INTERNATIONAL AUDIO LABORATORIES ERLANGEN

AUDIO LABS

Tutorial

Audio Structure Analysis of Music

Meinard Müller

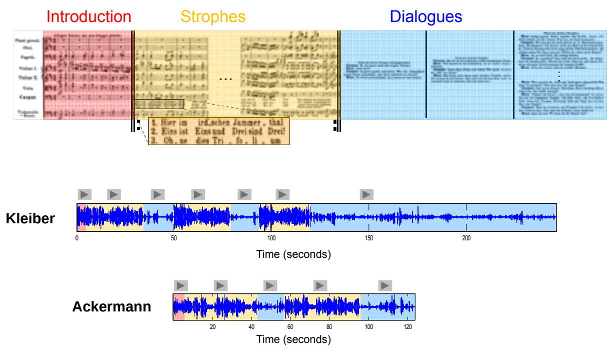
DAFx

FAU FRIEDRICH-ALEXANDER UNIVERSITÄT ERLANGEN-NÜRNBERG

Fraunhofer IIS

Music Structure Analysis

Example: Weber, Song (No. 4) from “Der Freischütz”



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

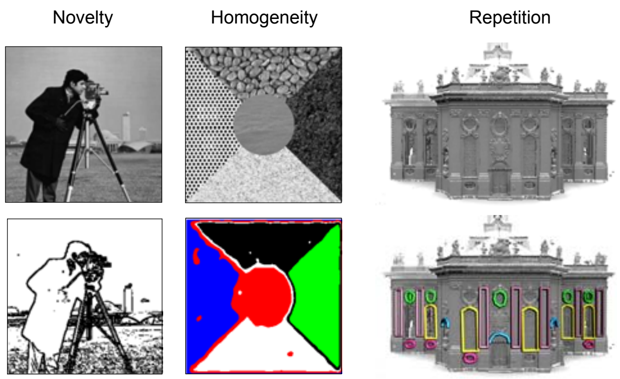
Music Structure Analysis

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

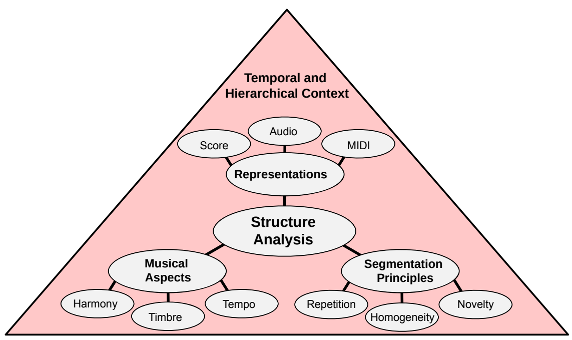
Challenge: There are many different principles for creating relationships that form the basis for the musical structure.

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

Music Structure Analysis



Music Structure Analysis



Overview

- Introduction
- Self-Similarity Matrices
- Audio Thumbnailing
- Novelty-based Segmentation
- Converting Path to Block Structures

Thanks:

- Clausen, Ewert, Kurth, Grohganz, …
- Dannenberg, Goto
- Grosche, Jiang
- Paulus, Klapuri
- Peeters, Kaiser, …
- Serra, Gómez, …
- Smith, Fujinaga, …
- Wand, Sunkel, Jansen
- …

Overview

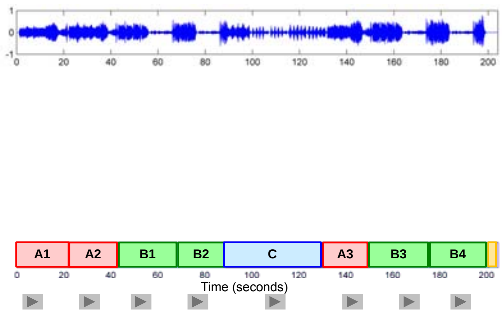
- Introduction
- Self-Similarity Matrices
- Audio Thumbnailing
- Novelty-based Segmentation
- Converting Path to Block Structures

Thanks:

- Clausen, Ewert, Kurth, Grohganz, …
- Dannenberg, Goto
- Grosche, Jiang
- Paulus, Klapuri
- Peeters, Kaiser, …
- Serra, Gómez, …
- Smith, Fujinaga, …
- Wand, Sunkel, Jansen
- …

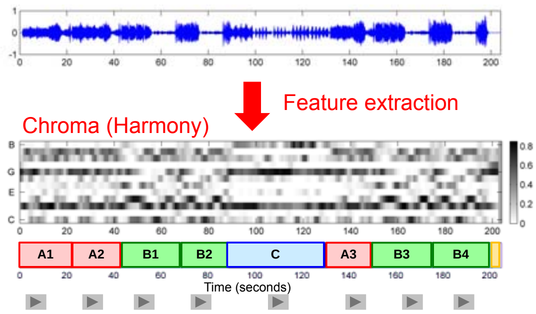
Feature Representation

Example: Brahms Hungarian Dance No. 5 (Ormandy)



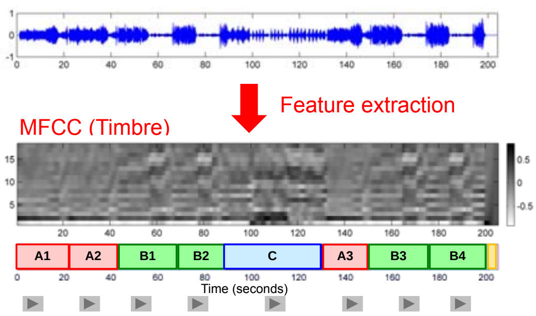
Feature Representation

Example: Brahms Hungarian Dance No. 5 (Ormandy)



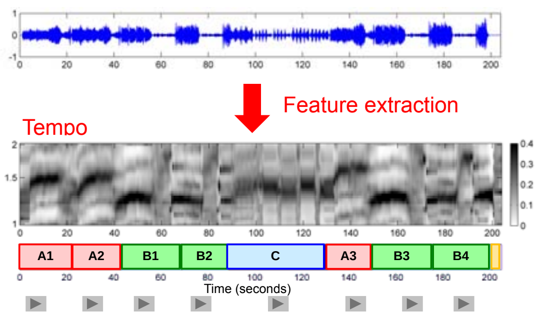
Feature Representation

Example: Brahms Hungarian Dance No. 5 (Ormandy)



Feature Representation

Example: Brahms Hungarian Dance No. 5 (Ormandy)



Self-Similarity Matrix (SSM)

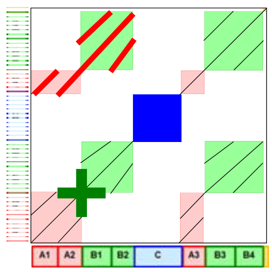
Example: Brahms Hungarian Dance No. 5 (Ormandy)

Blocks: Homogeneity

Paths: Repetition

Corners: Novelty

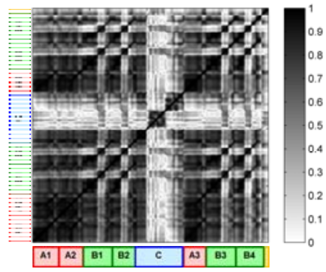
Idealized SSM



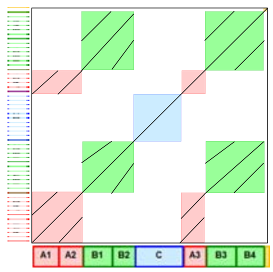
Self-Similarity Matrix (SSM)

Example: Brahms Hungarian Dance No. 5 (Ormandy)

MFCC (Timbre)



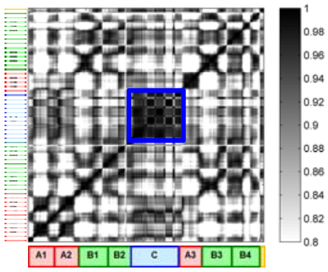
Idealized SSM



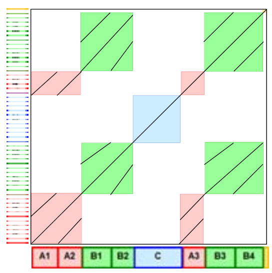
Self-Similarity Matrix (SSM)

Example: Brahms Hungarian Dance No. 5 (Ormandy)

Tempo



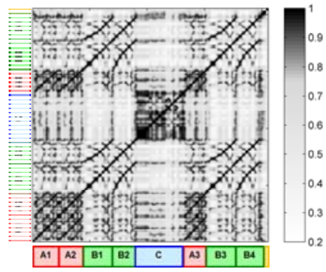
Idealized SSM



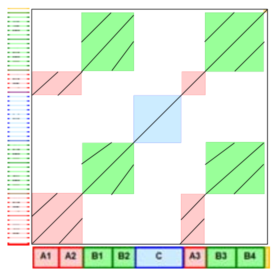
Self-Similarity Matrix (SSM)

Example: Brahms Hungarian Dance No. 5 (Ormandy)

Chroma (Harmony)



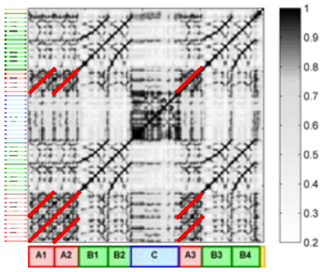
Idealized SSM



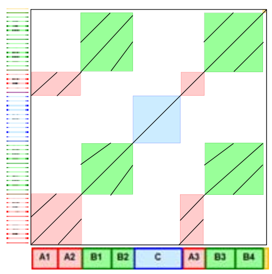
Self-Similarity Matrix (SSM)

Example: Brahms Hungarian Dance No. 5 (Ormandy)

Chroma (Harmony)



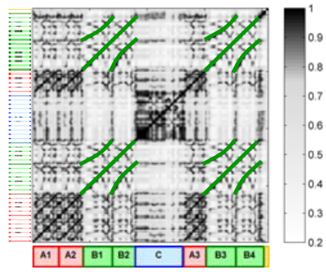
Idealized SSM



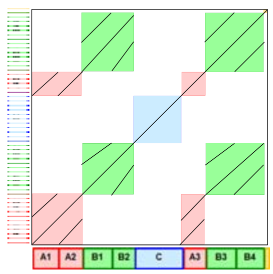
Self-Similarity Matrix (SSM)

Example: Brahms Hungarian Dance No. 5 (Ormandy)

Chroma (Harmony)



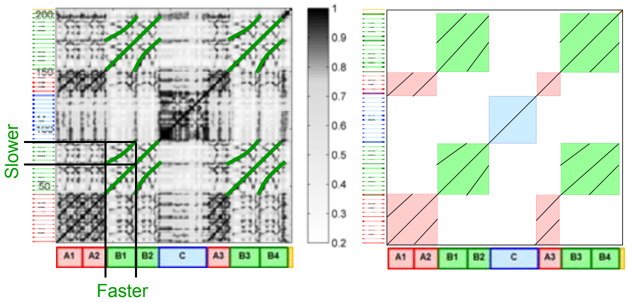
Idealized SSM



Self-Similarity Matrix (SSM)

Example: Brahms Hungarian Dance No. 5 (Ormandy)

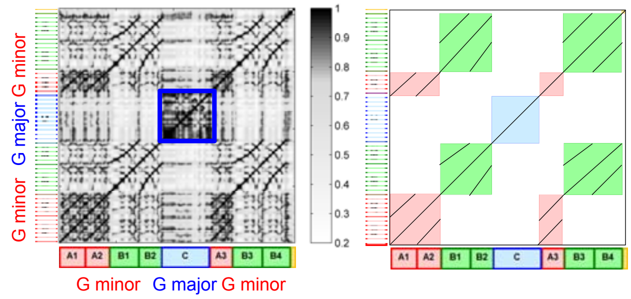
Chroma (Harmony) Idealized SSM



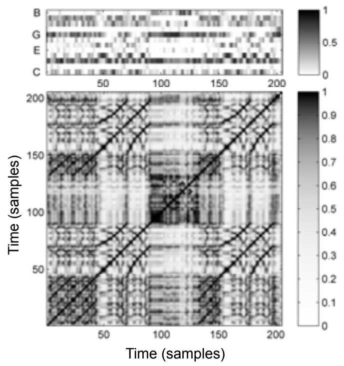
Self-Similarity Matrix (SSM)

Example: Brahms Hungarian Dance No. 5 (Ormandy)

Chroma (Harmony) Idealized SSM



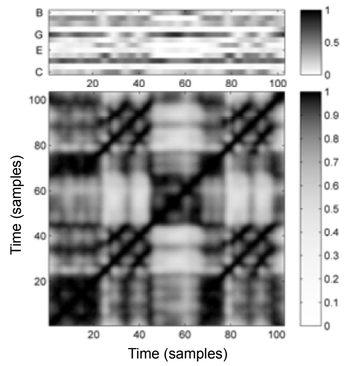
SSM Enhancement



Block Enhancement

- Feature smoothing
- Coarsening

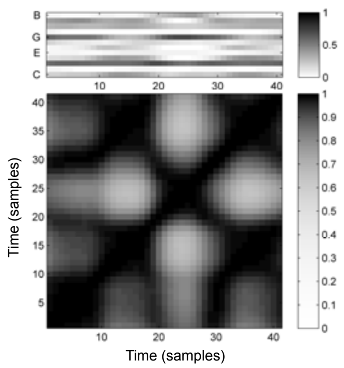
SSM Enhancement



Block Enhancement

- Feature smoothing
- Coarsening

SSM Enhancement

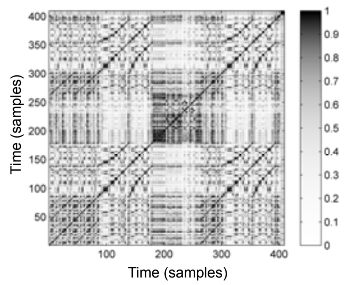


Block Enhancement

- Feature smoothing
- Coarsening

SSM Enhancement

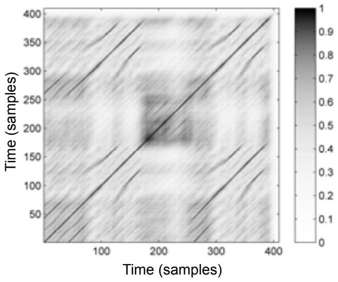
Path Enhancement



SSM Enhancement

Path Enhancement

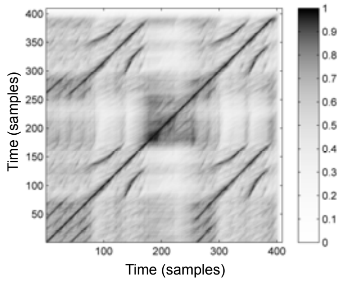
- Diagonal smoothing



SSM Enhancement

Path Enhancement

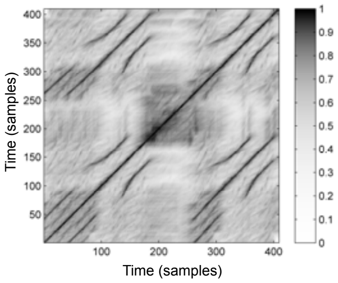
- Diagonal smoothing
- Multiple filtering



SSM Enhancement

Path Enhancement

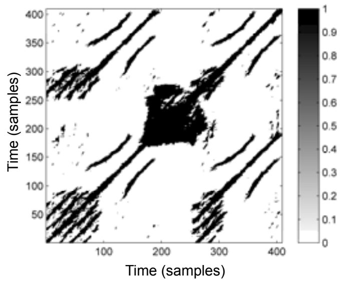
- Diagonal smoothing
- Multiple filtering
- Forward-backward



SSM Enhancement

Path Enhancement

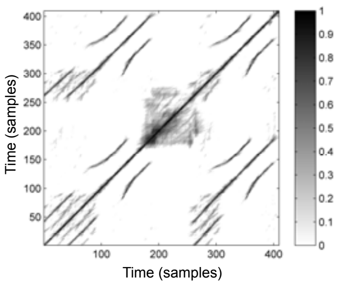
- Diagonal smoothing
- Multiple filtering
- Forward-backward
- Thresholding (binary)



SSM Enhancement

Path Enhancement

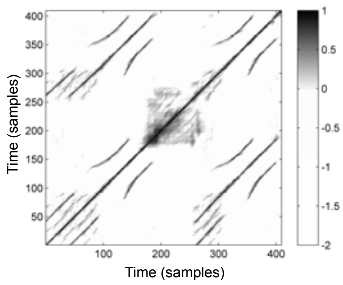
- Diagonal smoothing
- Multiple filtering
- Forward-backward
- Thresholding (relative)



SSM Enhancement

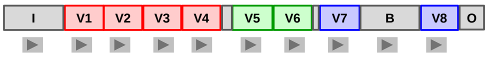
Path Enhancement

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



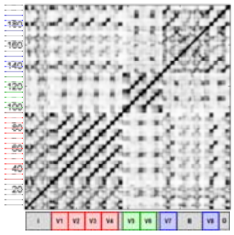
SSM Enhancement

Example: Zager & Evans “In The Year 2525”



SSM Enhancement

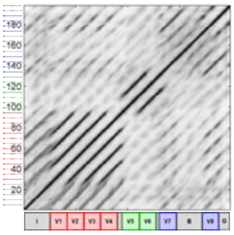
Example: Zager & Evans “In The Year 2525”



SSM Enhancement

Example: Zager & Evans “In The Year 2525”

Missing relations because of transposed sections

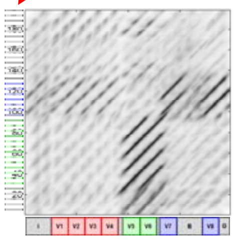


SSM Enhancement

Example: Zager & Evans “In The Year 2525”

Idea: Cyclic shift of one of the chroma sequences

One semitone up

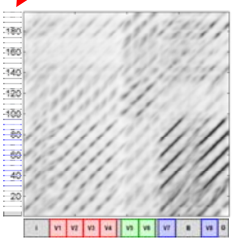


SSM Enhancement

Example: Zager & Evans “In The Year 2525”

Idea: Cyclic shift of one of the chroma sequences

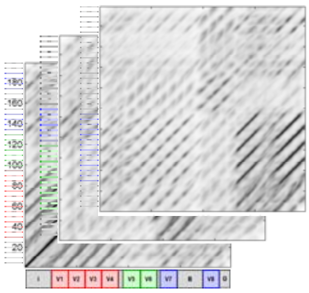
Two semitones up

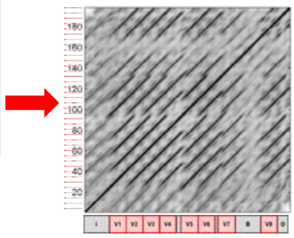


SSM Enhancement

Example: Zager & Evans “In The Year 2525”

Idea: Overlay & add up → Transposition-invariant SSM



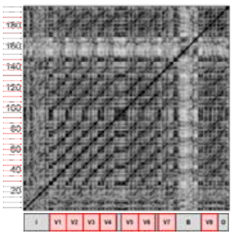


SSM Enhancement

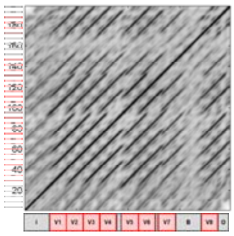
Example: Zager & Evans "In The Year 2525"

Note: Order of enhancement steps important!

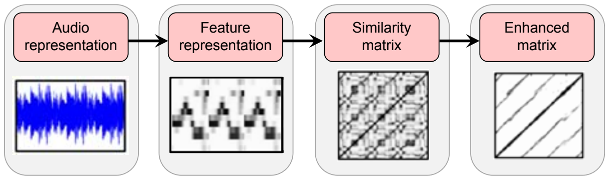
Adding up



Smoothing & adding up



Similarity Matrix Toolbox



Meinard Müller, Nanzhu Jiang, Harald Grohganz
SM Toolbox: MATLAB Implementations for Computing and Enhancing Similarity Matrices

http://www.audiolabs-erlangen.de/resources/MIR/SMtoolbox/

Overview

- Introduction
- Self-Similarity Matrices
- Audio Thumbnailing
- Novelty-based Segmentation
- Converting Path to Block Structures

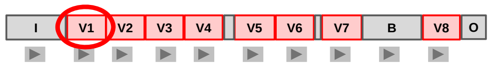
Thanks:

- Jiang, Grosche
- Peeters
- Cooper, Foote
- Goto
- Levy, Sandler
- Mauch
- Sapp

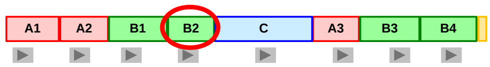
Audio Thumbnailing

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

Example: Zager & Evans "In The Year 2525"



Example: Brahms Hungarian Dance No. 5 (Ormandy)



Thumbnail is often assumed to be the most repetitive segment

Audio Thumbnailing

Two steps

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

Both steps are problematic!

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

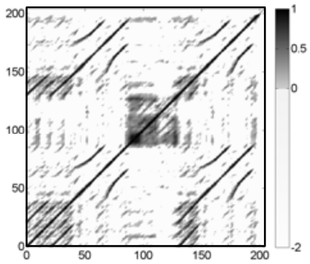
- One optimization scheme for both steps
- Stabilizing effect
- Efficient

Audio Thumbnailing

Main idea: Do both path extraction and grouping jointly

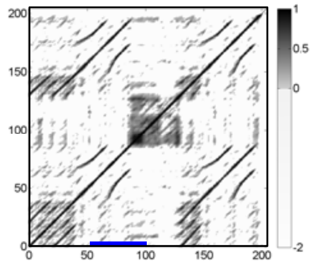
- For each audio segment we define a fitness value
- This fitness value expresses "how well" the segment explains the entire audio recording
- The segment with the highest fitness value is considered to be the thumbnail
- As main technical concept we introduce the notion of a path family

Fitness Measure



Enhanced SSM

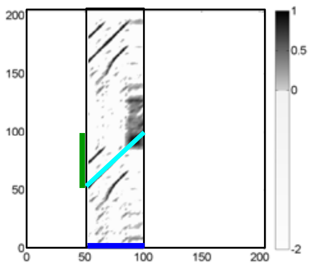
Fitness Measure



Path over segment

- Consider a fixed segment

Fitness Measure

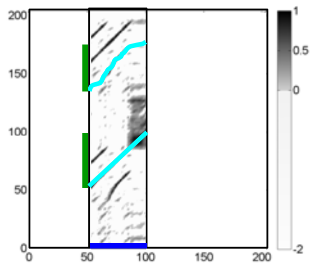


Path over segment

- Consider a fixed segment

- Path over segment
- Induced segment
- Score is high

Fitness Measure



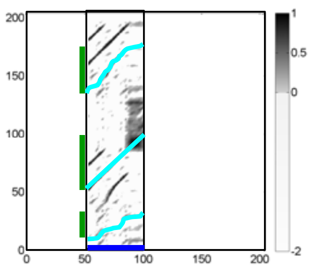
Path over segment

- 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

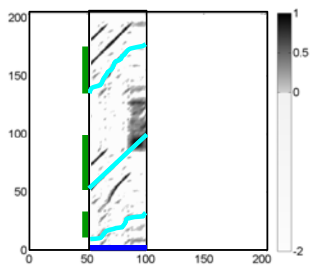
- Consider a fixed segment

- 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

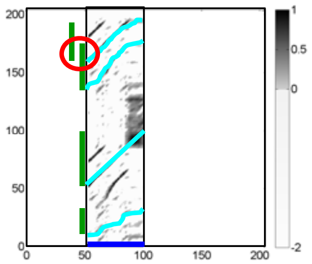


Path family

- 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

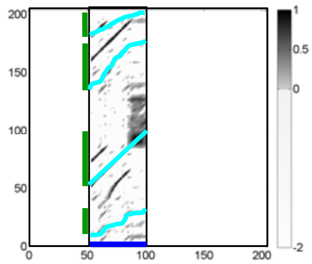


Path family

- 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



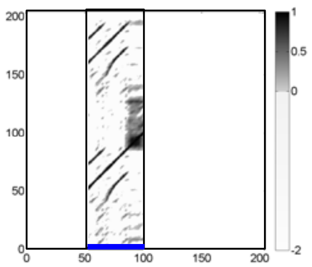
Path family

- 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)

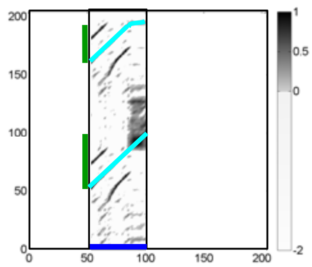
Fitness Measure



Optimal path family

- Consider a fixed segment

Fitness Measure



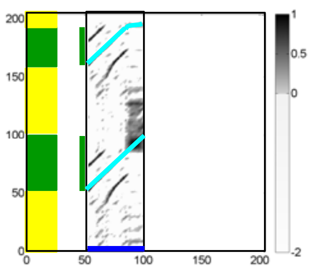
Optimal path family

- 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

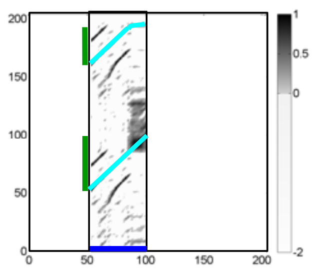
- Consider a fixed segment
- Consider over the segment the optimal path family, i.e., the path family having maximal overall score.
- Call this value:

  Score(segment)

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

  Coverage(segment)

Fitness Measure



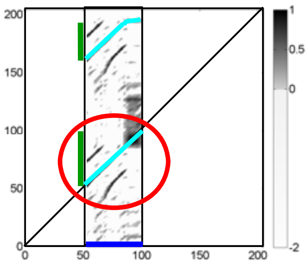
Fitness

- Consider a fixed segment

P := Score(segment)

R := Coverage(segment)

Fitness Measure



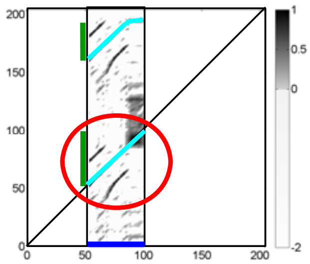
Fitness

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

P := Score(segment)

R := Coverage(segment)

Fitness Measure



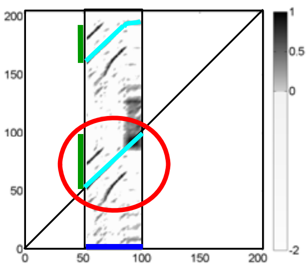
Fitness

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

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

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

Fitness Measure



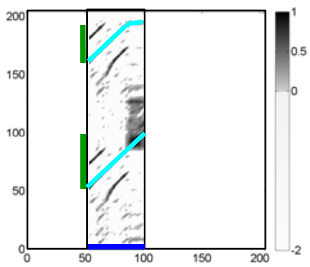
Fitness

- 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

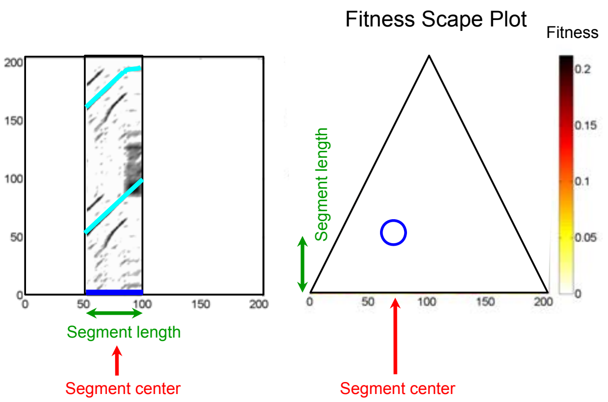
Fitness(segment)

F := 2 • P • R / (P + R)

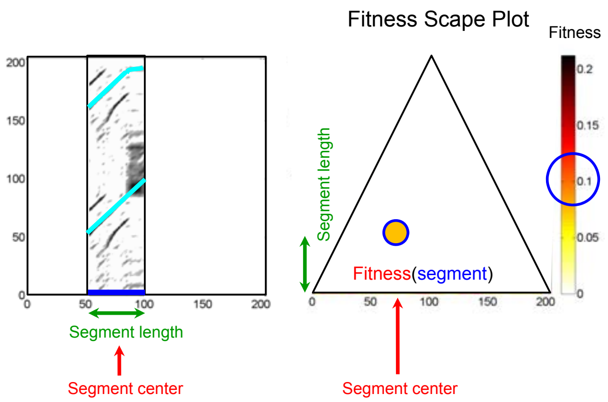
P := Normalize(Score(segment) - length(segment)) $\in [0,1]$

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

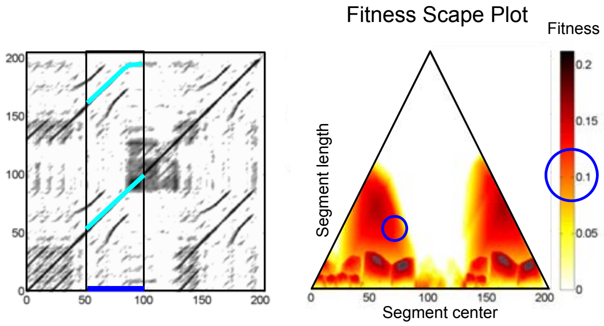
Thumbnail



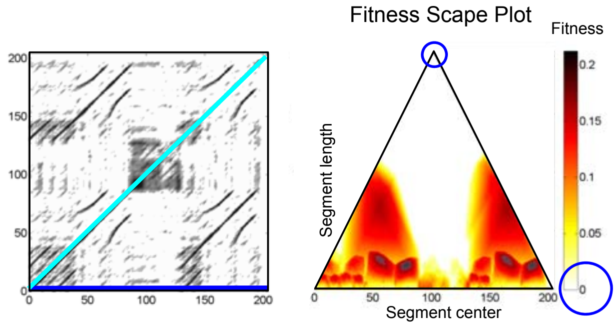
Thumbnail



Thumbnail

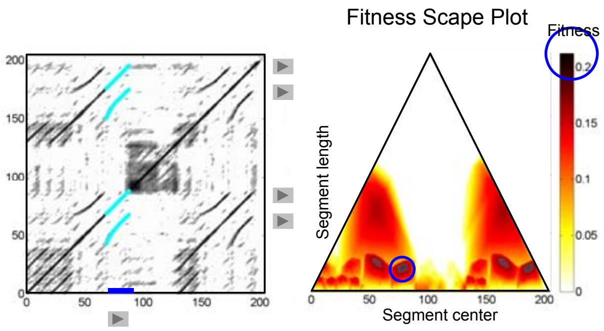


Thumbnail



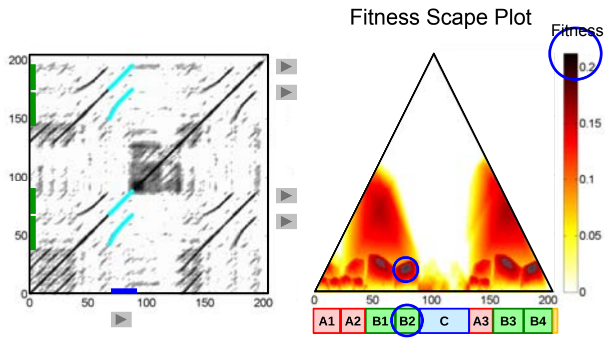
Note: Self-explanations are ignored → fitness is zero

Thumbnail



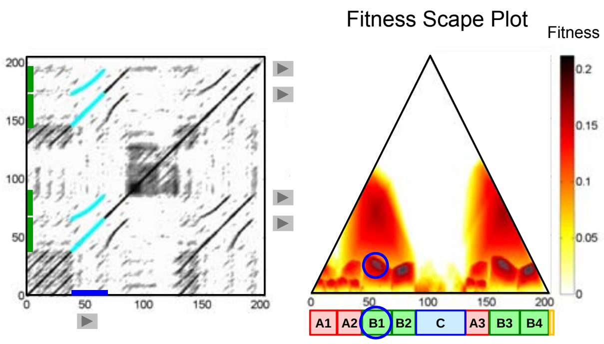
Thumbnail := segment having the highest fitness

Thumbnail



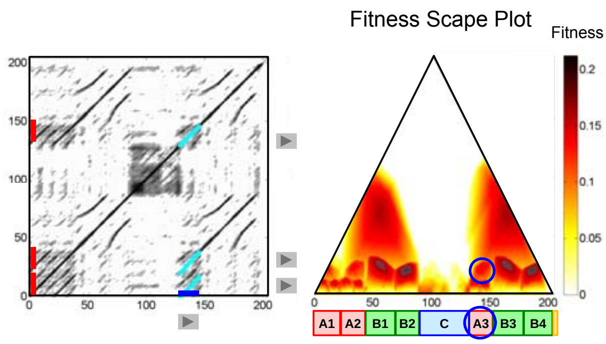
Example: Brahms Hungarian Dance No. 5 (Ormandy)

Thumbnail



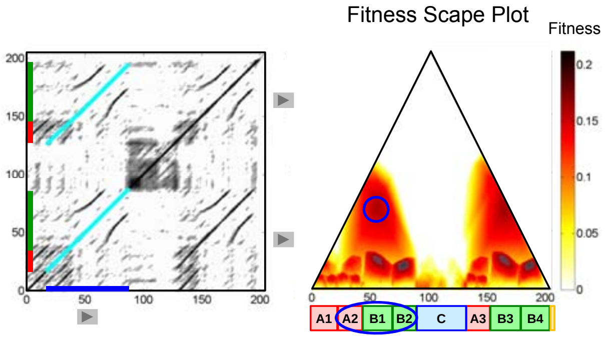
Example: Brahms Hungarian Dance No. 5 (Ormandy)

Thumbnail



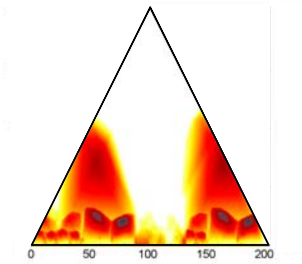
Example: Brahms Hungarian Dance No. 5 (Ormandy)

Thumbnail



Example: Brahms Hungarian Dance No. 5 (Ormandy)

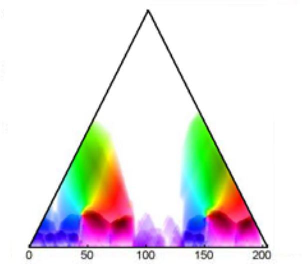
Scape Plot



Example: Brahms Hungarian Dance No. 5 (Ormandy)

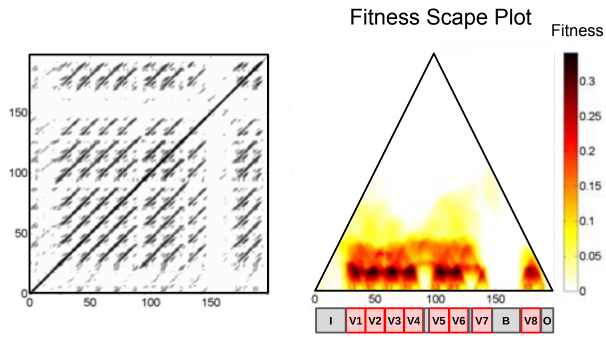
Scape Plot

Coloring according to clustering result (grouping)



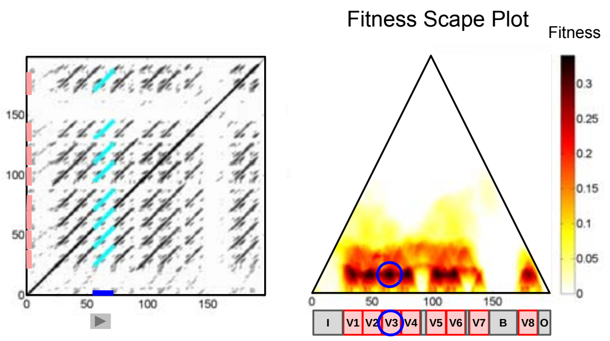
Example: Brahms Hungarian Dance No. 5 (Ormandy)

Thumbnail



Example: Zager & Evans “In The Year 2525”

Thumbnail



Example: Zager & Evans “In The Year 2525”

Overview

- Introduction
- Self-Similarity Matrices
- Audio Thumbnailing
- Novelty-based Segmentation
- Converting Path to Block Structures

Thanks:

- Foote
- Serra, Grosche, Arcos
- Goto
- Tzanetakis, Cook

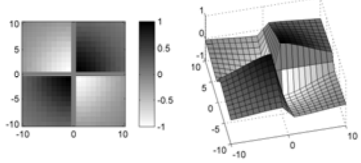
Novelty-based Segmentation

General goals:

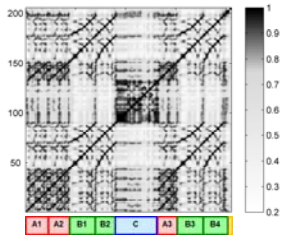
- Find instances where musical changes occur.
- Find transition between subsequent musical parts.

Idea (Foote):

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



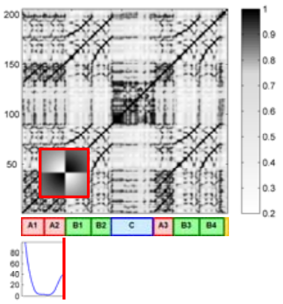
Novelty-based Segmentation



Idea (Foote):

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

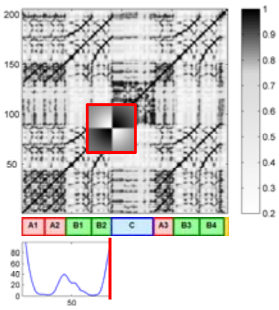
Novelty-based Segmentation



Idea (Foote):

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

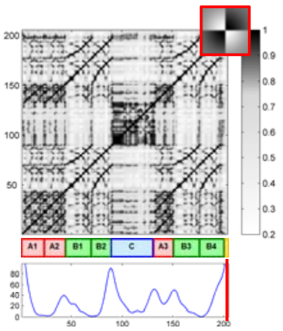
Novelty-based Segmentation



Idea (Foote):

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

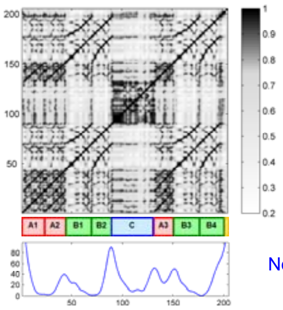
Novelty-based Segmentation



Idea (Foote):

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

Novelty-based Segmentation

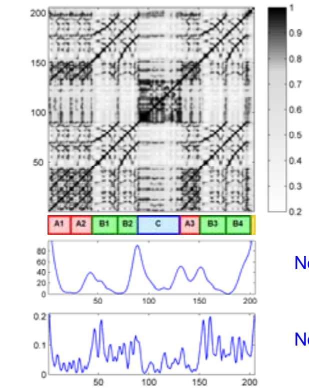


Idea (Foote):

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 

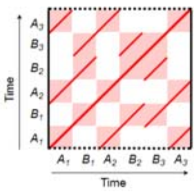
Novelty-based Segmentation

Idea:

- Find instances where structural changes occur.
- Combine global and local aspects within a unifying framework

Structure features

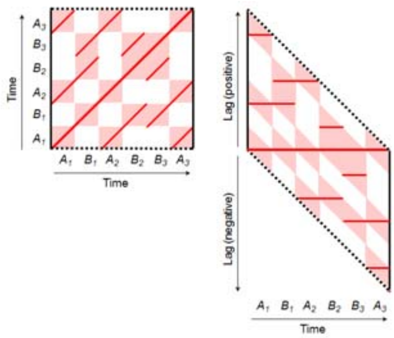
Novelty-based Segmentation



Structure features

- Enhanced SSM

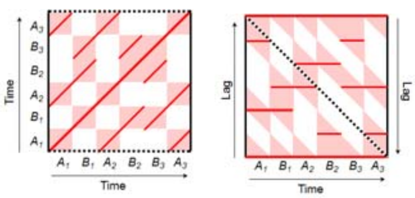
Novelty-based Segmentation



Structure features

- Enhanced SSM
- Time-lag SSM

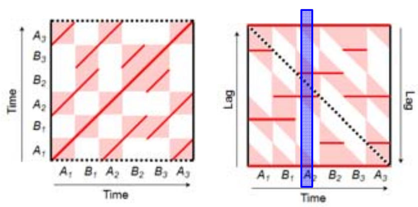
Novelty-based Segmentation



Structure features

- Enhanced SSM
- Time-lag SSM
- Cyclic time-lag SSM

Novelty-based Segmentation

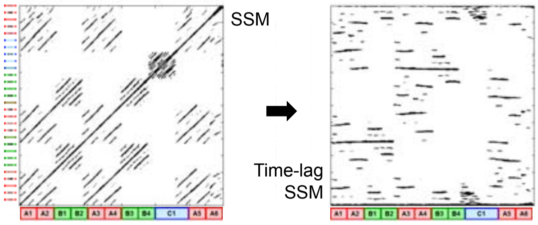


Structure features

- Enhanced SSM
- Time-lag SSM
- Cyclic time-lag SSM
- Columns as features

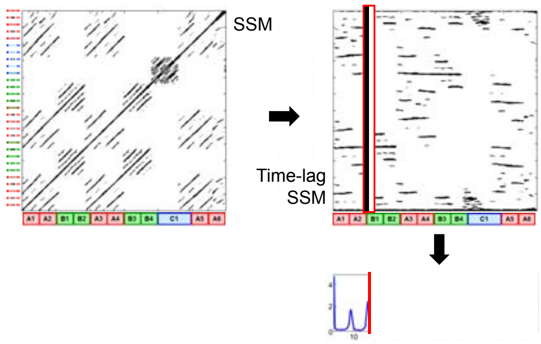
Novelty-based Segmentation

Example: Chopin Mazurka Op. 24, No. 1



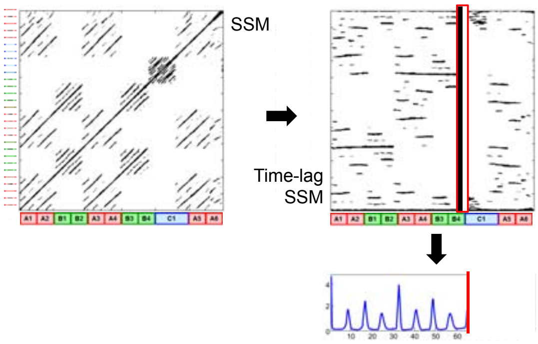
Novelty-based Segmentation

Example: Chopin Mazurka Op. 24, No. 1



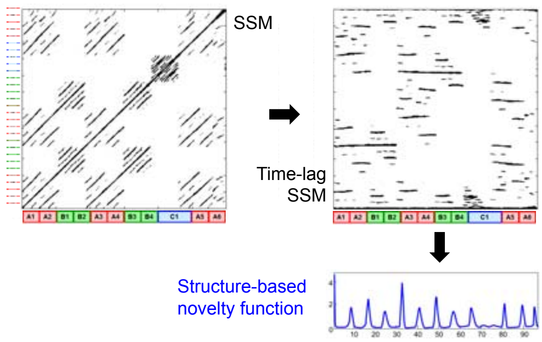
Novelty-based Segmentation

Example: Chopin Mazurka Op. 24, No. 1



Novelty-based Segmentation

Example: Chopin Mazurka Op. 24, No. 1



Overview

- Introduction
- Self-Similarity Matrices
- Audio Thumbnailing
- Novelty-based Segmentation
- Converting Path to Block Structures

Thanks:

- Grohganz, Clausen
- Kaiser
- Peeters
- Dubnov, Apel
- Serra, Grosche, Arcos

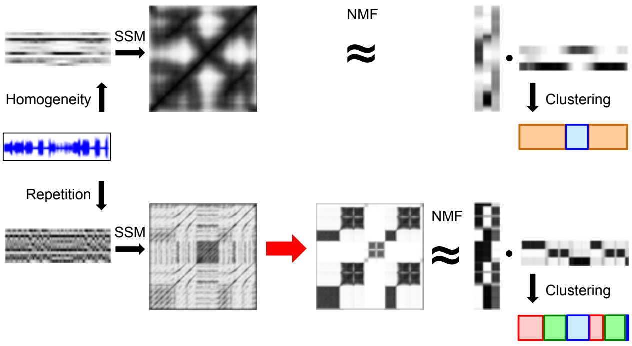
Converting Path to Block Structures

Motivation

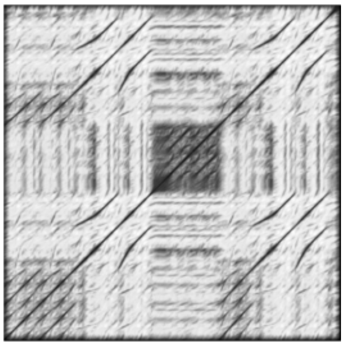
- Perform joint analysis using repetitive as well as homogeneous aspects
- Make homogeneity-based methods applicable to repetition-based analysis

Converting Path to Block Structures

Motivation



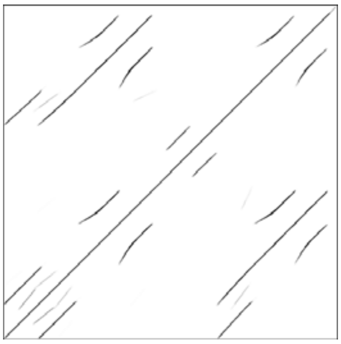
Converting Path to Block Structures



Procedure

- Enhanced SSM

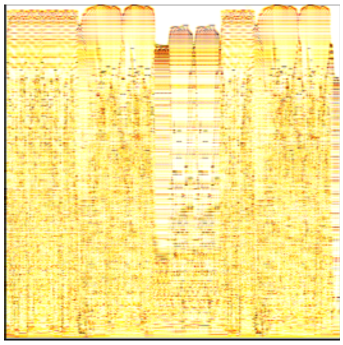
Converting Path to Block Structures



Procedure

- Enhanced SSM
- Thresholding & image processing

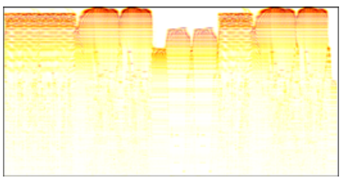
Converting Path to Block Structures



Procedure

- Enhanced SSM
- Thresholding & image processing
- Eigenvalue decomposition

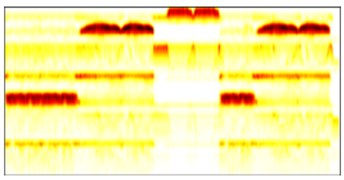
Converting Path to Block Structures



Procedure

- Enhanced SSM
- Thresholding & image processing
- Eigenvalue decomposition
- Weigthing

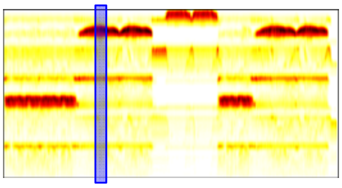
Converting Path to Block Structures



Procedure

- Enhanced SSM
- Thresholding & image processing
- Eigenvalue decomposition
- Weigthing
- Clustering & smoothing

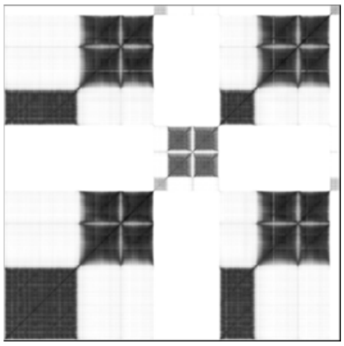
Converting Path to Block Structures



Procedure

- Enhanced SSM
- Thresholding & image processing
- Eigenvalue decomposition
- Weigthing
- Clustering & smoothing
- **Columns as features**

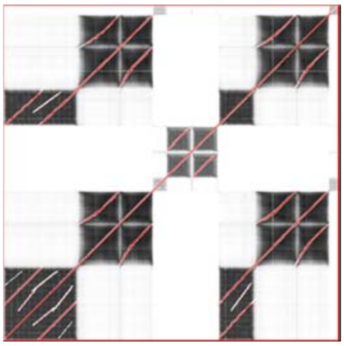
Converting Path to Block Structures



Procedure

- Enhanced SSM
- Thresholding & image processing
- Eigenvalue decomposition
- Weigthing
- Clustering & smoothing
- **Columns as features**
- SSM from these features

Converting Path to Block Structures



Procedure

- Enhanced SSM
- Thresholding & image processing
- Eigenvalue decomposition
- Weigthing
- Clustering & smoothing
- **Columns as features**
- SSM from these features

Final matrix shows paths as blocks

Conclusions

- Repetition, Homogeneity, Novelty
- Combined Approaches
- Hierarchical Approaches
- Evaluation
- Explaining Structure

- MIREX
- SALAMI-Project
- Smith, Chew

PhD Projects (Final Stage)

- Nanzhu Jiang
  Universtät Erlangen-Nürnberg
  Supervisor: Meinard Müller
- Harald Grohganz
  Universität Bonn
  Supervisors: Michael Clausen, Meinard Müller
- Jordan Smith
  Queen Mary University of London
  Supervisor: Elaine Chew
- Oriol Nieto
  New York University
  Supervisor: Juan P. Bello

Book Project

A First Course on Music Processing

Textbook (approx. 500 pages)

1. Music Representations
2. Fourier Analysis of Signals
3. Music Synchronization
4. **Music Structure Analysis**
5. Chord Recogntion
6. Temo and Beat Tracking
7. Content-based Audio Retrieval
8. Music Transcription

Springer

To appear (plan):
End of 2015

References

- W. CHAI AND B. VERCOE, Music thumbnailing via structural analysis, in Proceedings of the ACM International Conference on Multimedia, Berkeley, CA, USA, 2003, pp. 223–226.
- M. COOPER AND J. FOOTE, Automatic music summarization via similarity analysis, in Proceedings of the International Conference on Music Information Retrieval (ISMIR), Paris, France, 2002, pp. 81–85.
- R. B. DANNENBERG AND M. GOTO, Music structure analysis from acoustic signals, in Handbook of Signal Processing in Acoustics, D. Havelock, S.
- J. FOOTE, Visualizing music and audio using self-similarity, in Proceedings of the ACM International Conference on Multimedia, Orlando, FL, USA, 1999, pp. 77–80.
- J. FOOTE, Automatic audio segmentation using a measure of audio novelty, in Proceedings of the IEEE International Conference on Multimedia and Expo (ICME), New York, NY, USA, 2000, pp. 452–455.
- M. GOTO, A chorus section detection method for musical audio signals and its application to a music listening station, IEEE Transactions on Audio, Speech and Language Processing, 14 (2006), pp. 1783–1794
- H. GROHGANZ, M. CLAUSEN, N. JIANG, AND M. MÜLLER, Converting path structures into block structures using eigenvalue decompositions of self-similarity matrices, in Proceedings of the 14th International Conference on Music Information Retrieval (ISMIR), Curitiba, Brazil, 2013, pp. 209–214.
- K. JENSEN, Multiple scale music segmentation using rhythm, timbre, and harmony, EURASIP Journal on Advances in Signal Processing, 2007 (2007).
- F. KAISER AND T. SIKORA, Music structure discovery in popular music using non-negative matrix factorization, in Proceedings of the International Society for Music Information Retrieval Conference (ISMIR), Utrecht, The Netherlands, 2010, pp. 429–434.

References

- M. LEVY, M. SANDLER, AND M. A. CASEY, Extraction of high-level musical structure from audio data and its application to thumbnail generation, in Proceedings of the IEEE International Conference on Acoustics, Speech, and Signal Processing (ICASSP), Toulouse, France, 2006, pp. 13–16.
- H. LUKASHEVICH, Towards quantitative measures of evaluating song segmentation, in Proceedings of the International Conference on Music Information Retrieval (ISMIR), Philadelphia, USA, 2008, pp. 375–380.
- M. MÜLLER AND M. CLAUSEN, Transposition-invariant self-similarity matrices, in Proceedings of the 8th International Conference on Music Information Retrieval (ISMIR), Vienna, Austria, 2007, pp. 47–50.
- M. MÜLLER AND N. JIANG, A scape plot representation for visualizing repetitive structures of music recordings, in Proceedings of the 13th International Conference on Music Information Retrieval (ISMIR), Porto, Portugal, 2012, pp. 97–102.
- M. MÜLLER, N. JIANG, AND H. GROHGANZ, SM Toolbox: MATLAB implementations for computing and enhancing similiarty matrices, in Proceedings of the 53rd AES Conference on Semantic Audio, London, GB, 2014.
- M. MÜLLER, N. JIANG, AND P. GROSCHE, A robust fitness measure for capturing repetitions in music recordings with applications to audio thumbnailing, IEEE Transactions on Audio, Speech & Language Processing, 21 (2013), pp. 531–543.
- M. MÜLLER AND F. KURTH, Enhancing similarity matrices for music audio analysis, in Proceedings of the International Conference on Acoustics, Speech and Signal Processing (ICASSP), Toulouse, France, 2006, pp. 437–440.
- M. MÜLLER AND F. KURTH, Towards structural analysis of audio recordings in the presence of musical variations, EURASIP Journal on Advances in Signal Processing, 2007 (2007).

References

- J. PAULUS AND A. P. KLAPURI, Music structure analysis using a probabilistic fitness measure and a greedy search algorithm, IEEE Transactions on Audio, Speech, and Language Processing, 17 (2009), pp. 1159–1170.
- J. PAULUS, M. MÜLLER, AND A. P. KLAPURI, Audio-based music structure analysis, in Proceedings of the 11th International Conference on Music Information Retrieval (ISMIR), Utrecht, The Netherlands, 2010, pp. 625–636.
- G. PEETERS, Deriving musical structure from signal analysis for music audio summary generation: “sequence” and “state” approach, in Computer Music Modeling and Retrieval, vol. 2771 of Lecture Notes in Computer Science, Springer Berlin / Heidelberg, 2004, pp. 143– 166.
- G. PEETERS, Sequence representation of music structure using higher-order similarity matrix and maximum-likelihood approach, in Proceedings of the International Conference on Music Information Retrieval (ISMIR), Vienna, Austria, 2007, pp. 35–40.
- C. RHODES AND M. A. CASEY, Algorithms for determining and labelling approximate hierarchical self-similarity, in Proceedings of the International Conference on Music Information Retrieval (ISMIR), Vienna, Austria, 2007, pp. 41–46.
- J. SERRÀ , M. MÜLLER, P. GROSCHE, AND J. L. ARCOS, Unsupervised detection of music boundaries by time series structure features, in Proceedings of the AAAI International Conference on Artificial Intelligence, Toronto, Ontario, Canada, 2012, pp. 1613–1619.
- J. B. L. SMITH, J. A. BURGOYNE, I. FUJINAGA, D. D. ROURE, AND J. S. DOWNIE, Design and creation of a large-scale database of structural annotations, in Proceedings of the International Society for Music Information Retrieval Conference (ISMIR), Miami, FL, USA, 2011, pp. 555–560.
- J. B. L. SMITH AND E. CHEW, Using quadratic programming to estimate feature relevance in structural analyses of music, in Proceedings of the ACM International Conference on Multimedia, 2013, pp. 113–122.

References

- M. SUNKEL, S. JANSEN, M. WAND, E. EISEMANN, H.-P. SEIDEL, Learning Line Features in 3D Geometry, in Computer Graphics Forum (Proc. Eurographics), 2011.
- D. TURNBULL, G. LANCKRIET, E. PAMPALK, AND M. GOTO, A supervised approach for detecting boundaries in music using difference features and boosting, in Proceedings of the International Conference on Music Information Retrieval (ISMIR), Vienna, Austria, 2007, pp. 51–54.
- G. TZANETAKIS AND P. COOK, Multifeature audio segmentation for browsing and annotation, in Proceedings of the IEEEWorkshop on Applications of Signal Processing to Audio and Acoustics (WASPAA), New Platz, NY, USA, 1999, pp. 103–106.