

Advanced Course Computer Science

Music Processing

Summer Term 2010

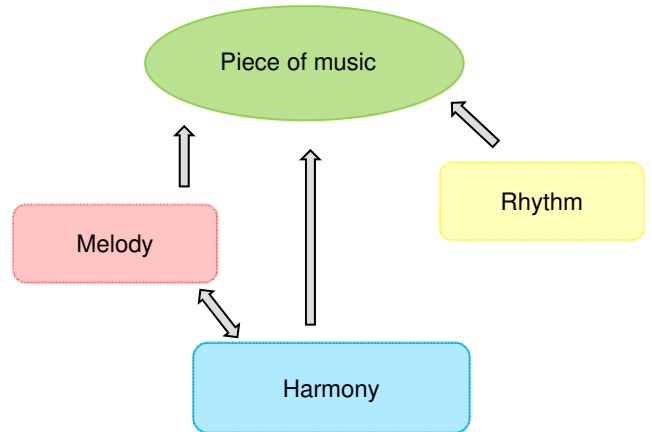
Meinard Müller, Verena Konz

Saarland University and MPI Informatik
meinard@mpi-inf.mpg.de

Chord Recognition



Aspects of Music



Harmony: The Basis of Music

Pachelbel's Canon



Coversong *Die Eine (Die Firma)*



Musical Chords

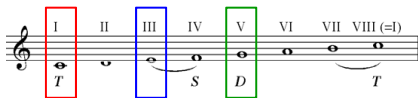
- Combination of three or more tones which sound simultaneously
- Chord classes
 - Triads including major, minor, diminished, augmented chords
 - many other more complex chords such as seventh chords
- Here: focus on major and minor triads

Musical Chords

The C **major** chord



Derived from the C **major** scale



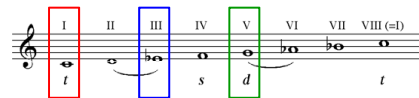
C ---- the **root**
E ---- the (**major**) **third**
G ---- the **fifth**

Musical Chords

The C **minor** chord



Derived from the C **minor** scale



C ---- the **root**
E_b ---- the (**minor**) **third**
G ---- the **fifth**

Structure of the 24 Major/Minor Chords



	0	1	2	3	4	5	6	7	8	9	10	11
	C	C#	D	D#	E	F	F#	G	G#	A	A#	B
C major	✓				✓			✓				
C minor	✓			✓				✓				



Chord Recognition

- Development of automatic methods for the harmonic analysis of audio data
- Applications in the field of music information retrieval:
 - music segmentation
 - cover song identification
 - audio matching
 - music structure analysis
 - ...

Chord Recognition

Given: Audio file

Output: Segmentation and chord labeling



Andantino Moderato
Johann Pachelbel
George Winston

Chord Templates

	C major	C# major	D major	D# major	.....	C minor	C# minor	.....
C	1	0	0	0	.....	1	0	.....
C#	0	1	0	0	.....	0	1	.....
D	0	0	1	0	.....	0	0	.....
D#	0	0	0	1	.....	1	0	.....
E	1	0	0	0	.....	0	1	.....
F	0	1	0	0	.....	0	0	.....
F#	0	0	1	0	.....	0	0	.....
G	1	0	0	1	.....	1	0	.....
G#	0	1	0	0	.....	0	1	.....
A	0	0	1	0	.....	0	0	.....
A#	0	0	0	1	.....	0	0	.....
B	0	0	0	0	.....	0	0	.....

Baseline Method for Chord Recognition

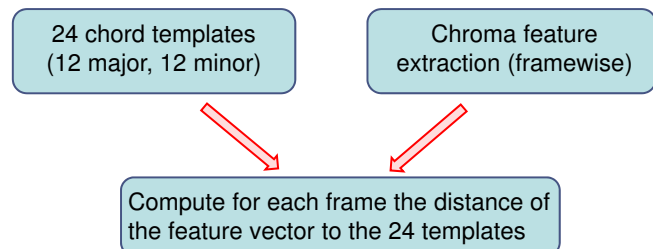
24 chord templates
(12 major, 12 minor)

Baseline Method for Chord Recognition

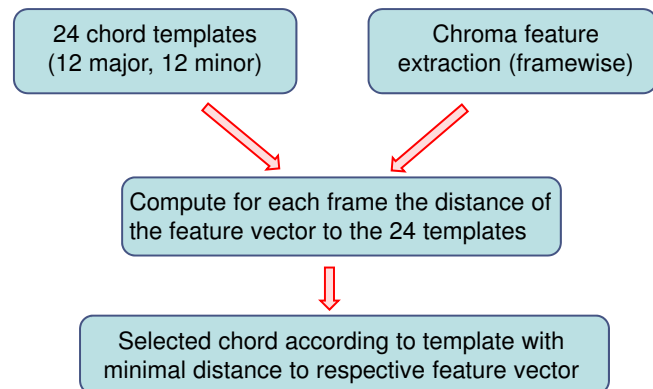
24 chord templates
(12 major, 12 minor)

Chroma feature
extraction (framewise)

Baseline Method for Chord Recognition

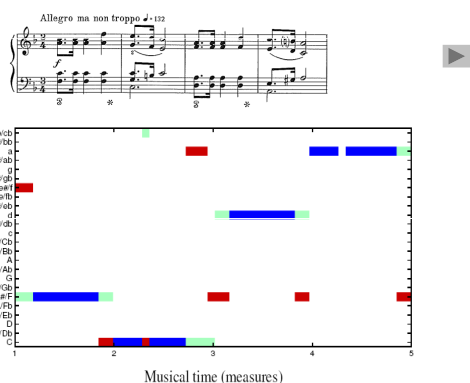


Baseline Method for Chord Recognition



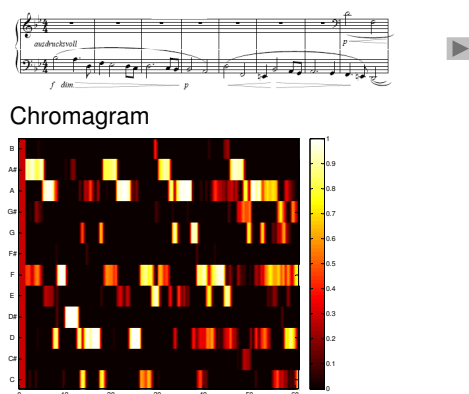
Problems in Chord Recognition

Example: Chopin Mazurka Op. 68 No.3



Problems in Chord Recognition

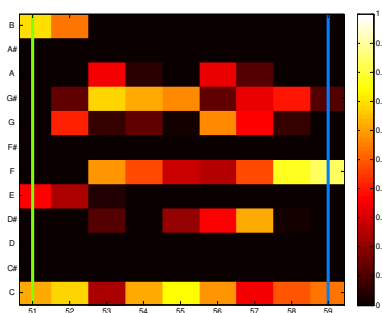
Example: Excerpt of Wagner's Meistersinger



Problems in Chord Recognition

Example: Beethoven's Appassionata (mm.16-19, f minor)

Chromagram



Problems in Chord Recognition

Problem: Frame-wise chord analysis may not be meaningful

Example: Bach: Prelude C major, BWV 846

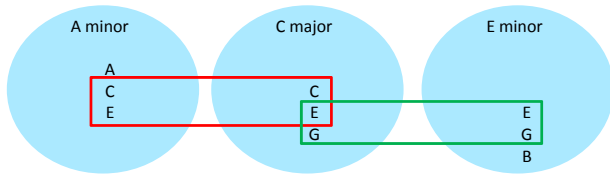


Problem: Broken chords

→ Measure-wise chord analysis necessary

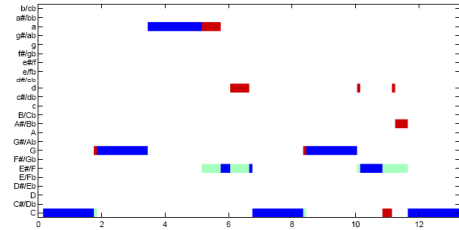
Problems in Chord Recognition

Problem: Ambiguity of chords



Problems in Chord Recognition

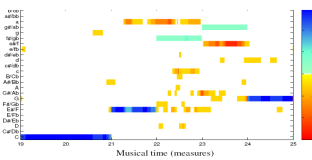
Example: The Beatles "Let it be"



Problems in Chord Recognition

Problem: Reduction to the 24 major/minor chords makes the recognition of more complex chords difficult/impossible!

Example: Prelude C major, BWV 846, mm.19-25

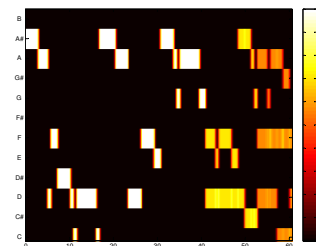


Importance of Tuning

Example: Excerpt of Wagner's Meistersinger



Chromagram (from MIDI)

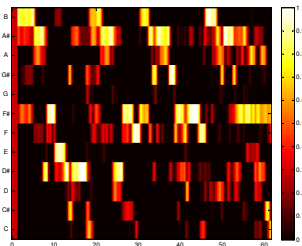


Importance of Tuning

Example: Excerpt of Wagner's Meistersinger



Chromagram (from audio)



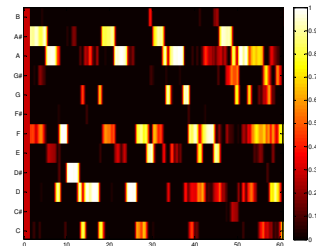
Problem: Audio is tuned more than half a semi-tone upwards

Importance of Tuning

Example: Excerpt of Wagner's Meistersinger



Chromagram (from audio)



Problem: Audio is tuned more than half a semi-tone upwards

Solution: Adjust frequency-chroma binning (e.g., by shifting filter bank)

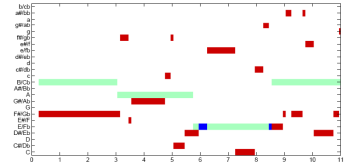
Importance of Tuning

- Dataset: 180 Beatles songs (manually annotated)
- Usage of 6 differently shifted pitch filter banks (fractional semitone shifts 0, 0.25, 0.33, 0.5, 0.67, 0.75) in combination with the 12 cyclic chroma shifts → 72 chroma feature versions
- Computation of chord labels for all 72 chroma versions using template-based chord recognizer
- Computation of F-measures for all 72 chroma versions
- Consider chroma version resulting in maximal F-measure

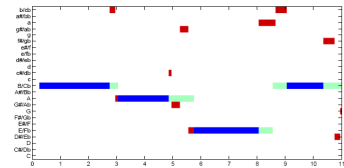
Importance of Tuning

Example: The Beatles "Lovely Rita" ▶

Without tuning



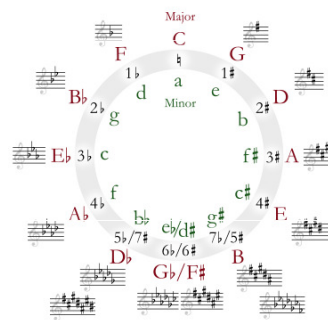
With tuning



Importance of Tuning

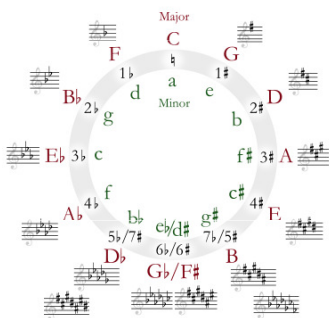
Song Title	Year	Tuning	F-measure (original)	F-measure (tuning)
Lovely Rita	1967	0.67	0.030	0.642
Strawberry Fields Forever	1967	0.25	0.519	0.547
Wild Honey Pie	1968	0.50	0.078	0.366
Ticket To Ride	1965	0.25	0.361	0.604
Another Girl	1965	0.67	0.181	0.446
Boys	1963	0.33	0.304	0.434
You've Got To Hide Your Love Away	1965	0.33	0.577	0.704
Do You Want To Know A Secret	1963	0.50	0.346	0.503
Average			0.300	0.531
Average for all 180 songs			0.526	0.559

Key Relations: Circle of Fifths



From http://en.wikipedia.org/wiki/Circle_of_fifths

Key Relations: Circle of Fifths

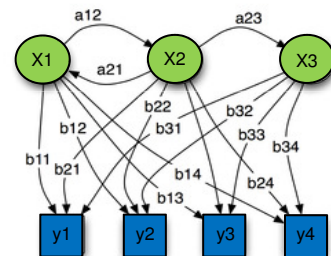


Observation:
For tonality reasons,
some chord progressions
are more likely than
others.

Idea:
Usage of Hidden Markov
Models (HMMs) to model
chord dependencies

From http://en.wikipedia.org/wiki/Circle_of_fifths

Hidden Markov Models



Model Parameters:
X: States
y: Possible observations
a: State transition probabilities
b: Output probabilities

Hidden Markov Models

Example: Weather

States Probability

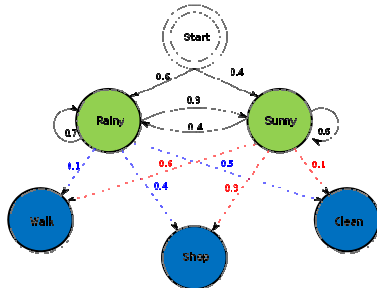
$P(\text{Rainy}) = 0.6$ $P(\text{Sunny}) = 0.4$

Transition Probability

	Rainy	Sunny
Rainy	0.7	0.3
Sunny	0.6	0.4

Observation Probability

	Walk	Shop	Clean
Rainy	0.1	0.4	0.5
Sunny	0.5	0.3	0.1



Hidden Markov Models

Example: Chords

States Probabilities

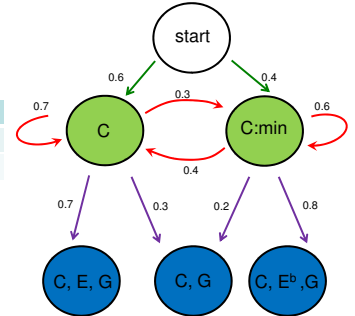
$P(C) = 0.6$ $P(C:\text{min}) = 0.4$

Transition Probabilities

	C	C:min
C	0.7	0.3
C:min	0.4	0.6

Observation Probabilities

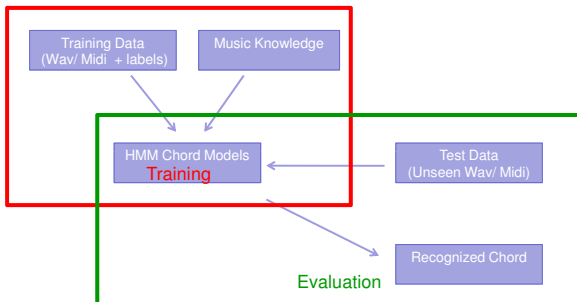
	C E G	C G	C E ^b G
C	0.7	0.3	0
C:min	0	0.2	0.8



Hidden Markov Models

Two computational problems

1. Training: set model parameters (Forward-Backward Algorithm)
2. Evaluation: find optimal state sequence (Viterbi Algorithm)



Multi-Perspective Evaluation

- For automatically evaluating chord recognizers one needs chord-labeled ground truth data
- MIR researcher often need ground truth labels for audio data → time-consuming task
- Musicians usually annotate chords on the basis of a musical score (not audio data)

Multi-Perspective Evaluation

Given:

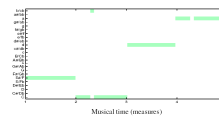
- Chord labels for a musical score
- Uninterpreted MIDI file representing the score
- Computed chord-labels for an audio recording

Strategy

- Synchronize the MIDI file with the audio recording
- Transfer the computed audio chord-labels to the MIDI time-axis (measure-axis) by using the synchronization result

Multi-Perspective Evaluation

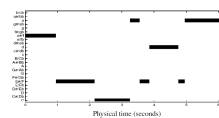
Score-based groundtruth chord-labels



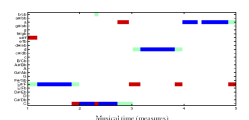
Chopin Mazurka Op. 68 No. 3 (mm.1-4)



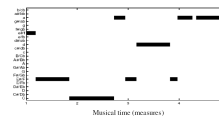
Audio chord-labels



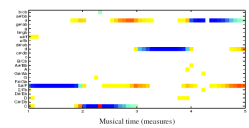
Overlaid score and audio chord labels



Warped audio chord-labels



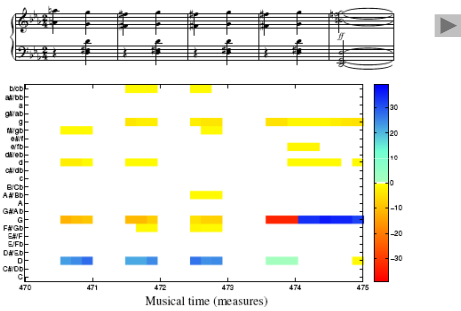
Multi-perspective overlay of score and audio chord labels



Multi-Perspective Evaluation

Example: Beethoven's Fifth (mm.470-475)

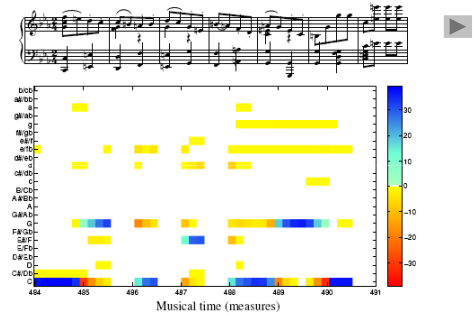
Joint chord recognition result (37 different performances)



Multi-Perspective Evaluation

Example: Beethoven's Fifth (mm.484-491)

Joint chord recognition result (37 different performances)



Multi-Perspective Evaluation

Summary

- Bridges the gap between musicians and MIR researchers
- Allows for an in-depth error analysis on a musically meaningful time-axis (given in measures or beats)
- Allows for comparing chord labeling procedures across different domains and different performances