INTERNATIONAL AUDIO LABORATORIES ERLANGEN

AUDIO LABS

ISMIR 2019

Tutorial T1
Fundamentals of Music Processing:
An Introduction using Python and Jupyter Notebooks

Audio Structure Analysis

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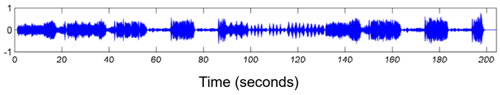
Fraunhofer IIS

Music Structure Analysis

Example: Brahms Hungarian Dance No. 5 (Ormandy)



Music Structure Analysis

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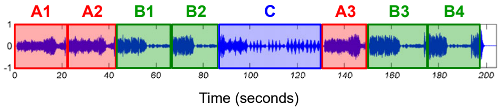


Music Structure Analysis

General goal: Divide an audio recording into temporal segments corresponding to musical parts and group these segments into musically meaningful categories.

Examples:

- Stanzas of a folk song
- Intro, verse, chorus, bridge, outro sections of a pop song
- Exposition, development, recapitulation, coda of a sonata
- Musical form ABACADA … of a rondo

Music Structure Analysis

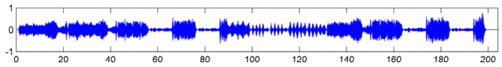
General goal: Divide an audio recording into temporal segments corresponding to musical parts and group these segments into musically meaningful categories.

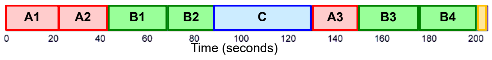
Challenge: There are many different principles for creating relationships that form the basis for the musical structure.

- Homogeneity: Consistency in tempo, instrumentation, key, …
- Novelty: Sudden changes, surprising elements …
- Repetition: Repeating themes, motives, rhythmic patterns,…

Feature Representation

Example: Brahms Hungarian Dance No. 5 (Ormandy)





Feature Representation

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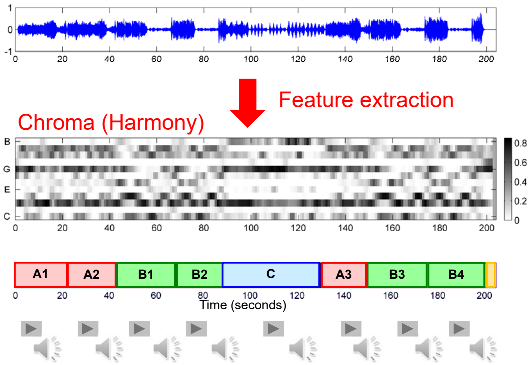

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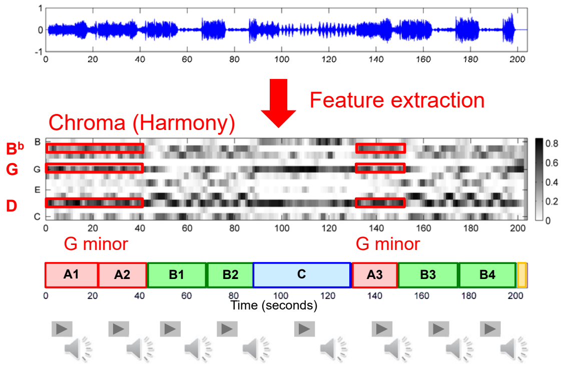

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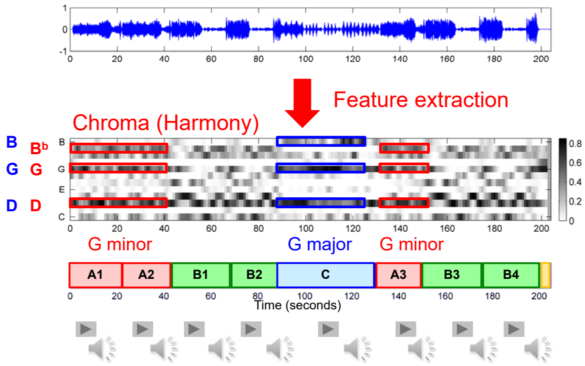

Self-Similarity Matrix (SSM)

General idea: Compare each element of the feature sequence with each other element of the feature sequence based on a suitable similarity measure.

→ Quadratic self-similarity matrix

Self-Similarity Matrix (SSM)

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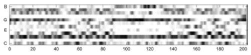
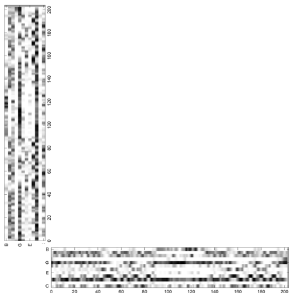


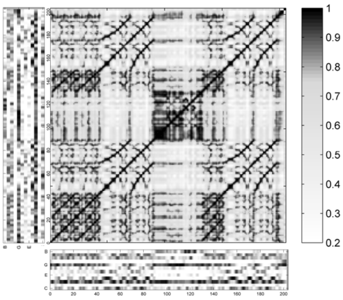
Self-Similarity Matrix (SSM)

Example: Brahms Hungarian Dance No. 5 (Ormandy)



Self-Similarity Matrix (SSM)

Example: Brahms Hungarian Dance No. 5 (Ormandy)



Self-Similarity Matrix (SSM)

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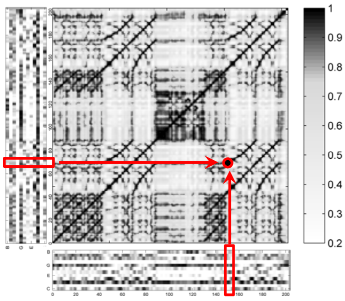

Self-Similarity Matrix (SSM)

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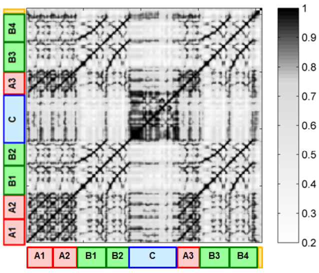

Self-Similarity Matrix (SSM)

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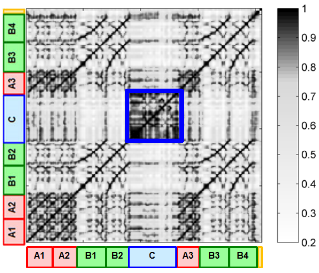

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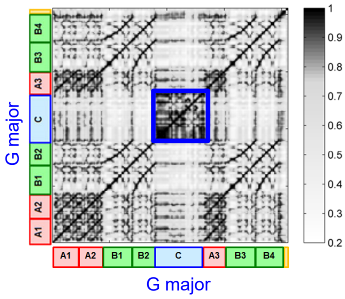

Self-Similarity Matrix (SSM)

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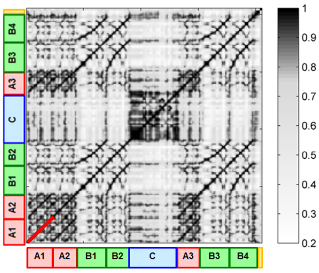

Self-Similarity Matrix (SSM)

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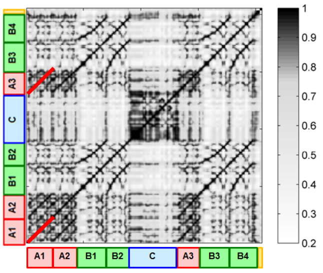

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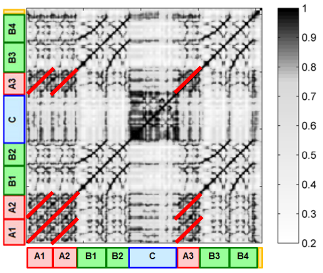

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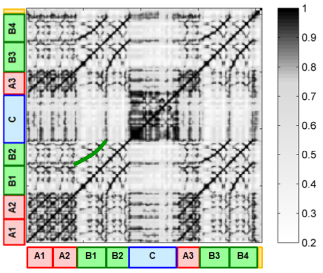

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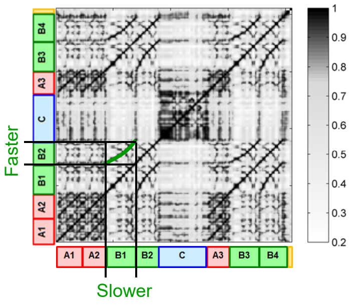

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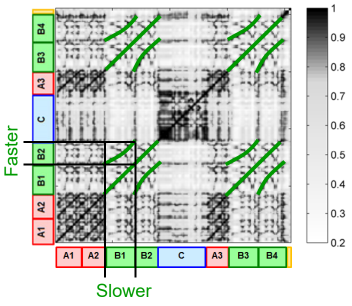

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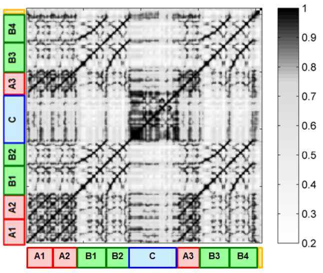
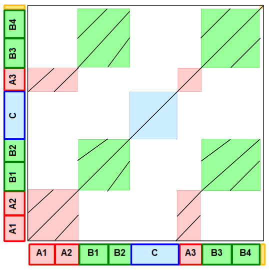


Idealized SSM



Self-Similarity Matrix (SSM)

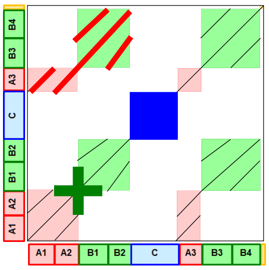
Example: Brahms Hungarian Dance No. 5 (Ormandy)

Idealized SSM

Blocks: Homogeneity

Paths: Repetition

Corners: Novelty



SSM Enhancement

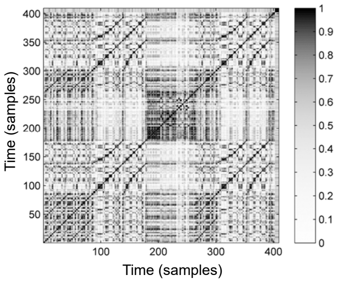
Challenge: Presence of musical variations

- Fragmented paths and gaps
- Paths of poor quality
- Regions of constant (low) cost
- Curved paths

Idea: Enhancement of path structure

SSM Enhancement

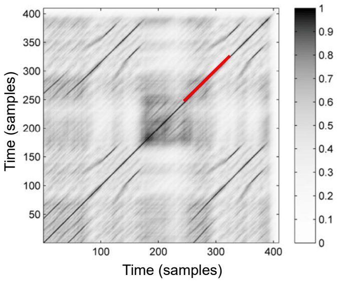
Path Enhancement



SSM Enhancement

Path Enhancement

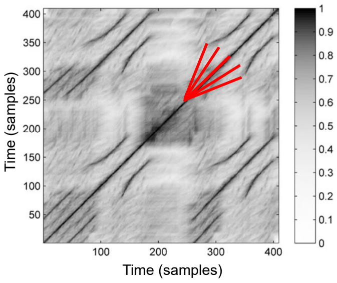
- Diagonal smoothing



SSM Enhancement

Path Enhancement

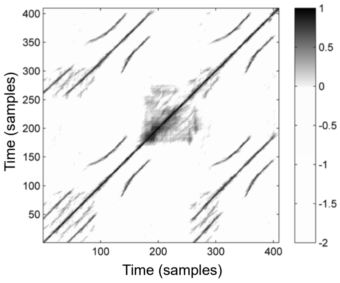
- Diagonal smoothing
- Multiple filtering



SSM Enhancement

Path Enhancement

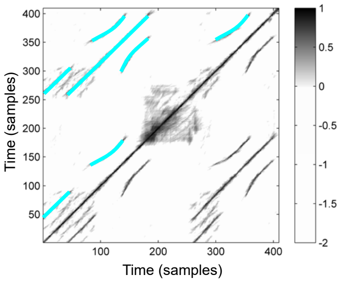
- Diagonal smoothing
- Multiple filtering
- Thresholding (relative)
- Scaling & penalty



SSM Enhancement

Further Processing

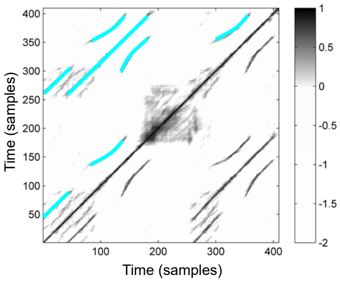
- Path extraction

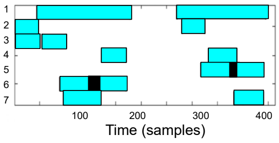


SSM Enhancement

Further Processing

- Path extraction
- Pairwise relations

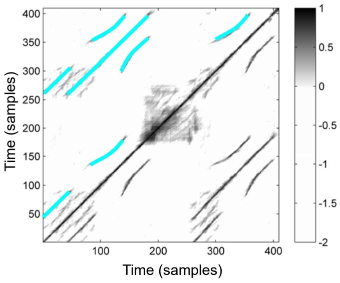


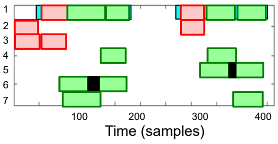


SSM Enhancement

Further Processing

- Path extraction
- Pairwise relations
- Grouping (transitivity)





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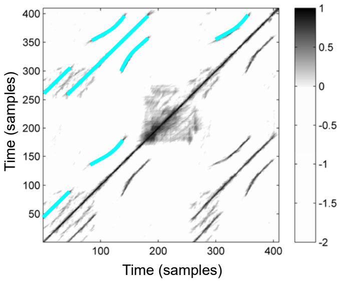
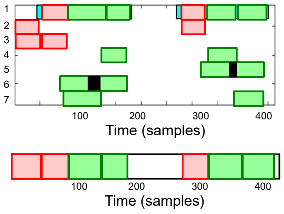




Novelty-Based Segmentation

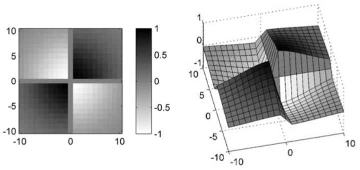
Novelty-Based Segmentation

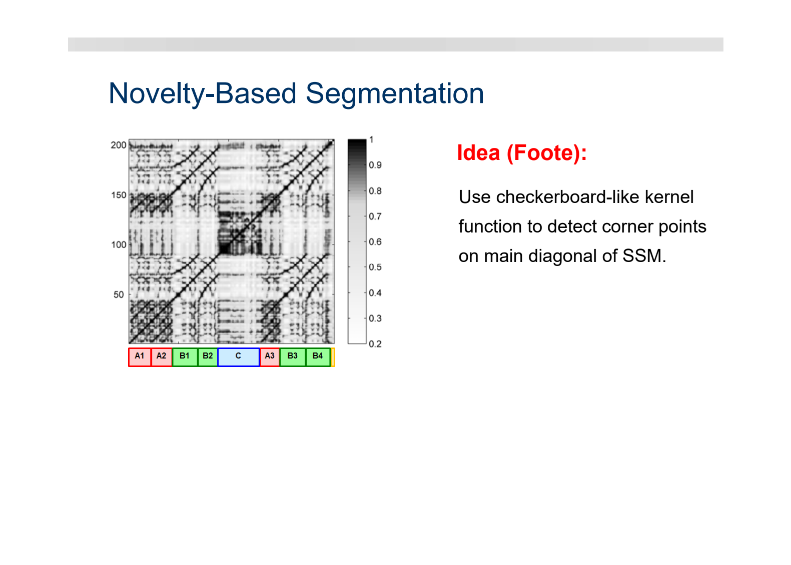
General goals:

- Find instances where musical changes occur.
- Find transition between subsequent musical parts.

Idea (Foote):

Use checkerboard-like kernel function to detect corner points on main diagonal of SSM.





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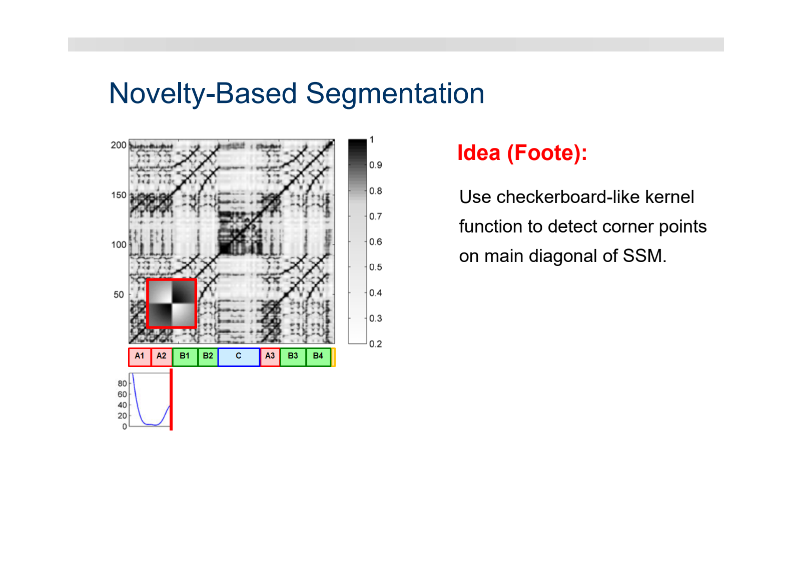

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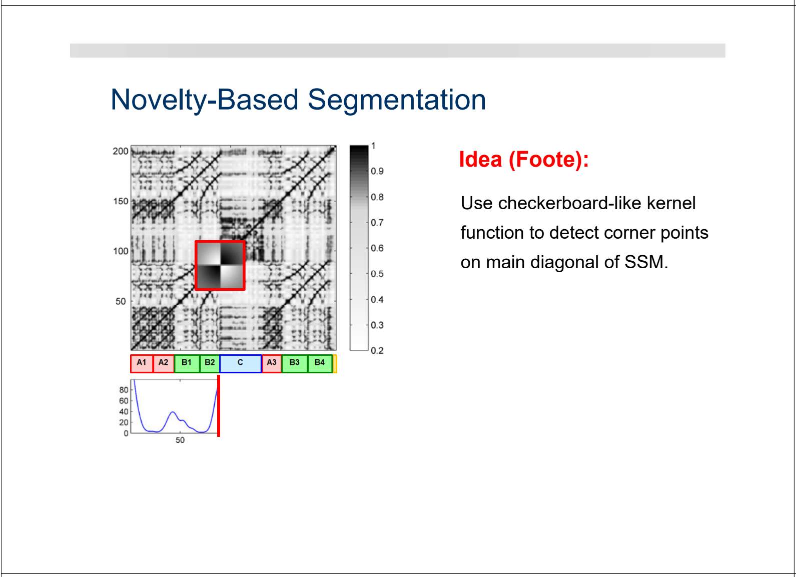

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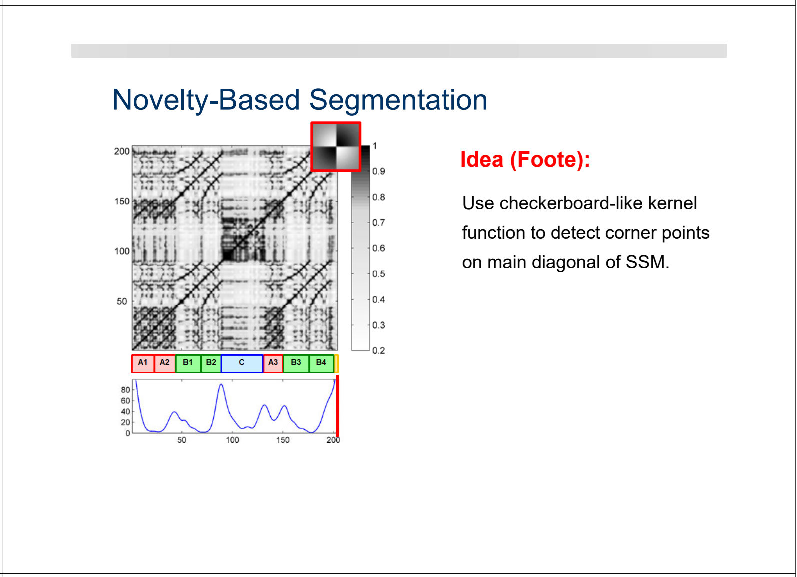

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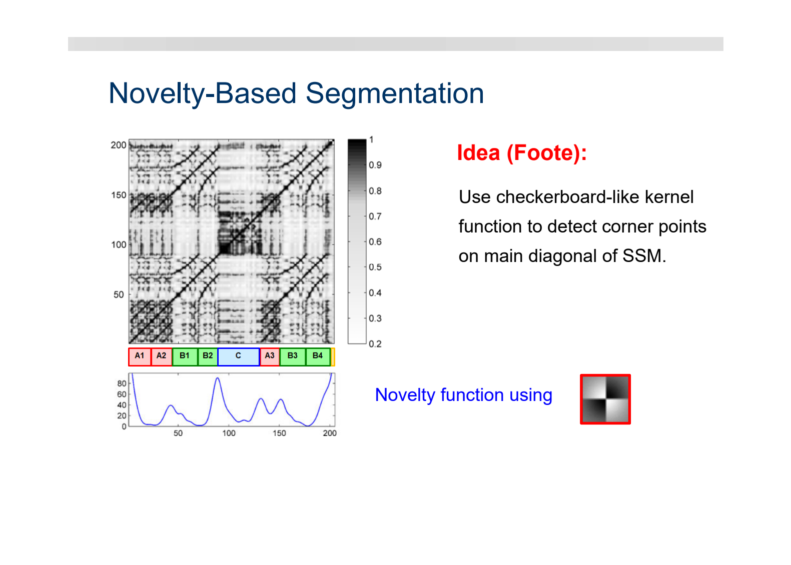
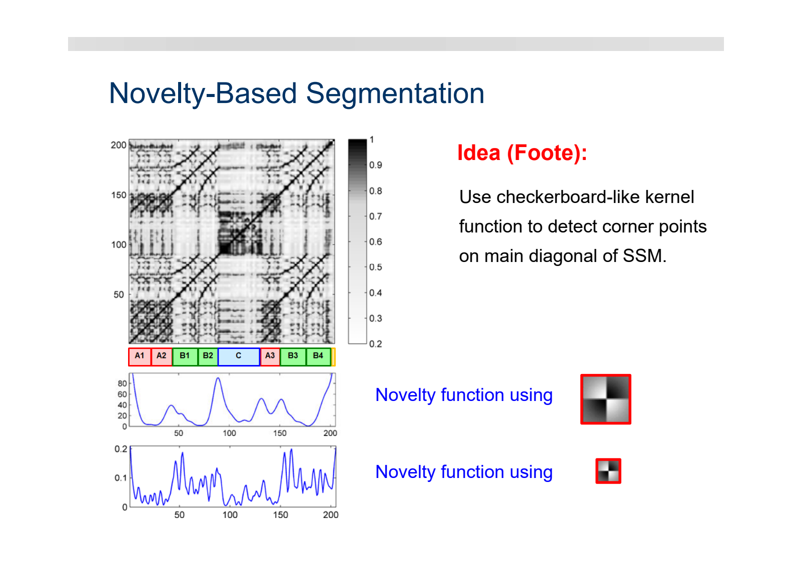


Novelty-Based Segmentation

Idea (Foote):

Use checkerboard-like kernel function to detect corner points on main diagonal of SSM.

Novelty function using



Novelty-Based Segmentation

Idea (Foote):

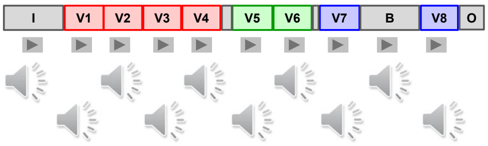
Use checkerboard-like kernel function to detect corner points on main diagonal of SSM.

Novelty function using

Novelty function using

SSM Enhancement

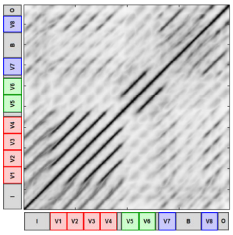
Example: Zager & Evans “In The Year 2525”



SSM Enhancement

Example: Zager & Evans “In The Year 2525”

Missing relations because of transposed sections

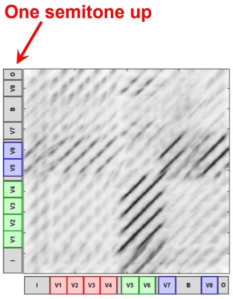


SSM Enhancement

Example: Zager & Evans “In The Year 2525”

Idea: Cyclic shift of one of the chroma sequences

One semitone up



SSM Enhancement

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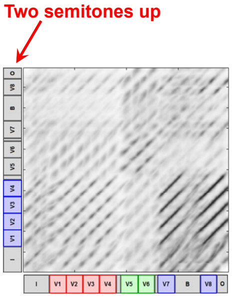
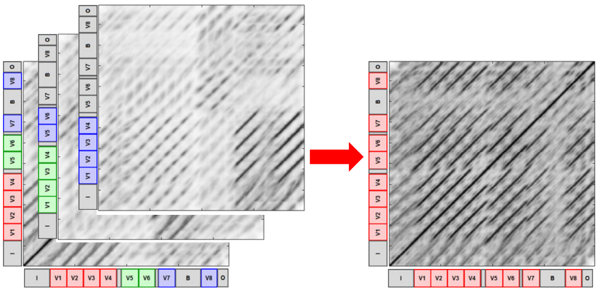
Two semitones up



SSM Enhancement

Example: Zager & Evans “In The Year 2525”

Idea: Overlay & Maximize → Transposition-invariant SSM

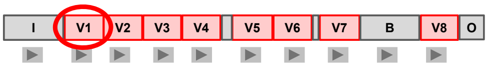


Audio Thumbnailing

Audio Thumbnailing

General goal: Determine the most representative section ("Thumbnail") of a given music recording.

Example: Zager & Evans "In The Year 2525"



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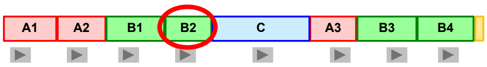


Thumbnail is often assumed to be the most repetitive segment

Audio Thumbnailing

Two steps	Both steps are problematic!
1. Path extraction	Paths of poor quality (fragmented, gaps) Block-like structures Curved paths
2. Grouping	Noisy relations (missing, distorted, overlapping) Transitivity computation difficult

Main idea: Do both, path extraction and grouping, jointly

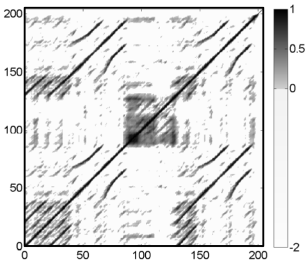
- One optimization scheme for both steps
- Stabilizing effect
- Efficient

Audio Thumbnailing

Main idea: Do both path extraction and grouping jointly

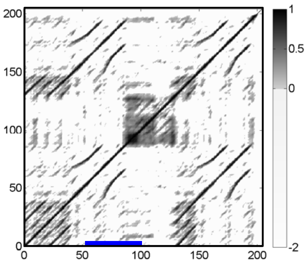
- For each audio segment we define a fitness value
- This fitness value expresses "how well" the segment explains the entire audio recording
- The segment with the highest fitness value is considered to be the thumbnail
- As main technical concept we introduce the notion of a path family

Fitness Measure



Enhanced SSM

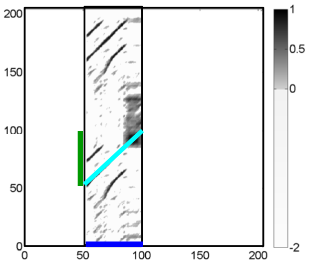
Fitness Measure



Path over segment

- Consider a fixed segment

Fitness Measure

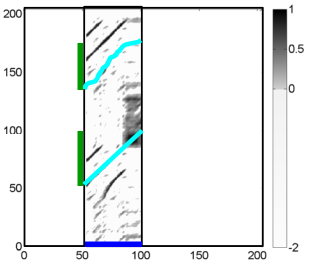


Path over segment

- Consider a fixed segment

- Path over segment
- Induced segment
- Score is high

Fitness Measure



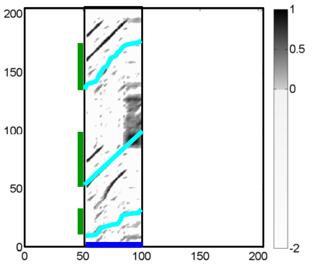
Path over segment

- Consider a fixed segment

- Path over segment
- Induced segment
- Score is high

- A second path over segment
- Induced segment
- Score is not so high

Fitness Measure



Path over segment

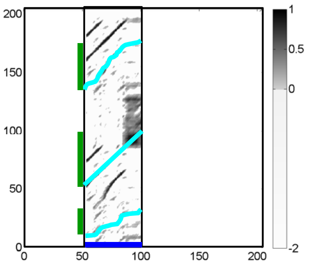
- Consider a fixed segment

- Path over segment
- Induced segment
- Score is high

- A second path over segment
- Induced segment
- Score is not so high

- A third path over segment
- Induced segment
- Score is very low

Fitness Measure

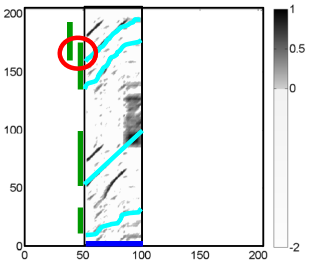


Path family

- Consider a fixed segment

- A path family over a segment is a family of paths such that the induced segments do not overlap.

Fitness Measure



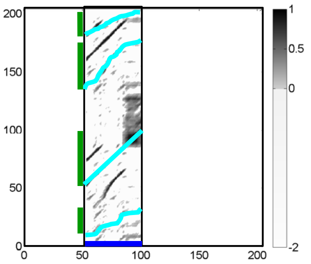
Path family

- Consider a fixed segment

- A path family over a segment is a family of paths such that the induced segments do not overlap.

This is not a path family!

Fitness Measure



Path family

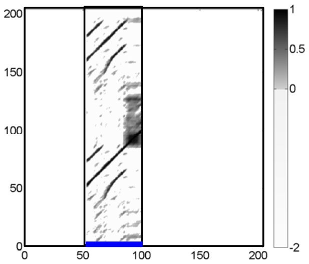
- Consider a fixed segment

- A path family over a segment is a family of paths such that the induced segments do not overlap.

This is a path family!

(Even though not a good one)

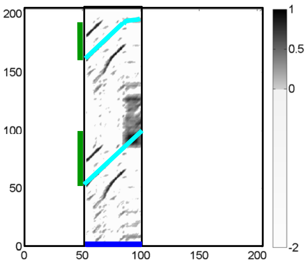
Fitness Measure



Optimal path family

- Consider a fixed segment

Fitness Measure



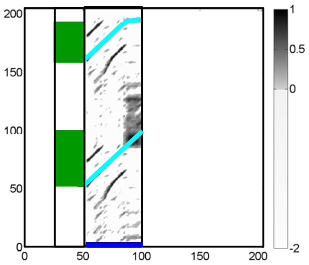
Optimal path family

- Consider a fixed segment
- Consider over the segment the optimal path family, i.e., the path family having maximal overall score.
- Call this value:

  Score(segment)

Note: This optimal path family can be computed using dynamic programming.

Fitness Measure



Optimal path family

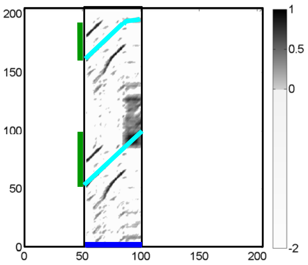
- Consider a fixed segment
- Consider over the segment the optimal path family, i.e., the path family having maximal overall score.
- Call this value:

  Score(segment)

- Furthermore consider the amount covered by the induced segments.
- Call this value:

  Coverage(segment)

Fitness Measure



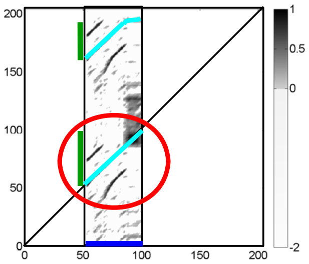
P := Score(segment)

R := Coverage(segment)

Fitness

- Consider a fixed segment

Fitness Measure



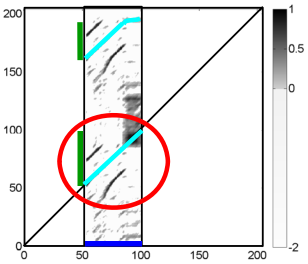
P := Score(segment)

R := Coverage(segment)

Fitness

- Consider a fixed segment
- Self-explanation are trivial!

Fitness Measure



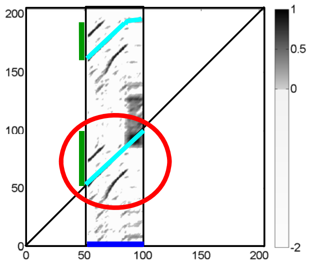
P := Score(segment) - length(segment)

R := Coverage(segment) - length(segment)

Fitness

- Consider a fixed segment
- Self-explanation are trivial!
- Subtract length of segment

Fitness Measure



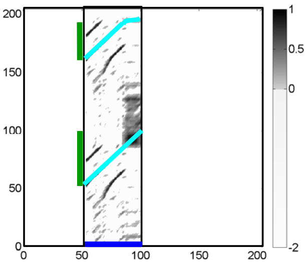
Fitness

- Consider a fixed segment
- Self-explanation are trivial!
- Subtract length of segment
- Normalization

P := Normalize(Score(segment) - length(segment)) $\in [0,1]$

R := Normalize(Coverage(segment) - length(segment)) $\in [0,1]$

Fitness Measure



Fitness

- Consider a fixed segment

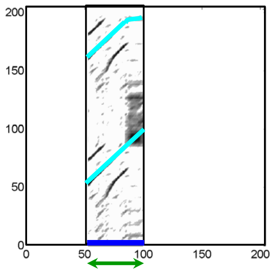
Fitness(segment)

F := 2 • P • R / (P + R)

P := Normalize(Score(segment) - length(segment)) $\in [0,1]$

R := Normalize(Coverage(segment) - length(segment)) $\in [0,1]$

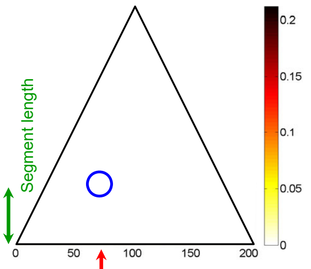
Thumbnail



Segment length

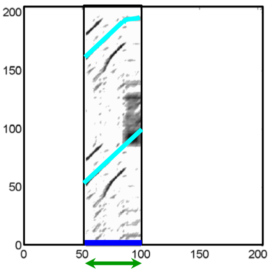
Segment center

Fitness Scape Plot



Segment center

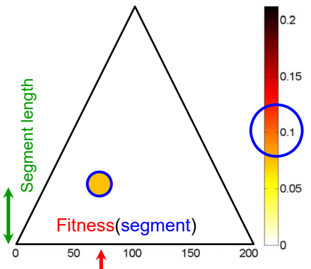
Thumbnail



Segment length

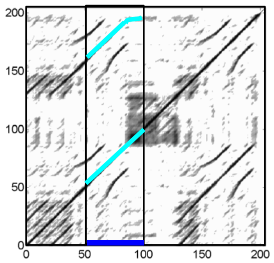
Segment center

Fitness Scape Plot

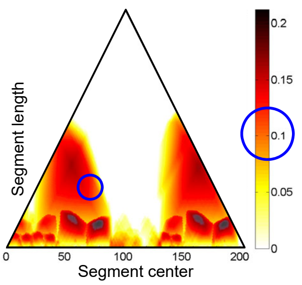


Segment center

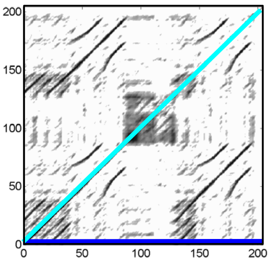
Thumbnail



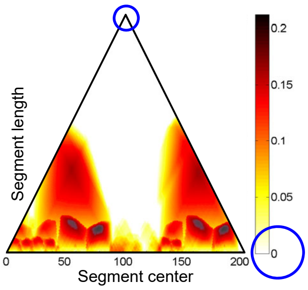
Fitness Scape Plot



Thumbnail

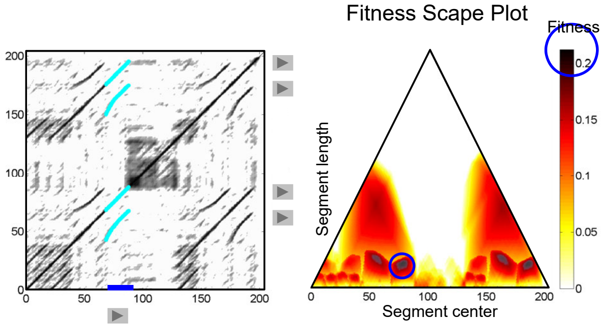


Fitness Scape Plot



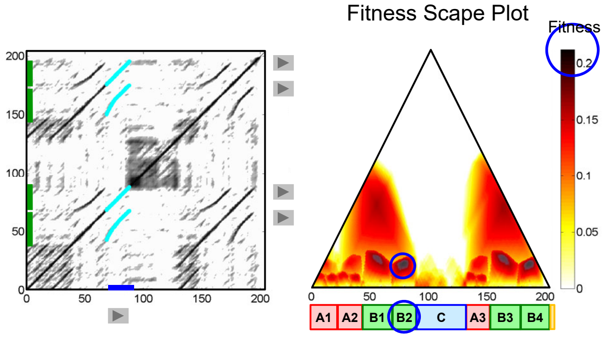
Note: Self-explanations are ignored → fitness is zero

Thumbnail



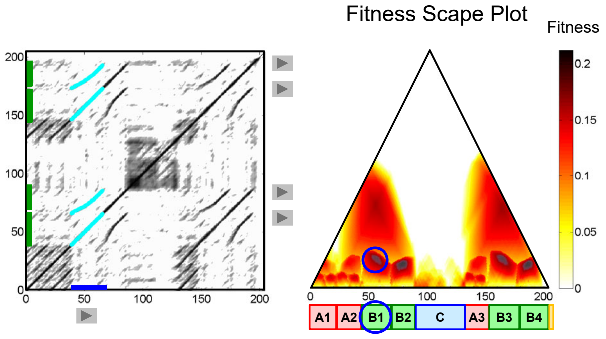
Thumbnail := segment having the highest fitness

Thumbnail



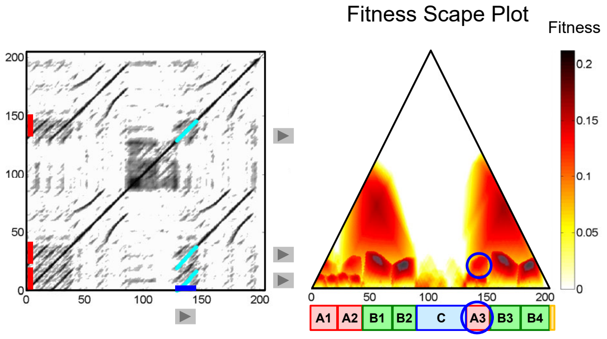
Example: Brahms Hungarian Dance No. 5 (Ormandy)

Thumbnail



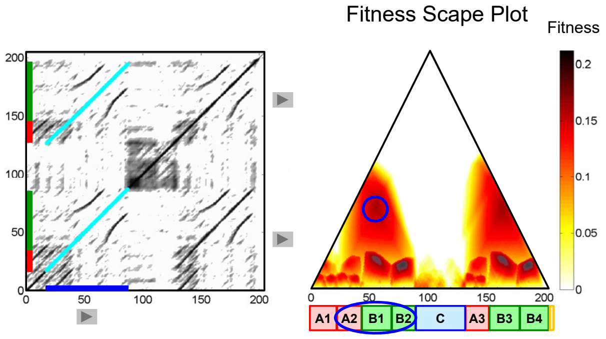
Example: Brahms Hungarian Dance No. 5 (Ormandy)

Thumbnail



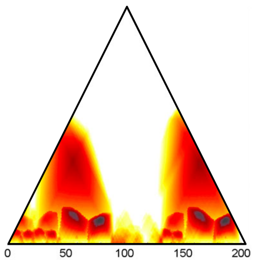
Example: Brahms Hungarian Dance No. 5 (Ormandy)

Thumbnail



Example: Brahms Hungarian Dance No. 5 (Ormandy)

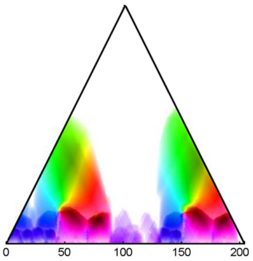
Scape Plot



Example: Brahms Hungarian Dance No. 5 (Ormandy)

Scape Plot

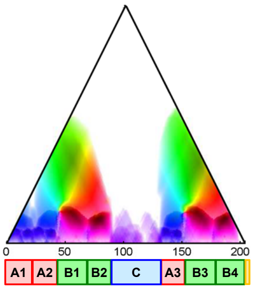
Coloring according to clustering result (grouping)



Example: Brahms Hungarian Dance No. 5 (Ormandy)

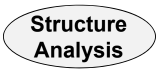
Scape Plot

Coloring according to clustering result (grouping)



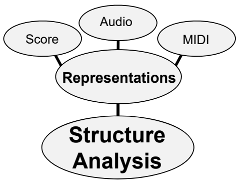
Example: Brahms Hungarian Dance No. 5 (Ormandy)

Conclusions



Structure Analysis

Conclusions



Audio

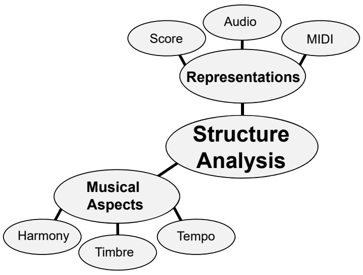
Score

MIDI

Representations

Structure Analysis

Conclusions



Audio

Score

MIDI

Representations

Structure Analysis

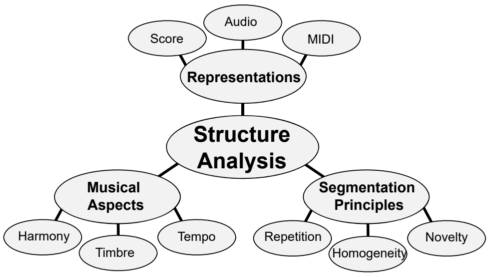
Musical Aspects

Harmony

Timbre

Tempo

Conclusions



Audio

Score

MIDI

Representations

Structure Analysis

Musical Aspects

Segmentation Principles

Harmony

Timbre

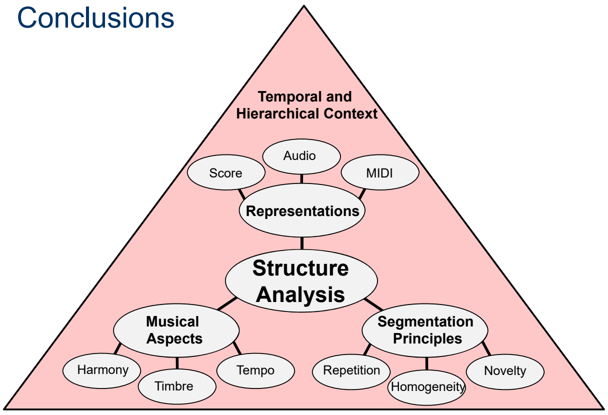
Tempo

Repetition

Homogeneity

Novelty

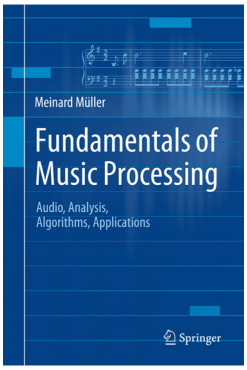
Conclusions



Links

- SM Toolbox (MATLAB)
  http://www.audiolabs-erlangen.de/resources/MIR/SMtoolbox/
- MSAF: Music Structure Analysis Framework (Python)
  https://github.com/urinieto/msaf
- SALAMI Annotation Data
  http://ddmal.music.mcgill.ca/research/salami/annotations
- LibROSA (Python)
  https://librosa.github.io/librosa/
- Evaluation: mir_eval (Python)
  https://craffel.github.io/mir_eval/
- Deep Learning: Boundary Detection
  Jan Schlüter (PhD thesis)

Book: Fundamentals of Music Processing


Meinard Müller
Fundamentals of Music Processing
Audio, Analysis, Algorithms, Applications
Springer

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483 p., 249 illus., hardcover
ISBN: 978-3-319-21944-8
Springer, 2015

Accompanying website:
www.music-processing.de

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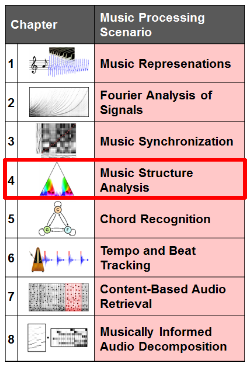

Chapter	Music Processing Scenario
1	Music Represenations
2	Fourier Analysis of Signals
3	Music Synchronization
4	Music Structure Analysis
5	Chord Recognition
6	Tempo and Beat Tracking
7	Content-Based Audio Retrieval
8	Musically Informed Audio Decomposition

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