonic analysis by parsing
- Practical statistical parsing of chord sequences
- Extension to analysis of performance data

Thesis Contributions

Thesis:

- Music has a syntax like that of language
- Parsing can be used to recover structures important to musical understanding

Contributions:

- Formal grammars for syntax of harmony
- Harmonic analysis by parsing
- Practical statistical parsing of chord sequences
- Extension to analysis of performance data

Thesis Contributions

Thesis:

- Music has a syntax like that of language
- Parsing can be used to recover structures important to musical understanding

Contributions:

- Formal grammars for syntax of harmony
- Harmonic analysis by parsing
- Practical statistical parsing of chord sequences
- Extension to analysis of performance data

Thesis Contributions

Thesis:

- Music has a syntax like that of language
- Parsing can be used to recover structures important to musical understanding

Contributions:

- Formal grammars for syntax of harmony
- Harmonic analysis by parsing
- Practical statistical parsing of chord sequences
- Extension to analysis of performance data

Thesis Contributions

Thesis:

- Music has a syntax like that of language
- Parsing can be used to recover structures important to musical understanding

Contributions:

- Formal grammars for syntax of harmony
- Harmonic analysis by parsing
- Practical statistical parsing of chord sequences
- Extension to analysis of performance data

Thesis Contributions

Thesis:

- Music has a syntax like that of language
- Parsing can be used to recover structures important to musical understanding

Contributions:

- Formal grammars for syntax of harmony
- Harmonic analysis by parsing
- Practical statistical parsing of chord sequences
- Extension to analysis of performance data

Thesis Contributions

Thesis:

- Music has a syntax like that of language
- Parsing can be used to recover structures important to musical understanding

Contributions:

- Formal grammars for syntax of harmony
- Harmonic analysis by parsing
- Practical statistical parsing of chord sequences
- Extension to analysis of performance data

Harmonic Analysis

- Functional harmonic structure
- Tension-resolution patterns

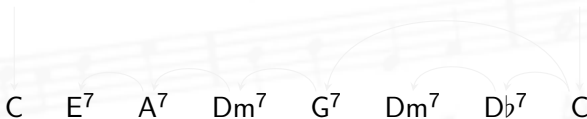


Harmonic Analysis

- Functional harmonic structure
- Tension-resolution patterns between *chords*

Harmonic Analysis

- Functional harmonic structure
- Tension-resolution patterns between *chords*



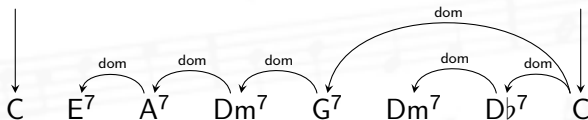
Harmonic Analysis

- Functional harmonic structure
- Tension-resolution patterns between *chords*



Harmonic Analysis

- Functional harmonic structure
- Tension-resolution patterns between *chords*

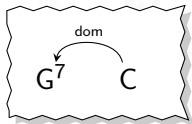


Harmonic Analysis

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

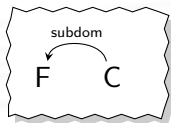
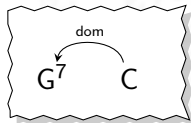
Harmonic Analysis

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



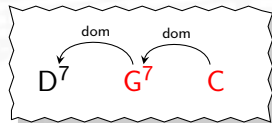
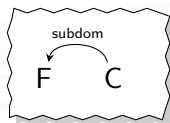
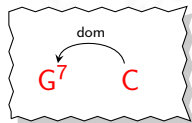
Harmonic Analysis

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



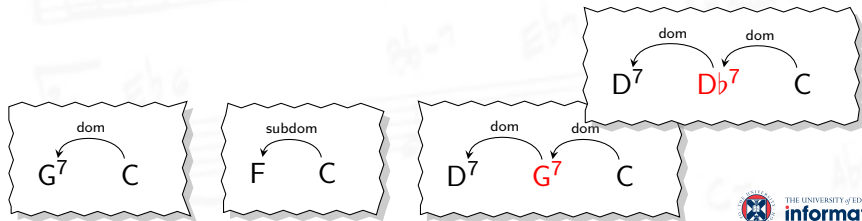
Harmonic Analysis

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



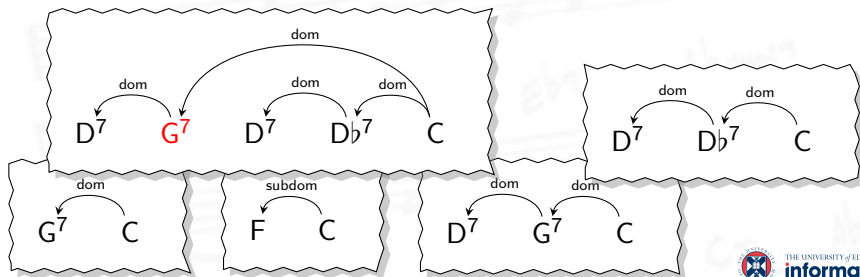
Harmonic Analysis

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



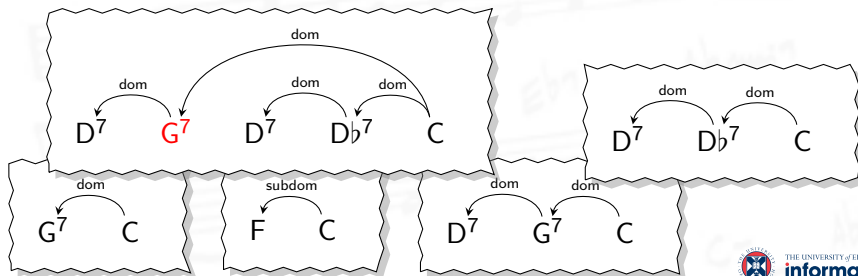
Harmonic Analysis

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



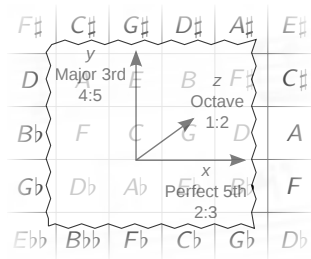
Harmonic Analysis

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



Tonal Space

- Longuet-Higgin's formalization of tonal theory
- Distinguishes tonal relations ambiguous in performance



- Harmonic analysis disambiguates tonal relations

Tonal Space

- Longuet-Higgin's formalization of tonal theory
- Distinguishes tonal relations ambiguous in performance

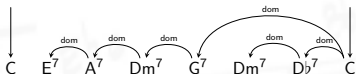
<i>F</i> ♯	<i>C</i> ♯	<i>G</i> ♯	<i>D</i> ♯	<i>A</i> ♯	<i>E</i> ♯
<i>D</i>	<i>A</i>	<i>E</i>	<i>B</i>	<i>F</i> ♯	<i>C</i> ♯
<i>B</i> ♭	<i>F</i>	<i>C</i>	<i>G</i>	<i>D</i>	<i>A</i>
<i>G</i> ♭	<i>D</i> ♭	<i>A</i> ♭	<i>E</i> ♭	<i>B</i> ♭	<i>F</i>
<i>E</i> ♭♭	<i>B</i> ♭♭	<i>F</i> ♭	<i>C</i> ♭	<i>G</i> ♭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

- Harmonic analysis disambiguates tonal relations

Tonal Space

- Longuet-Higgin's formalization of tonal theory
- Distinguishes tonal relations ambiguous in performance
- Harmonic analysis disambiguates tonal relations

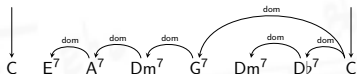
<i>F#</i>	<i>C#</i>	<i>G#</i>	<i>D#</i>	<i>A#</i>	<i>E#</i>
<i>D</i>	<i>A</i>	<i>E</i>	<i>B</i>	<i>F#</i>	<i>C#</i>
<i>Bb</i>	<i>F</i>	<i>C</i>	<i>G</i>	<i>D</i>	<i>A</i>
<i>Gb</i>	<i>Db</i>	<i>Ab</i>	<i>Eb</i>	<i>Bb</i>	<i>F</i>
<i>Ebb</i>	<i>Bbb</i>	<i>Fb</i>	<i>Cb</i>	<i>Gb</i>	<i>Db</i>



Tonal Space

- Longuet-Higgin's formalization of tonal theory
- Distinguishes tonal relations ambiguous in performance
- Harmonic analysis disambiguates tonal relations

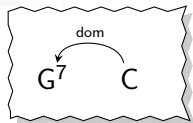
$F\sharp$	$C\sharp$	$G\sharp$	$D\sharp$	$A\sharp$	$E\sharp$
D	A	E	B	$F\sharp$	$C\sharp$
$B\flat$	F	C	G	D	A
$G\flat$	$D\flat$	$A\flat$	$E\flat$	$B\flat$	F
$E\flat\flat$	$B\flat\flat$	$F\flat$	$C\flat$	$G\flat$	$D\flat$



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

Harmonic Combinatory Categorical Grammar

$$G^7 \Rightarrow G/C$$

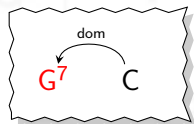


$$C \Rightarrow C$$

$$\begin{array}{c} G^7 \quad C \\ \hline G/C \quad C \\ \hline \xrightarrow{\quad} \\ G=C \end{array}$$

Harmonic Combinatory Categorical Grammar

$$G^7 \Rightarrow G/C : \lambda x. \text{leftonto}(x)$$

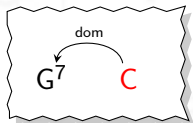


$$C \Rightarrow C$$

$$\frac{\frac{G^7}{G/C} \quad C}{G=C}$$

Harmonic Combinatory Categorical Grammar

$$G^7 \Rightarrow G/C : \lambda x. \text{leftonto}(x)$$

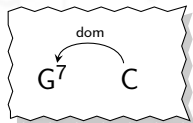


$$C \Rightarrow C : (0, 0)$$

$$\begin{array}{cc} G^7 & C \\ \hline G/C & C \\ \hline G=C & \rightarrow \end{array}$$

Harmonic Combinatory Categorical Grammar

$$G^7 \Rightarrow G/C : \lambda x. \text{leftonto}(x)$$

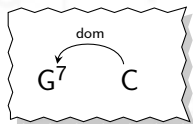
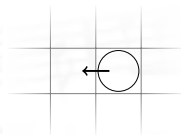


$$C \Rightarrow C \quad (0, 0)$$

$$\frac{\frac{G^7}{G/C} \quad C}{G-C} \rightarrow$$

Harmonic Combinatory Categorical Grammar

$$G^7 \Rightarrow G/C : \lambda x. \text{leftonto}(x)$$

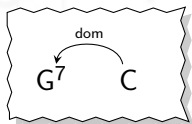
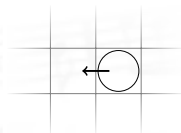


$$C \Rightarrow C \quad (0, 0)$$

$$\frac{\frac{G^7}{G/C} \quad C}{G-C} \rightarrow$$

Harmonic Combinatory Categorical Grammar

$$G^7 \Rightarrow G/C : \lambda x. \text{leftonto}(x)$$



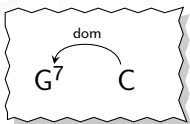
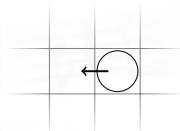
$$C \Rightarrow C : (0, 0)$$

A	E	B
F	C	G
D _b	A _b	E _b

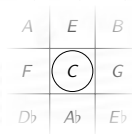
$$\frac{\frac{G^7}{G/C} \quad C}{G-C} \rightarrow$$

Harmonic Combinatory Categorical Grammar

$$G^7 \Rightarrow G/C : \lambda x. \text{leftonto}(x)$$



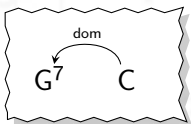
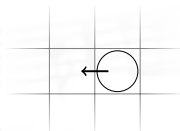
$$C \Rightarrow C : (0,0)$$



$$\frac{\frac{G^7}{G/C : \lambda x. \text{leftonto}(x)} \quad \frac{C}{C : (0,0)}}{G-C : \text{leftonto}((0,0))} >$$

Harmonic Combinatory Categorical Grammar

$$G^7 \Rightarrow G/C : \lambda x. \text{leftonto}(x)$$



$$C \Rightarrow C : (0,0)$$

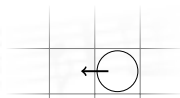
A	E	B
F	C	G
D $\flat$	A $\flat$	E $\flat$

$$\frac{\frac{G^7}{G/C : \lambda x. \text{leftonto}(x)} \quad \frac{C}{C : (0,0)}}{G-C : \text{leftonto}((0,0))} >$$

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

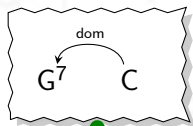
Harmonic Combinatory Categorical Grammar

$$G^7 \Rightarrow G/C : \lambda x. \text{leftonto}(x)$$



A	E	B
F	C	G
D _b	A _b	E _b

$$C \Rightarrow C : (0,0)$$

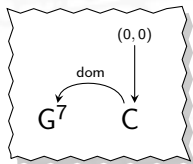
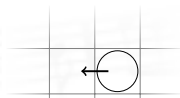


$$\frac{\frac{G^7}{G/C : \lambda x. \text{leftonto}(x)} \quad \frac{C}{C : (0,0)}}{G-C : \text{leftonto}((0,0))} >$$

A	E	B	F _‡
F	C	G	D
D _b	A _b	E _b	B _b

Harmonic Combinatory Categorical Grammar

$$G^7 \Rightarrow G/C : \lambda x. \text{leftonto}(x)$$



$$C \Rightarrow C : (0,0)$$

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

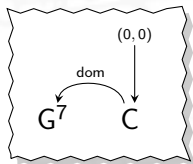
$$\frac{\frac{G^7}{G/C : \lambda x. \text{leftonto}(x)} \quad \frac{C}{C : (0,0)}}{G-C : \text{leftonto}((0,0))} >$$

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

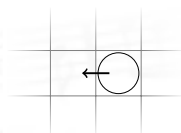
Harmonic Combinatory Categorical Grammar

$$G^7 \Rightarrow G/C : \lambda x. \text{leftonto}(x)$$

$$X^7 \Rightarrow I/IV : \lambda x. \text{leftonto}(x)$$



$$C \Rightarrow C : (0,0)$$



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

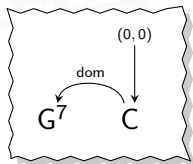
$$\frac{\frac{G^7}{G/C : \lambda x. \text{leftonto}(x)} \quad \frac{C}{C : (0,0)}}{G-C : \text{leftonto}((0,0))} >$$

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

Harmonic Combinatory Categorical Grammar

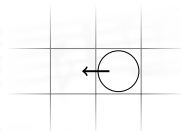
$$G^7 \Rightarrow G/C : \lambda x. \text{leftonto}(x)$$

$$X^7 \Rightarrow I/IV : \lambda x. \text{leftonto}(x)$$



$$C \Rightarrow C : (0,0)$$

$$X \Rightarrow I : \text{point}(X)$$

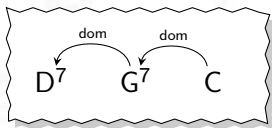


A	E	B
F	C	G
D $\flat$	A $\flat$	E $\flat$

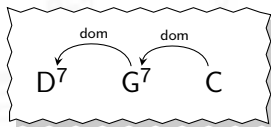
$$\frac{\frac{G^7}{G/C : \lambda x. \text{leftonto}(x)} \quad \frac{C}{C : (0,0)}}{G-C : \text{leftonto}((0,0))} >$$

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

Harmonic CCG



Harmonic CCG

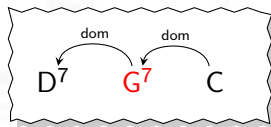
 D^7 G^7 C

$$\begin{array}{l}
 D/G : \lambda x. \text{leftonto}(x) \quad G/C : \lambda x. \text{leftonto}(x) \quad C : (0,0) \\
 \xrightarrow{G-C : \text{leftonto}((0,0))} \\
 \xrightarrow{D-C : \text{leftonto}(\text{leftonto}((0,0)))}
 \end{array}$$

$$X^7 \Rightarrow I/IV : \lambda x. \text{leftonto}(x)$$

$$X \Rightarrow I : \text{point}(X)$$

Harmonic CCG

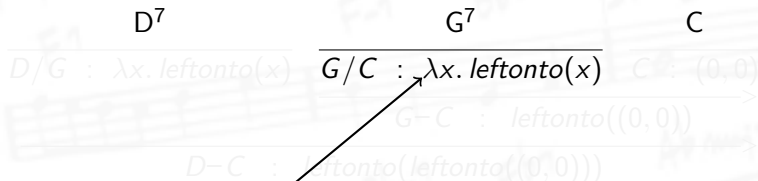
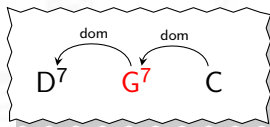
 D^7 G^7 C

$$\begin{array}{l}
 D/G : \lambda x. \text{leftonto}(x) \quad G/C : \lambda x. \text{leftonto}(x) \quad C : (0,0) \\
 \hline
 G-C : \text{leftonto}((0,0)) \\
 \hline
 D-C : \text{leftonto}(\text{leftonto}((0,0)))
 \end{array}$$

$$X^7 \Rightarrow I/IV : \lambda x. \text{leftonto}(x)$$

$$X \Rightarrow I : \text{point}(X)$$

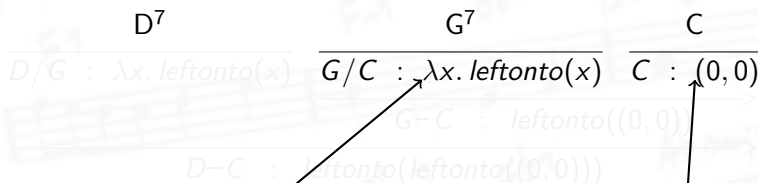
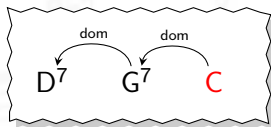
Harmonic CCG



$X^7 \Rightarrow I/IV : \lambda x. \text{leftonto}(x)$

$X \Rightarrow I : \text{point}(X)$

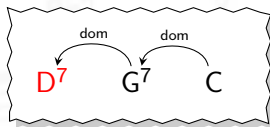
Harmonic CCG



$X^7 \Rightarrow I/IV : \lambda x. \text{leftonto}(x)$

$X \Rightarrow I : \text{point}(X)$

Harmonic CCG

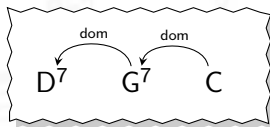


$\frac{D^7}{D/G : \lambda x. \text{leftonto}(x)}$
 $\frac{G^7}{G/C : \lambda x. \text{leftonto}(x)}$
 $\frac{C}{C : (0,0)}$

$X^7 \Rightarrow I/IV : \lambda x. \text{leftonto}(x)$

$X \Rightarrow I : \text{point}(X)$

Harmonic CCG

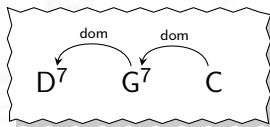


$$\begin{array}{c}
 \begin{array}{ccc}
 \overline{D^7} & \overline{G^7} & \overline{C} \\
 D/G : \lambda x. \text{leftonto}(x) & G/C : \lambda x. \text{leftonto}(x) & C : (0, 0)
 \end{array} \\
 \hline
 G-C : \text{leftonto}((0, 0)) \\
 \hline
 D-C : \text{leftonto}(\text{leftonto}((0, 0)))
 \end{array}$$

$$X^7 \Rightarrow I/IV : \lambda x. \text{leftonto}(x)$$

$$X \Rightarrow I : \text{point}(X)$$

Harmonic CCG

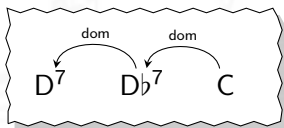


$$\begin{array}{c}
 \frac{D^7}{D/G : \lambda x. \text{leftonto}(x)} \quad \frac{G^7}{G/C : \lambda x. \text{leftonto}(x)} \quad \frac{C}{C : (0,0)} \\
 \hline
 \frac{D/C : \lambda x. \text{leftonto}(\text{leftonto}(x))}{D-C : \text{leftonto}(\text{leftonto}((0,0)))} \xrightarrow{B}
 \end{array}$$

$$X^7 \Rightarrow I/IV : \lambda x. \text{leftonto}(x)$$

$$X \Rightarrow I : \text{point}(X)$$

Harmonic CCG

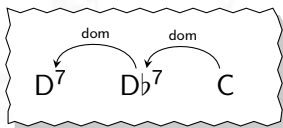


$$\begin{array}{ccc} D^7 & D^b7 & C \\ \hline D/G & G/C & C \\ \hline D/C & & \\ \hline \end{array} \xrightarrow{D-G}$$

$$X^7 \Rightarrow I/IV$$

$$X \Rightarrow I$$

Harmonic CCG



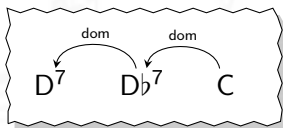
$$\begin{array}{ccc} D^7 & D_b^7 & C \\ \hline D/G & G/C & C \end{array}$$

$$X^7 \Rightarrow I/IV$$

$$X^7 \Rightarrow bV/VII$$

$$X \Rightarrow I$$

Harmonic CCG



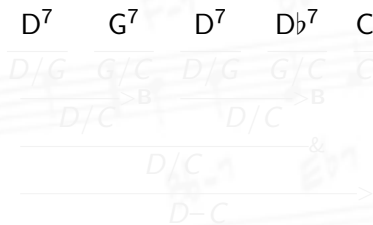
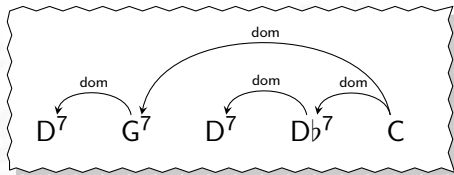
$$\begin{array}{ccc}
 D^7 & D^b7 & C \\
 \hline
 D/G & G/C & C \\
 \hline
 & D/C & \xrightarrow{B} \\
 \hline
 & D-C & \xrightarrow{\quad}
 \end{array}$$

$$X^7 \Rightarrow I/IV$$

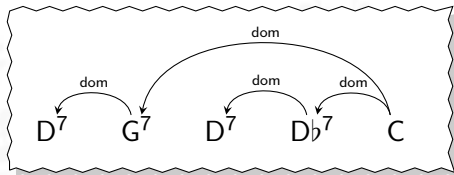
$$X^7 \Rightarrow {}^bV/VII$$

$$X \Rightarrow I$$

Harmonic CCG

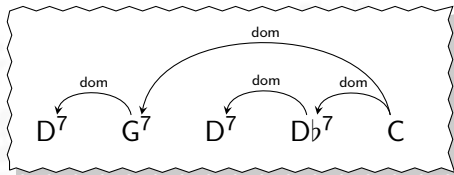


Harmonic CCG



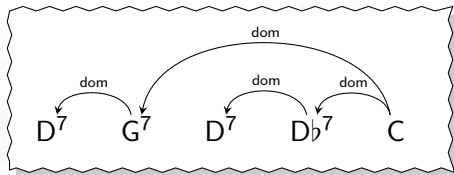
$$\begin{array}{ccccc}
 D^7 & G^7 & D^7 & D_b^7 & C \\
 \hline
 D/G & G/C & D/G & G/C & C \\
 \hline
 & \xrightarrow{D/C \triangleright B} & \xrightarrow{D/C \triangleright B} & \xrightarrow{\&} & \xrightarrow{D-C}
 \end{array}$$

Harmonic CCG



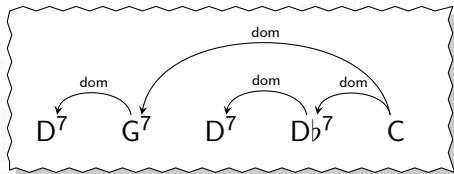
$$\begin{array}{ccccc}
 D^7 & G^7 & D^7 & D_b^7 & C \\
 \hline
 D/G & G/C & D/G & G/C & C \\
 \hline
 D/C >^B & D/C >^B & & & \\
 \hline
 & D/C & & & \\
 \hline
 & D-C & & &
 \end{array}$$

Harmonic CCG



$$\begin{array}{ccccc}
 D^7 & G^7 & D^7 & D_b^7 & C \\
 \hline
 D/G & G/C & D/G & G/C & C \\
 \hline
 D/C >^B & D/C >^B & & & \\
 \hline
 D/C & & & & & \& \\
 \hline
 D-C & & & & & \rightarrow
 \end{array}$$

Harmonic CCG



$$\begin{array}{ccccc}
 D^7 & G^7 & D^7 & D_b^7 & C \\
 \hline
 D/G & G/C & D/G & G/C & C \\
 \hline
 D/C >^B & D/C >^B & & & \\
 \hline
 & D/C & & & \& \\
 \hline
 & D-C & & & \rightarrow
 \end{array}$$

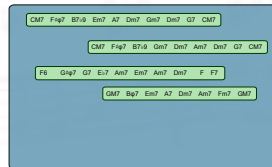
Corpus

- Annotated training corpus
 - Jazz chord sequences
 - Full normal-form derivations
 - $\rightarrow$ full harmonic analysis
 - 74 sequences
 - Cross-validation

Corpus

- Annotated training corpus

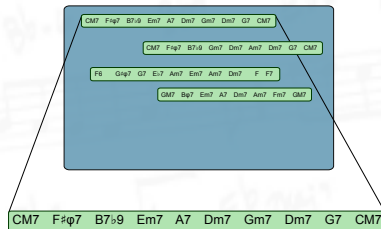
- Jazz chord sequences
- Full normal-form derivations
- $\rightarrow$ full harmonic analysis
- 74 sequences
- Cross-validation



Corpus

- Annotated training corpus

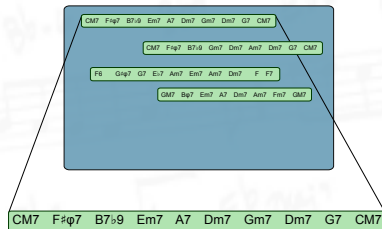
- Jazz chord sequences
- Full normal-form derivations
- $\rightarrow$ full harmonic analysis
- 74 sequences
- Cross-validation



Corpus

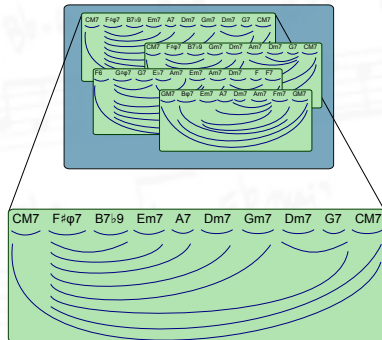
- Annotated training corpus
- Jazz chord sequences

- Full normal-form derivations
- $\Rightarrow$ full harmonic analysis
- 74 sequences
- Cross-validation



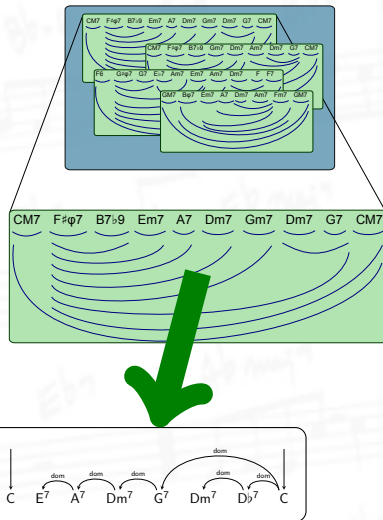
Corpus

- Annotated training corpus
- Jazz chord sequences
- Full normal-form derivations
 - $\rightarrow$ full harmonic analysis
 - 74 sequences
 - Cross-validation



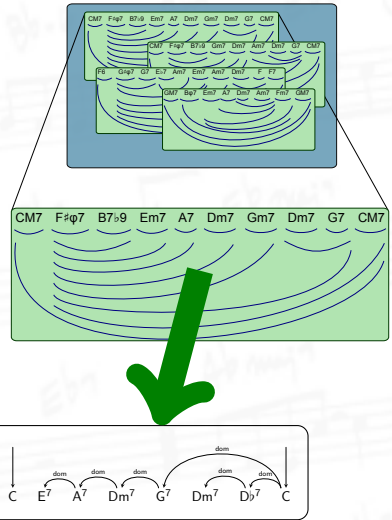
Corpus

- Annotated training corpus
- Jazz chord sequences
- Full normal-form derivations
 - $\rightarrow$ full harmonic analysis
 - 74 sequences
 - Cross-validation



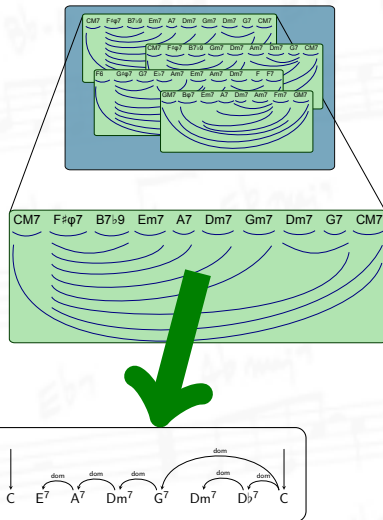
Corpus

- Annotated training corpus
- Jazz chord sequences
- Full normal-form derivations
- → full harmonic analysis
- 74 sequences
- Cross-validation



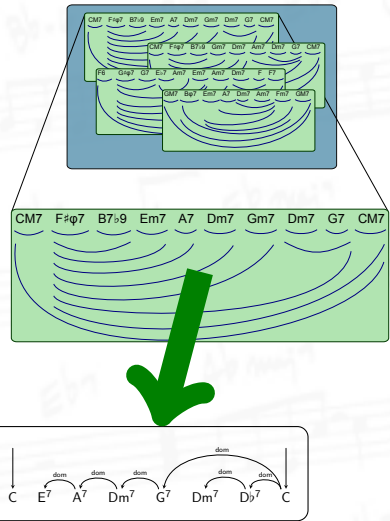
Corpus

- Annotated training corpus
- Jazz chord sequences
- Full normal-form derivations
- → full harmonic analysis
- 74 sequences
- Cross-validation



Corpus

- Annotated training corpus
- Jazz chord sequences
- Full normal-form derivations
- → full harmonic analysis
- 74 sequences
- Cross-validation



Statistical Parsing

- Supervised statistical parsing model
- Guides parse and ranks interpretations
- **Parsing model:** Hockenmaier & Steedman (2002)¹
- Supervised training

¹Generative models for statistical parsing with Combinatory Catego

Statistical Parsing

- Supervised statistical parsing model
- Guides parse and ranks interpretations
- **Parsing model:** Hockenmaier & Steedman (2002)¹
- Supervised training

¹Generative models for statistical parsing with Combinatory Categorical

Statistical Parsing

- Supervised statistical parsing model
- Guides parse and ranks interpretations
- **Parsing model:** Hockenmaier & Steedman (2002)¹
- Supervised training

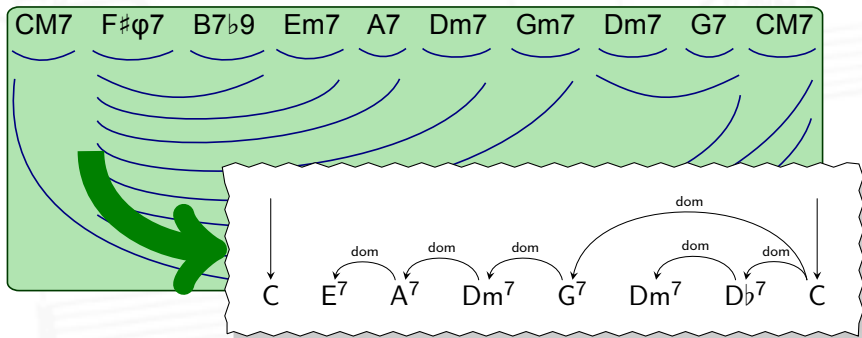
CM7 F#ø7 B7b9 Em7 A7 Dm7 Gm7 Dm7 G7 CM7

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



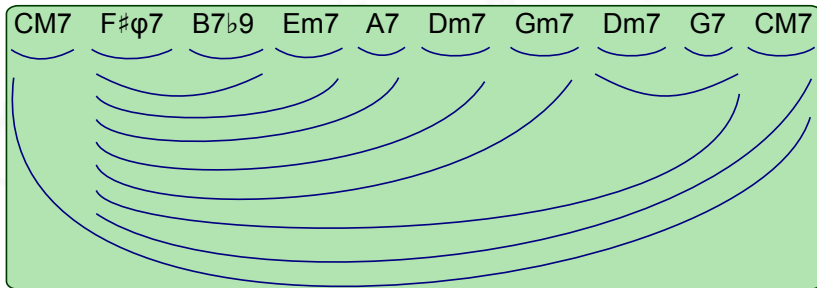
Statistical Parsing

- Supervised statistical parsing model
- Guides parse and ranks interpretations
- **Parsing model:** Hockenmaier & Steedman (2002)¹
- Supervised training



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

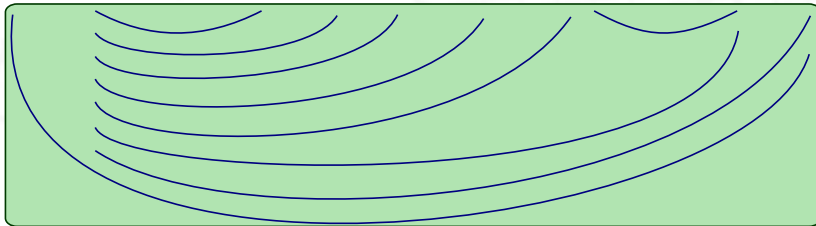
Supertagging



- Experimented with n-gram models
- Trigrams don't help
- For parsing experiments:

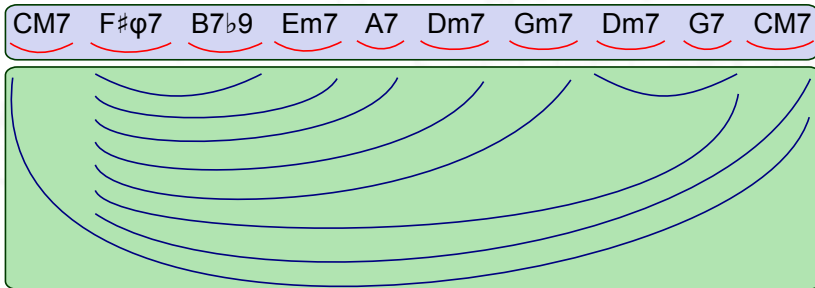
Supertagging

CM7 F# ϕ 7 B7 $\flat$ 9 Em7 A7 Dm7 Gm7 Dm7 G7 CM7



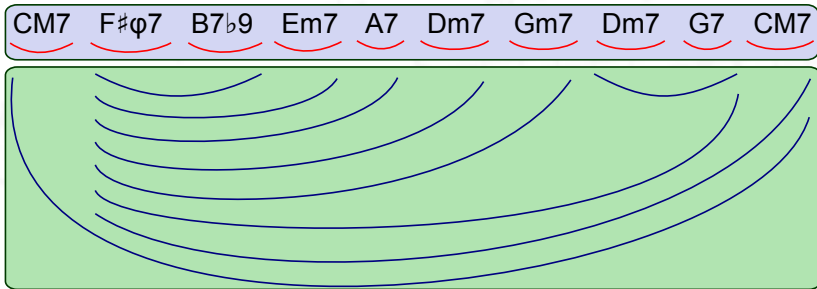
- Experimented with n-gram models
- Trigrams don't help
- For parsing experiments:

Supertagging



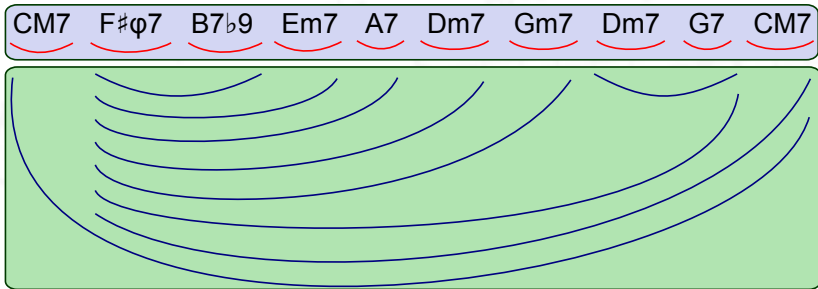
- Experimented with n-gram models
 - Trigrams don't help
 - For parsing experiments:

Supertagging



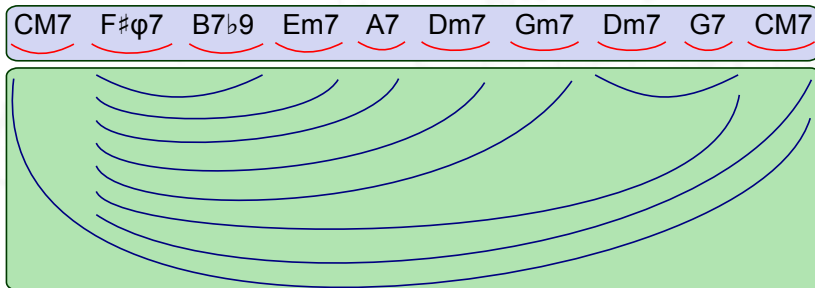
- Experimented with n-gram models
- Trigrams don't help
- For parsing experiments:

Supertagging



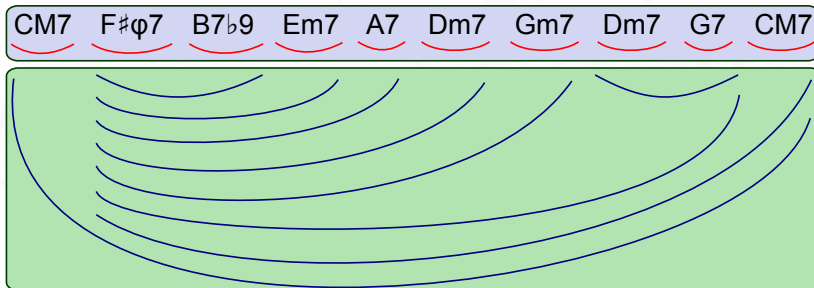
- Experimented with n-gram models
- Trigrams don't help
- For parsing experiments:
 - bigram (HMM)
 - Katz backoff
 - Witten-Bell smoothing

Supertagging



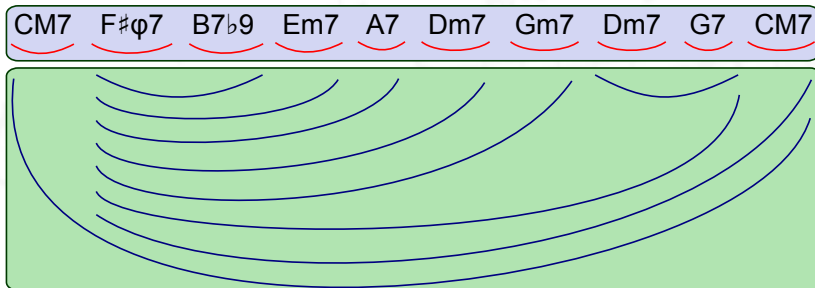
- Experimented with n-gram models
- Trigrams don't help
- For parsing experiments:
 - bigram (HMM)
 - Katz backoff
 - Witten-Bell smoothing

Supertagging



- Experimented with n-gram models
- Trigrams don't help
- For parsing experiments:
 - bigram (HMM)
 - Katz backoff
 - Witten-Bell smoothing

Supertagging



- Experimented with n-gram models
- Trigrams don't help
- For parsing experiments:
 - bigram (HMM)
 - Katz backoff
 - Witten-Bell smoothing

Evaluation Metrics

$(0, 0)$, $\text{leftonto}(\text{leftonto}((0, 0)))$



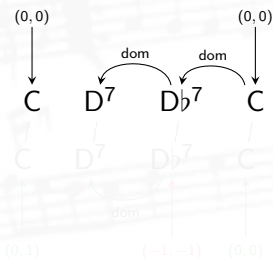
Dependency recovery
(DR)



Tonal space edit distance
(TSED)

Evaluation Metrics

$(0, 0)$, *leftonto*(*leftonto*(($0, 0$)))



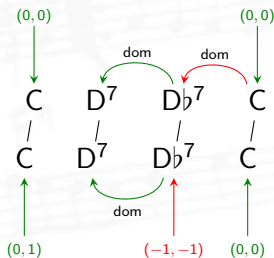
Dependency recovery
(DR)



Tonal space edit distance
(TSED)

Evaluation Metrics

$(0, 0)$, $\text{leftonto}(\text{leftonto}((0, 0)))$

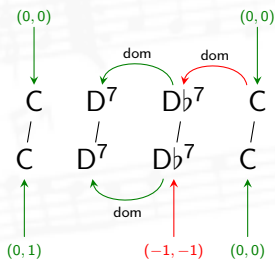


Dependency recovery
(DR)

Tonal space edit distance
(TSED)

Evaluation Metrics

$(0, 0)$, *leftonto(leftonto((0, 0)))*

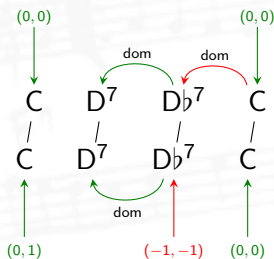


Dependency recovery
(DR)

Tonal space edit distance
(TSED)

Evaluation Metrics

$(0, 0)$, *leftonto(leftonto((0, 0)))*



*Dependency recovery
(DR)*

A	E	B	F [♯]	C [♯]
F	C	G	D	A
D [♭]	A [♭]	E [♭]	B [♭]	F

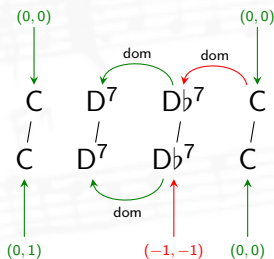
D [♭]	A [♭]	E [♭]	B [♭]
B [♭]	F	C	G
G [♭]	D [♭]	A [♭]	E [♭]
F [♯]	B [♭]	F [♯]	C [♯]

*Tonal space edit distance
(TSED)*



Evaluation Metrics

$(0, 0)$, $\text{leftonto}(\text{leftonto}((0, 0)))$



*Dependency recovery
(DR)*

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

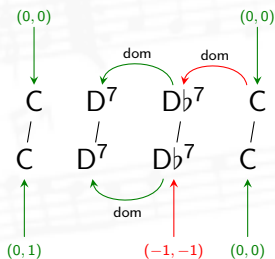
D	A	E	B
B ^b	F	C	G
G ^b	D ^b	A ^b	E ^b
E ^b	B ^b	F ^b	C ^b

*Tonal space edit distance
(TSED)*



Evaluation Metrics

$(0, 0)$, $\text{leftonto}(\text{leftonto}((0, 0)))$



*Dependency recovery
(DR)*

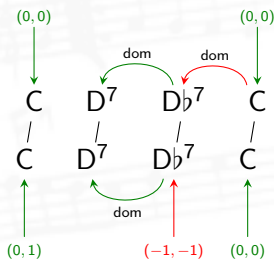
A	E	B	F [♯]	C [♯]
F	C	G	D	A
D ^b	A ^b	E ^b	B ^b	F

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

*Tonal space edit distance
(TSED)*

Evaluation Metrics

$(0, 0)$, *leftonto(leftonto((0, 0)))*



Dependency recovery
(DR)

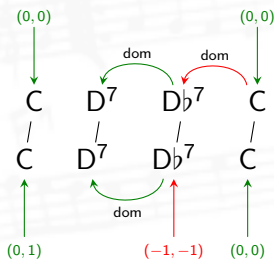
A	E	B	F [#]	C [#]
F	C	G	D	A
D ^b	A ^b	E ^b	B ^b	F

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

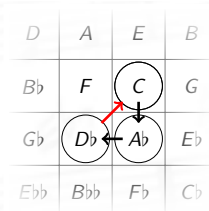
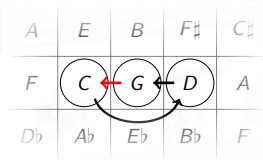
Tonal space edit distance
(TSED)

Evaluation Metrics

$(0, 0)$, $leftonto(leftonto((0, 0)))$



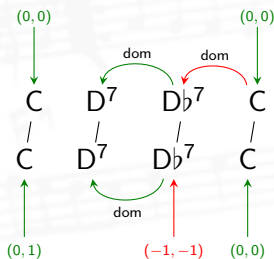
*Dependency recovery
(DR)*



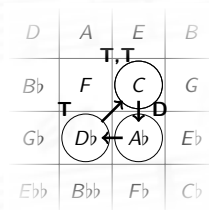
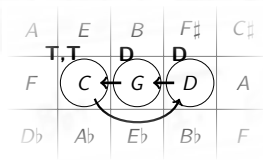
*Tonal space edit distance
(TSED)*

Evaluation Metrics

$(0, 0)$, $\text{leftonto}(\text{leftonto}((0, 0)))$



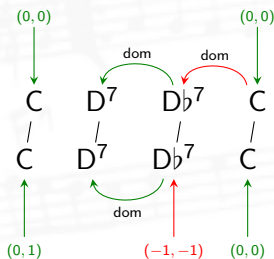
*Dependency recovery
(DR)*



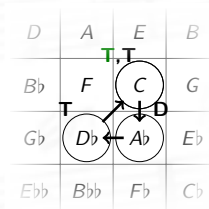
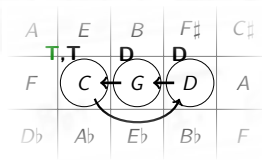
*Tonal space edit distance
(TSED)*

Evaluation Metrics

$(0, 0)$, $\text{leftonto}(\text{leftonto}((0, 0)))$



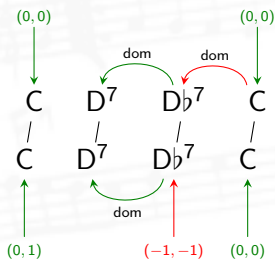
*Dependency recovery
(DR)*



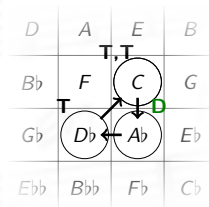
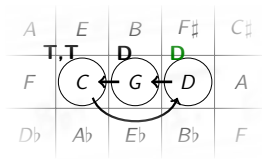
*Tonal space edit distance
(TSED)*

Evaluation Metrics

$(0, 0)$, *leftonto(leftonto((0, 0)))*



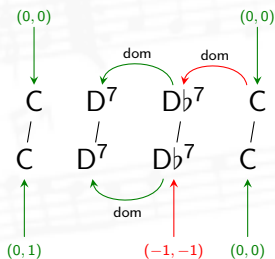
Dependency recovery
(DR)



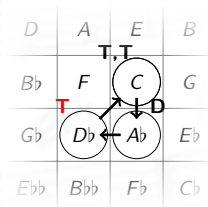
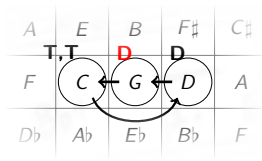
Tonal space edit distance
(TSED)

Evaluation Metrics

$(0, 0)$, $leftonto(leftonto((0, 0)))$



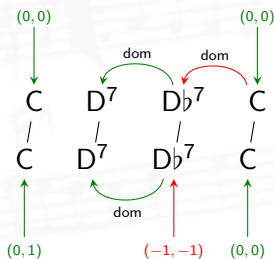
Dependency recovery
(DR)



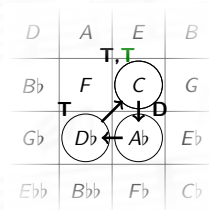
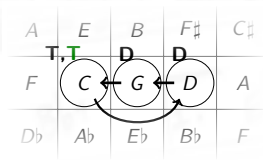
Tonal space edit distance
(TSED)

Evaluation Metrics

$(0, 0)$, $leftonto(leftonto((0, 0)))$



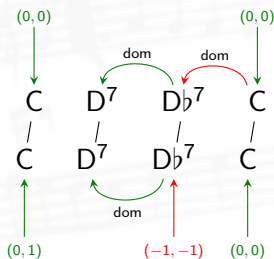
Dependency recovery
(DR)



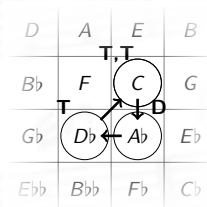
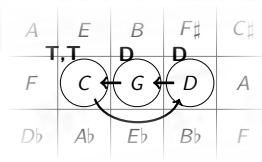
Tonal space edit distance
(TSED)

Evaluation Metrics

$(0, 0)$, *leftonto(leftonto((0, 0)))*



*Dependency recovery
(DR)*



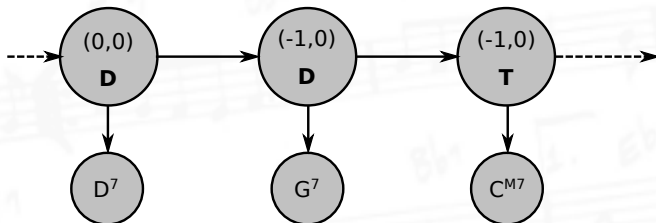
*Tonal space edit distance
(TSED)*

Baseline: HMMPATH

Construct path directly

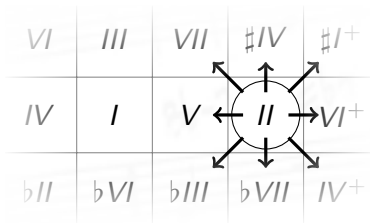
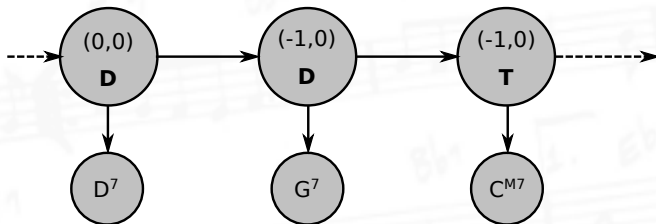
Baseline: HMMPATH

Construct path directly



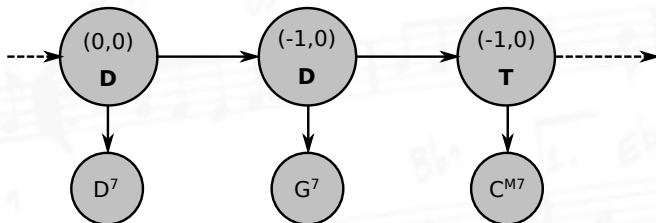
Baseline: HMMPATH

Construct path directly



Baseline: HMMPATH

Construct path directly



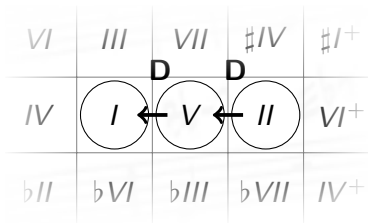
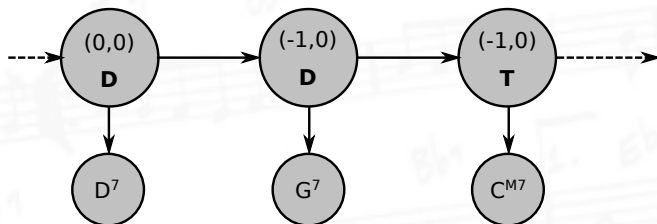
<i>VI</i>	<i>III</i>	<i>VII</i>	<i>#IV</i>	<i>#I⁺</i>
<i>IV</i>	<i>I</i>	<i>V</i>	<i>II</i>	<i>VI⁺</i>
<i>bII</i>	<i>bVI</i>	<i>bIII</i>	<i>bVII</i>	<i>IV⁺</i>

D

←

Baseline: HMMPATH

Construct path directly



Results: DR

Dependency recovery

<i>Model</i>	<i>P</i>	<i>R</i>	<i>F</i>	<i>Cov.</i>
PCCG	85.61	86.68	86.14	98.68
ST+PCCG	86.79	90.29	88.51	100

Results: TSED

Tonal space edit distance

<i>Model</i>	<i>P</i>	<i>R</i>	<i>F</i>	<i>Cov.</i>
HMMPATH	80.28	87.16	83.58	100
PCCG	86.84	89.52	88.16	98.68
ST+PCCG	88.87	92.25	90.67	100

Parsing Notes

- We can parse chord sequences

G C G C G D⁷ G

- Can we parse music?

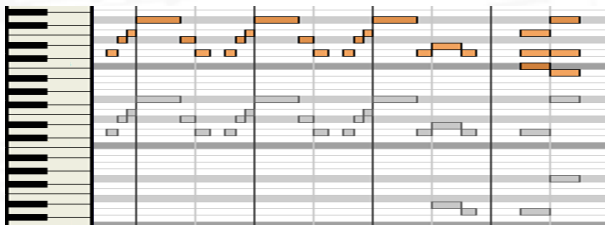
- Harder task
- Potentially more useful

Parsing Notes

- We can parse chord sequences

G C G C G D⁷ G

- Can we parse music?



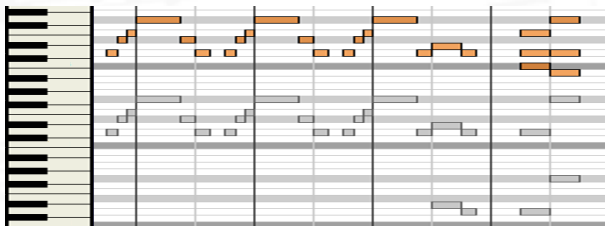
- Harder task
- Potentially more useful

Parsing Notes

- We can parse chord sequences

G C G C G D⁷ G

- Can we parse music?



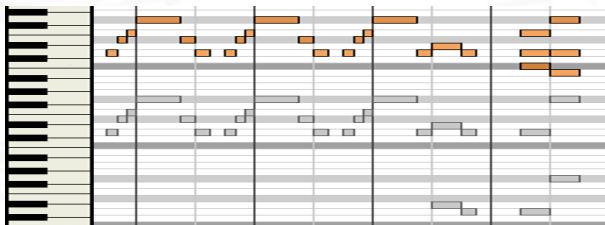
- Harder task
- Potentially more useful

Parsing Notes

- We can parse chord sequences

G C G C G D⁷ G

- Can we parse music?



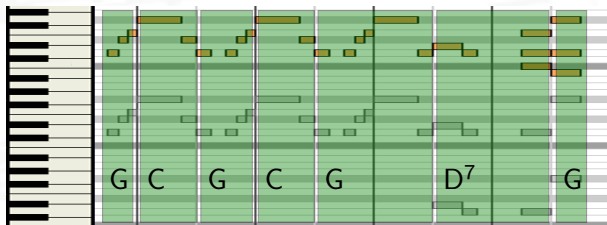
- Harder task
- Potentially more useful

Parsing Notes

- We can parse chord sequences

G C G C G D⁷ G

- Can we parse music?



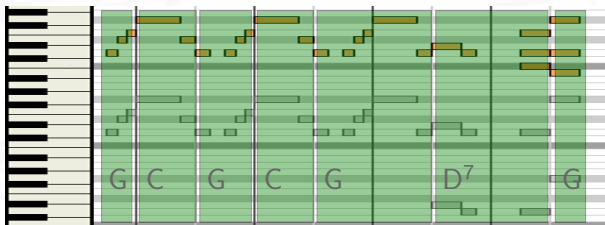
- Harder task
- Potentially more useful

Parsing Notes

- We can parse chord sequences

G C G C G D⁷ G

- Can we parse music?

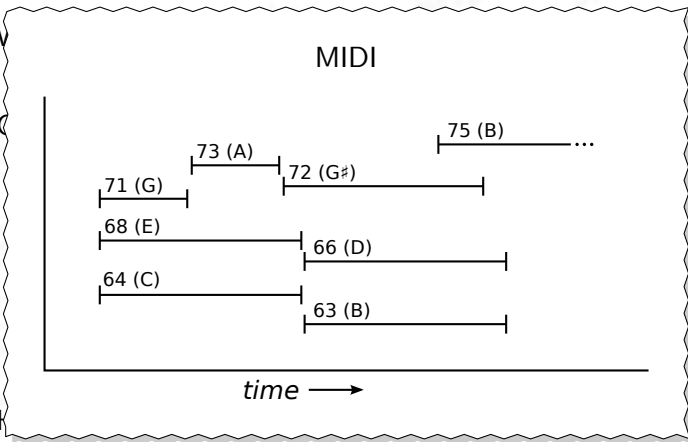


- Harder task
- Potentially more useful

Parsing Notes

-

-

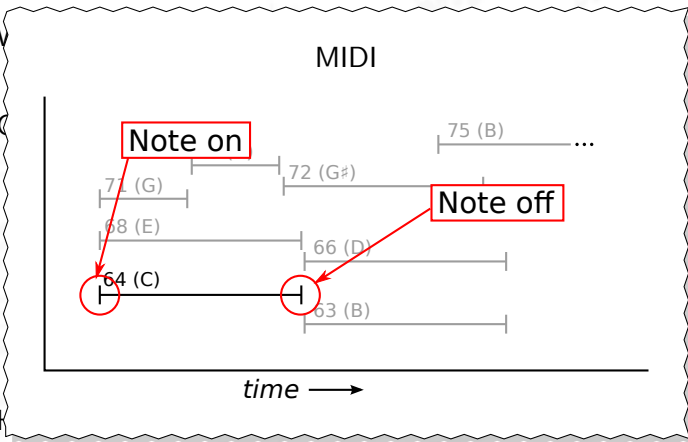


-

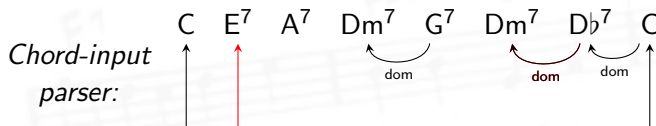
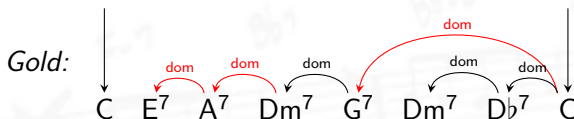
- Potentially more useful

Parsing Notes

- V
- C
- K
- Potentially more useful

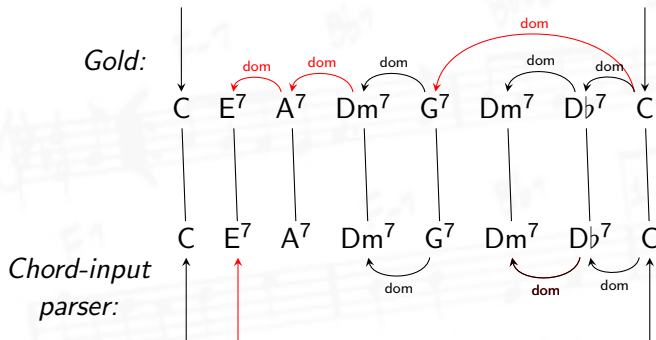


Parser Evaluation Metric



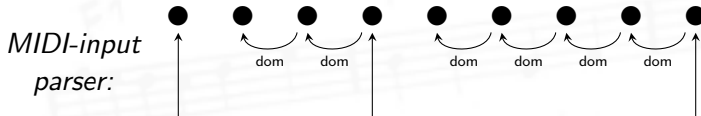
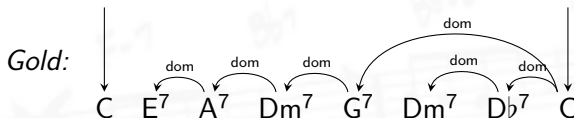
- System performs segmentation
- *Optimized* dependency recovery (ODR)

Parser Evaluation Metric



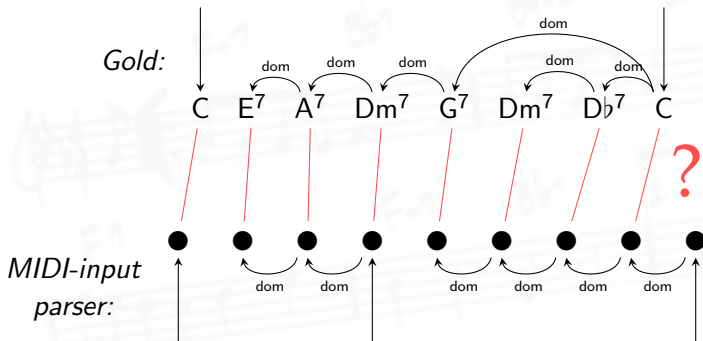
- System performs segmentation
- *Optimized* dependency recovery (ODR)

Parser Evaluation Metric



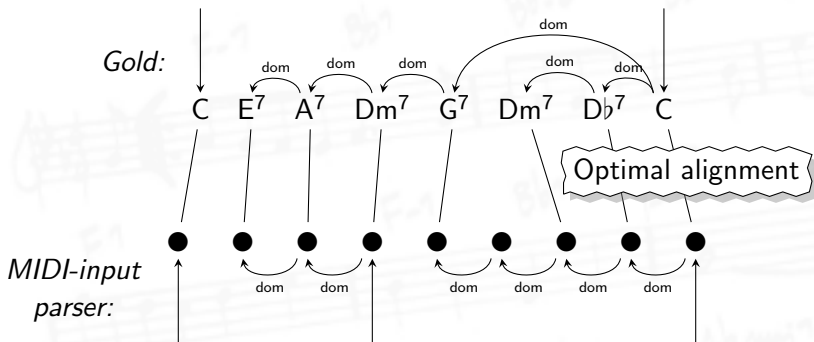
- System performs segmentation
- *Optimized dependency recovery (ODR)*

Parser Evaluation Metric



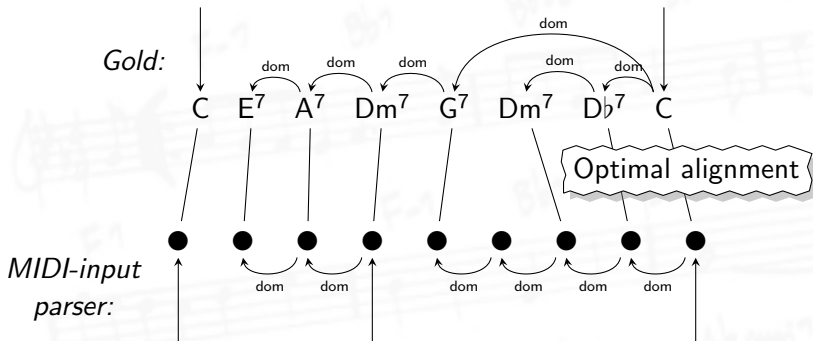
- System performs segmentation
- *Optimized dependency recovery (ODR)*

Parser Evaluation Metric



- System performs segmentation
- *Optimized dependency recovery (ODR)*

Parser Evaluation Metric



- System performs segmentation
- *Optimized* dependency recovery (ODR)

Metre

- Not modelling metre
- Barlines annotated

- These experiments: 41 MIDI files (~20 songs)

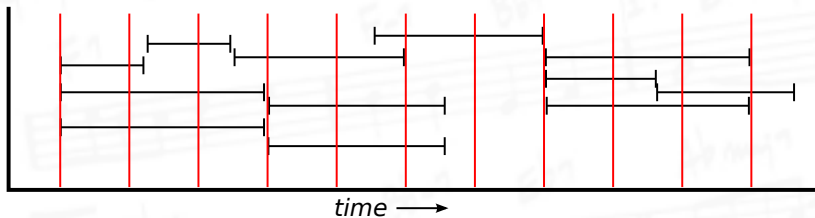
Metre

- Not modelling metre
- Barlines annotated

- These experiments: 41 MIDI files (~20 songs)

Metre

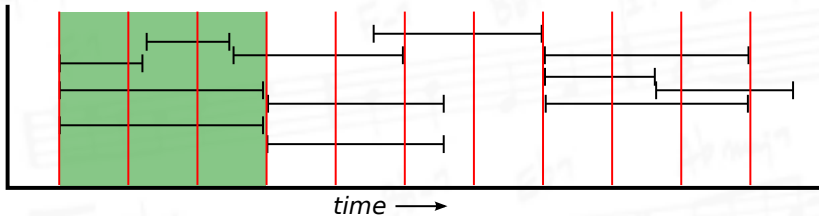
- Not modelling metre
- Barlines annotated



- These experiments: 41 MIDI files (~20 songs)

Metre

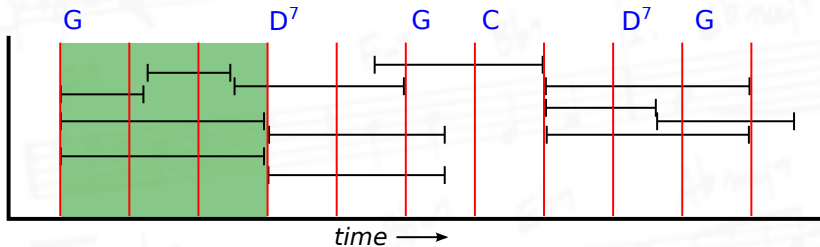
- Not modelling metre
- Barlines annotated



- These experiments: 41 MIDI files (~20 songs)

Metre

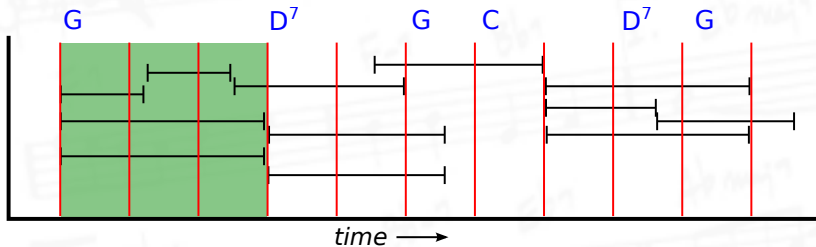
- Not modelling metre
- Barlines annotated



- These experiments: 41 MIDI files (~20 songs)

Metre

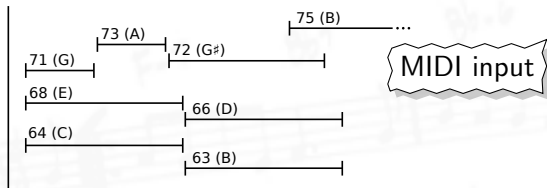
- Not modelling metre
- Barlines annotated



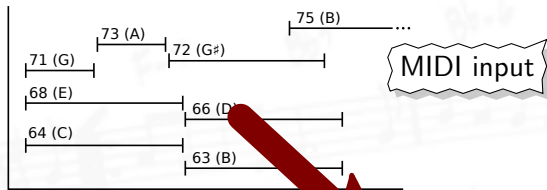
- These experiments: 41 MIDI files (~20 songs)

MIDI Parsing 1

MIDI Parsing 1

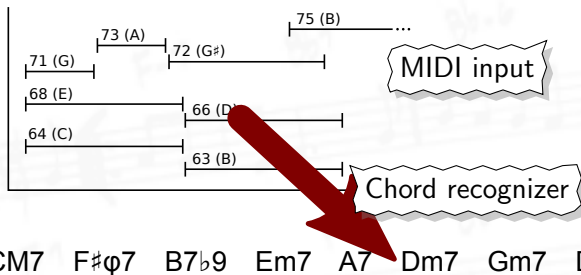


MIDI Parsing 1

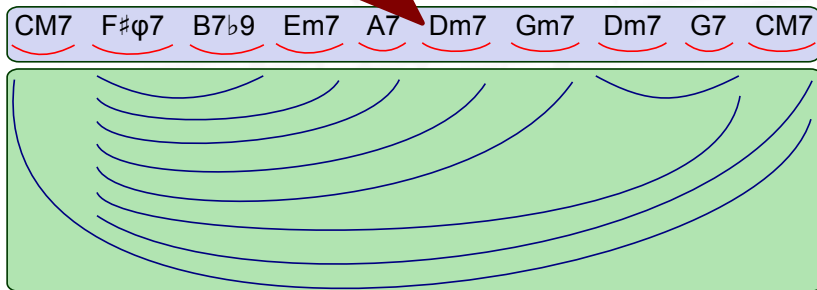
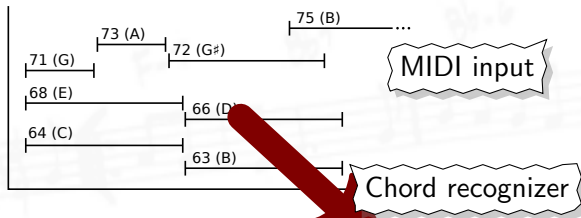


CM7 F# ϕ 7 B7 $\flat$ 9 Em7 A7 Dm7 Gm7 Dm7 G7 CM7

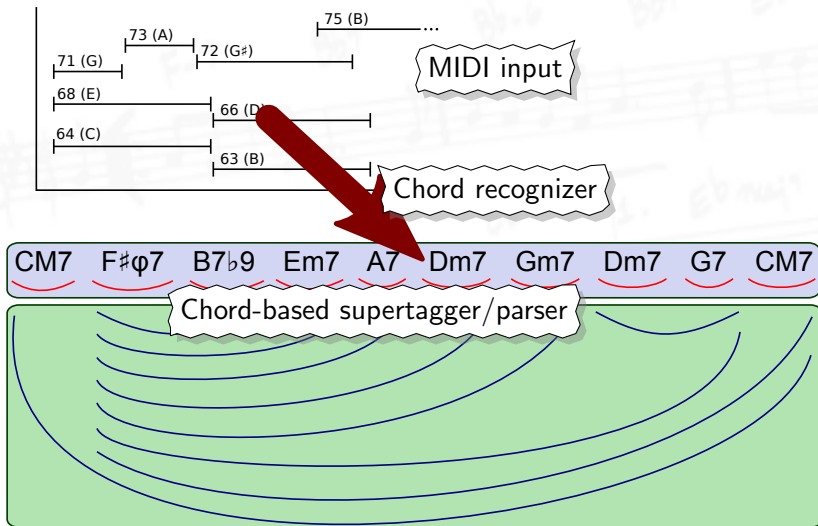
MIDI Parsing 1



MIDI Parsing 1



MIDI Parsing 1



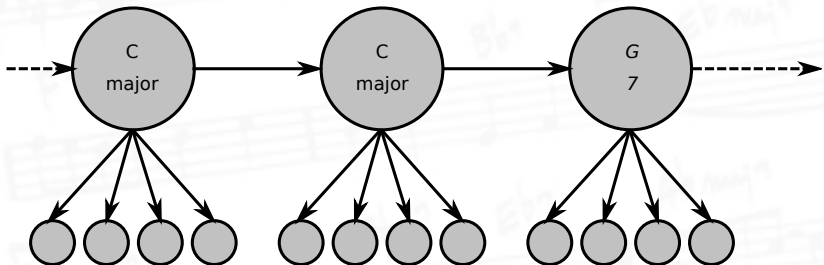
Chord Recognition Model

- Adaptation of audio chord recognition model: Ni et al. (2011)²
- HMM
- Train using EM

²Harmony Progression analyzer for Mirex 2011

Chord Recognition Model

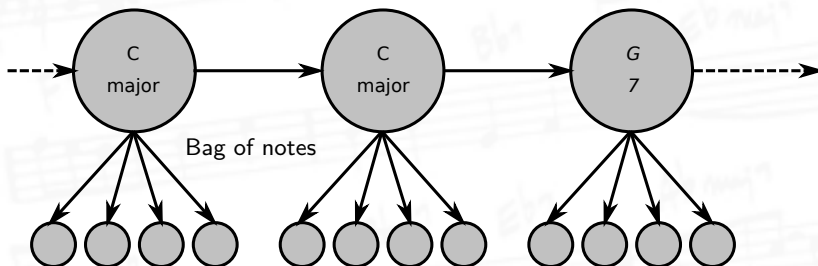
- Adaptation of audio chord recognition model: Ni et al. (2011)²
- HMM
- Train using EM



²Harmony Progression analyzer for Mirex 2011

Chord Recognition Model

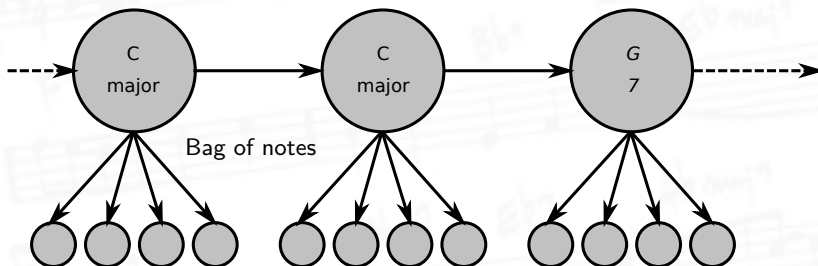
- Adaptation of audio chord recognition model: Ni et al. (2011)²
- HMM
- Train using EM



²Harmony Progression analyzer for Mirex 2011

Chord Recognition Model

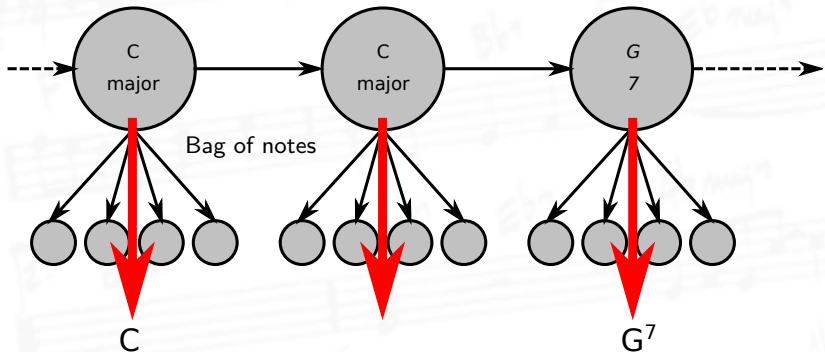
- Adaptation of audio chord recognition model: Ni et al. (2011)²
- HMM
- Train using EM



²Harmony Progression analyzer for Mirex 2011

Chord Recognition Model

- Adaptation of audio chord recognition model: Ni et al. (2011)²
- HMM
- Train using EM



²Harmony Progression analyzer for Mirex 2011

MIDI Parsing 1: Results

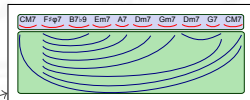
Optimized dependency recovery

	P (%)	R (%)	F (%)	Cov (%)
Chord parser (DR)	79.99	78.25	79.11	96.05
Chord parser (ODR)	83.46	81.63	82.53	96.05
MIDI pipeline	63.80	50.33	56.27	78.05

- Previous results with new metric
- Ceiling for MIDI-input parsers
- Pipeline: low coverage

MIDI Parsing 1: Results

Optimized dependency recovery

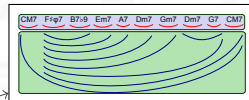


	P (%)	R (%)	F (%)	Cov (%)
Chord parser (DR)	79.99	78.25	79.11	96.05
Chord parser (ODR)	83.46	81.63	82.53	96.05
MIDI pipeline	63.80	50.33	56.27	78.05

- Previous results with new metric
- Ceiling for MIDI-input parsers
- Pipeline: low coverage

MIDI Parsing 1: Results

Optimized dependency recovery



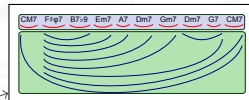
	P (%)	R (%)	F (%)	Cov (%)
Chord parser (DR)	79.99	78.25	79.11	96.05
Chord parser (ODR)	83.46	81.63	82.53	96.05
MIDI pipeline	63.80	50.33	56.27	78.05

- Previous results with new metric
- Ceiling for MIDI-input parsers
- Pipeline: low coverage

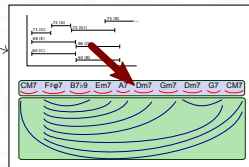
MIDI Parsing 1: Results

Optimized dependency recovery

	P (%)	R (%)	F (%)	Cov (%)
Chord parser (DR)	79.99	78.25	79.11	96.05
Chord parser (ODR)	83.46	81.63	82.53	96.05
MIDI pipeline	63.80	50.33	56.27	78.05



- Previous results with new metric
- Ceiling for MIDI-input parsers
- Pipeline: low coverage



MIDI Parsing 1: Results

Optimized dependency recovery

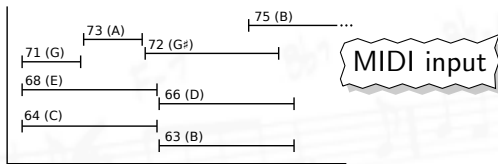
	P (%)	R (%)	F (%)	Cov (%)
Chord parser (DR)	79.99	78.25	79.11	96.05
Chord parser (ODR)	83.46	81.63	82.53	96.05
MIDI pipeline	63.80	50.33	56.27	78.05

- Previous results with new metric
- Ceiling for MIDI-input parsers
- Pipeline: low coverage

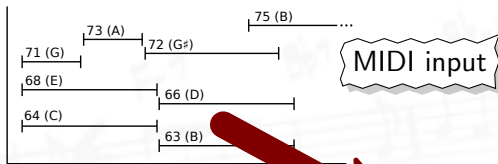
MIDI Parsing 2



MIDI Parsing 2

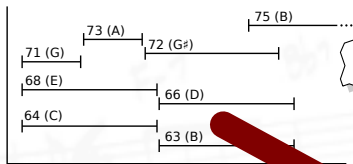


MIDI Parsing 2



CM7	F# ϕ 7	B ^{7b9}	Em7	F#m7	Dm7	Gm7	Dm7	G7	CM7
Em	Am	Co7	G7	F#m7	Am	Do7	F6	B ϕ 7	Am7
⋮	⋮	⋮	⋮	⋮	⋮	⋮	⋮	⋮	⋮

MIDI Parsing 2

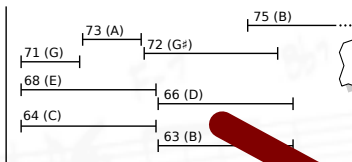


MIDI input

Chord recognizer: lattice

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

MIDI Parsing 2

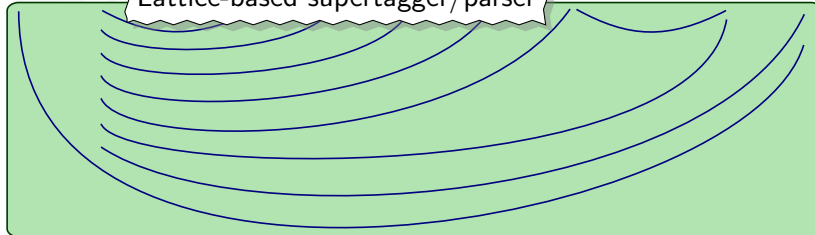


MIDI input

Chord recognizer: lattice

CM7	F# ϕ 7	B ^{7b9}	Em7	F#m7	Am	Do7	F6	B ϕ 7	Am7
Em	Am	Co7	G7	F#m7	Am	Do7	F6	B ϕ 7	Am7
⋮	⋮	⋮	⋮	⋮	⋮	⋮	⋮	⋮	⋮

Lattice-based supertagger/parser



MIDI Parsing 2: Results

Optimized dependency recovery

	P (%)	R (%)	F (%)	Coverage (%)
Chord-input parser	83.46	81.63	82.53	96.05
MIDI pipeline	63.80	50.33	56.27	78.05
MIDI lattice	69.94	54.30	61.14	92.68

- Lattice improves parser's coverage
- Still a long way off chord parser

MIDI Parsing 2: Results

Optimized dependency recovery

	P (%)	R (%)	F (%)	Coverage (%)
Chord-input parser	83.46	81.63	82.53	96.05
MIDI pipeline	63.80	50.33	56.27	78.05
MIDI lattice	69.94	54.30	61.14	92.68

- Lattice improves parser's coverage
- Still a long way off chord parser

MIDI Parsing 2: Results

Optimized dependency recovery

	P (%)	R (%)	F (%)	Coverage (%)
Chord-input parser	83.46	81.63	82.53	96.05
MIDI pipeline	63.80	50.33	56.27	78.05
MIDI lattice	69.94	54.30	61.14	92.68

- Lattice improves parser's coverage
- Still a long way off chord parser

Conclusion

- CCG for harmony
 - Tonal space for harmonic analysis
 - Harmonic analysis by parsing
 - Statistical parsing models
 - Jazz corpus
 - Parsing experiments
 - Simple MIDI parsing
 - MIDI parsing experiments

Conclusion

- CCG for harmony
- Tonal space for harmonic analysis
 - Harmonic analysis by parsing
 - Statistical parsing models
 - Jazz corpus
 - Parsing experiments
 - Simple MIDI parsing
 - MIDI parsing experiments

Conclusion

- CCG for harmony
- Tonal space for harmonic analysis
- Harmonic analysis by parsing
 - Statistical parsing models
 - Jazz corpus
 - Parsing experiments
 - Simple MIDI parsing
 - MIDI parsing experiments

Conclusion

- CCG for harmony
- Tonal space for harmonic analysis
- Harmonic analysis by parsing
- Statistical parsing models
- Jazz corpus
- Parsing experiments
- Simple MIDI parsing
- MIDI parsing experiments

Conclusion

- CCG for harmony
- Tonal space for harmonic analysis
- Harmonic analysis by parsing
- Statistical parsing models
- Jazz corpus
- Parsing experiments
- Simple MIDI parsing
- MIDI parsing experiments

Conclusion

- CCG for harmony
- Tonal space for harmonic analysis
- Harmonic analysis by parsing
- Statistical parsing models
- Jazz corpus
- Parsing experiments
 - Simple MIDI parsing
 - MIDI parsing experiments

Conclusion

- CCG for harmony
- Tonal space for harmonic analysis
- Harmonic analysis by parsing
- Statistical parsing models
- Jazz corpus
- Parsing experiments
- Simple MIDI parsing pipeline, lattice
- MIDI parsing experiments

Conclusion

- CCG for harmony
- Tonal space for harmonic analysis
- Harmonic analysis by parsing
- Statistical parsing models
- Jazz corpus
- Parsing experiments
- Simple MIDI parsing: pipeline, lattice
- MIDI parsing experiments

Conclusion

- CCG for harmony
- Tonal space for harmonic analysis
- Harmonic analysis by parsing
- Statistical parsing models
- Jazz corpus
- Parsing experiments
- Simple MIDI parsing: pipeline, lattice
- MIDI parsing experiments

Conclusion

- CCG for harmony
- Tonal space for harmonic analysis
- Harmonic analysis by parsing
- Statistical parsing models
- Jazz corpus
- Parsing experiments
- Simple MIDI parsing: pipeline, lattice
- MIDI parsing experiments

Future Work

- Full MIDI supertagging model
 - Metrical models
 - Better models of note data
 - Extend corpus: test set, more annotators
 - Evaluate annotator agreement
 - Other domains
 - Apply to music processing tasks

Future Work

- Full MIDI supertagging model
- Metrical models
 - Better models of note data
 - Extend corpus: test set, more annotators
 - Evaluate annotator agreement
 - Other domains
 - Apply to music processing tasks

Future Work

- Full MIDI supertagging model
- Metrical models
- Better models of note data
 - Extend corpus: test set, more annotators
 - Evaluate annotator agreement
 - Other domains
 - Apply to music processing tasks

Future Work

- Full MIDI supertagging model
- Metrical models
- Better models of note data
- Extend corpus: test set, more annotators
 - Evaluate annotator agreement
 - Other domains
 - Apply to music processing tasks

Future Work

- Full MIDI supertagging model
- Metrical models
- Better models of note data
- Extend corpus: test set, more annotators
- Evaluate annotator agreement
- Other domains
- Apply to music processing tasks

Future Work

- Full MIDI supertagging model
- Metrical models
- Better models of note data
- Extend corpus: test set, more annotators
- Evaluate annotator agreement
- Other domains
- Apply to music processing tasks

Future Work

- Full MIDI supertagging model
- Metrical models
- Better models of note data
- Extend corpus: test set, more annotators
- Evaluate annotator agreement
- Other domains
- Apply to music processing tasks

Thesis Timeline

Rest of Aug	Rerun experiments, update results and discussion
1st – 9th Sept	Write lit review, prepare for ICMC
9th – 14th Sept	ICMC
14th – 29th Sept	Finish writing
30th Sept	Submit

(Optimistic) Thesis Timeline

Rest of Aug	Rerun experiments, update results and discussion
1st – 9th Sept	Write lit review, prepare for ICMC
9th – 14th Sept	ICMC
14th – 29th Sept	Finish writing
30th Sept	Submit

(Optimistic) Thesis Timeline

Rest of Aug	Rerun experiments, update results and discussion
1st – 9th Sept	Write lit review, prepare for ICMC
9th – 14th Sept	ICMC
14th – 29th Sept	Finish writing
30th Sept	Submit

Bibliography

- Hockenmaier, J., & Steedman, M. (2002). Generative models for statistical parsing with Combinatory Categorical Grammar. In *Proceedings of the 40th Meeting of the ACL*, (pp. 335–342). Philadelphia, PA.
- Ni, Y., Mcvillar, M., Santos-rodriguez, R., & Bie, T. D. (2011). Harmony progression analyzer for mirex 2011. In *Proceedings of the 12th International Society for Music Information Retrieval (MIREX)*, (pp. 1–4).

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

Extra Slides

Tonal Space

Roman Tonal Space