

A Survey of Approaches to the Automatic Formal Analysis of Musical Audio

Jordan B. L. Smith
CIRMMT Music Technology colloquium
March 2nd 2010

STRUCTURE

STRUCTURE

The difference between arbitrary sound sequences and music is not well-defined: what is random noise for someone may be ingenious musical composition for somebody else. What can be generally agreed upon is that **it is the structure, or the relationships between the sound events** that create the perception of musicality.

- Paulus 2009

STRUCTURE

The difference between arbitrary sound sequences and music is not well-defined: what is random noise for someone may be ingenious musical composition for somebody else. What can be generally agreed upon is that **it is the structure, or the relationships between the sound events** that create the perception of musicality.

- Paulus 2009

Music is organized sound.

- Edgard Varèse

Definition

- Structure: the pattern of repetitions within a single piece of music.
- Example:
 - “Yesterday,” by The Beatles = AABABA
 - A = “verse”
 - B = “chorus”

Definition

- Structure: the pattern of repetitions within a single piece of music.
- Example:
 - “Yesterday,” by The Beatles = AABABA
 - A = “verse”
 - B = “chorus”
- Structural analysis aims to recover this structure from the music itself.

Definition

- Complication: “Yesterday,” by The Beatles

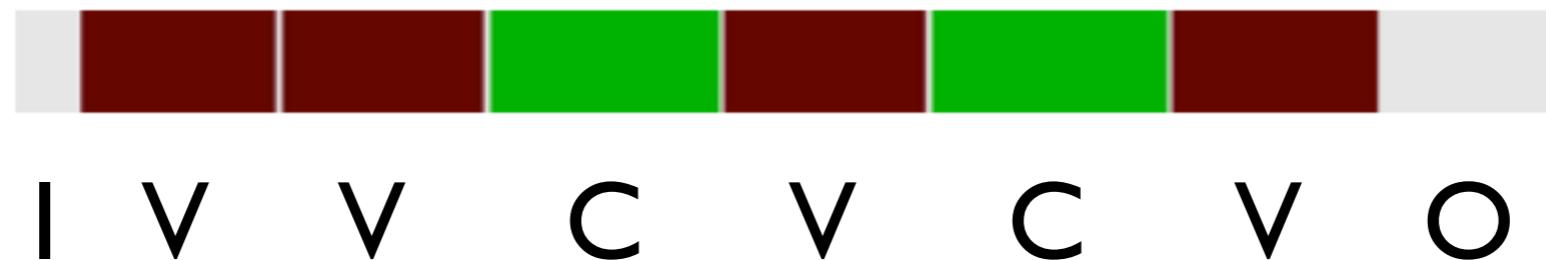


image: Chai 2005

audio: "Yesterday," by The Beatles

Definition

- Complication: “Yesterday,” by The Beatles

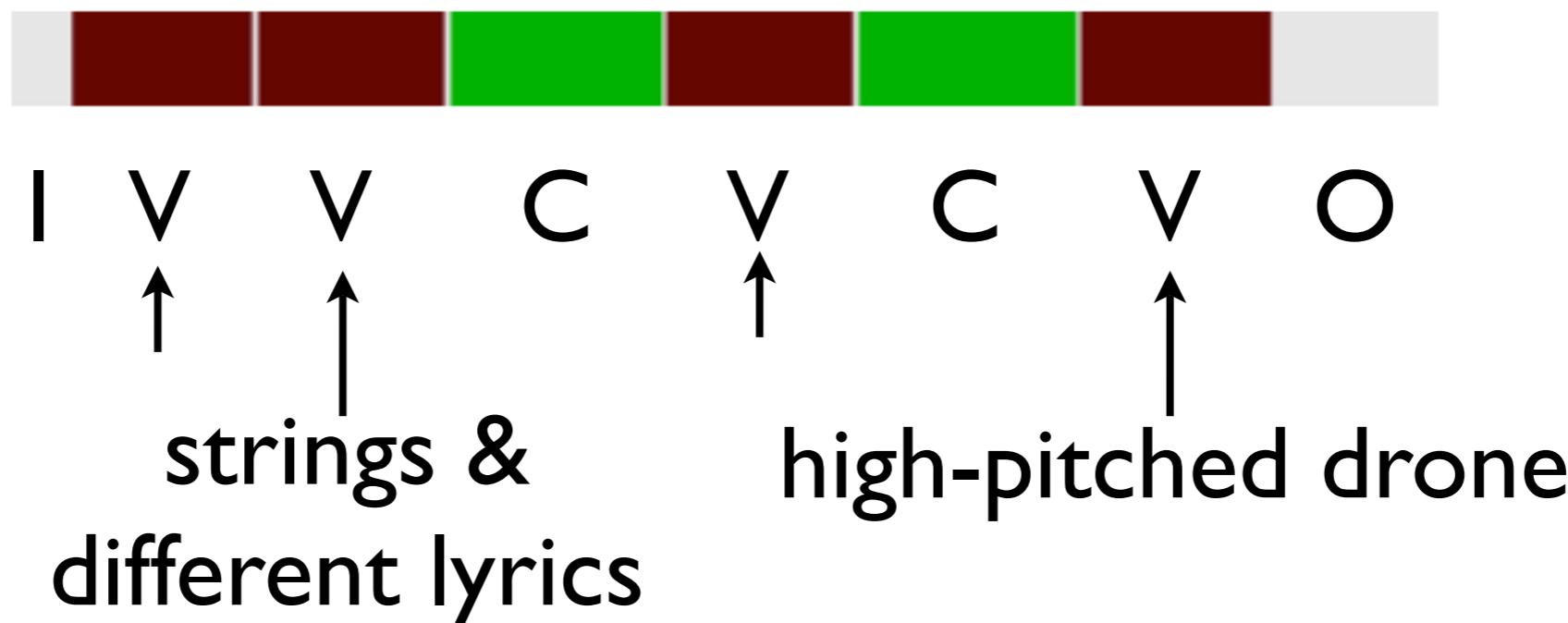
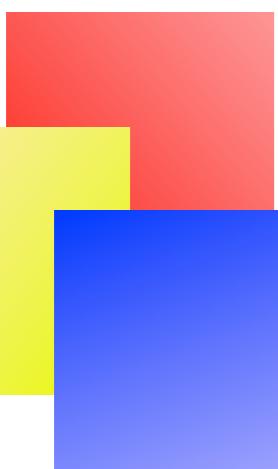


image: Chai 2005

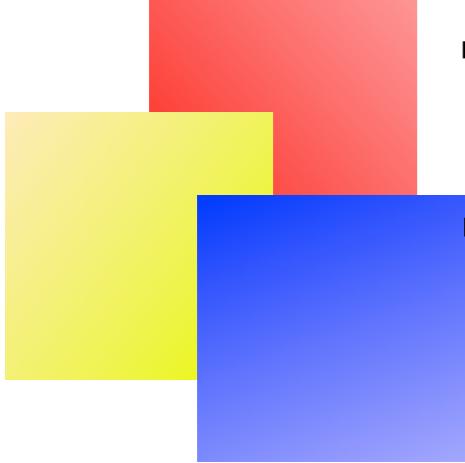
audio: “Yesterday,” by The Beatles

Outline

- Quick definition & Outline
- A brief history of segmentation:
Foote, Aucouturier
- Applications
- Future work



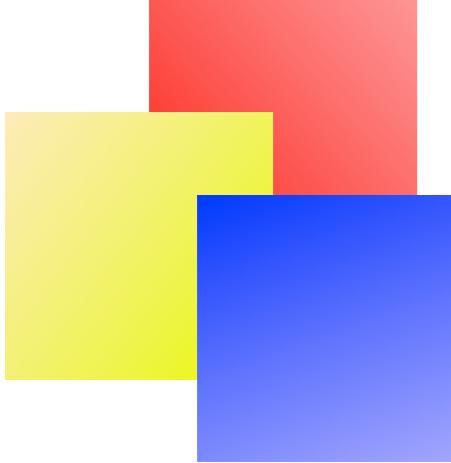
The Year 1999



The Year 1999

Question:

How can we analyze the
structure of a song
music without bothering
to listen to it?



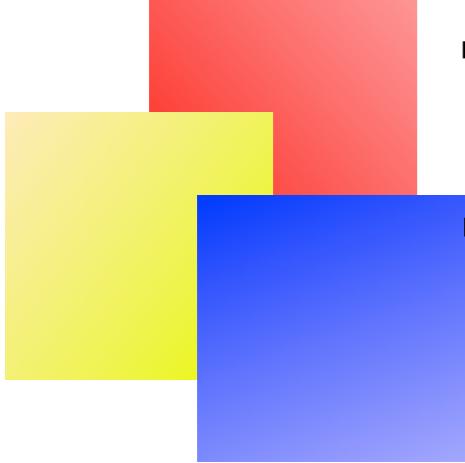
The Year 1999

Question:

How can we analyze the
structure of a song
music without bothering
to listen to it?

Answer:

Make a picture!



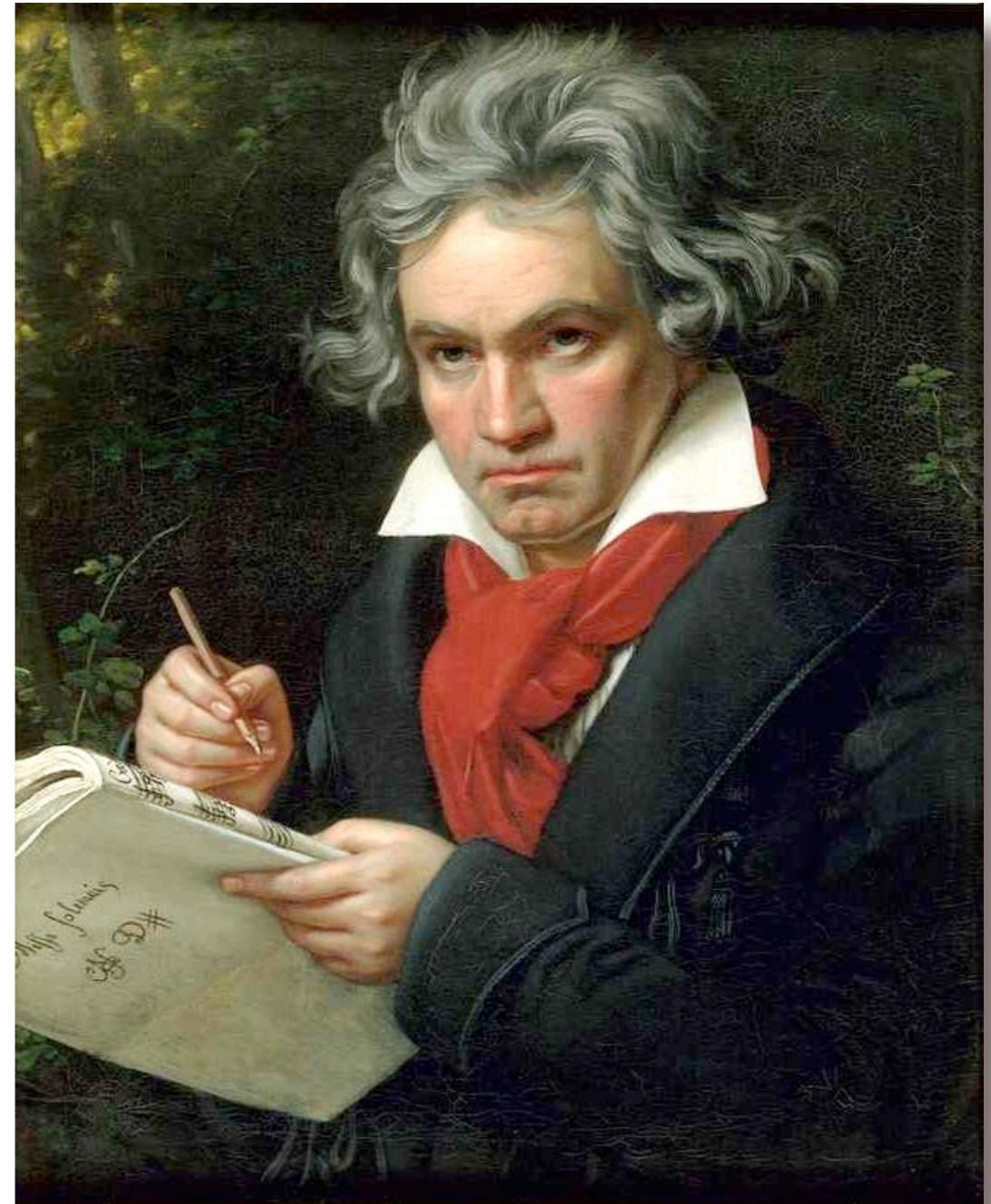
The Year 1999

Question:

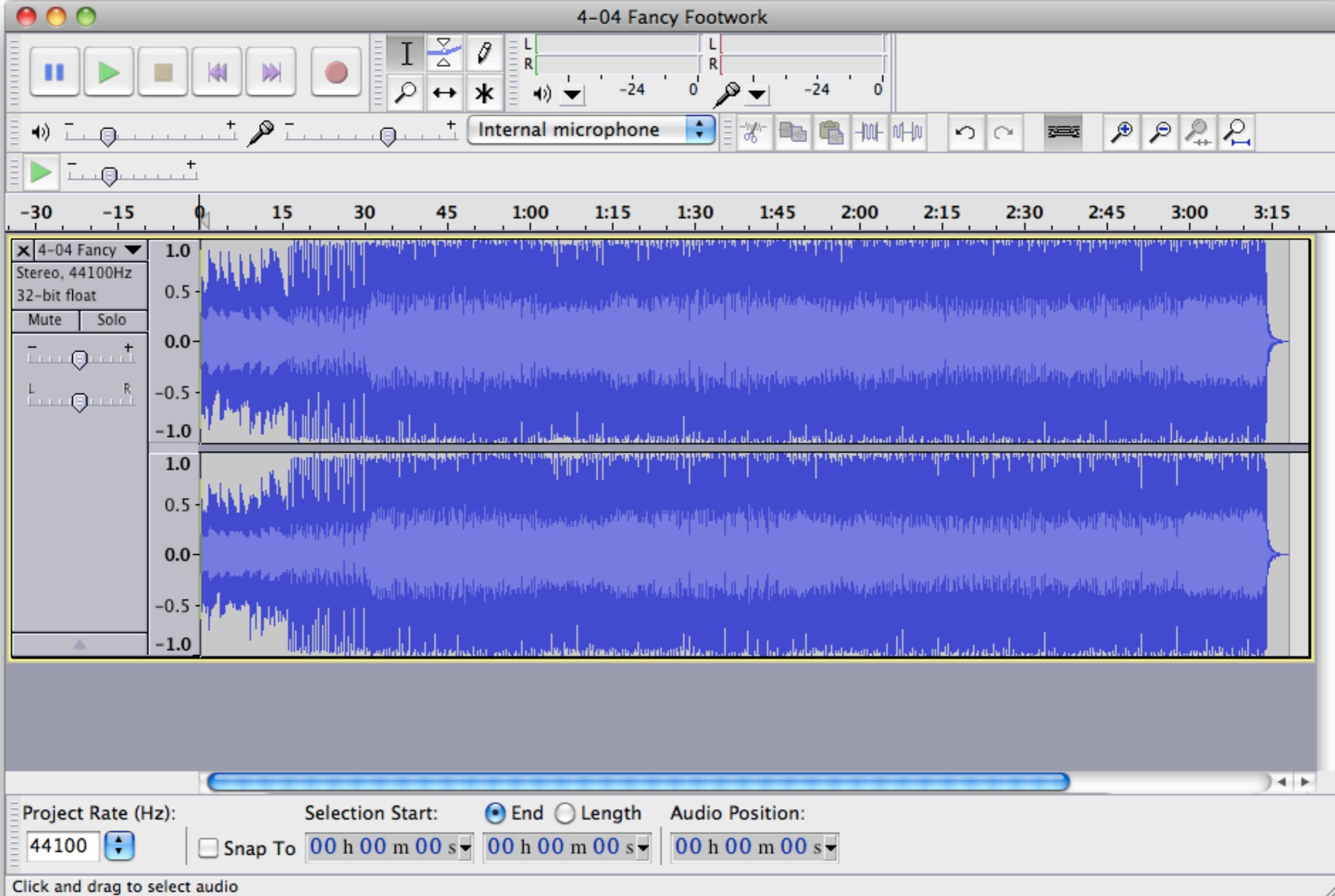
How can we analyze the structure of a song music without bothering to listen to it?

Answer:

Make a picture!



4-04 Fancy Footwork



audio: "Fancy Footwork" by Chromeo

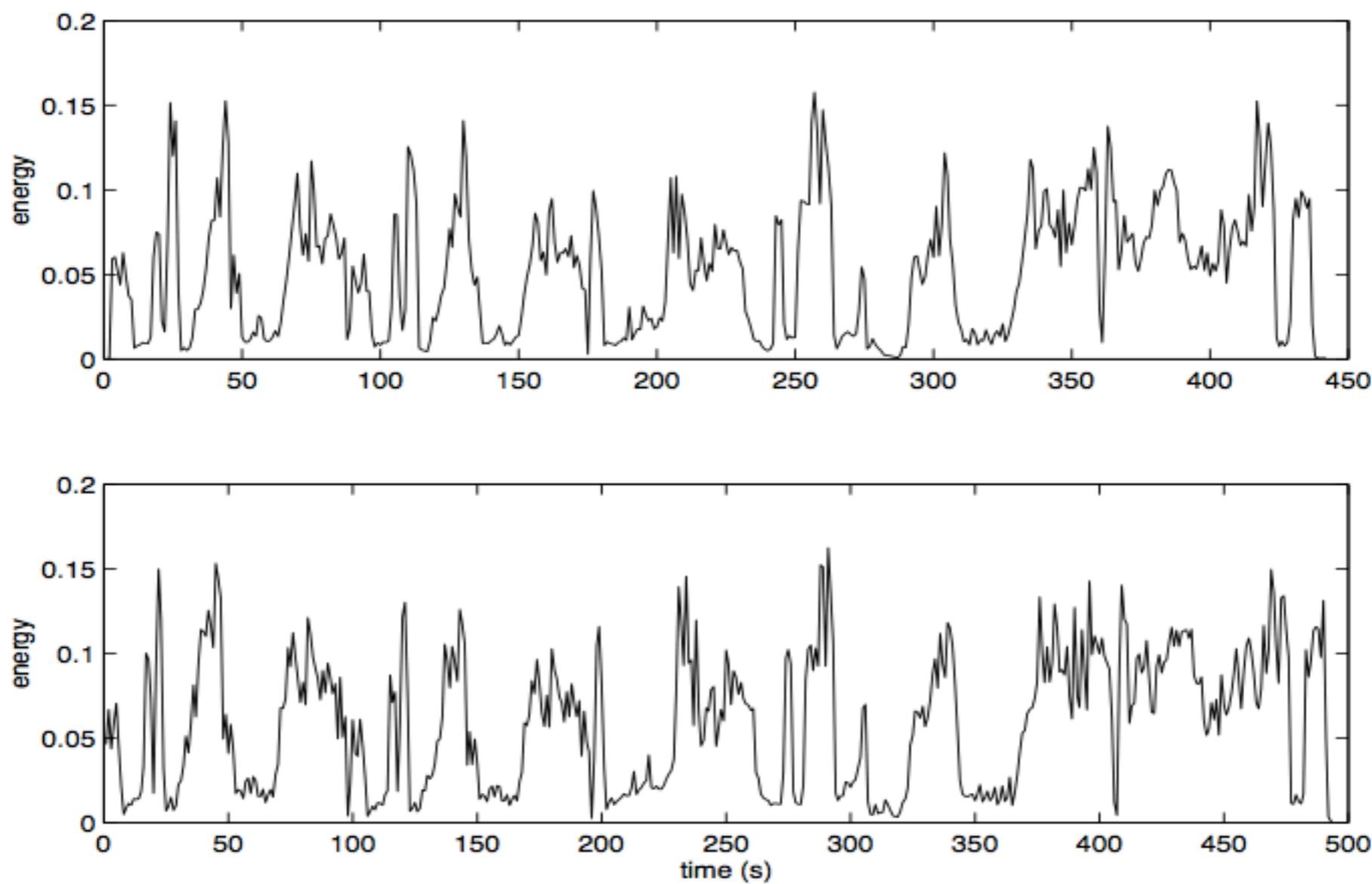


Figure 2. Energy profiles for two different performances of the first movement of Beethoven's *Fifth Symphony*
Top: Herbert von Karajan/Berliner Philharmoniker. Bottom: Eric Leinsdorf/Boston Symphony Orchestra.

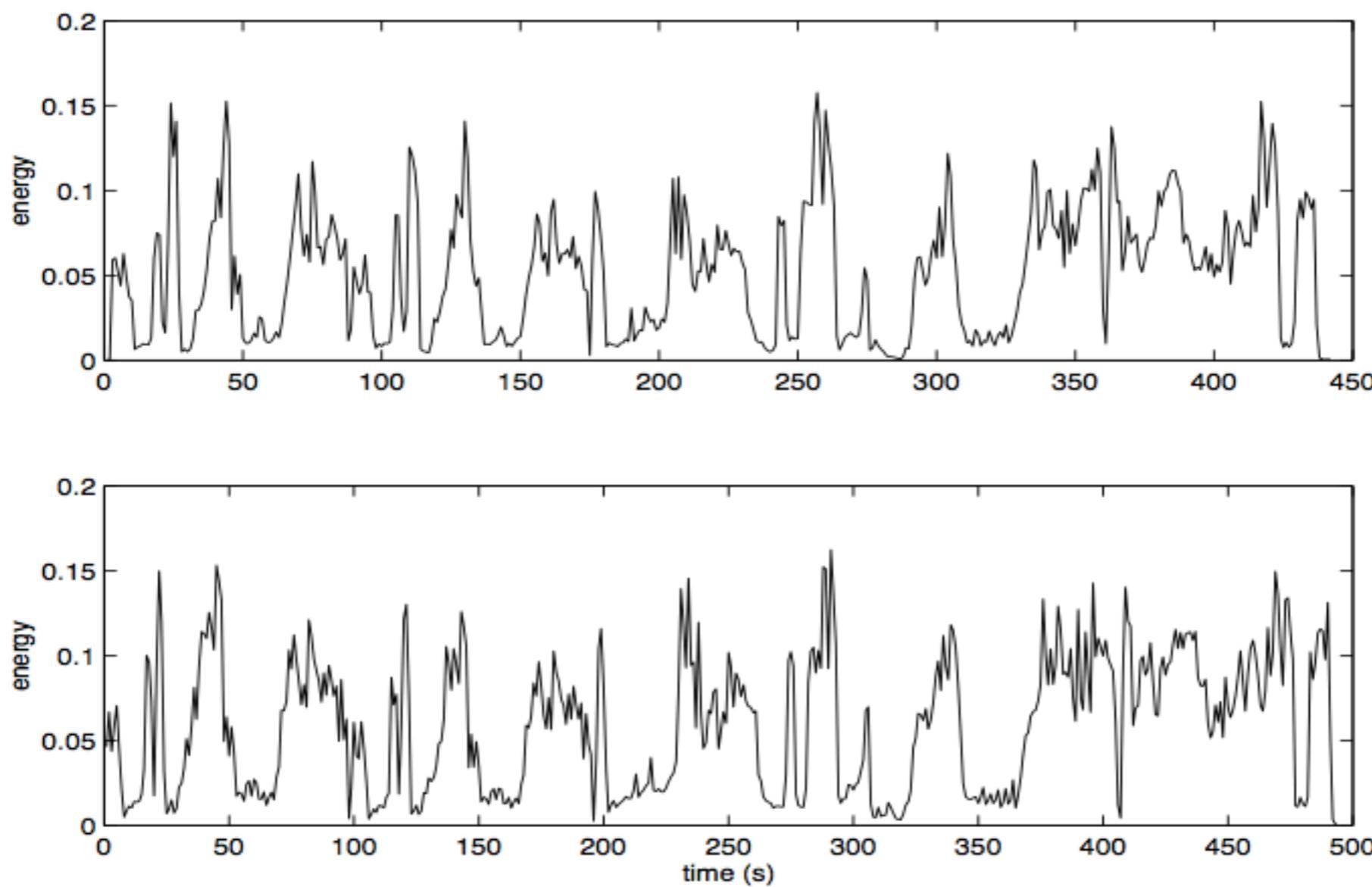
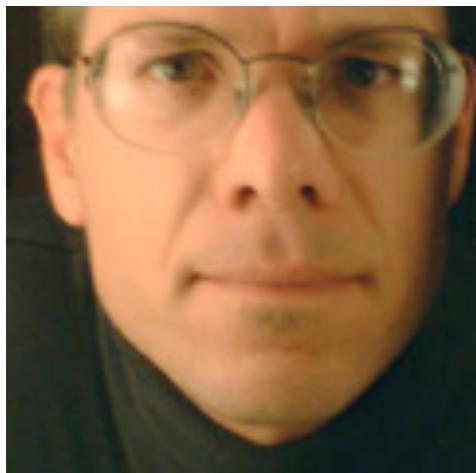


Figure 2. Energy profiles for two different performances of the first movement of Beethoven's *Fifth Symphony*
Top: Herbert von Karajan/Berliner Philharmoniker. Bottom: Eric Leinsdorf/Boston Symphony Orchestra.



Jonathan T. Foote

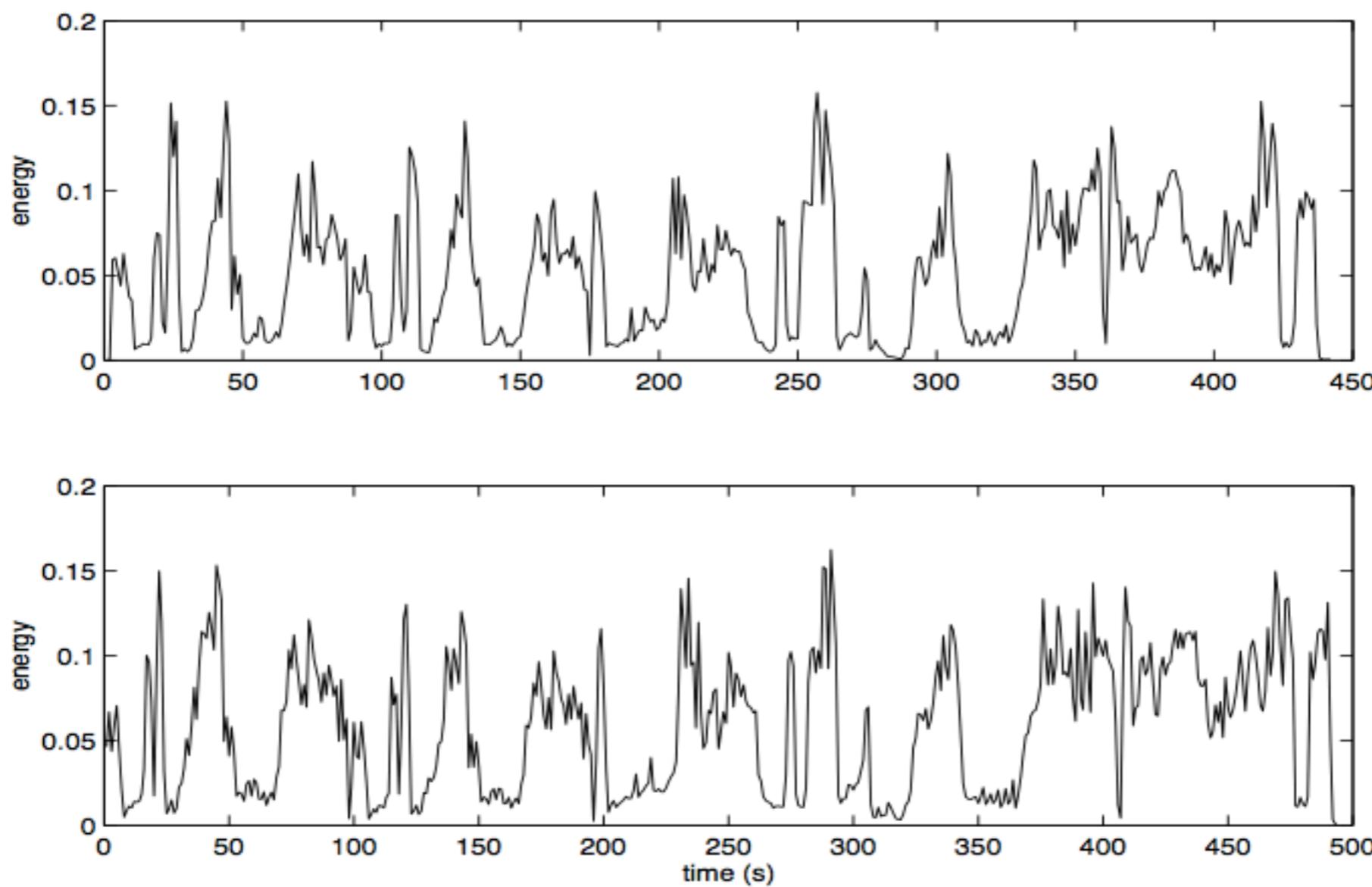
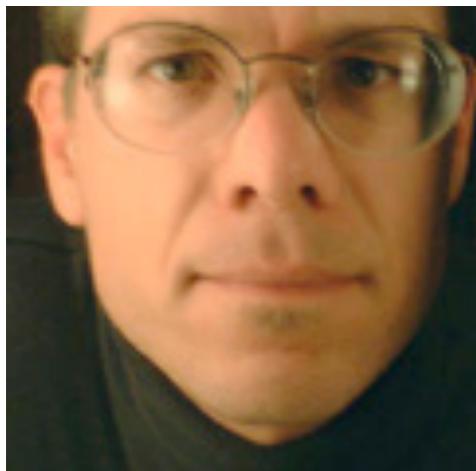


Figure 2. Energy profiles for two different performances of the first movement of Beethoven's *Fifth Symphony*
Top: Herbert von Karajan/Berliner Philharmoniker. Bottom: Eric Leinsdorf/Boston Symphony Orchestra.



Jonathan T. Foote

ARTHUR



Spectrogram: Foote 2000

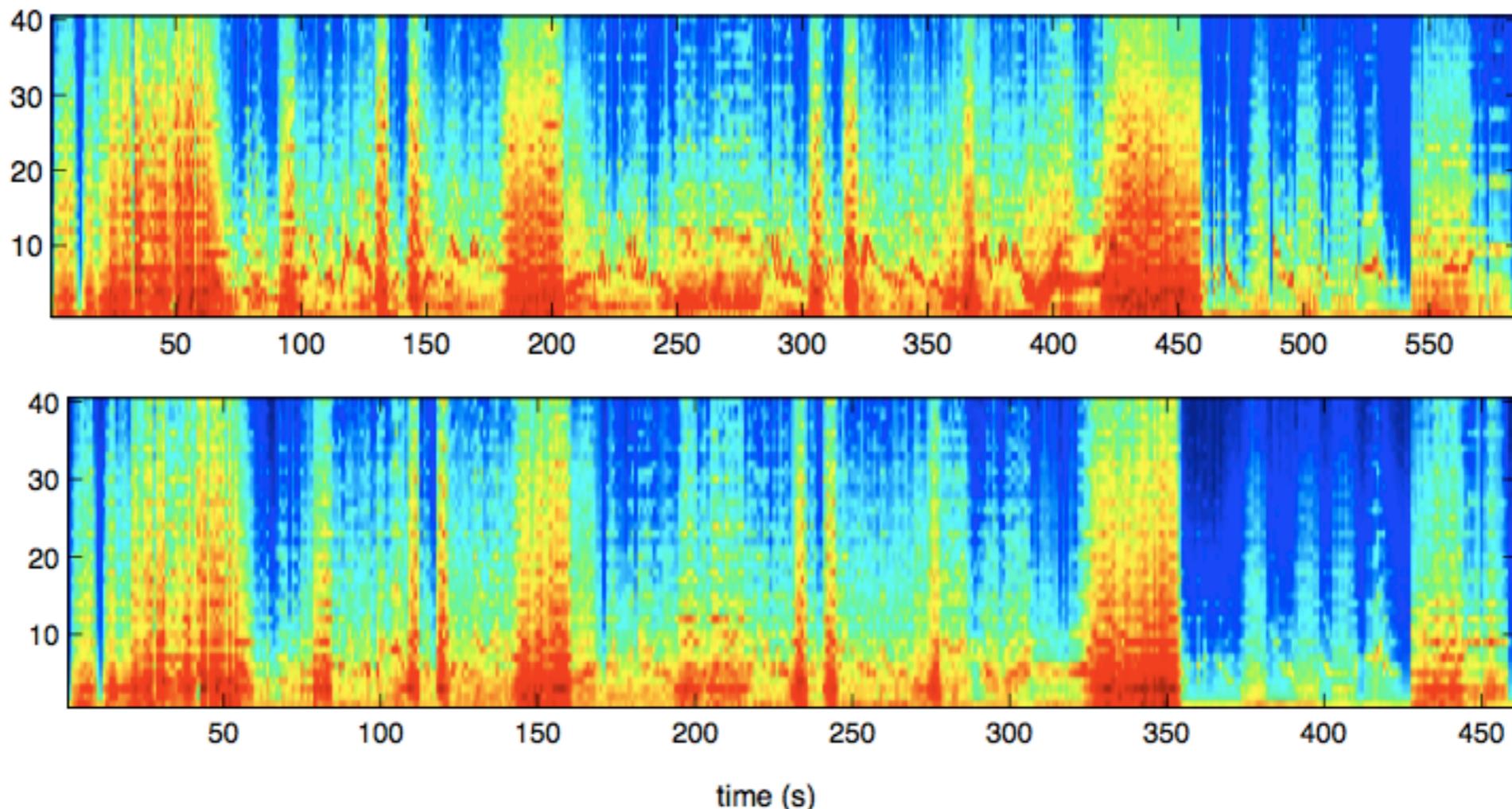


Figure 4. Spectrograms of different performances of the second movement of Beethoven's *Piano Concerto No. 2*.
Top: Arthur Rubenstein/Erich Leinsdorf. Bottom: Robert Levin/John Eliot Gardiner.

Spectrogram: Foote 2000

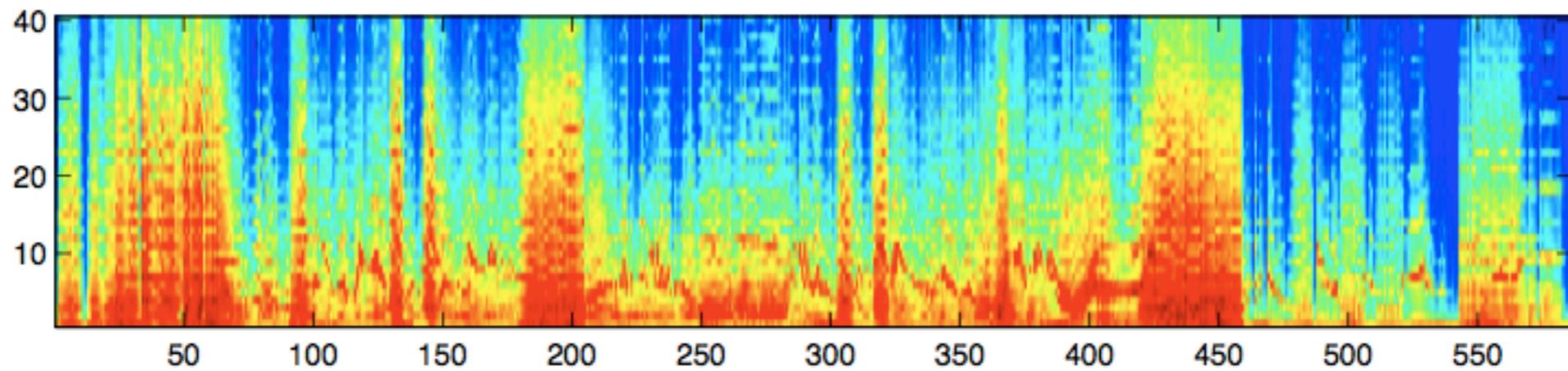


Image: Foote and Cooper 2003

Spectrogram: Foote 2000

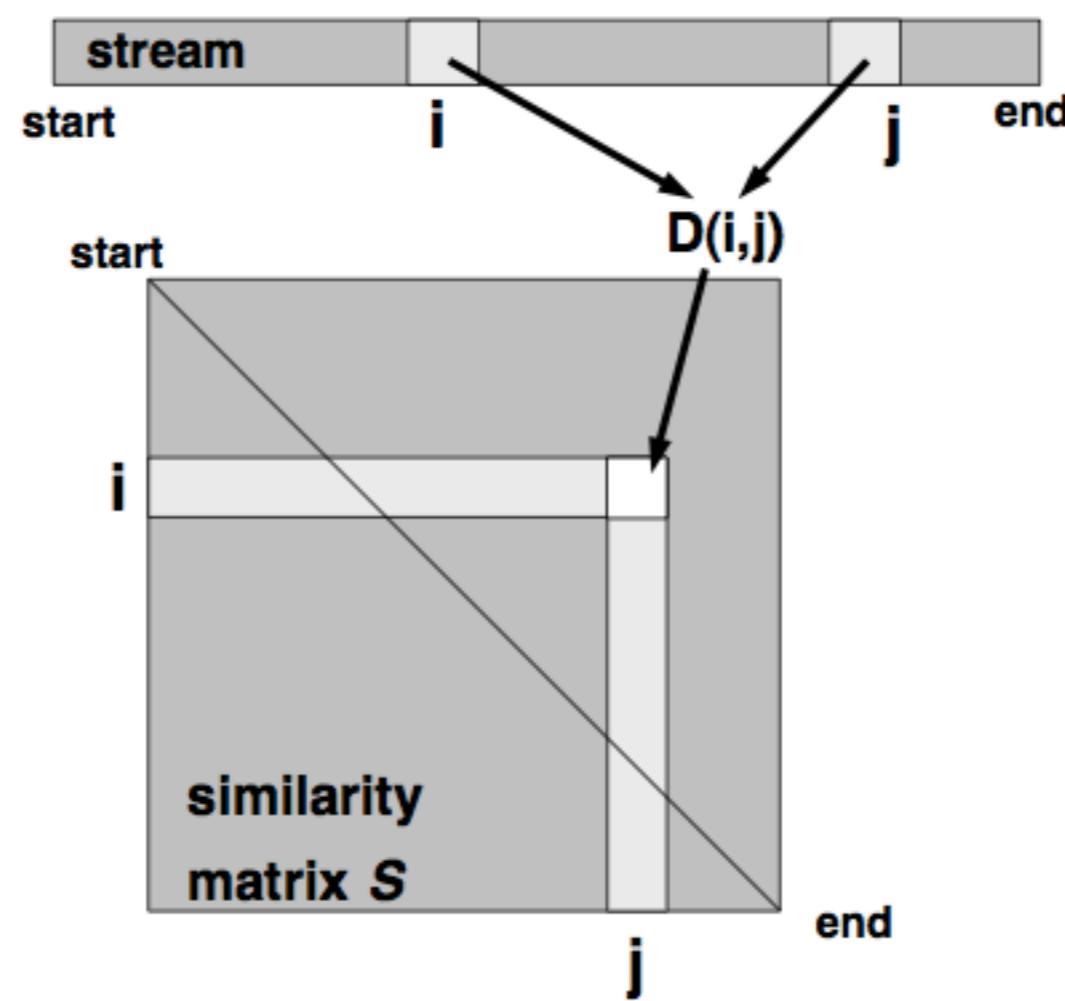
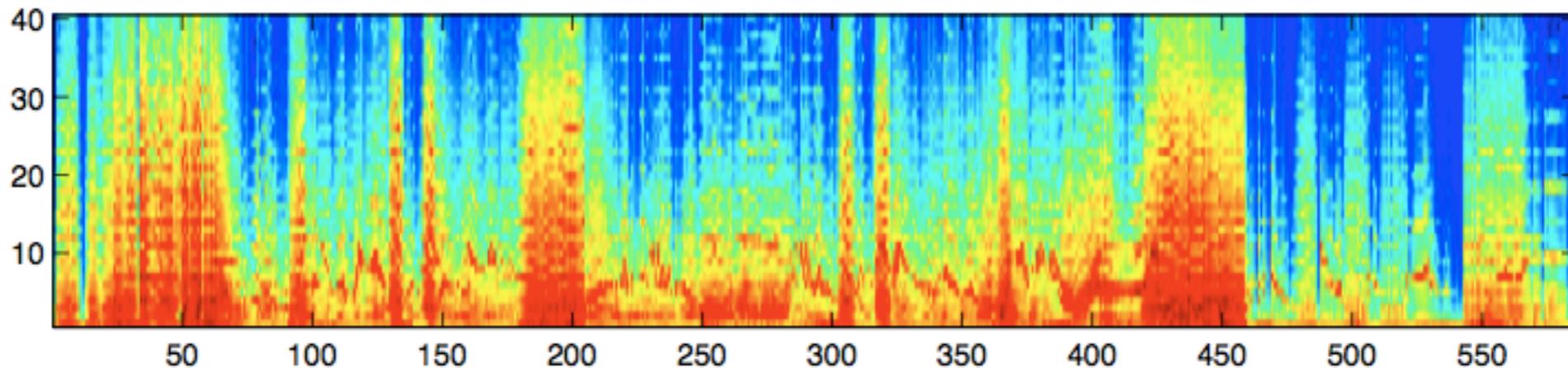


Image: Foote and Cooper 2003

Spectrogram: Foote 2000

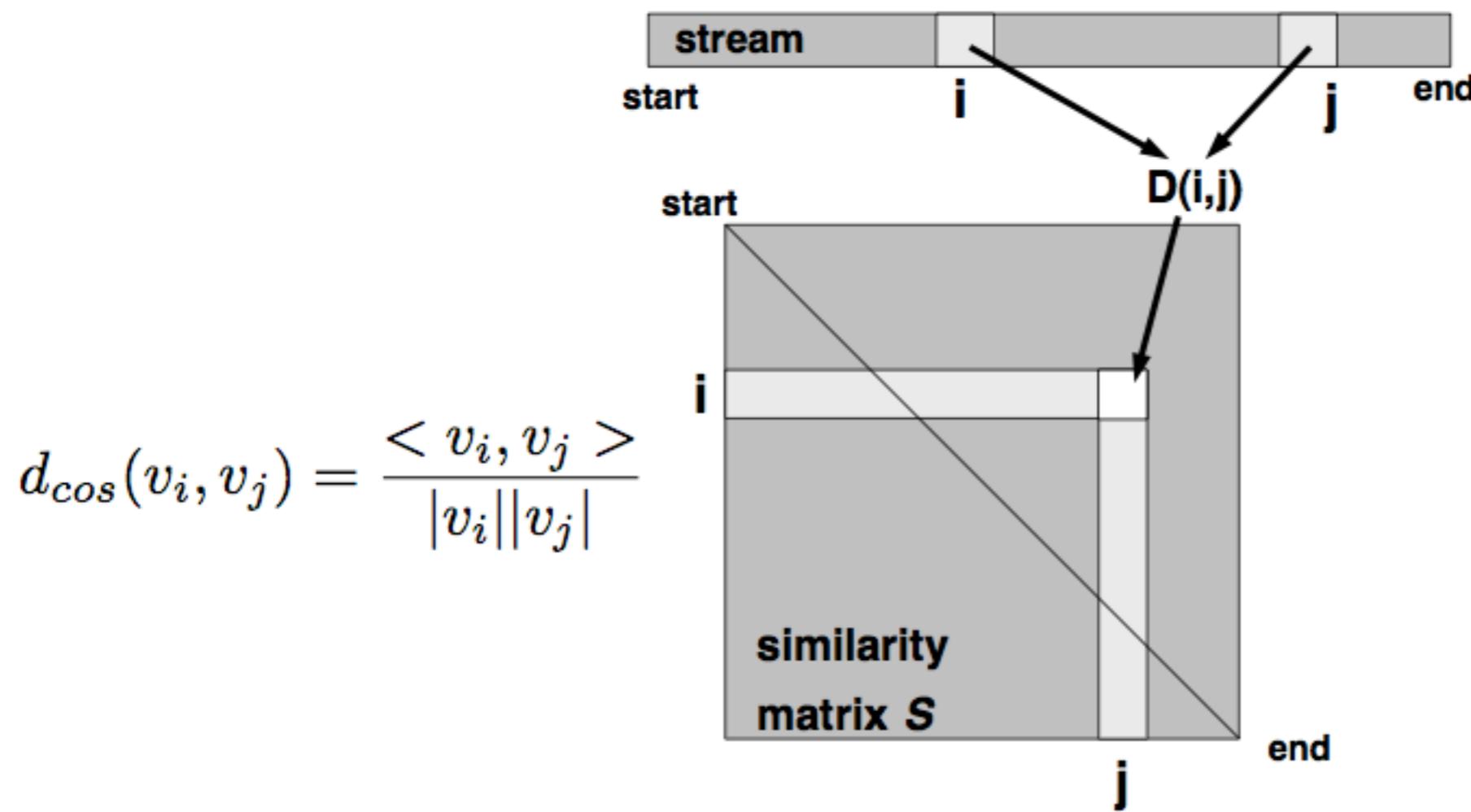
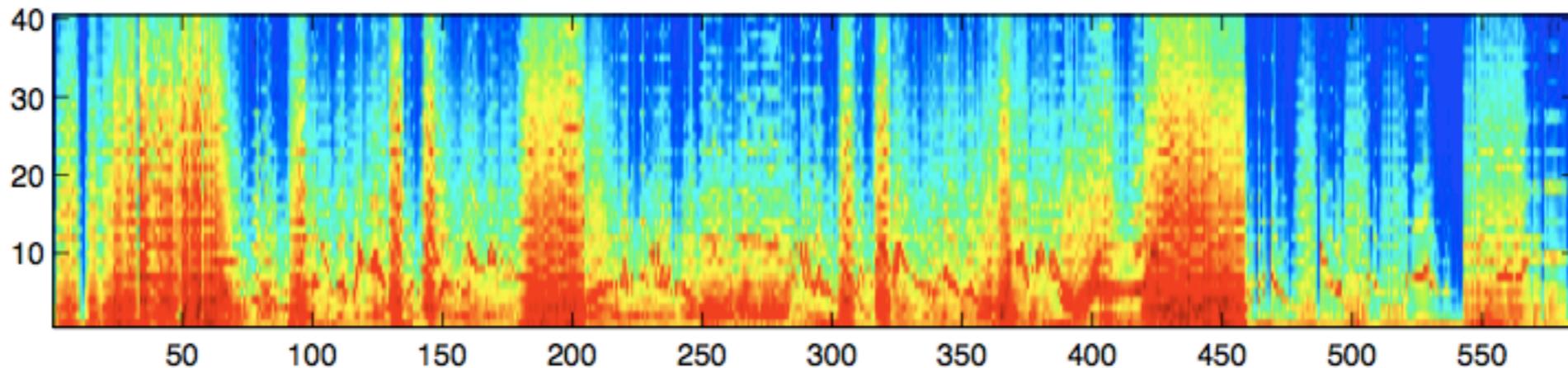


Image: Foote and Cooper 2003

Spectrogram: Foote 2000

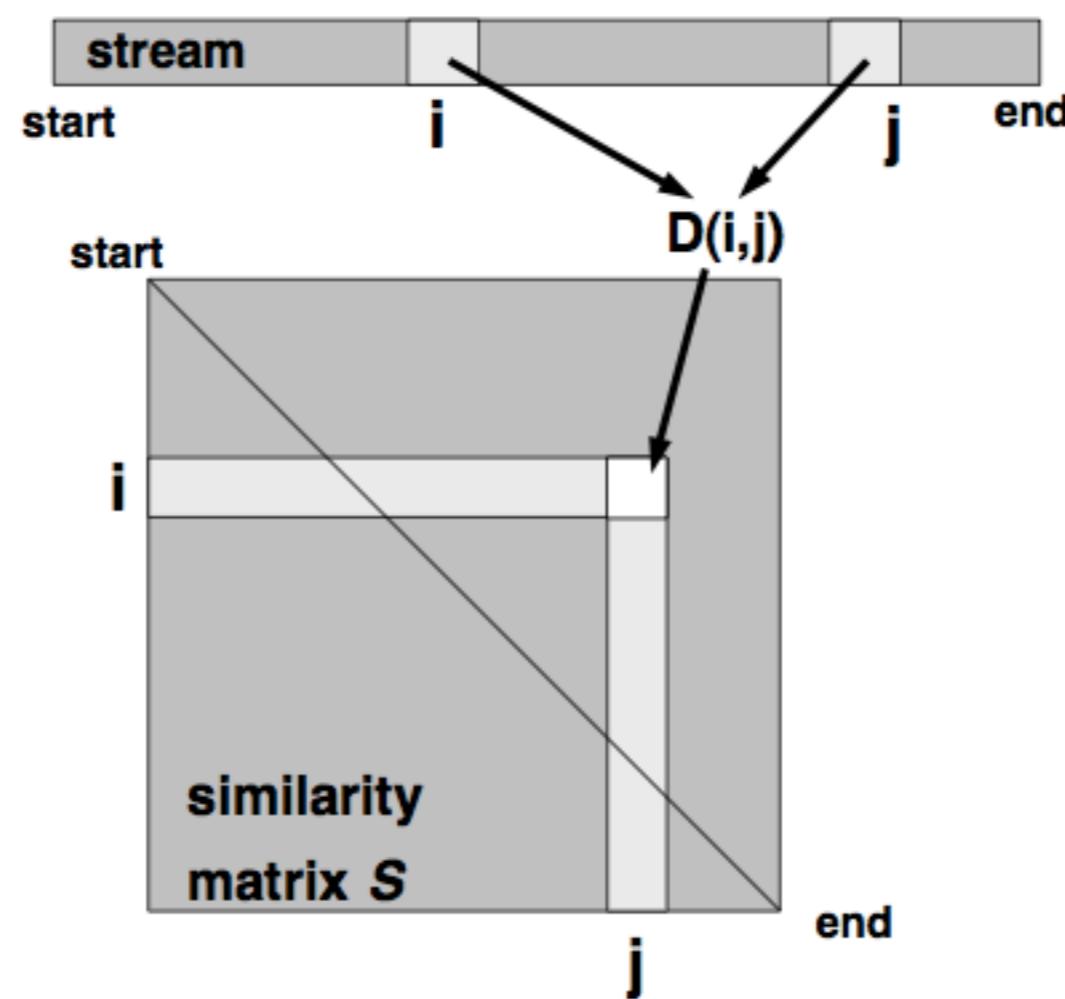
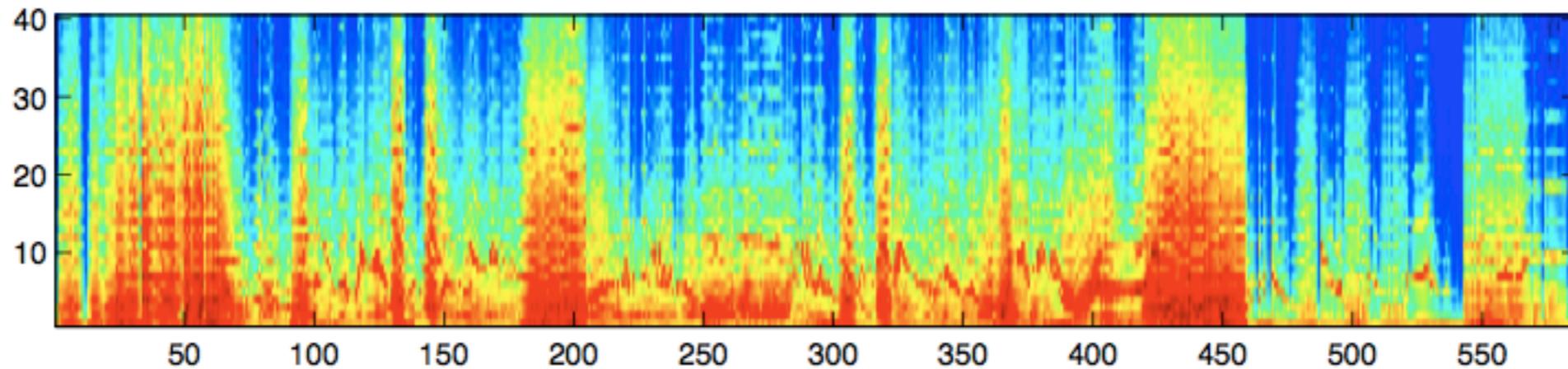


Image: Foote and Cooper 2003

Spectrogram: Foote 2000

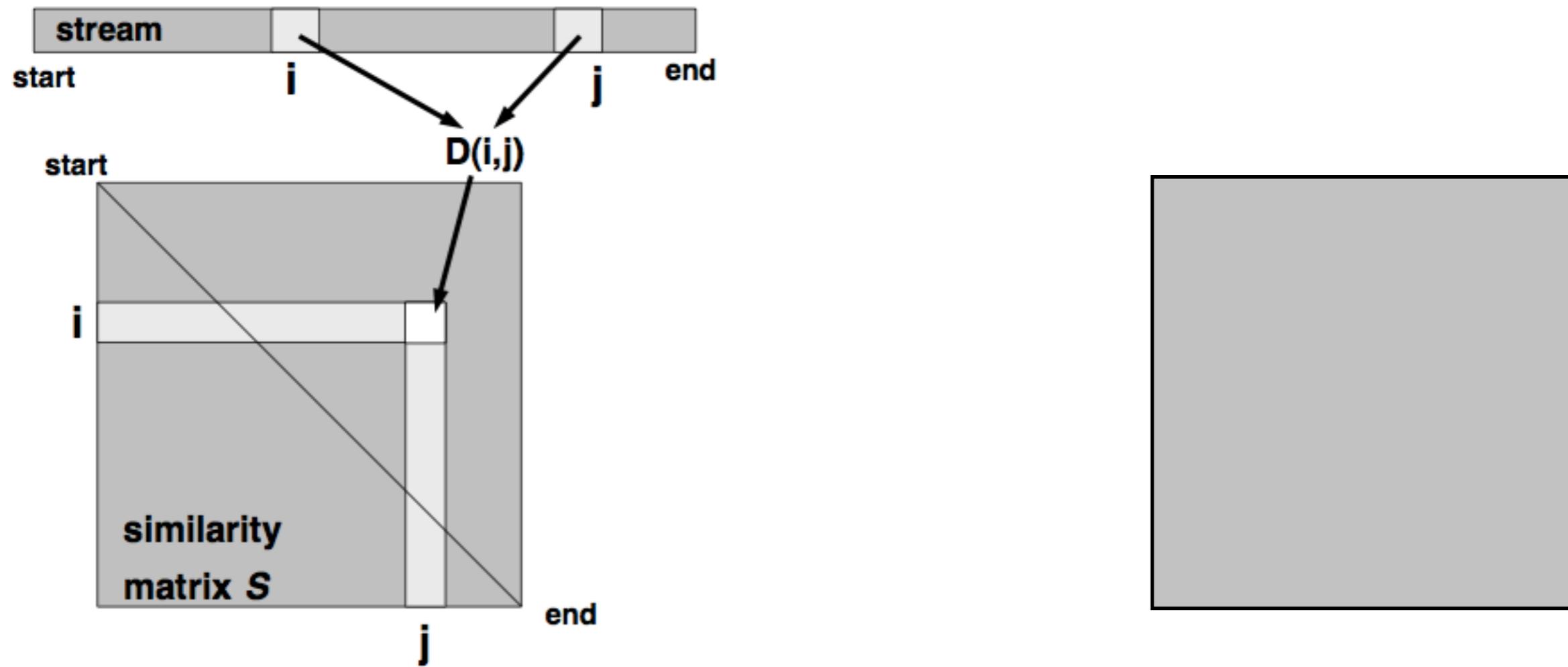
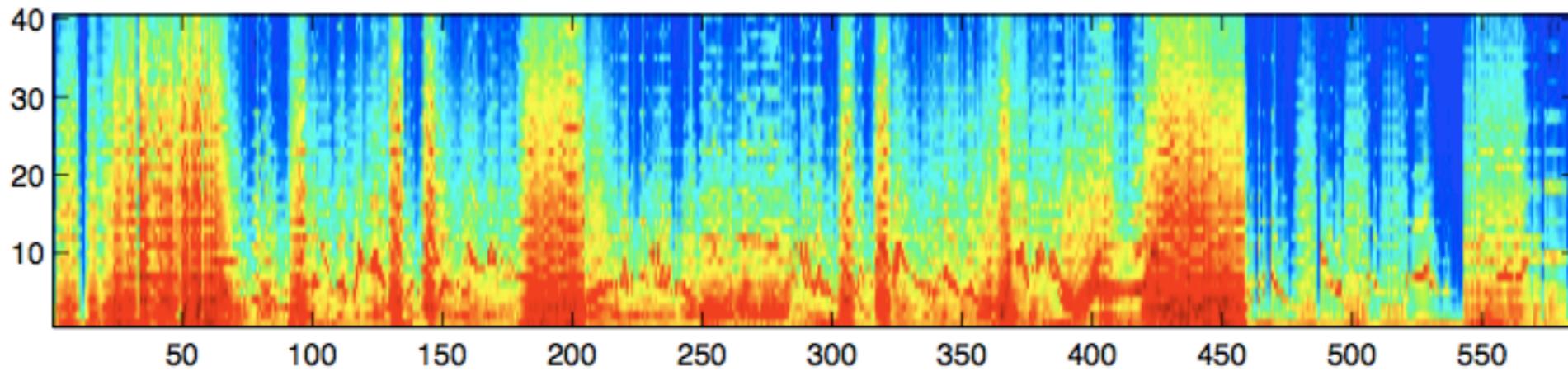


Image: Foote and Cooper 2003

Spectrogram: Foote 2000

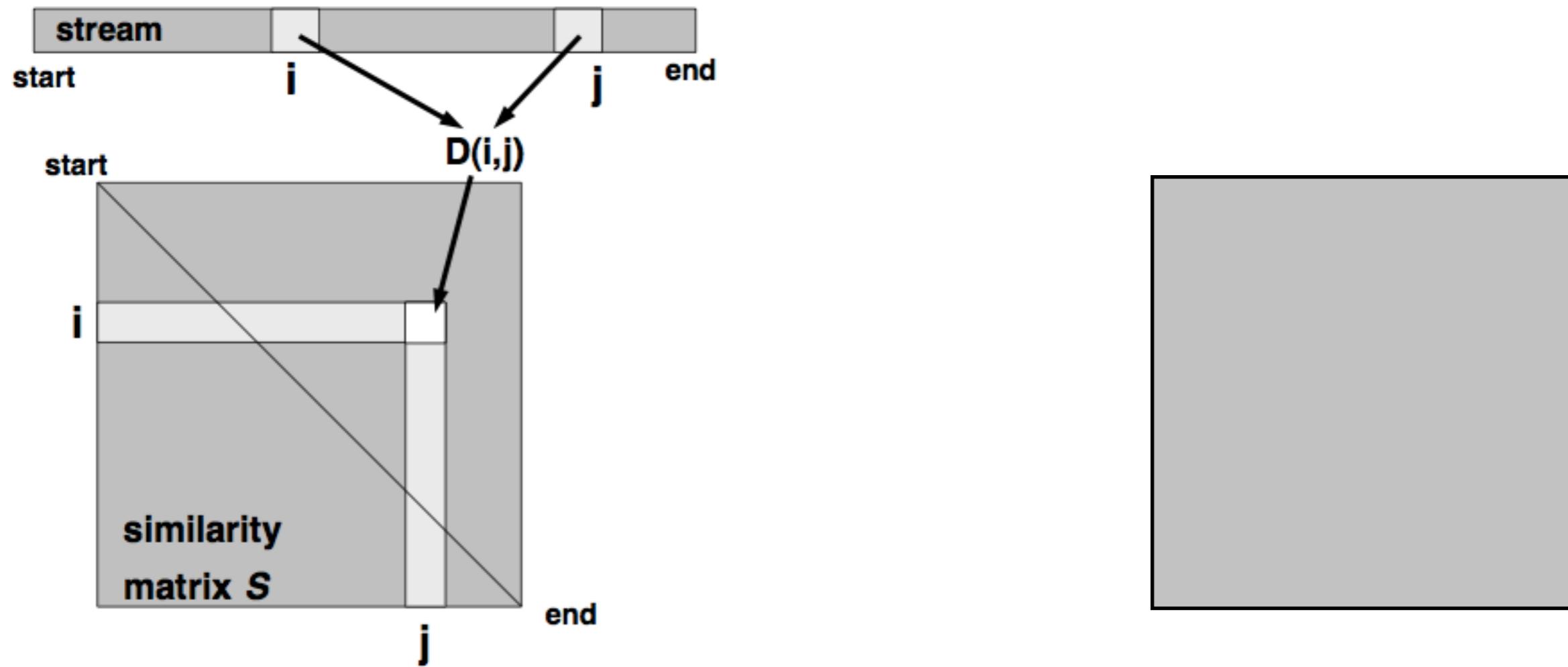
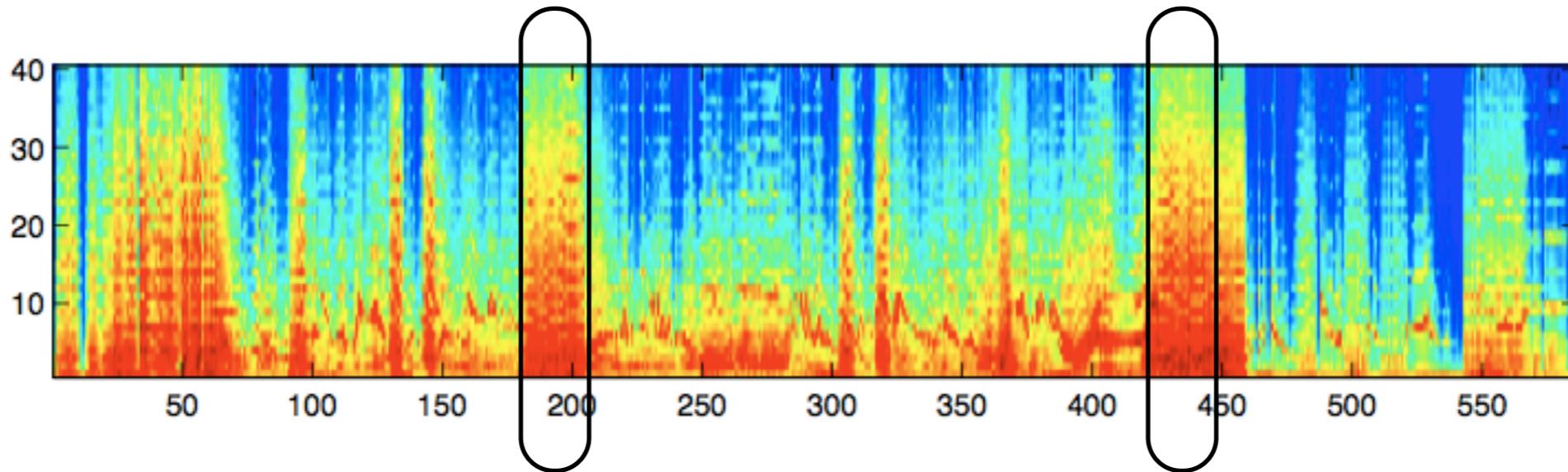
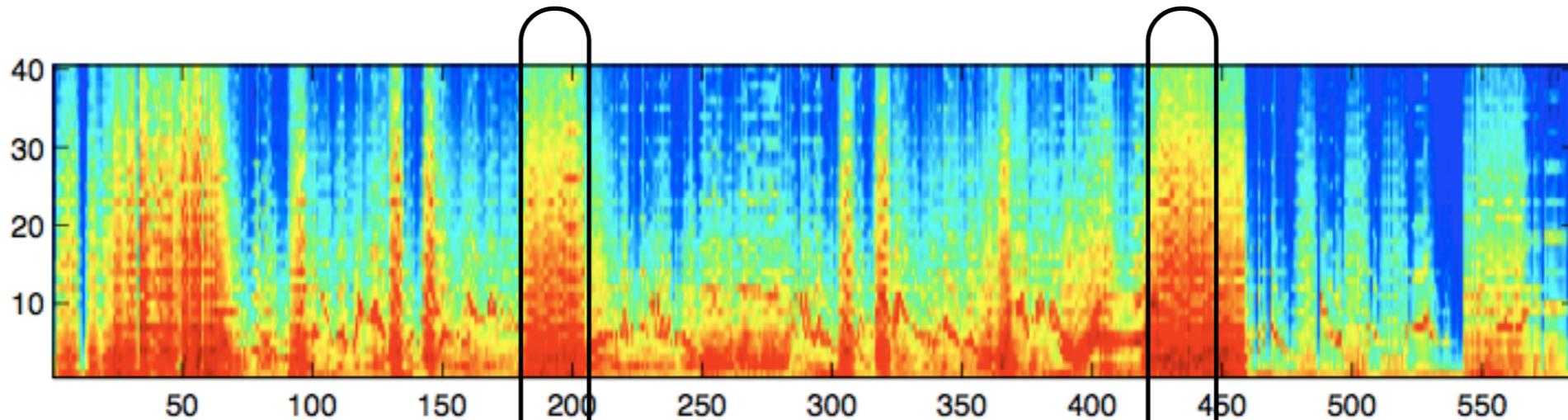
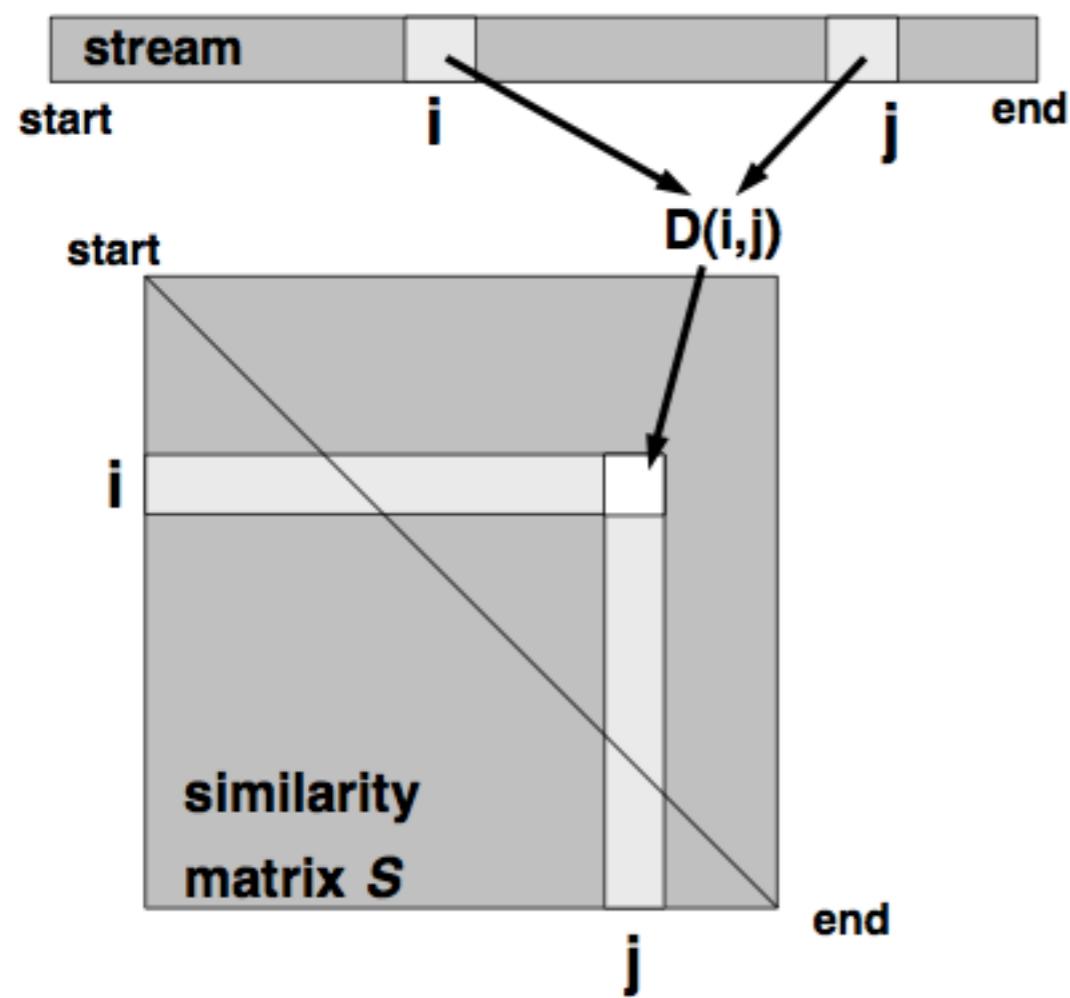


Image: Foote and Cooper 2003

Spectrogram: Foote 2000



0.9



Spectrogram: Foote 2000

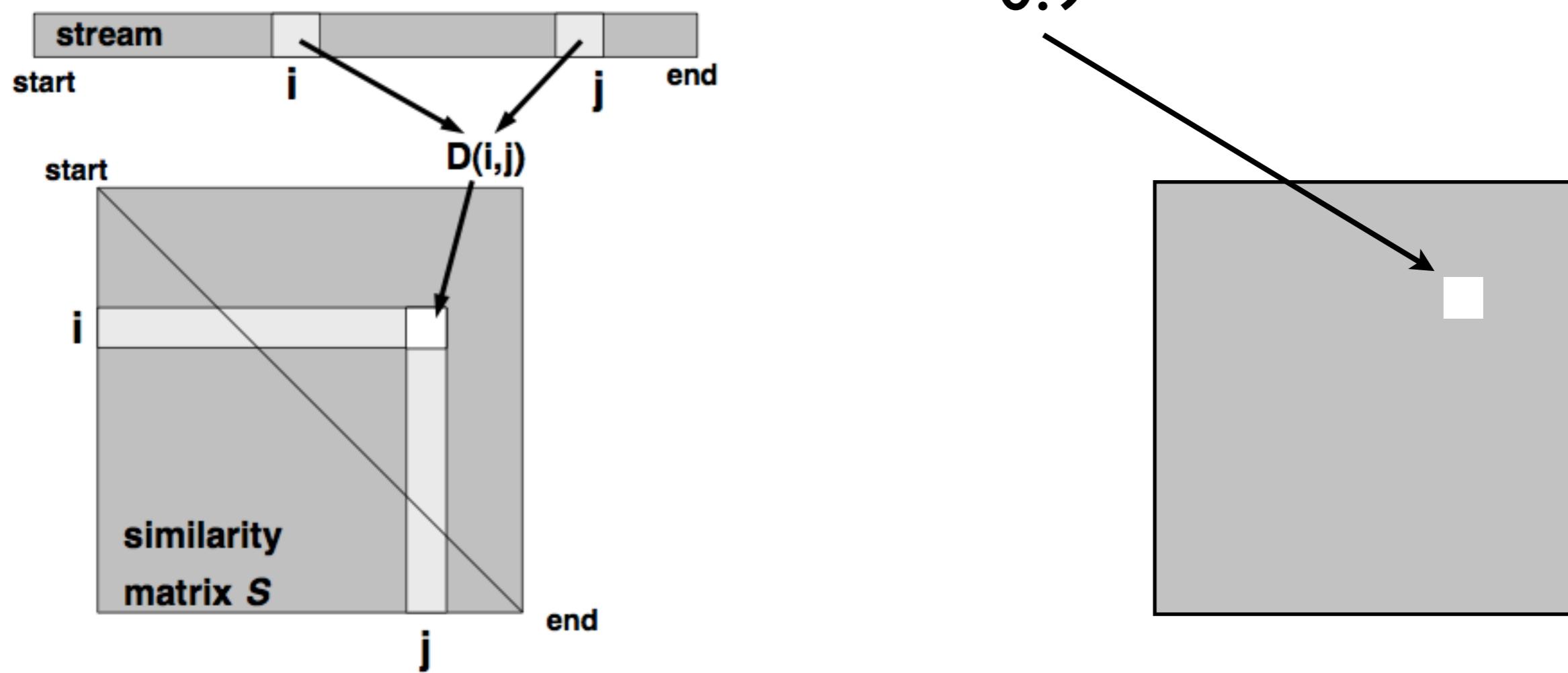
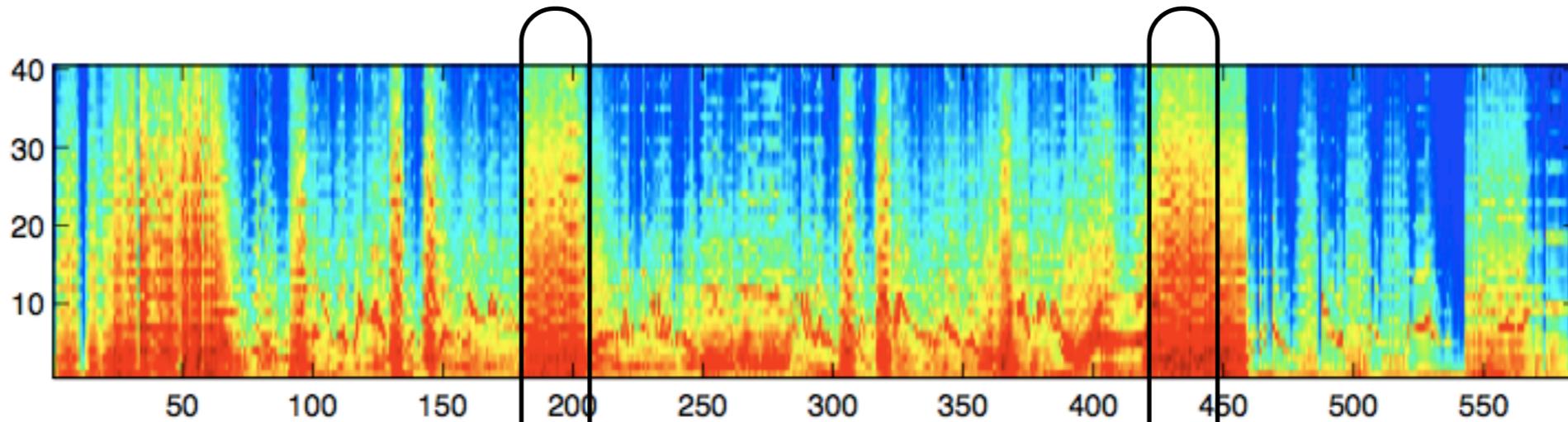


Image: Foote and Cooper 2003

Spectrogram: Foote 2000

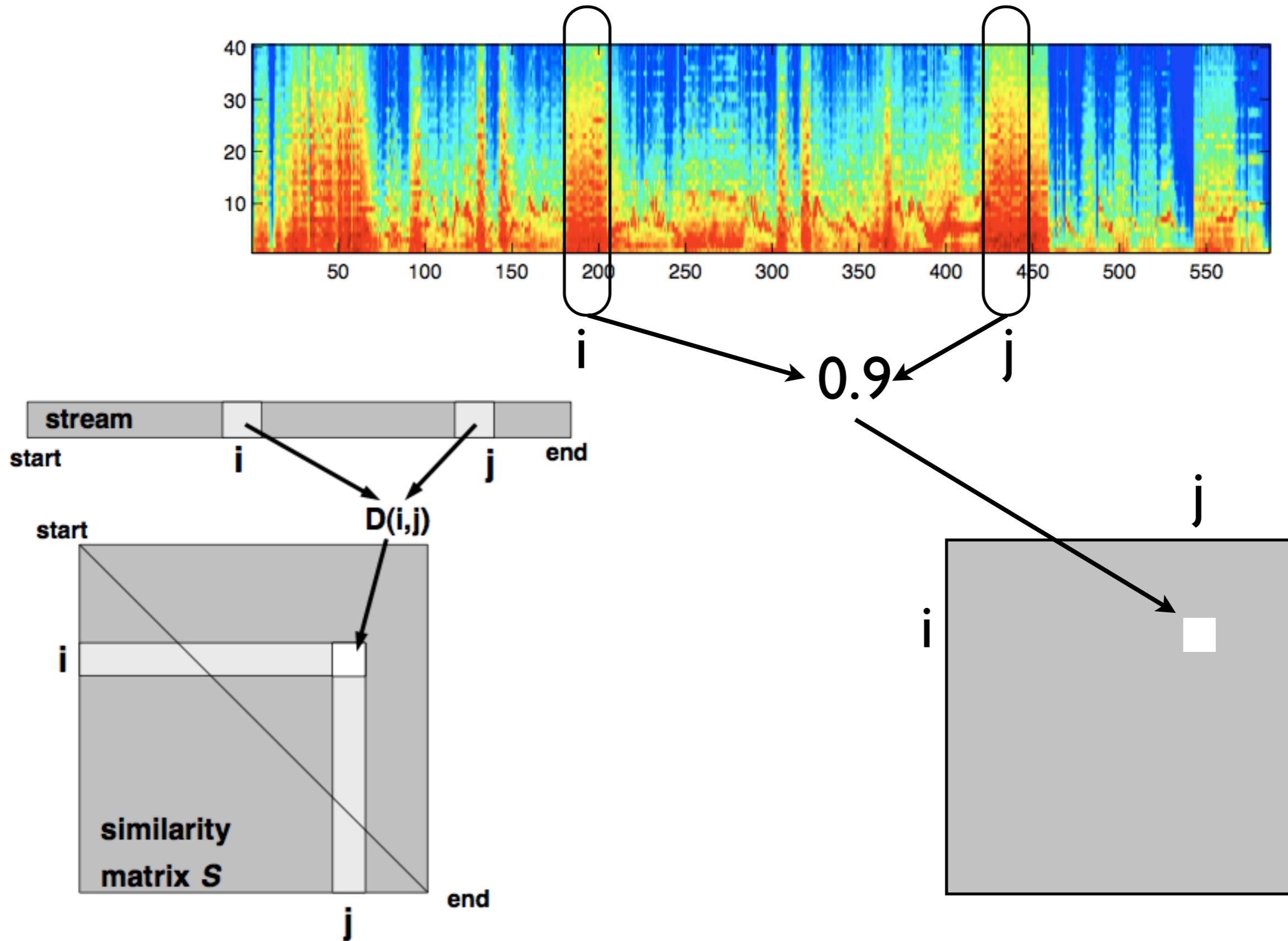


Image: Foote and Cooper 2003

Spectrogram: Foote 2000

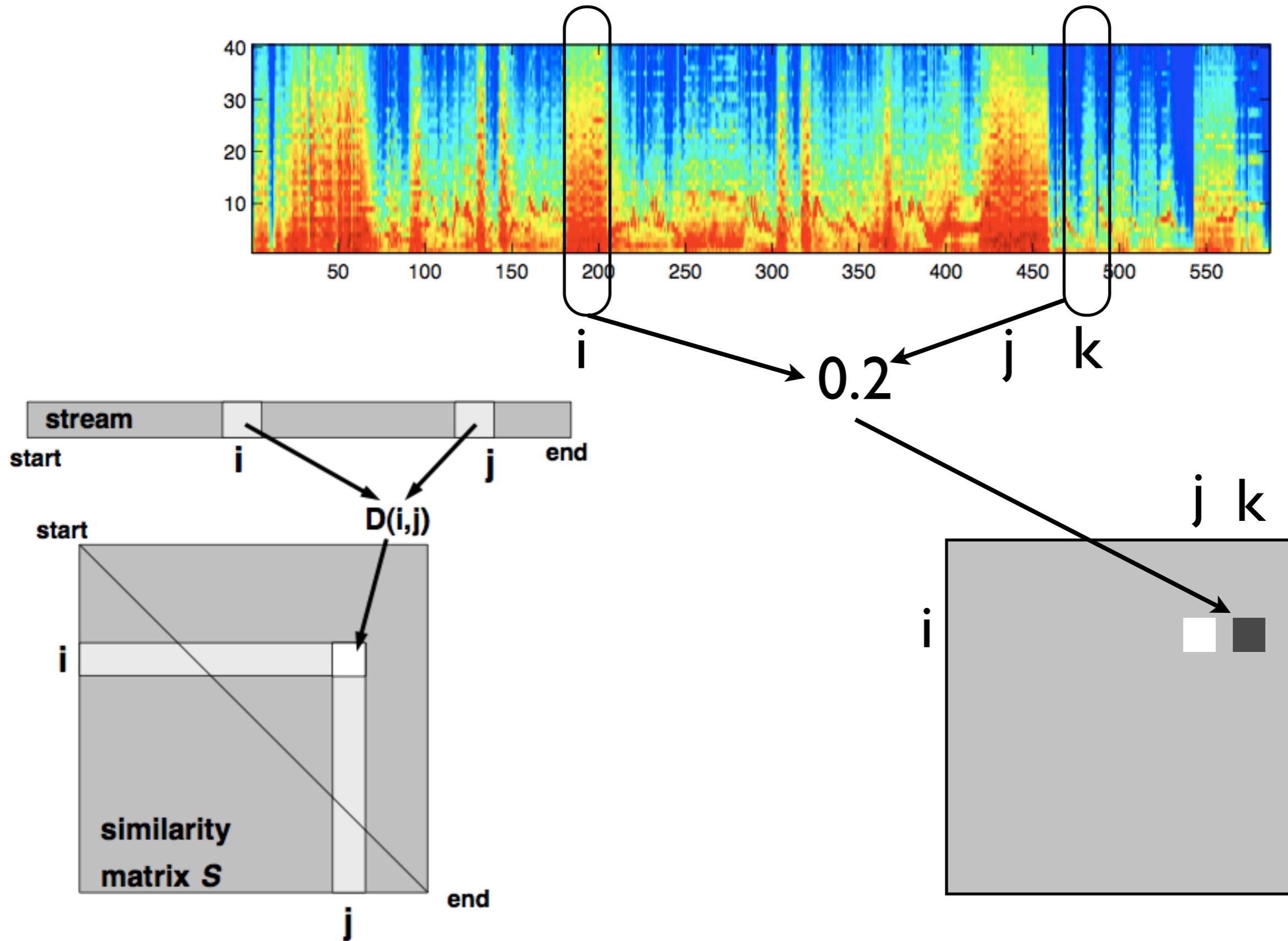


Image: Foote and Cooper 2003

Similarity Matrices

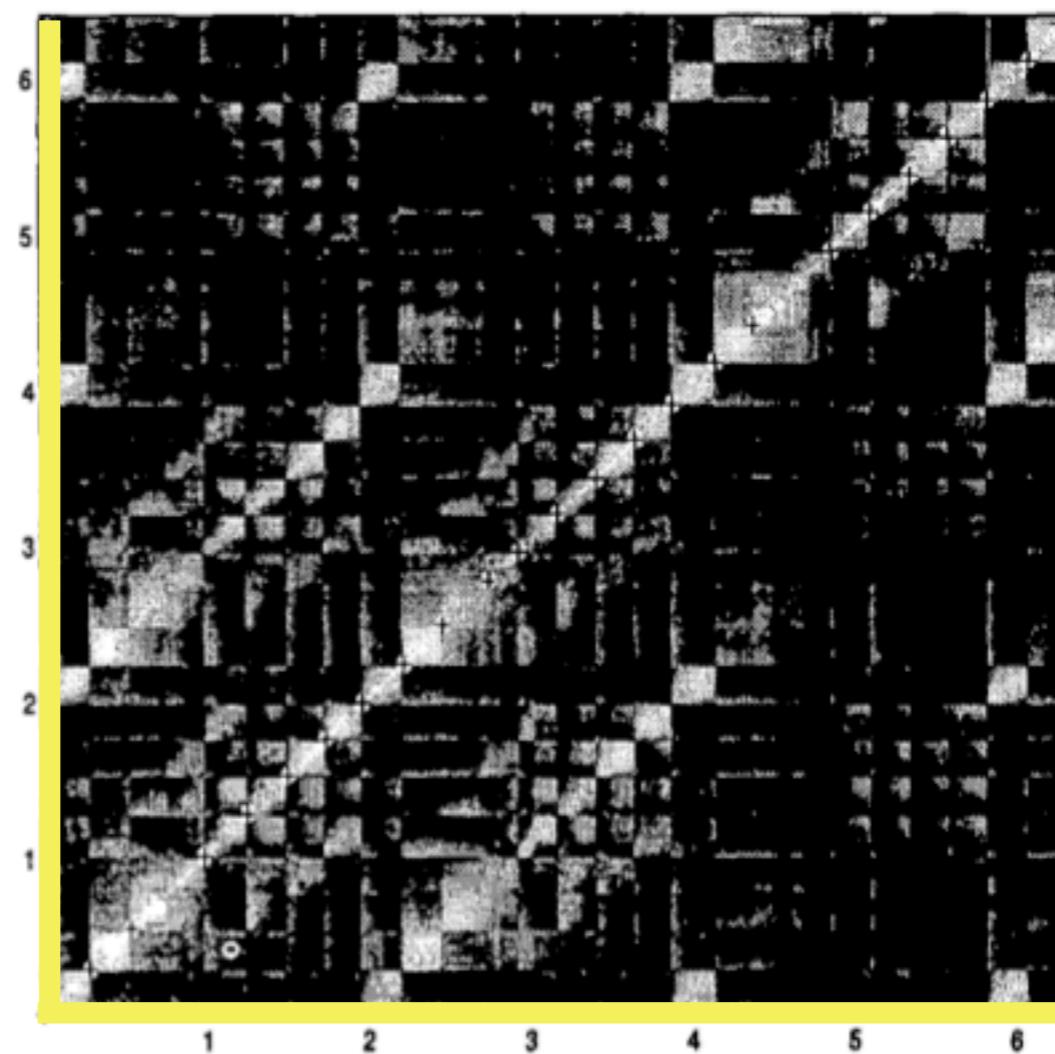


Figure 2. Gould performance showing note boundaries

image: Foote 1999
audio: <http://youtube.com/watch?v=bOTW2VS4w5w>

Similarity Matrices

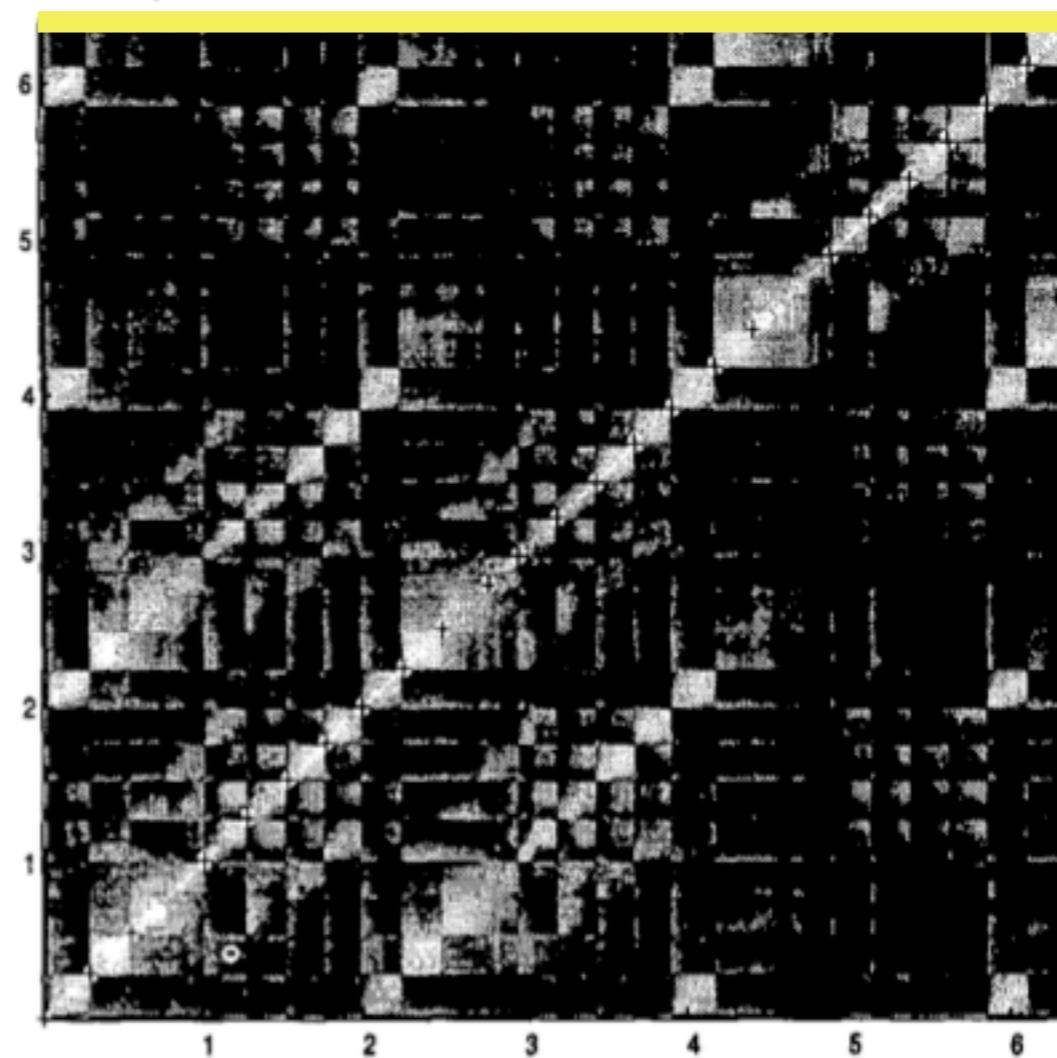


Figure 2. Gould performance showing note boundaries

image: Foote 1999

audio: <http://youtube.com/watch?v=bOTW2VS4w5w>

Similarity Matrices

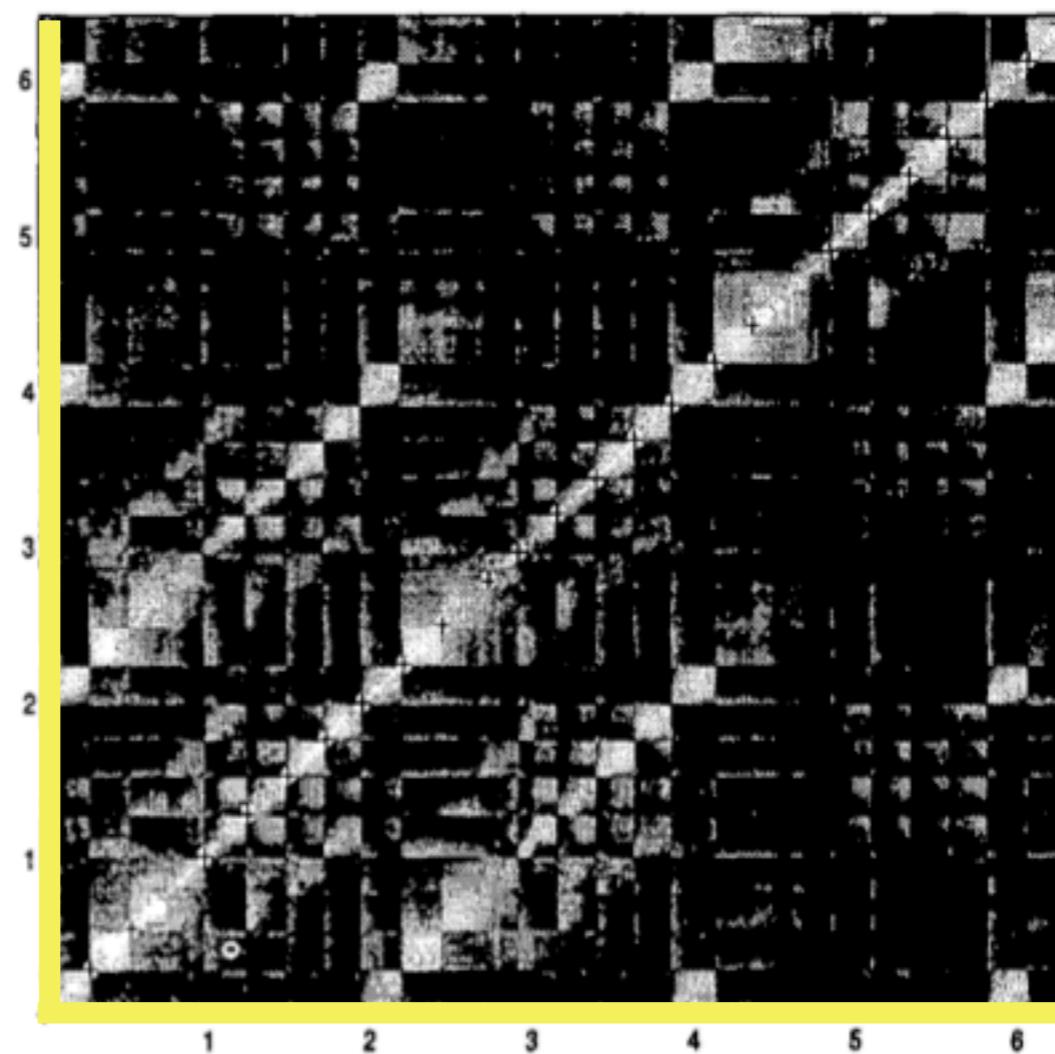


Figure 2. Gould performance showing note boundaries

image: Foote 1999
audio: <http://youtube.com/watch?v=bOTW2VS4w5w>

Similarity Matrices

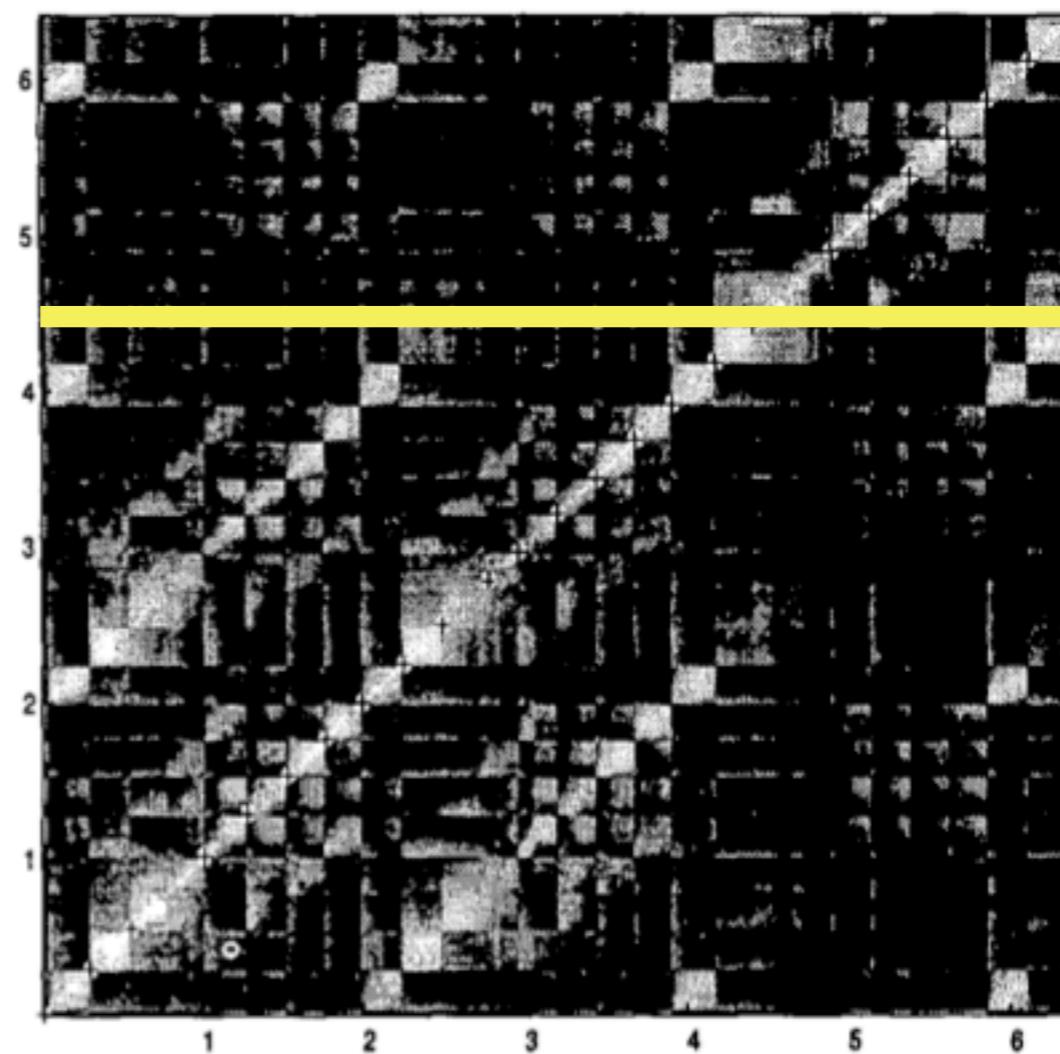


Figure 2. Gould performance showing note boundaries

image: Foote 1999

audio: <http://youtube.com/watch?v=bOTW2VS4w5w>

Similarity Matrices

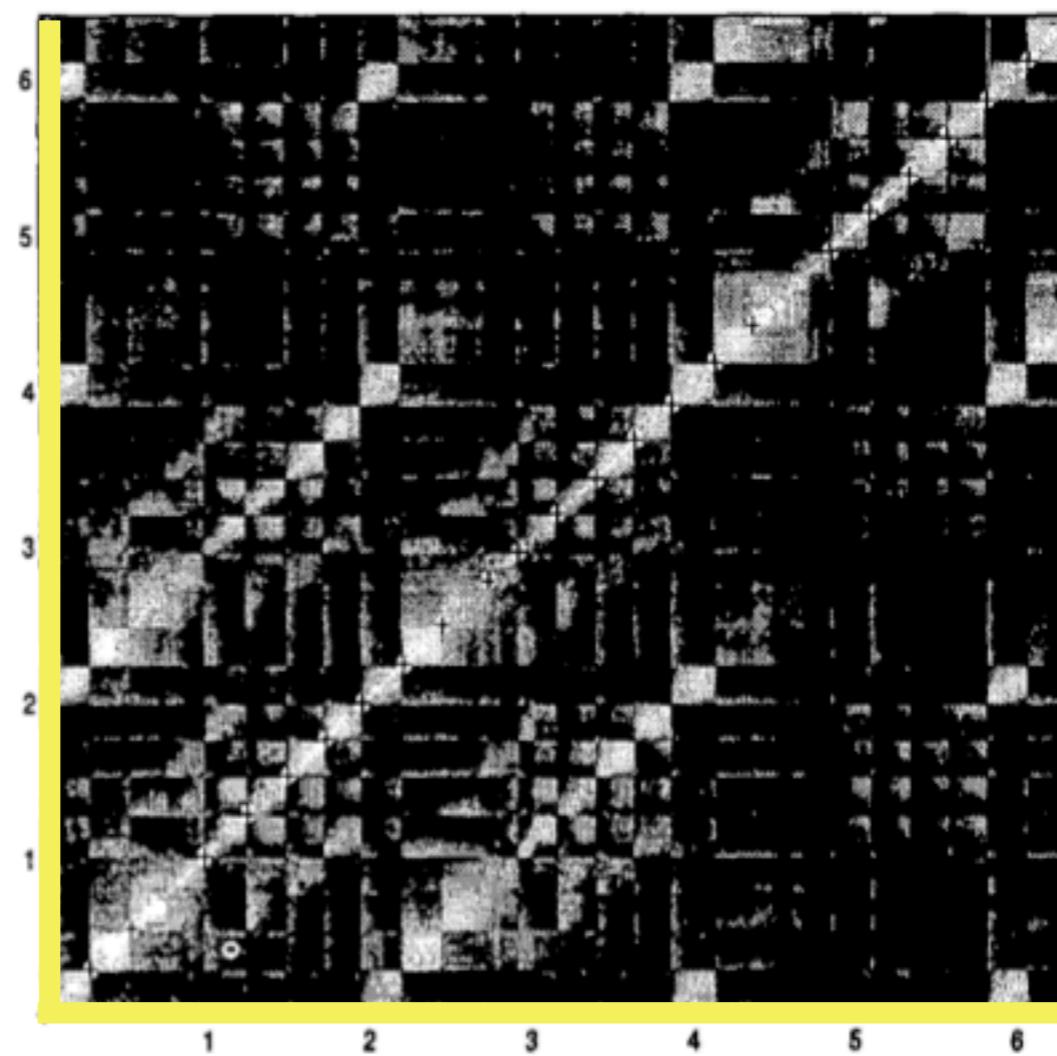


Figure 2. Gould performance showing note boundaries

image: Foote 1999
audio: <http://youtube.com/watch?v=bOTW2VS4w5w>

Similarity Matrices

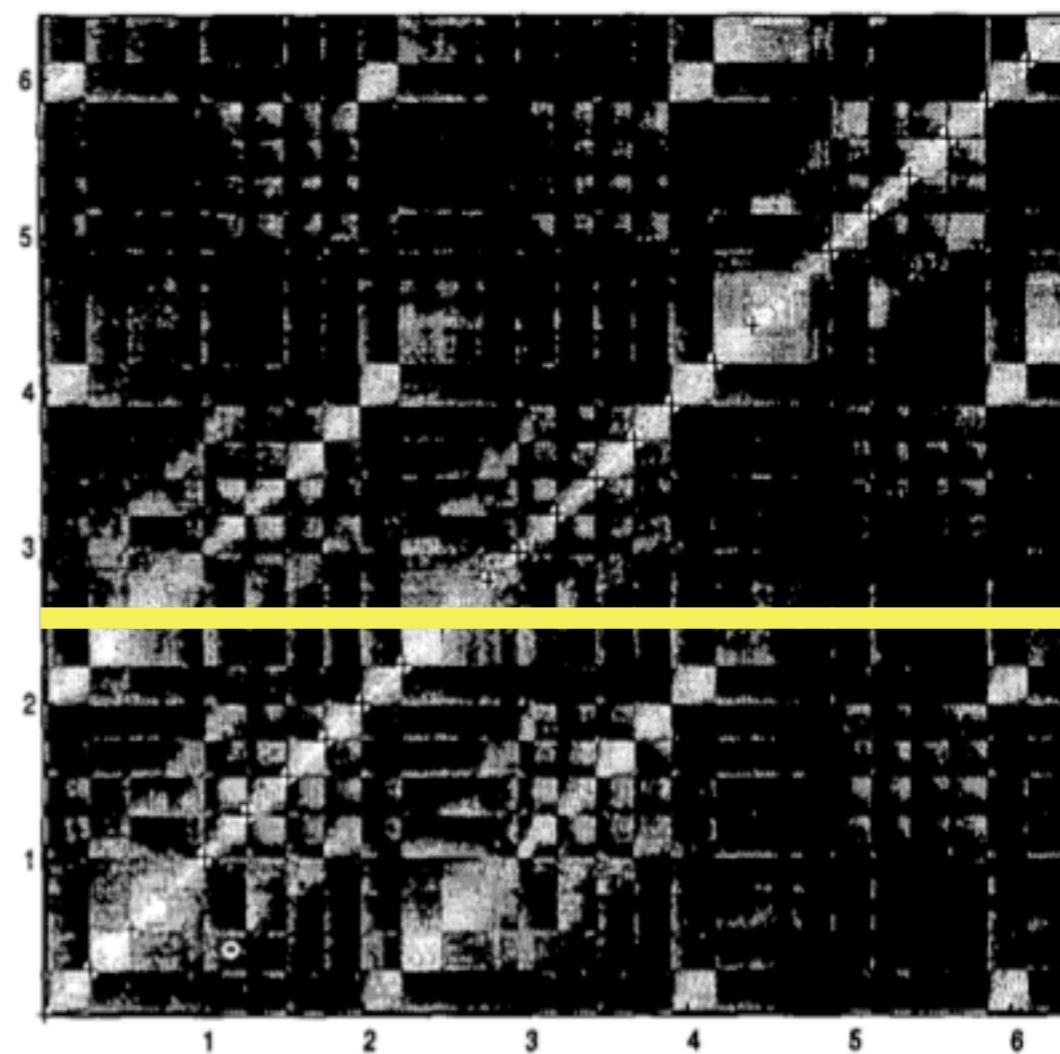


Figure 2. Gould performance showing note boundaries

image: Foote 1999

audio: <http://youtube.com/watch?v=bOTW2VS4w5w>

Novelty detection

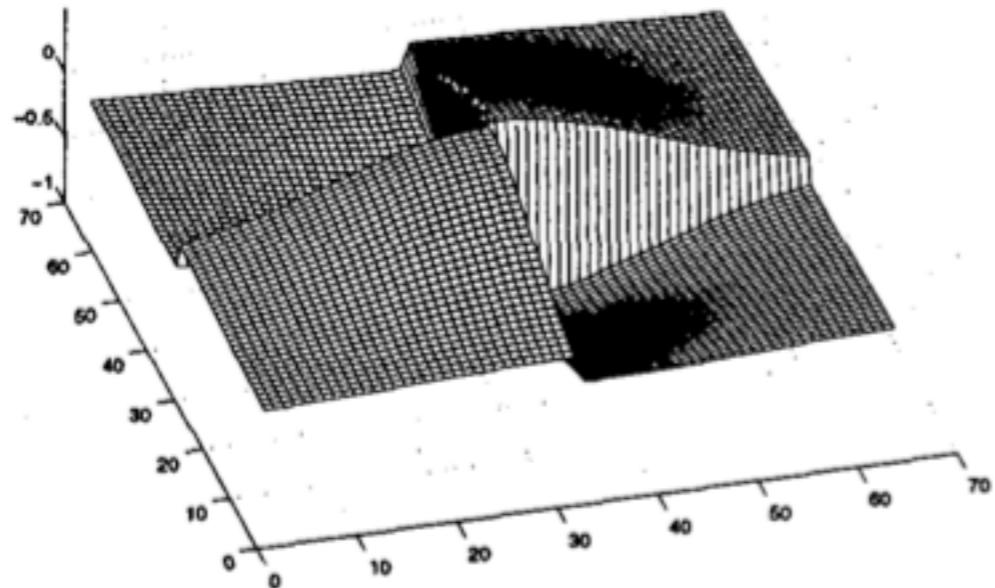


Figure 3. 64 x 64 checkerboard kernel with Gaussian taper

Novelty detection

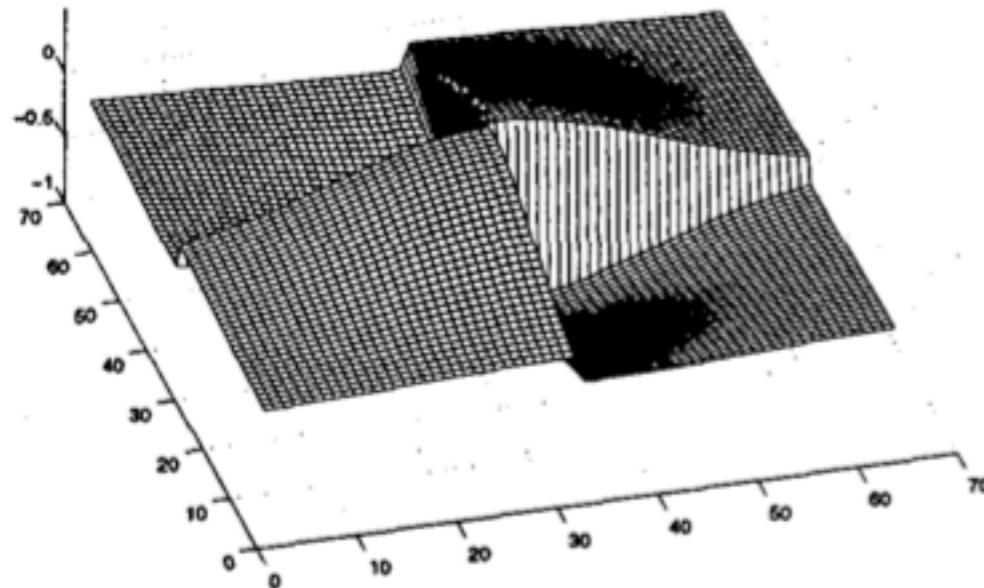


Figure 3. 64 x 64 checkerboard kernel with Gaussian taper

$$N(i) = \sum_{m=-L/2}^{L/2} \sum_{n=-L/2}^{L/2} C(m, n) S(i + m, i + n)$$

Novelty detection

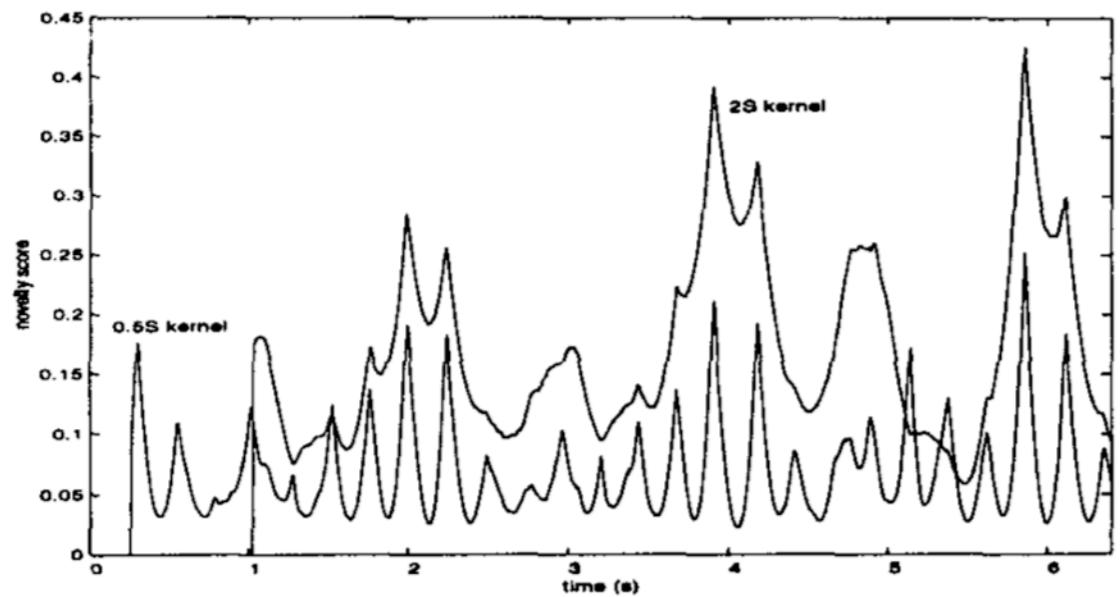


Figure 4. Novelty score for Gould performance and different kernel widths

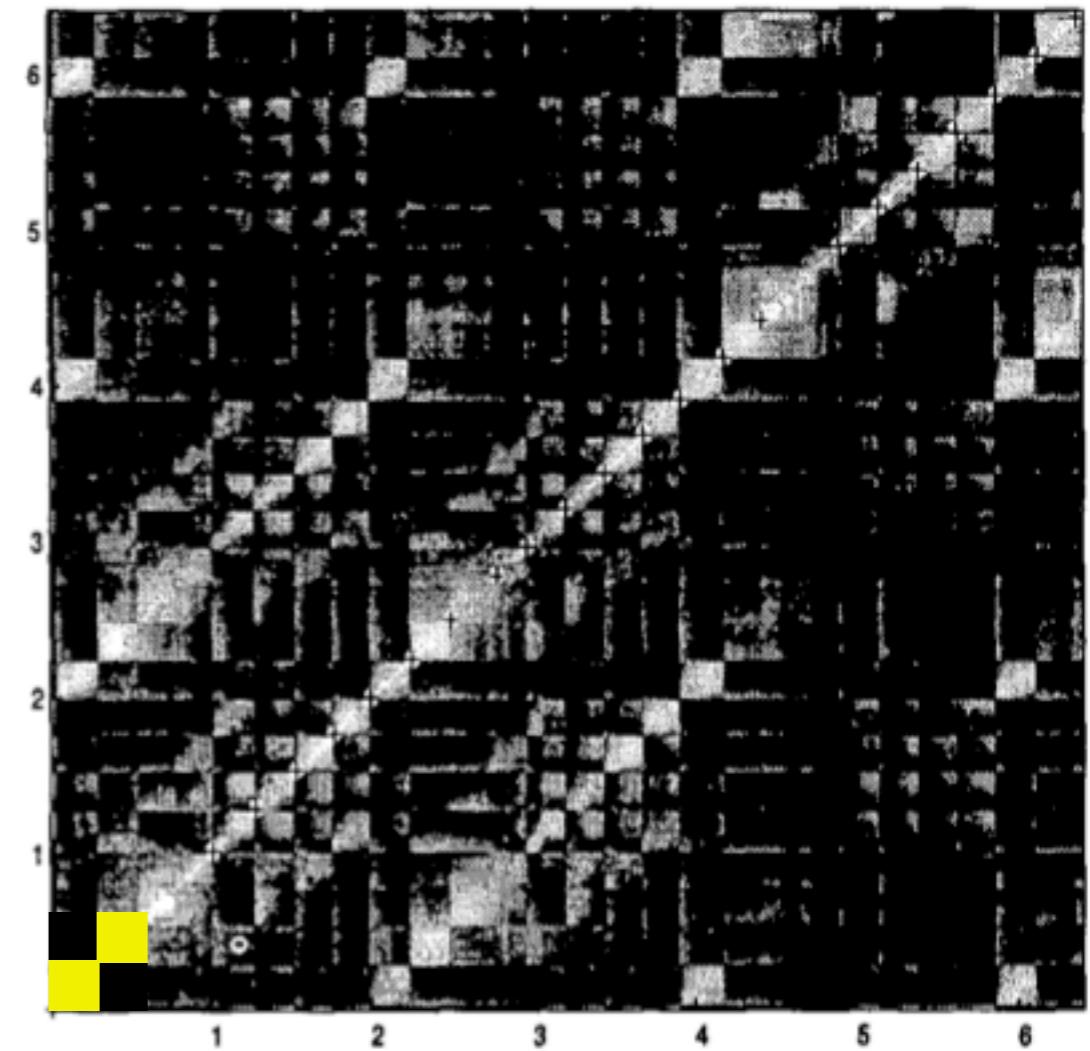


Figure 2. Gould performance showing note boundaries

images: Foote 1999

Novelty detection

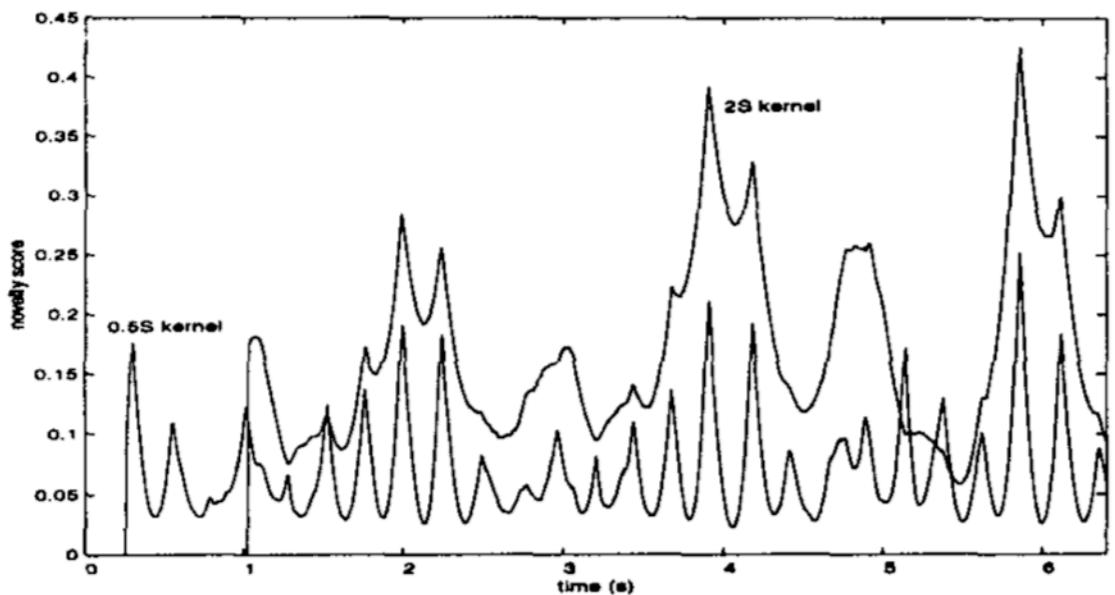


Figure 4. Novelty score for Gould performance and different kernel widths

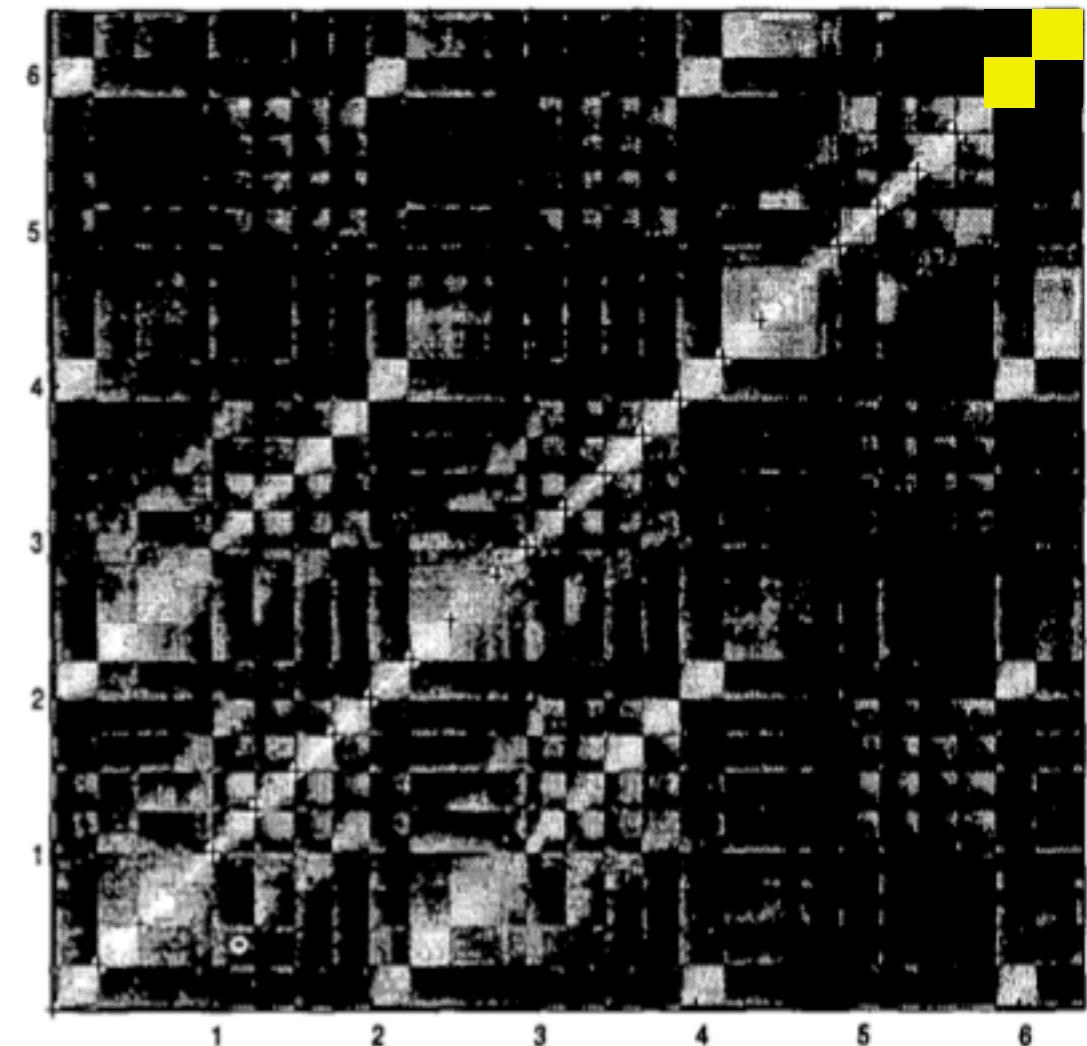


Figure 2. Gould performance showing note boundaries

Novelty detection

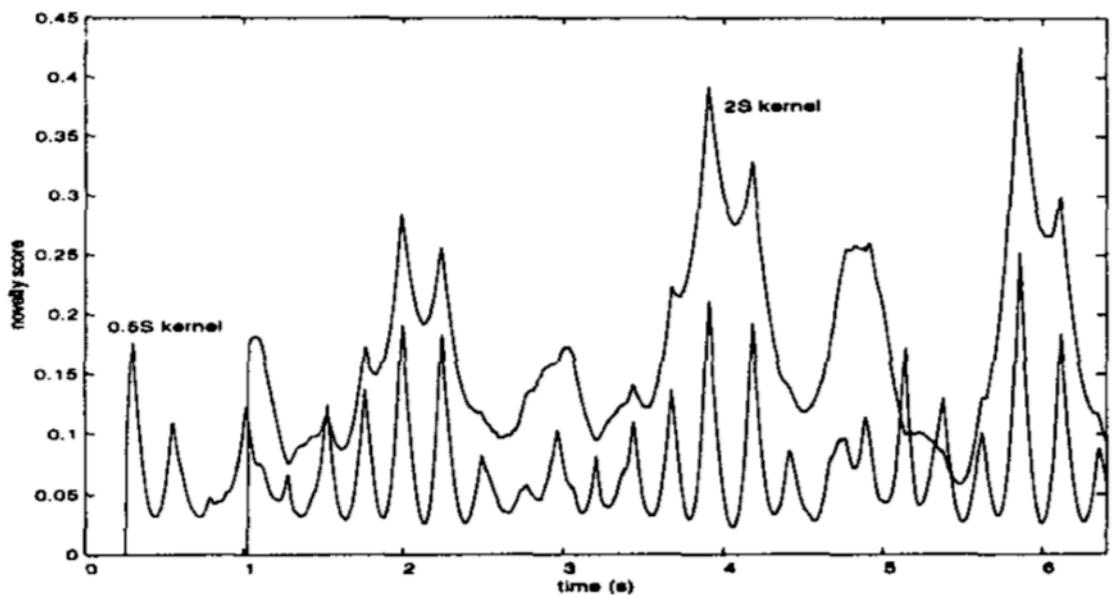


Figure 4. Novelty score for Gould performance and different kernel widths

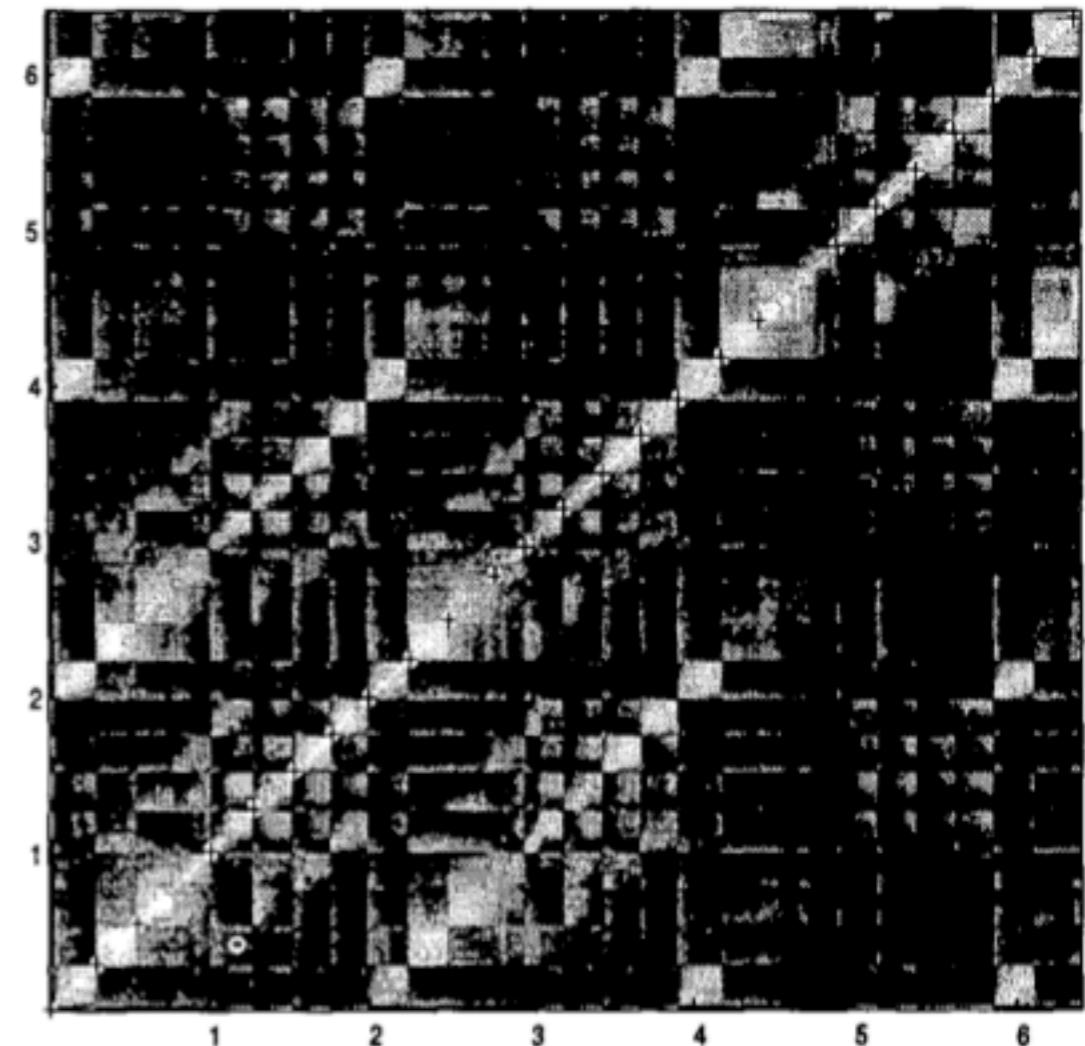


Figure 2. Gould performance showing note boundaries

Novelty detection

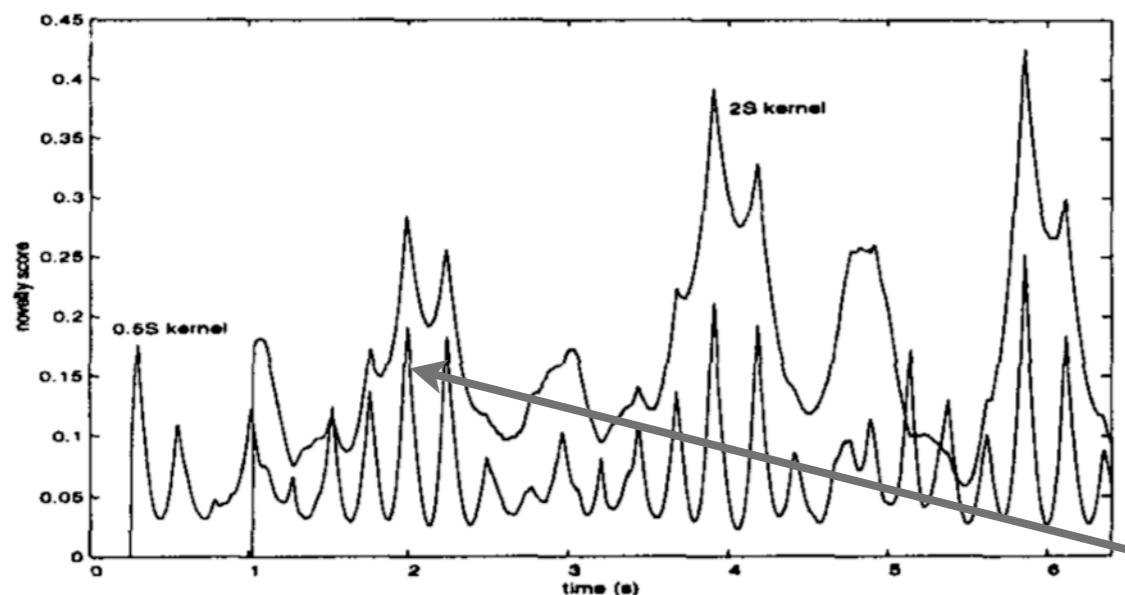


Figure 4. Novelty score for Gould performance and different kernel widths

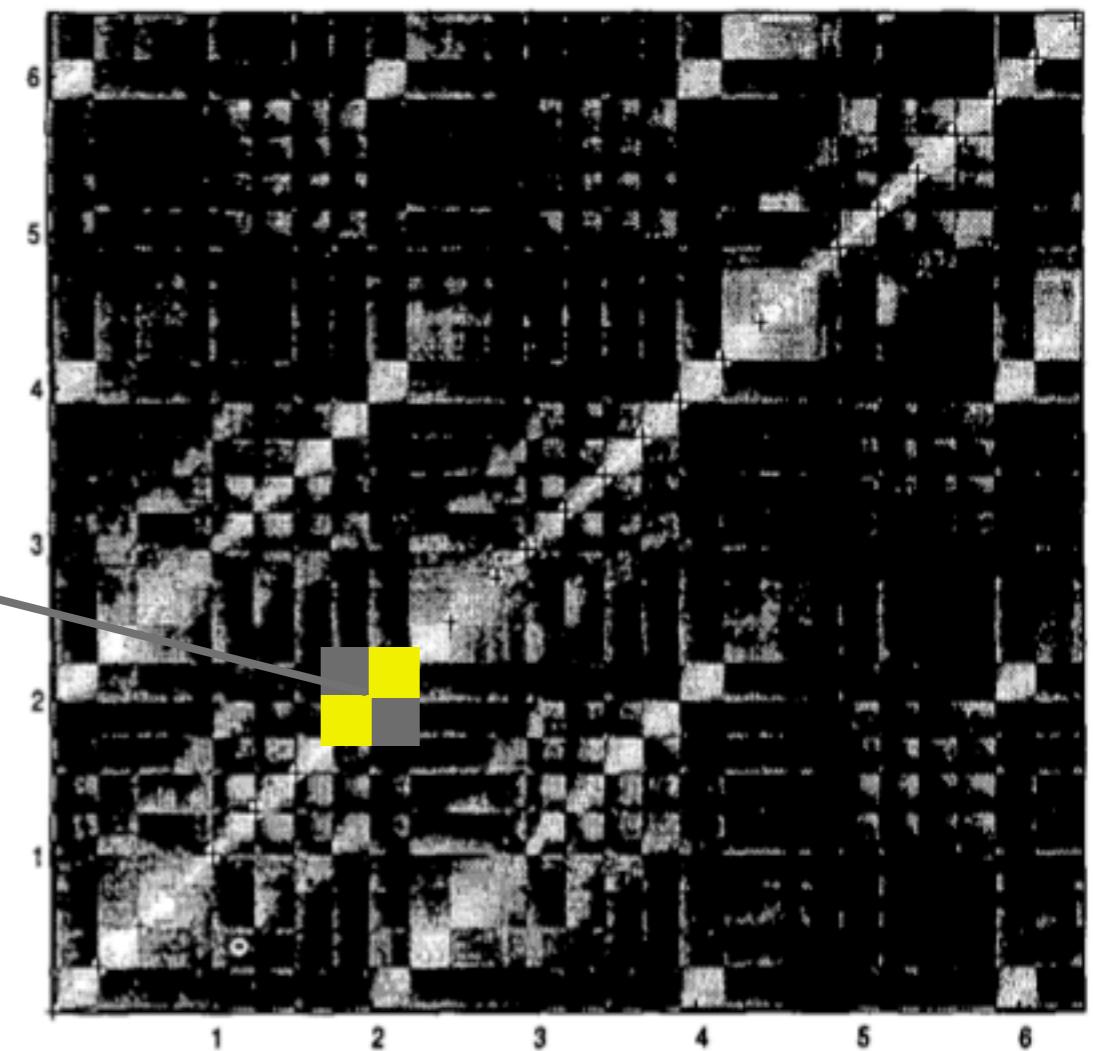


Figure 2. Gould performance showing note boundaries

Novelty detection

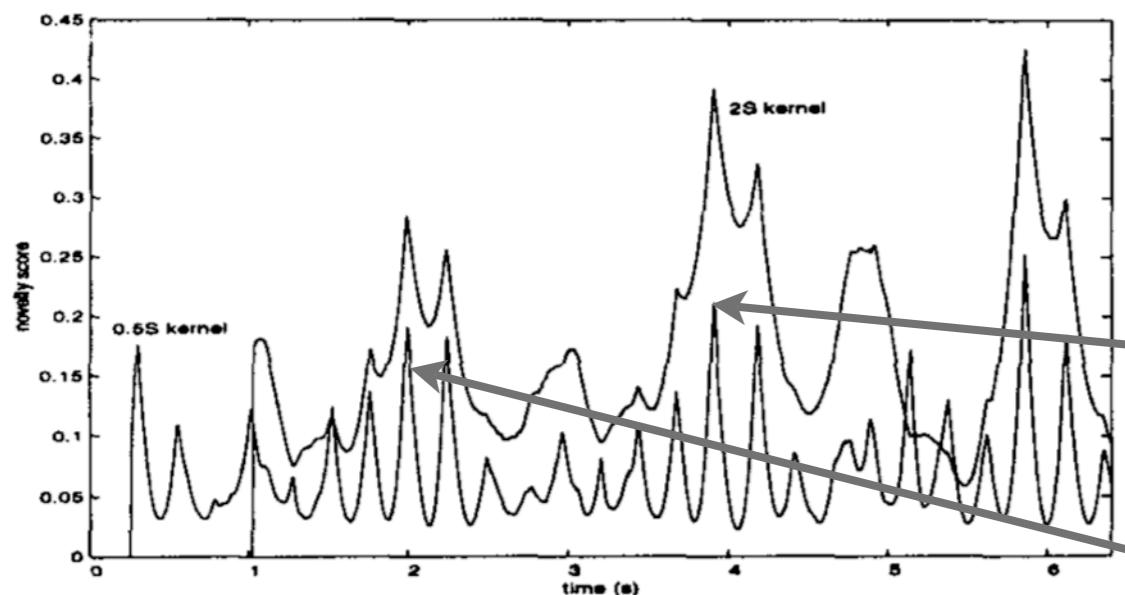


Figure 4. Novelty score for Gould performance and different kernel widths

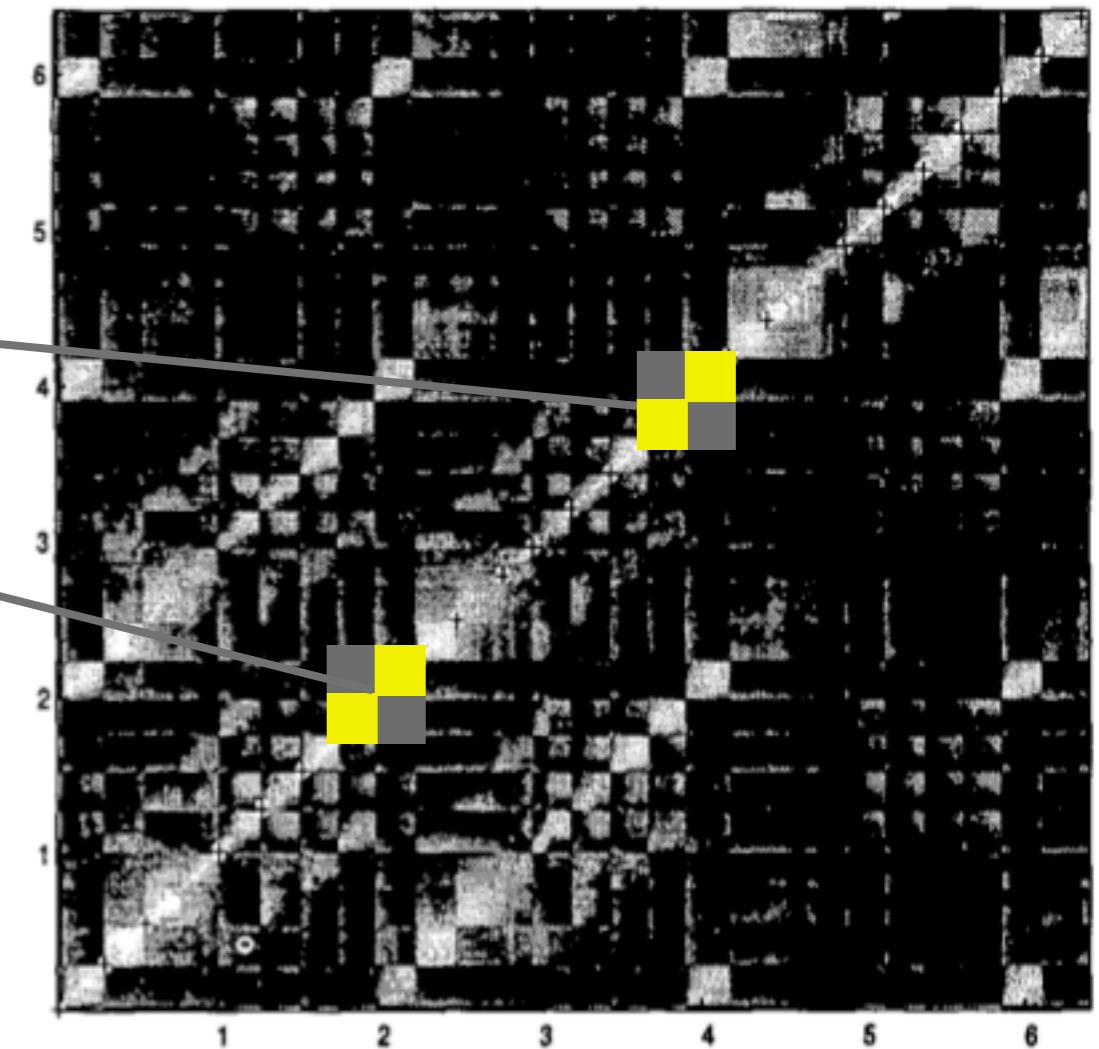


Figure 2. Gould performance showing note boundaries

Novelty detection

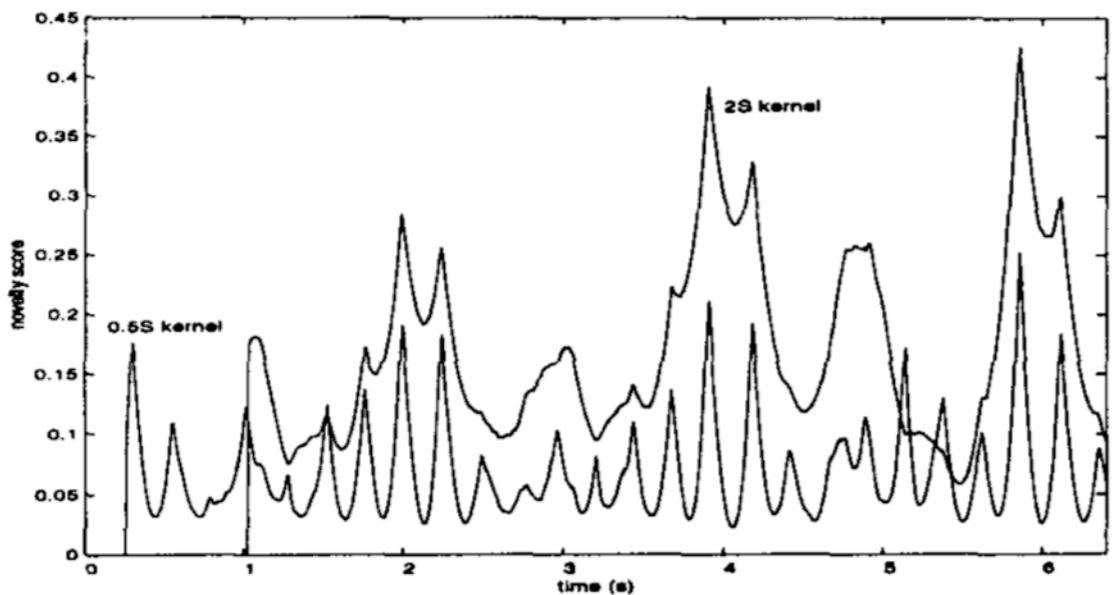


Figure 4. Novelty score for Gould performance and different kernel widths

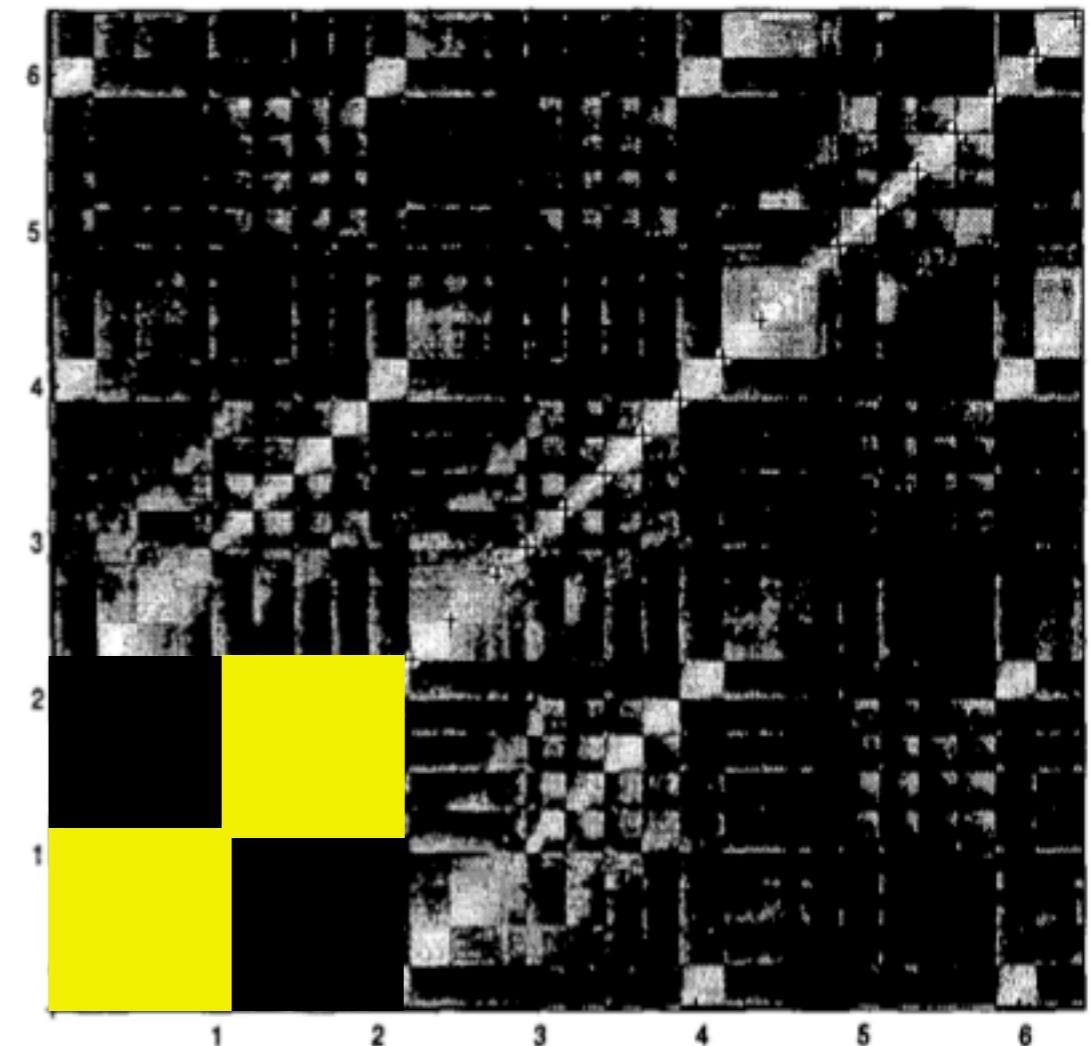


Figure 2. Gould performance showing note boundaries

Novelty detection

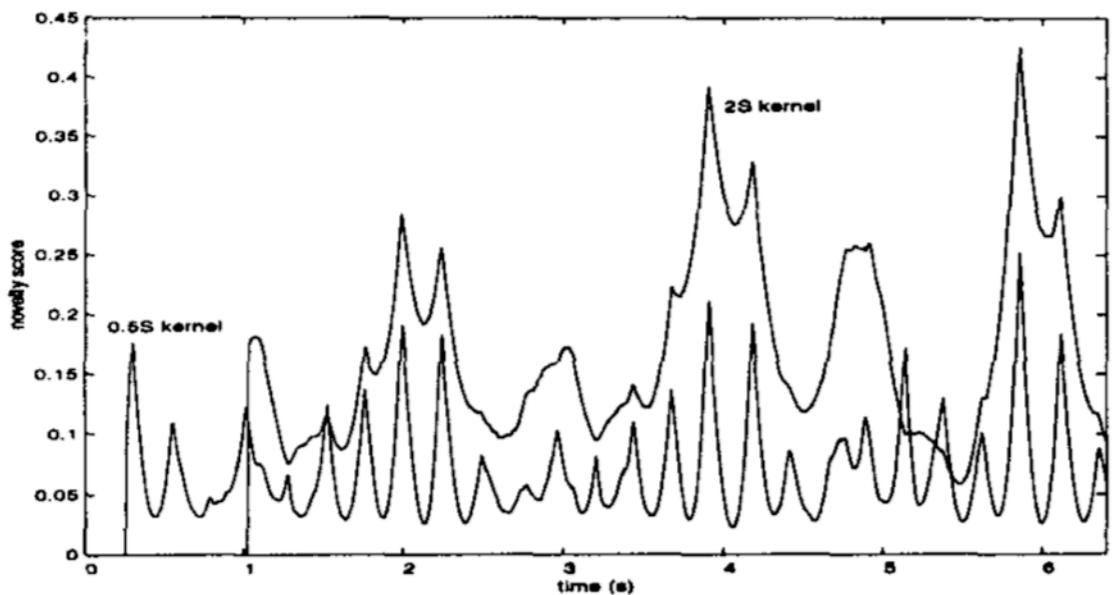


Figure 4. Novelty score for Gould performance and different kernel widths

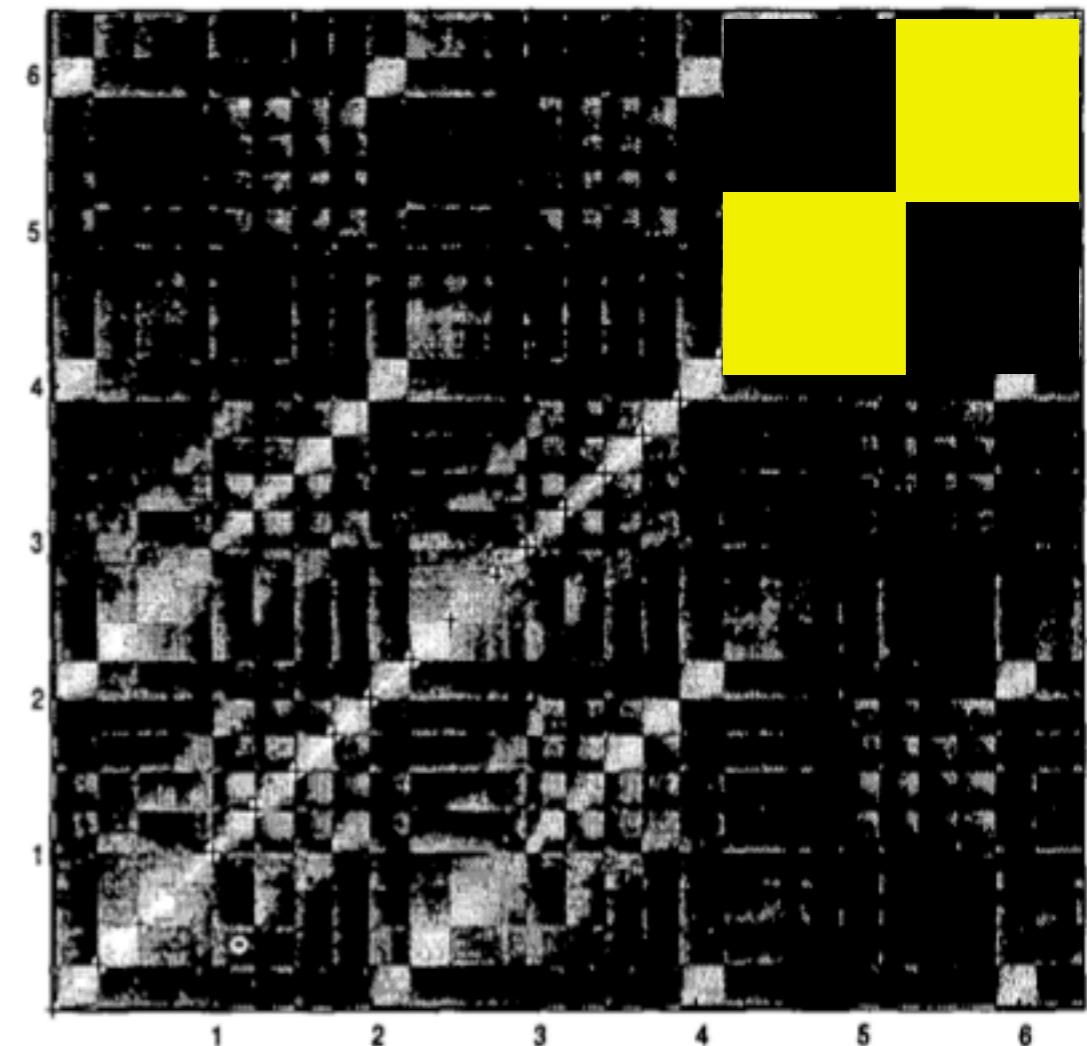


Figure 2. Gould performance showing note boundaries

images: Foote 1999

Novelty detection

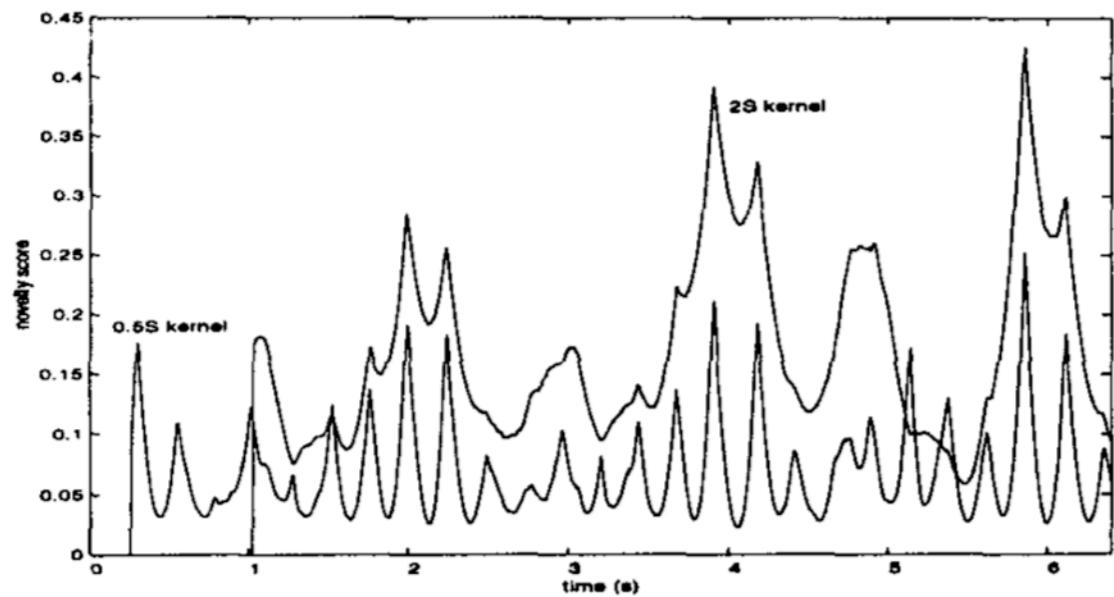


Figure 4. Novelty score for Gould performance and different kernel widths

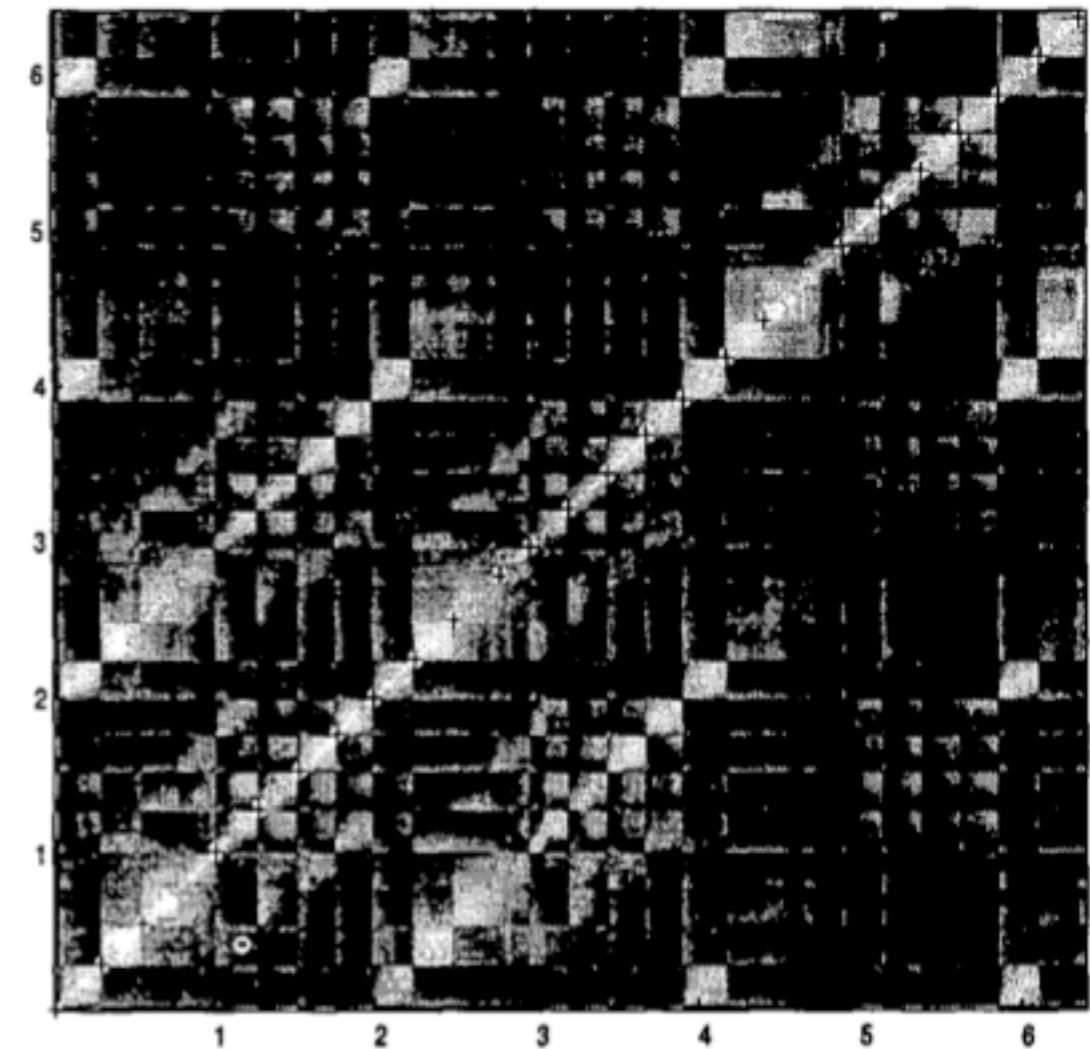


Figure 2. Gould performance showing note boundaries

Novelty detection

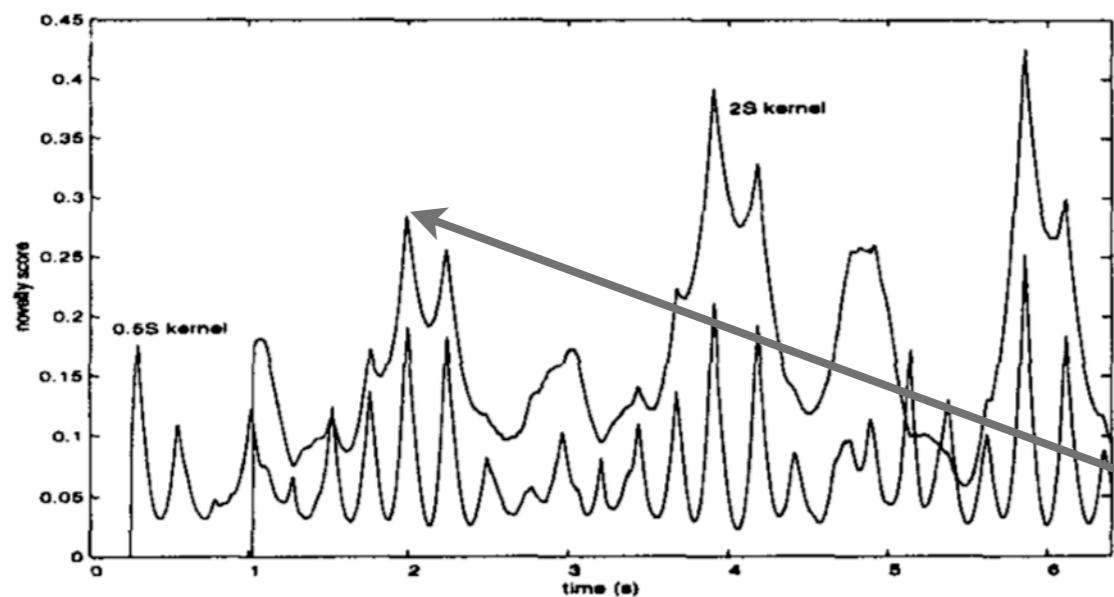


Figure 4. Novelty score for Gould performance and different kernel widths

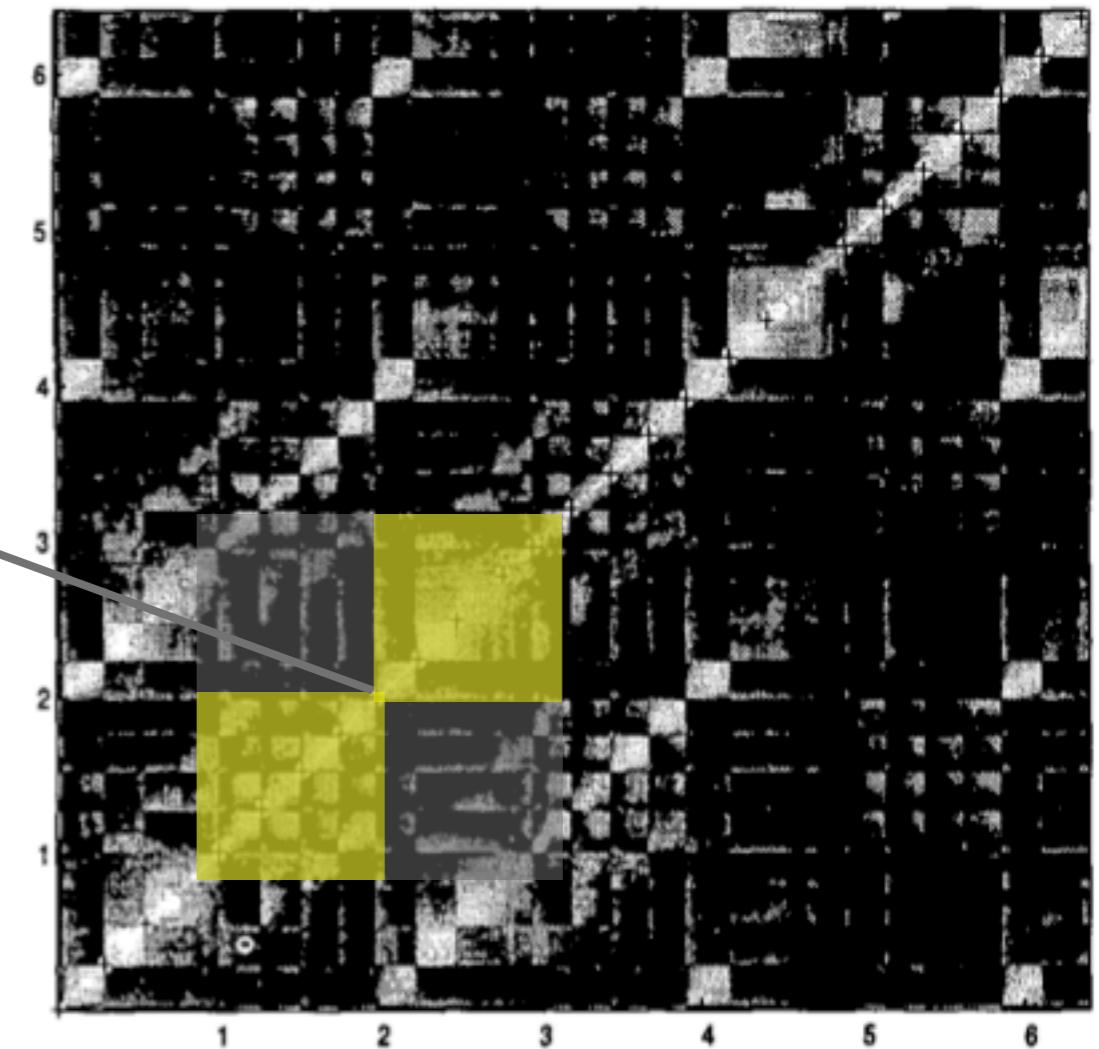


Figure 2. Gould performance showing note boundaries

Novelty detection

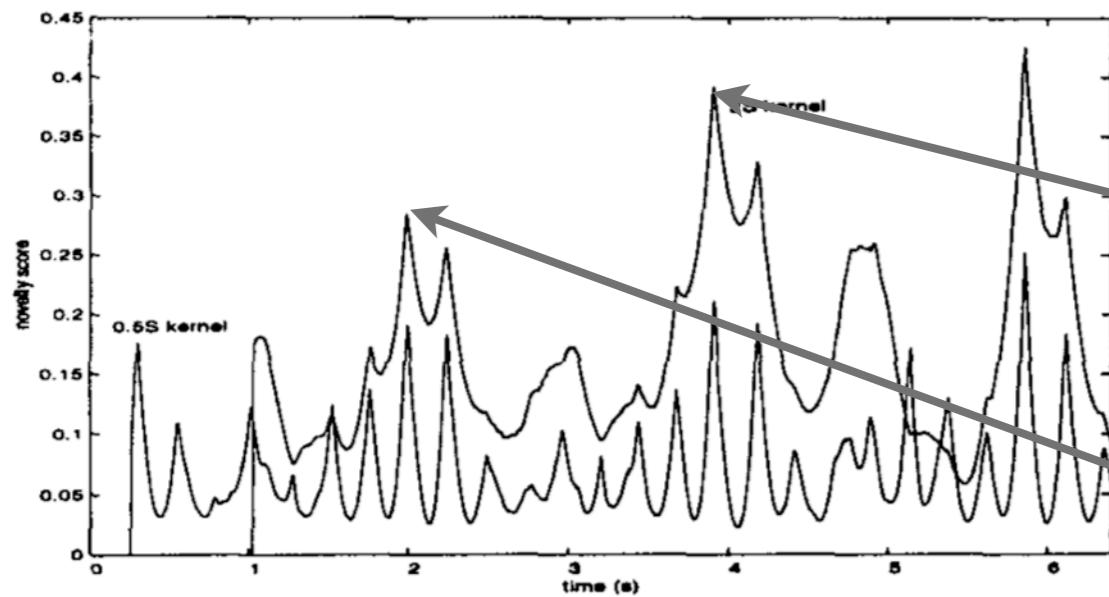


Figure 4. Novelty score for Gould performance and different kernel widths

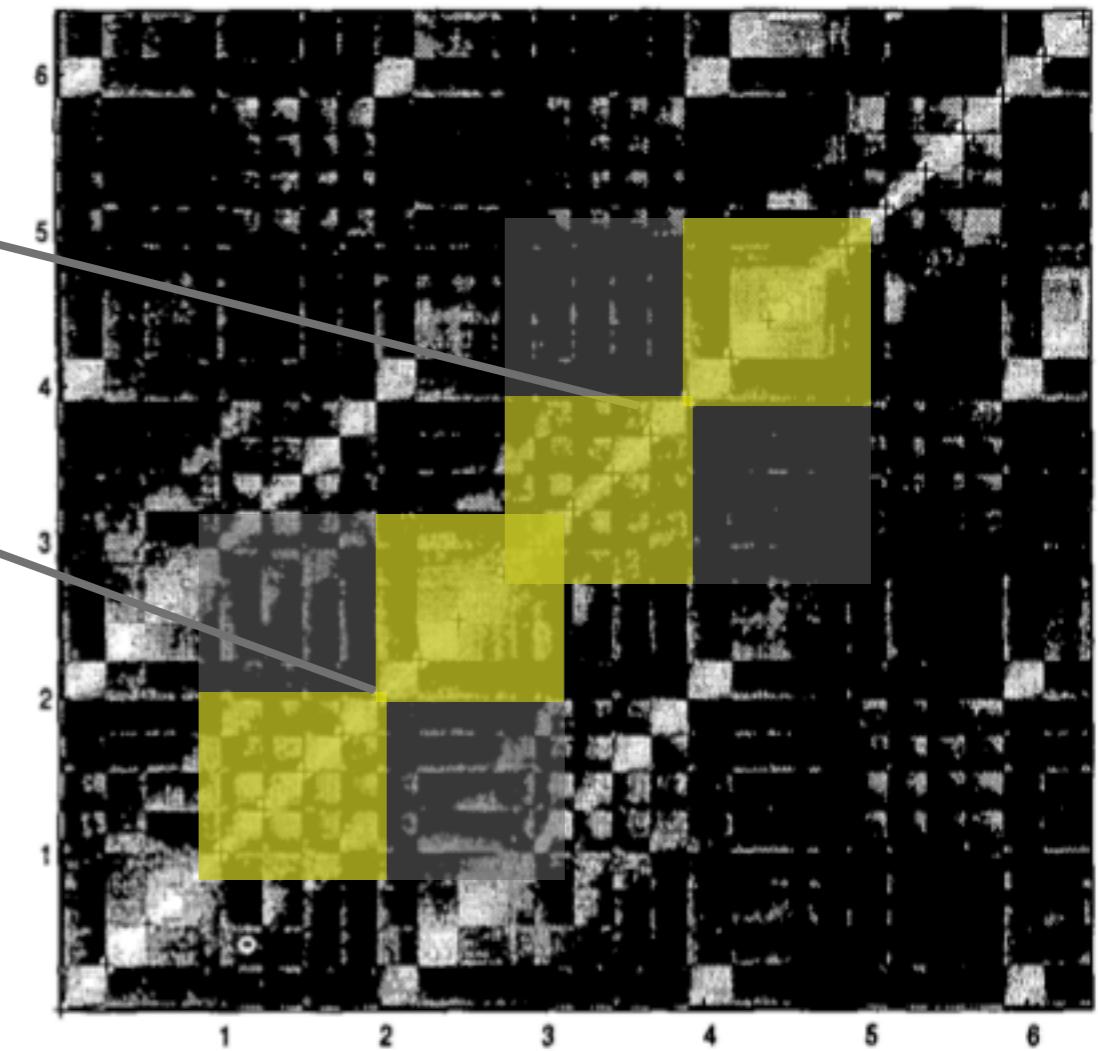
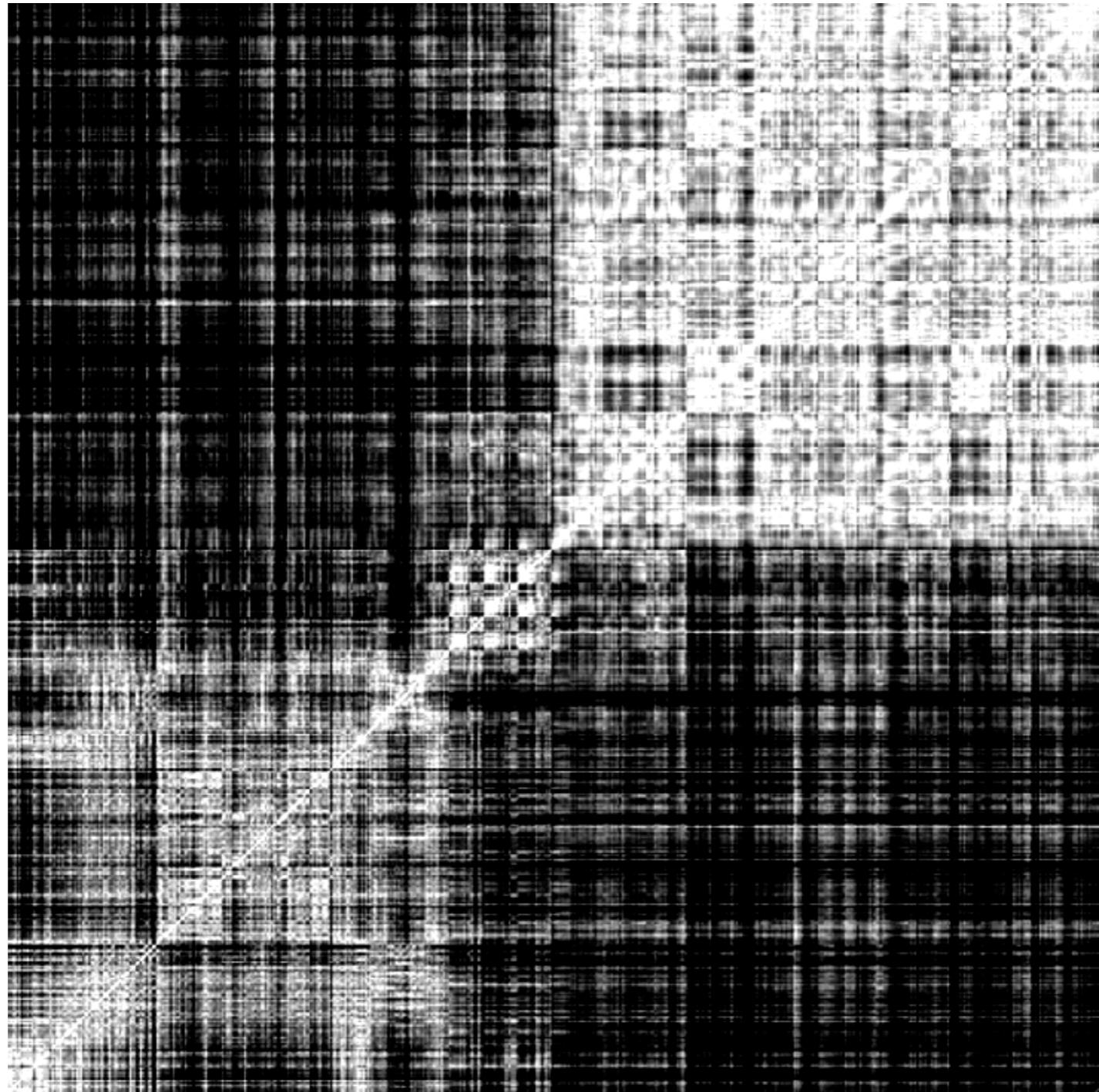


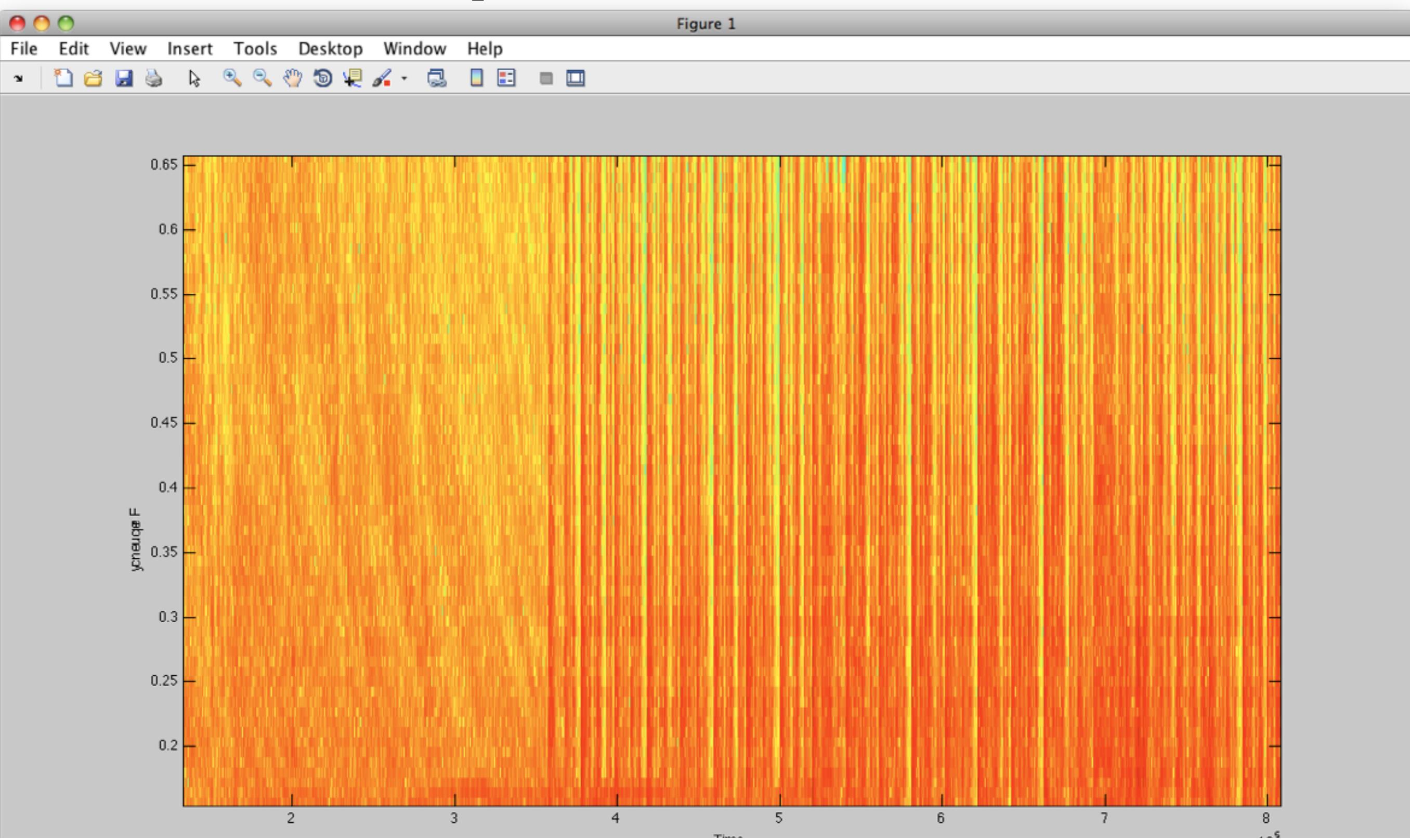
Figure 2. Gould performance showing note boundaries

Novelty detection

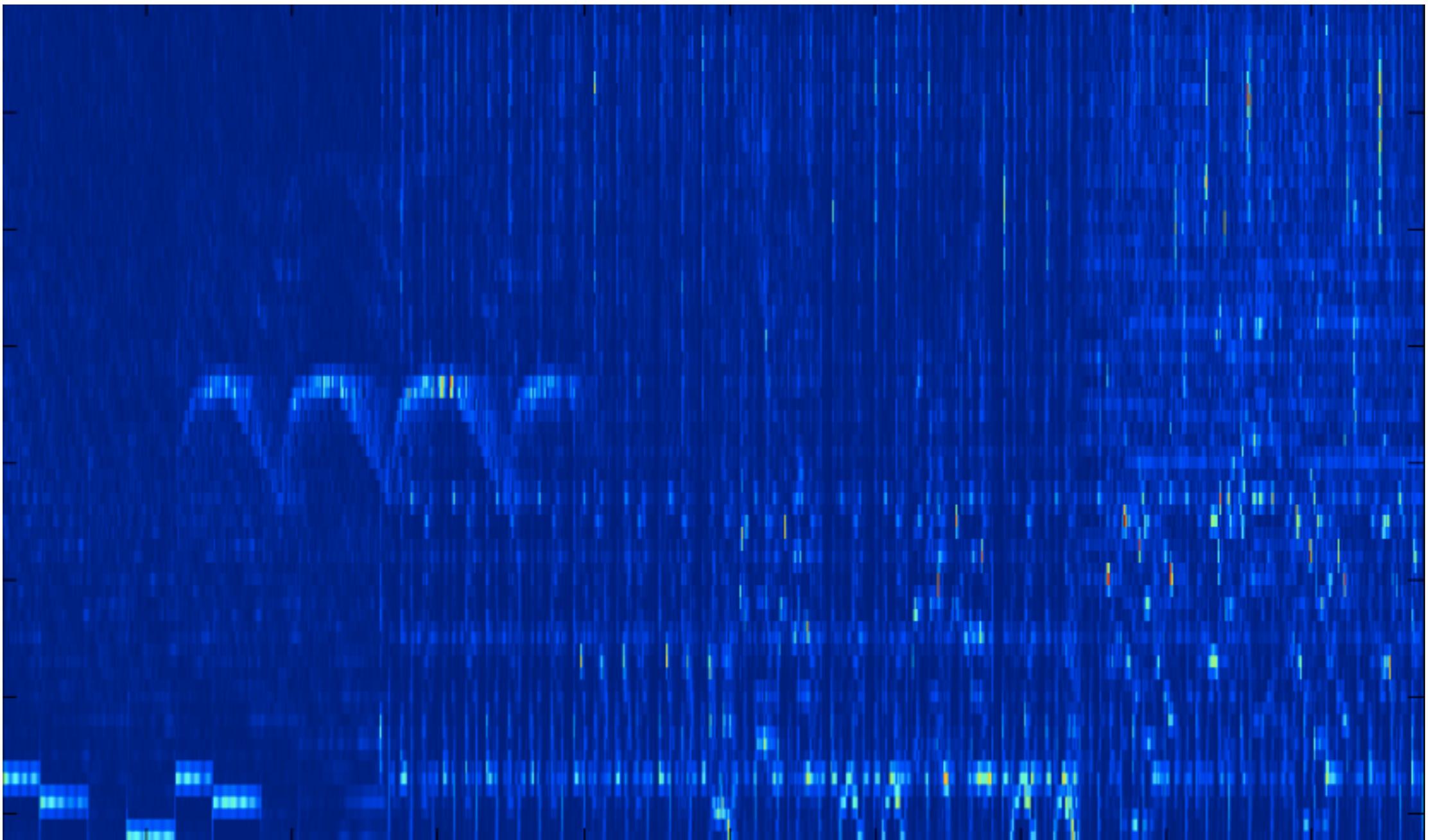


audio: "Layla" by Derek and the Dominoes

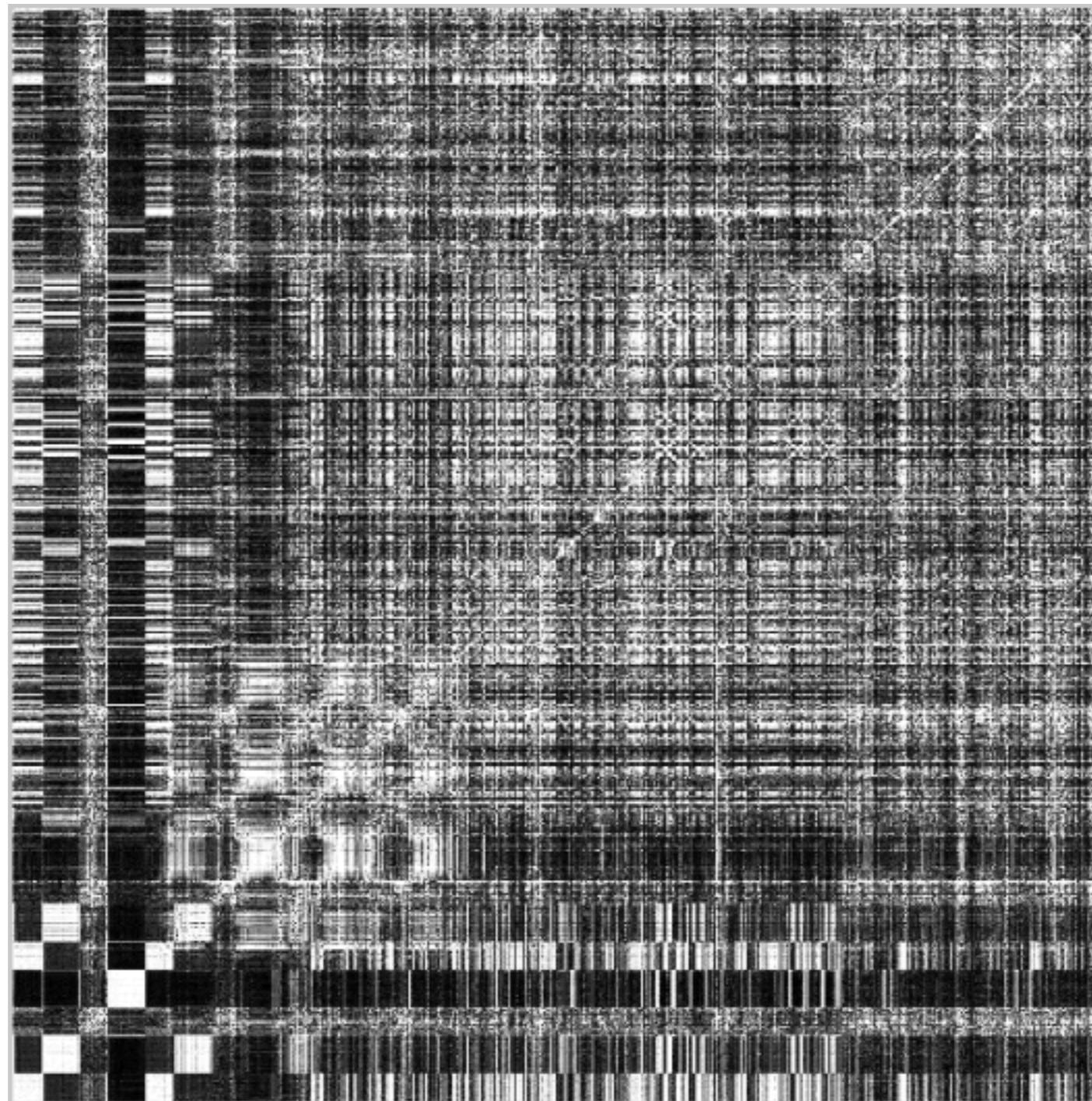
Fancy “Foote” work



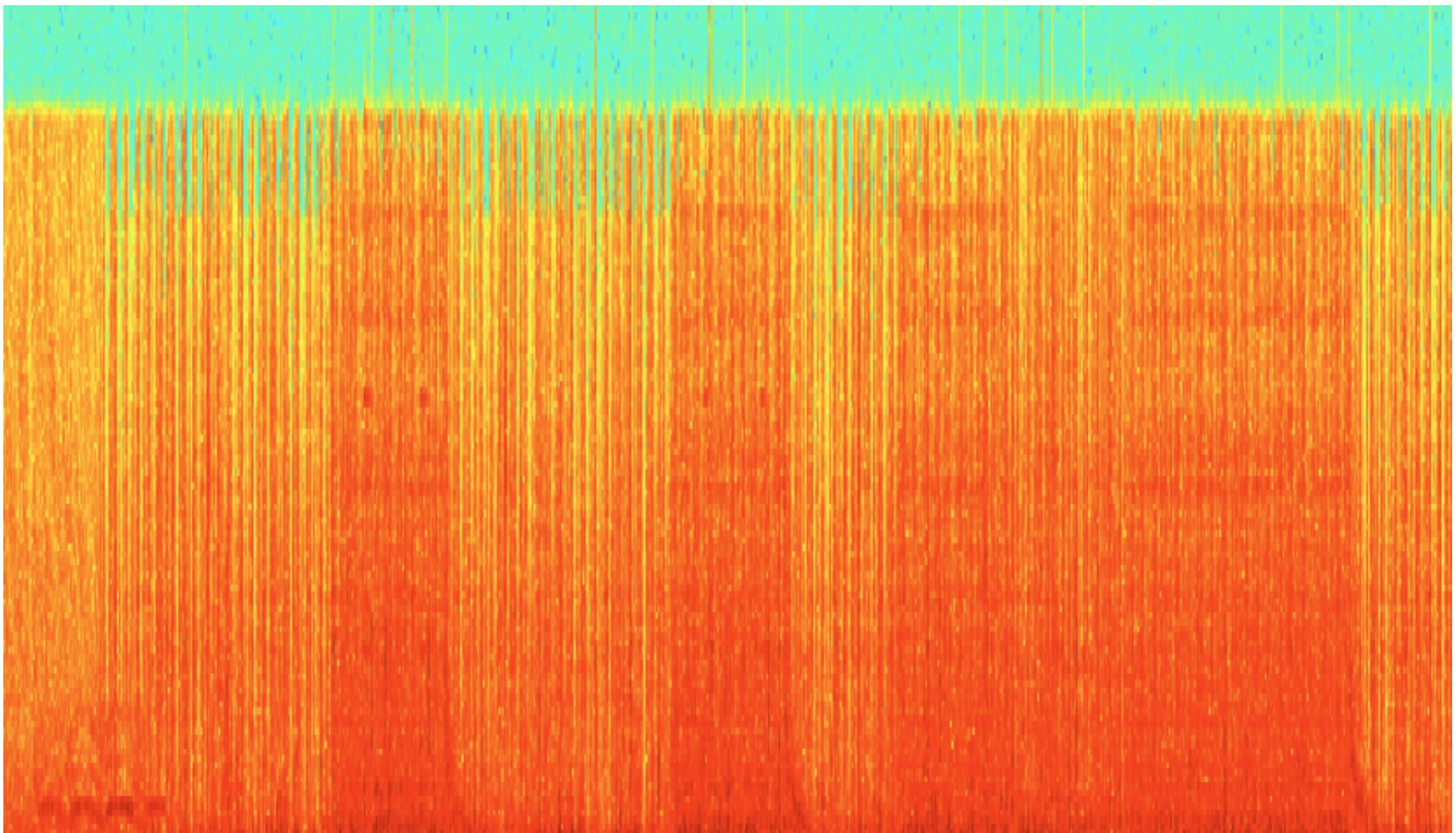
Fancy “Foote”work



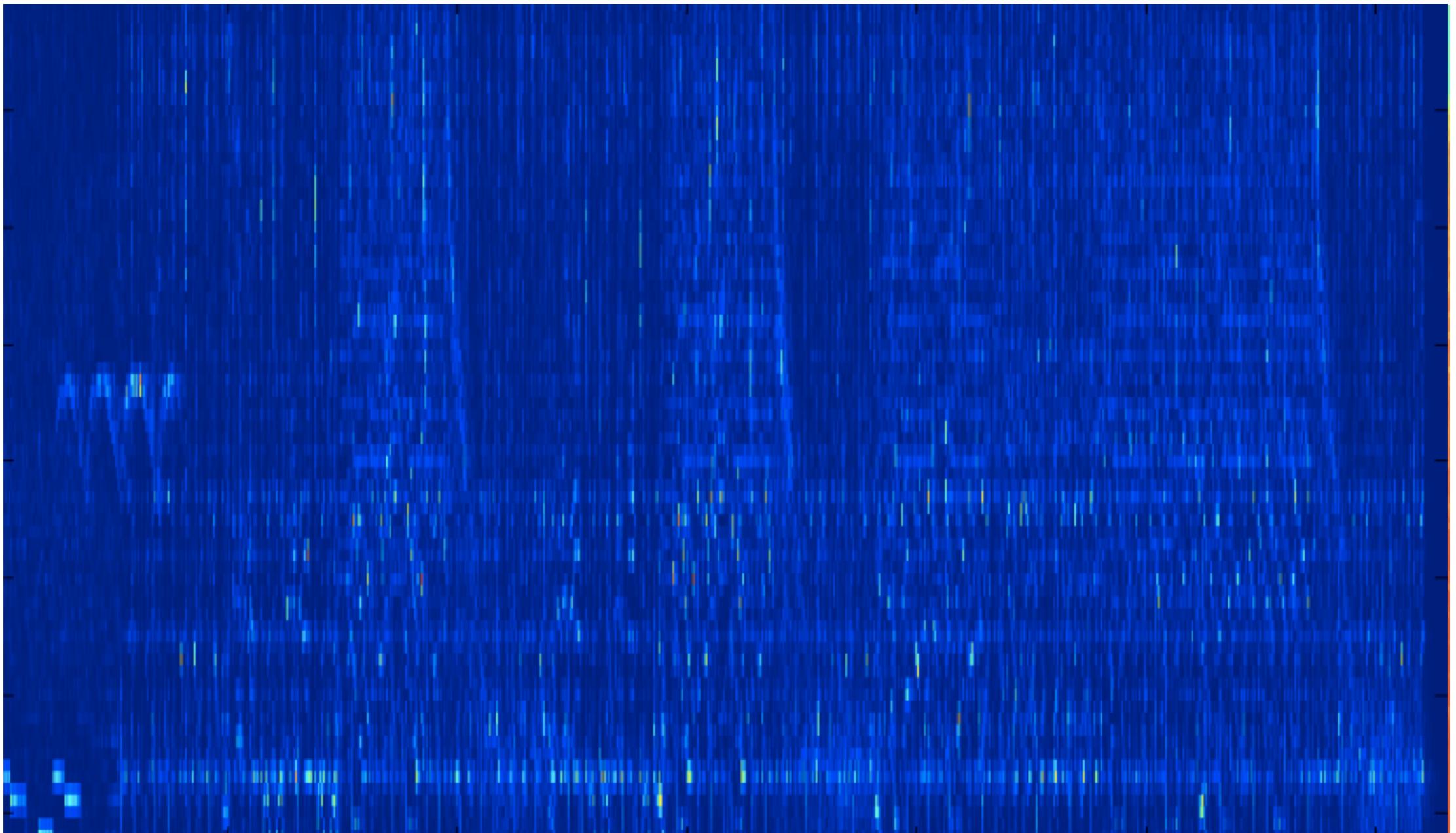
Fancy “Foote”work



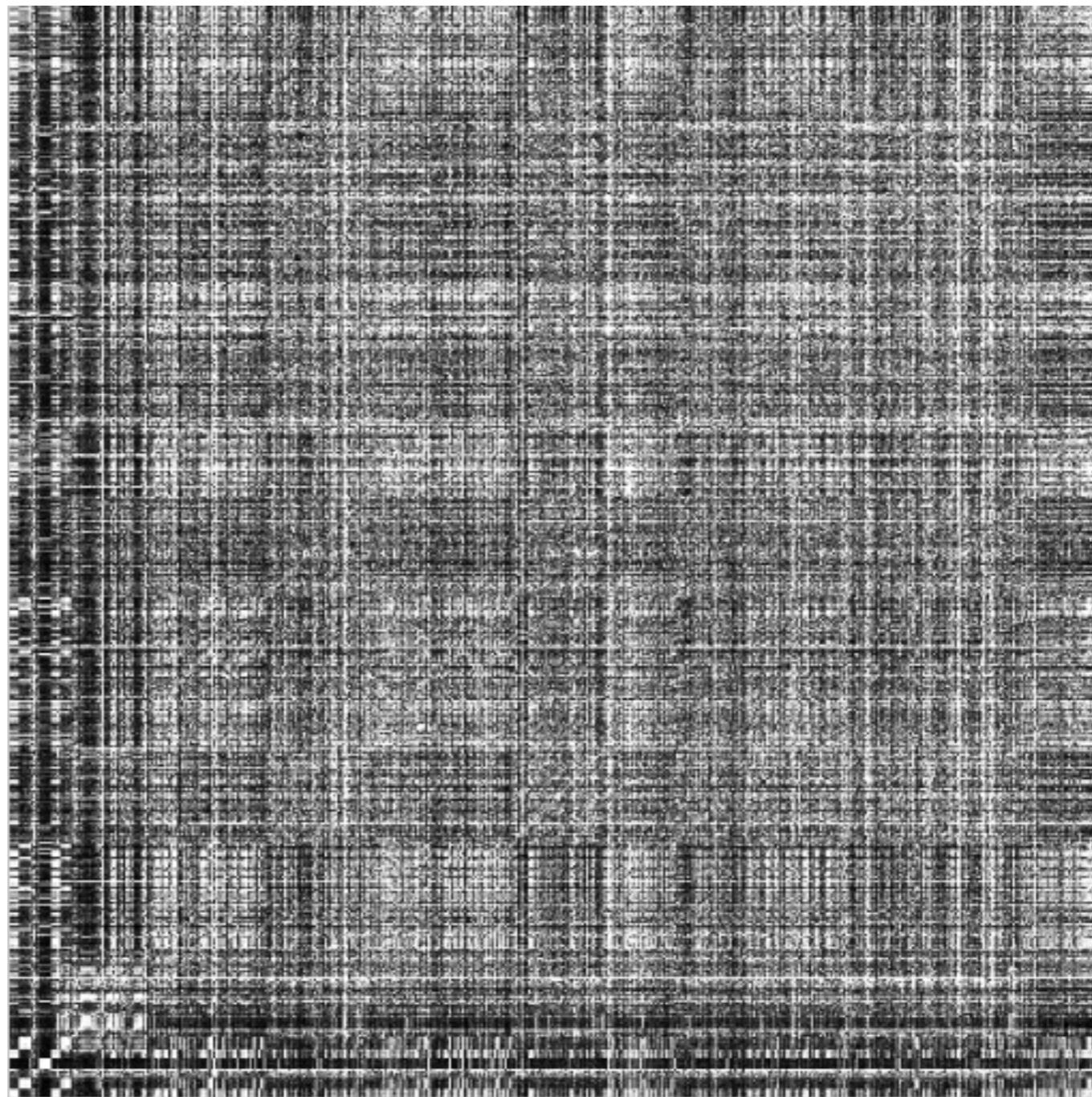
Fancy “Foote”work



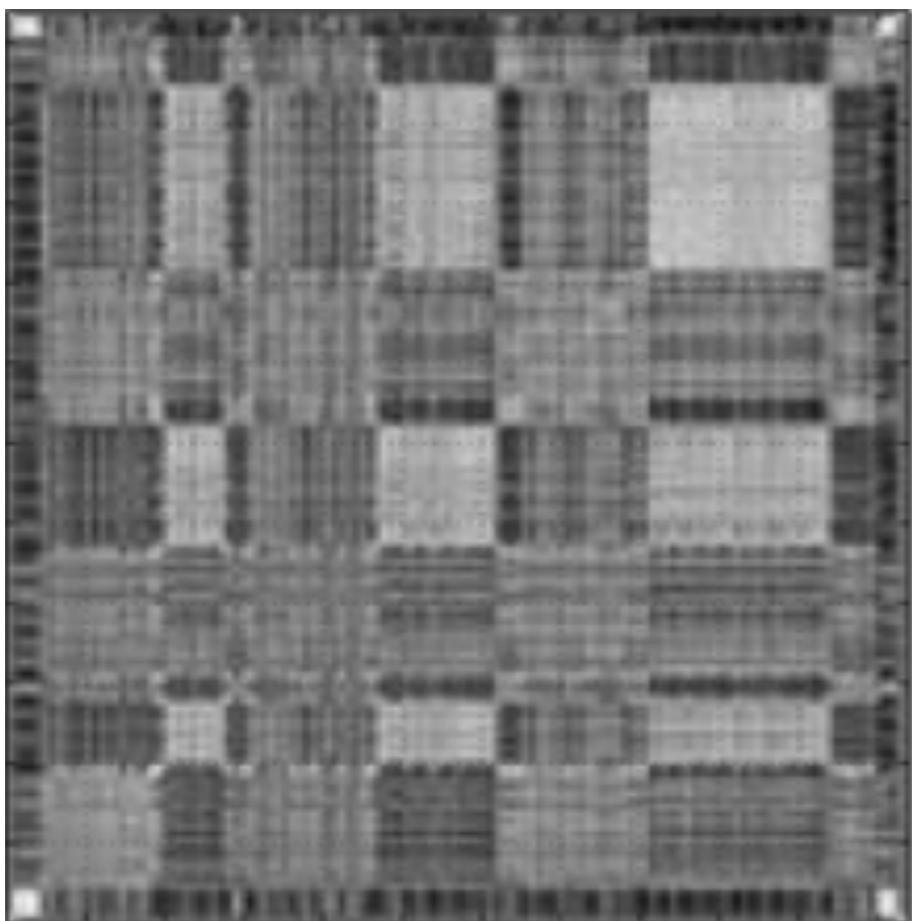
Fancy “Foote”work



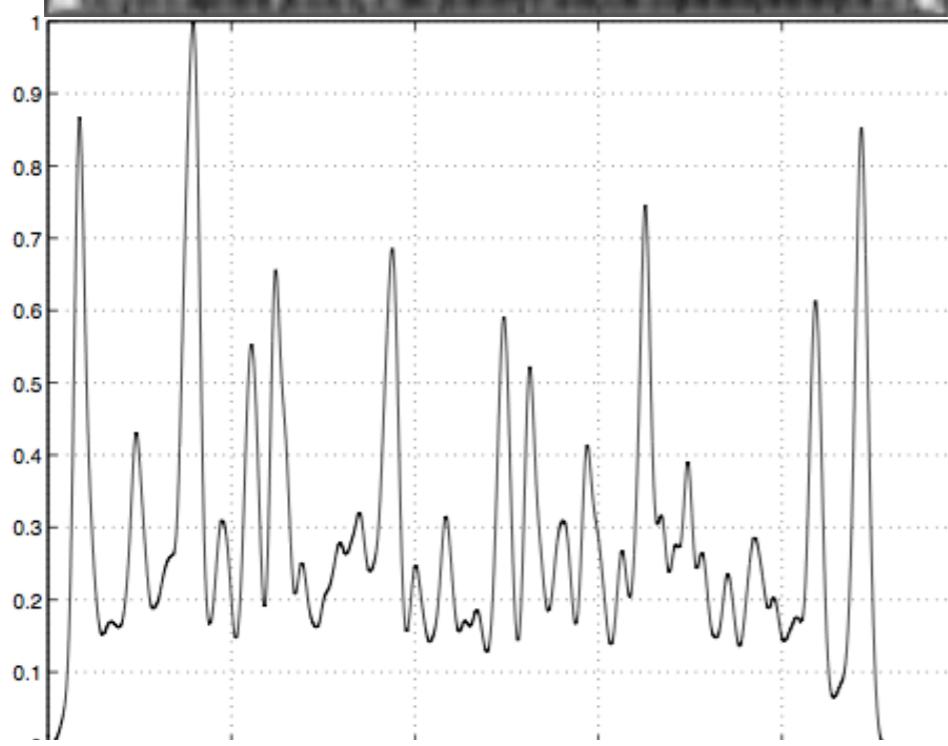
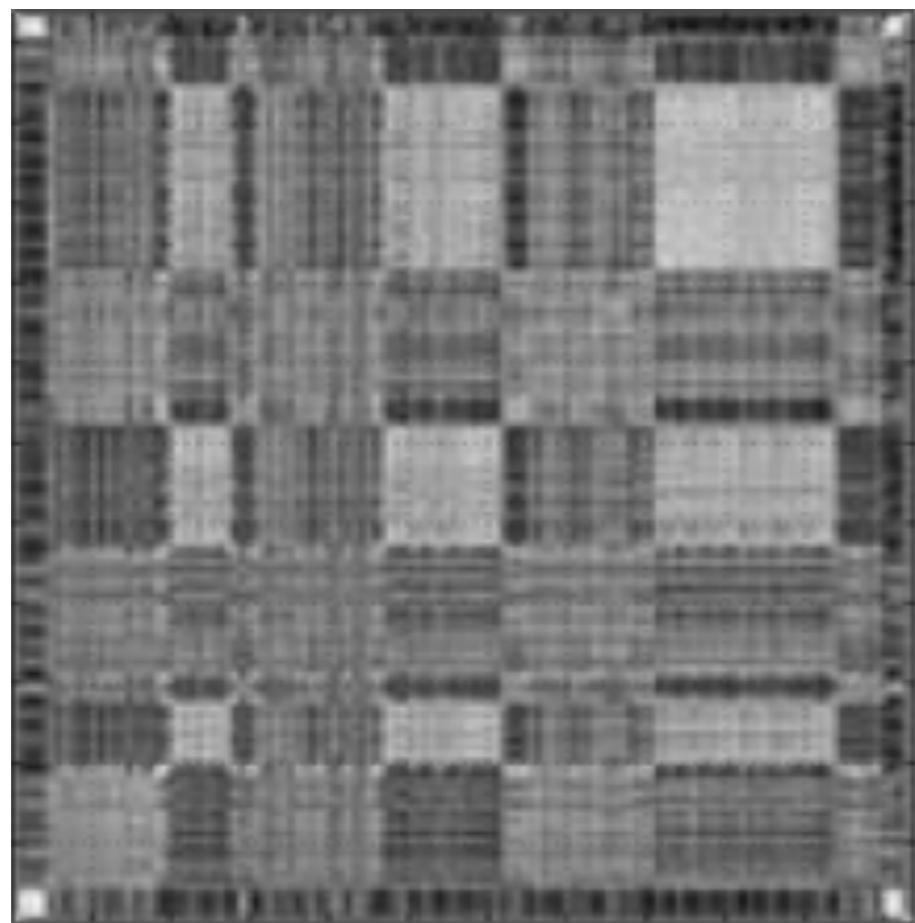
Fancy “Foote”work



Structural Analysis

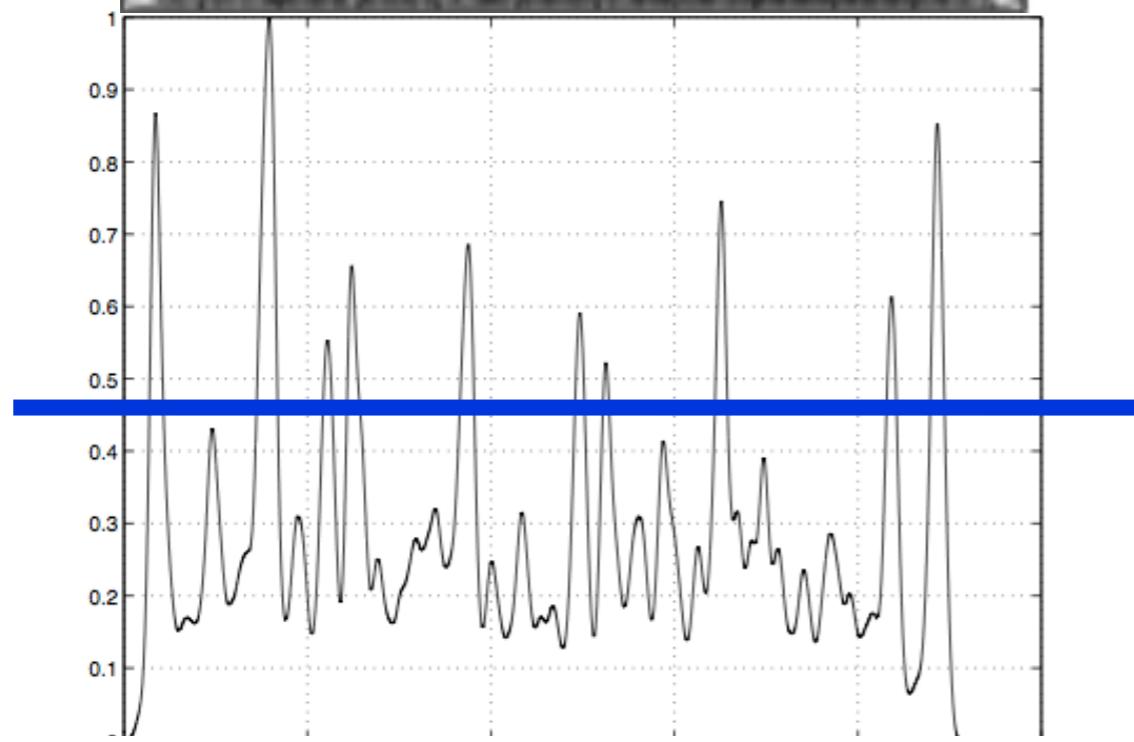
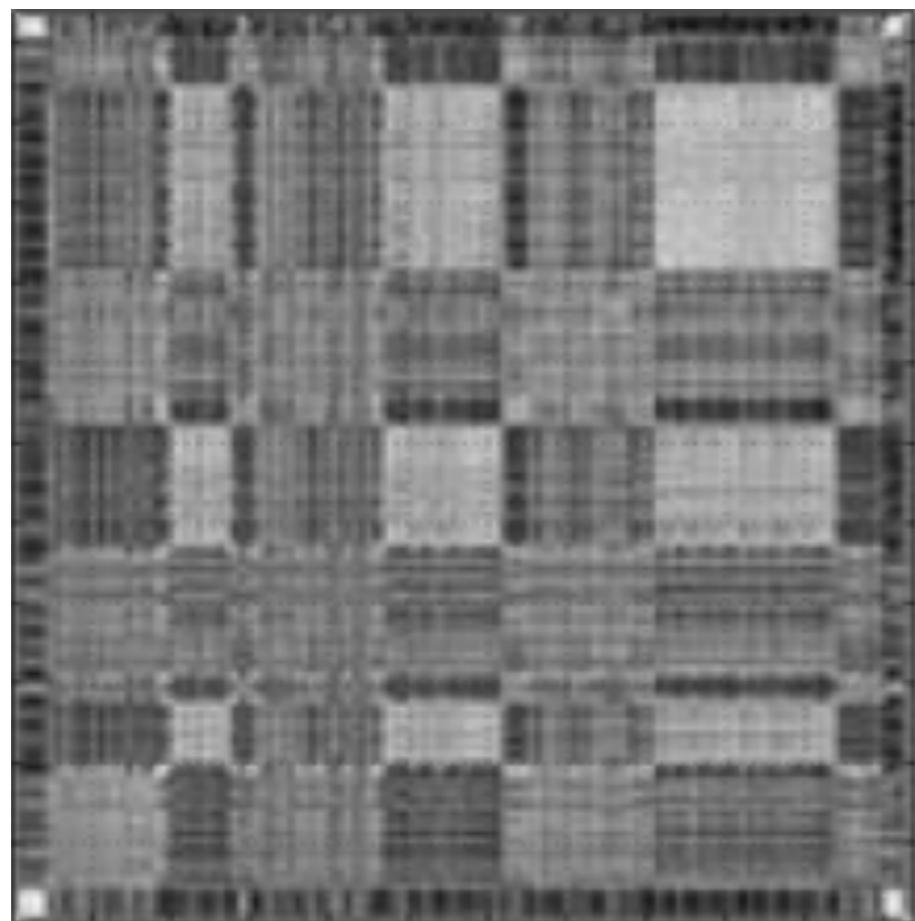


Structural Analysis



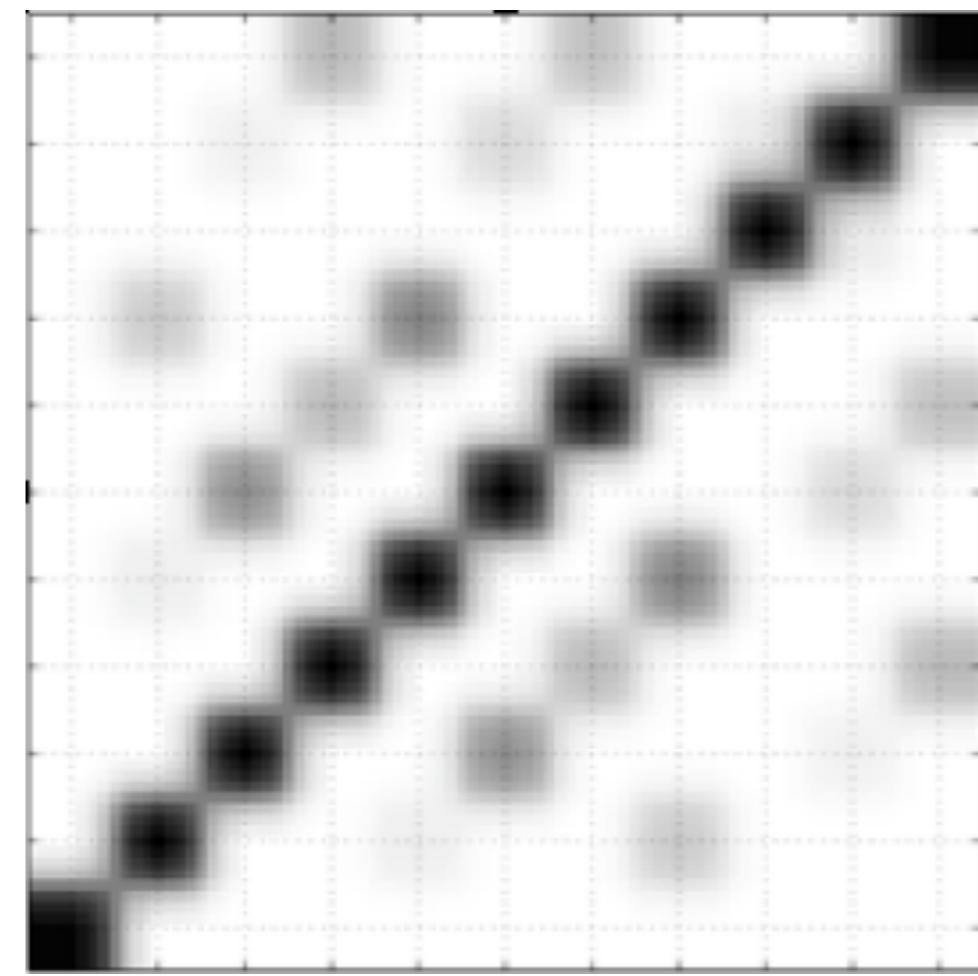
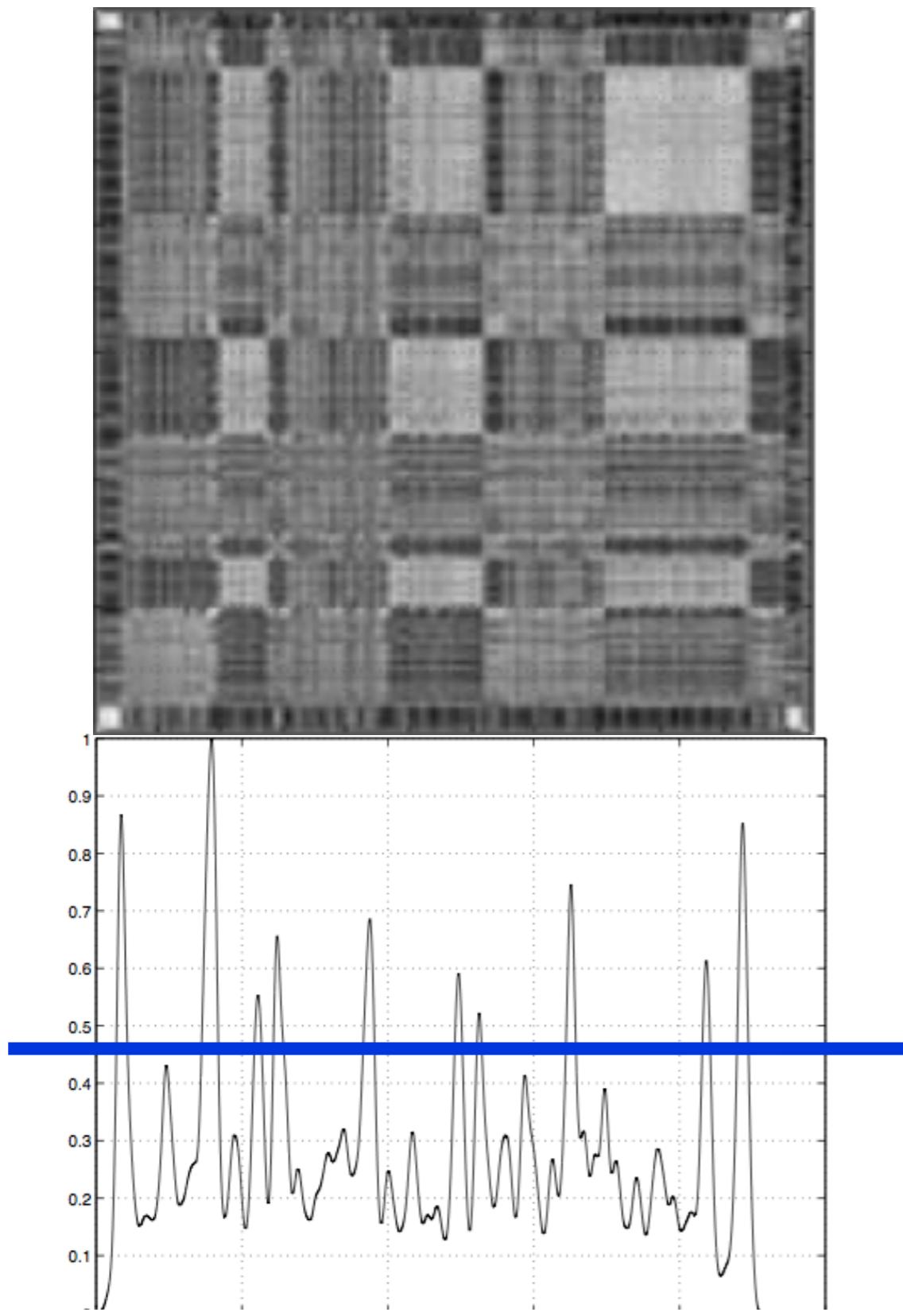
images: Foote & Cooper 2003

Structural Analysis



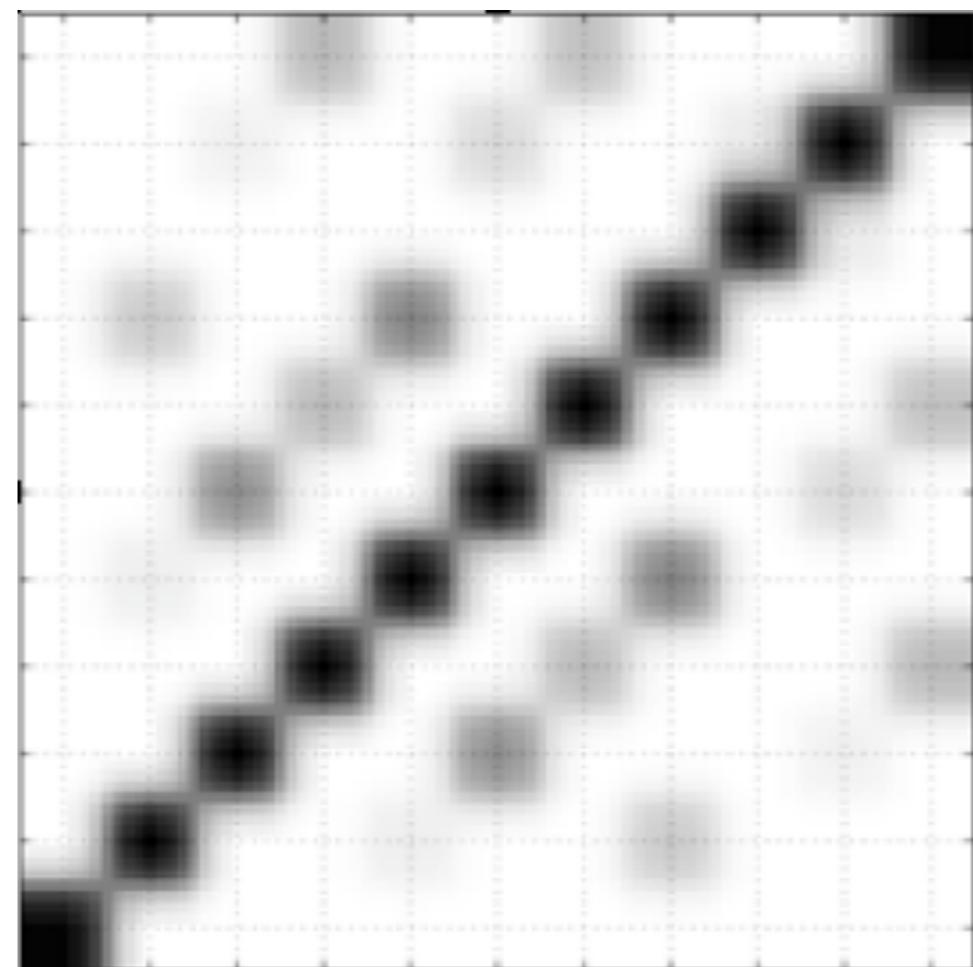
images: Foote & Cooper 2003

Structural Analysis



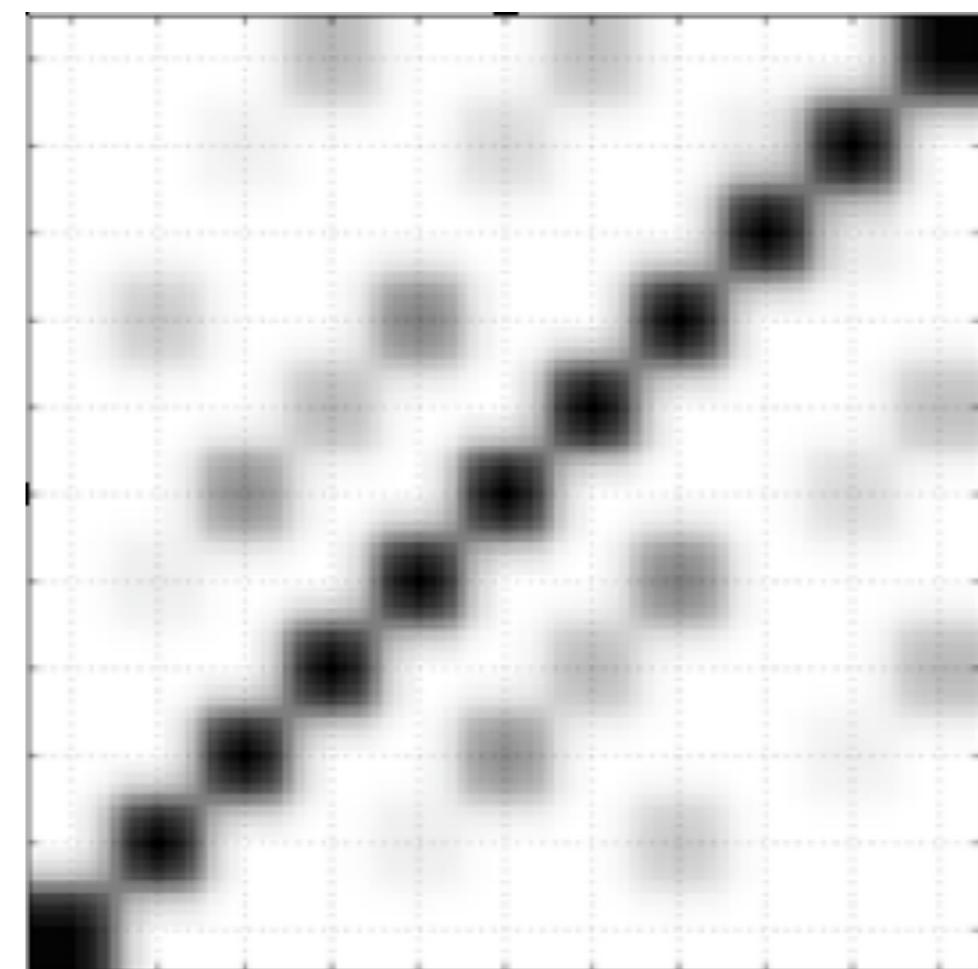
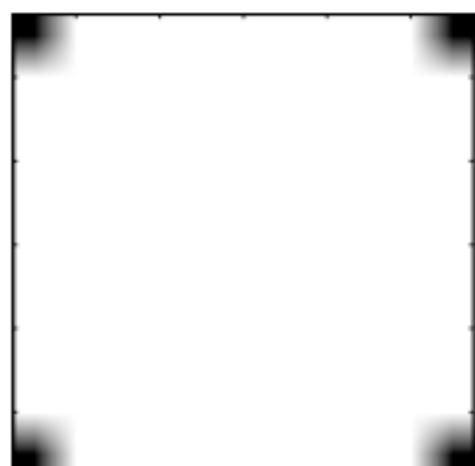
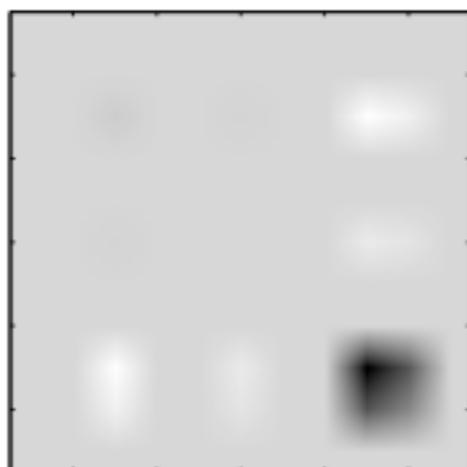
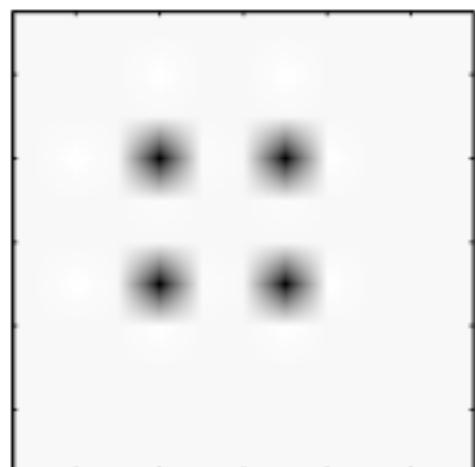
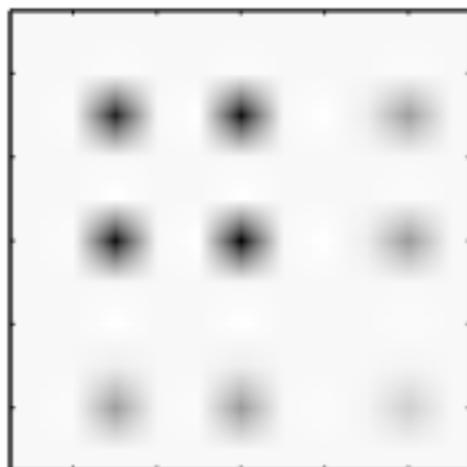
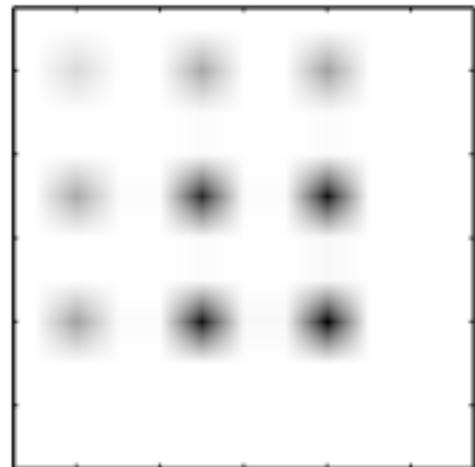
images: Foote & Cooper 2003

Structural Analysis



images: Foote & Cooper 2003

Structural Analysis



images: Foote & Cooper 2003

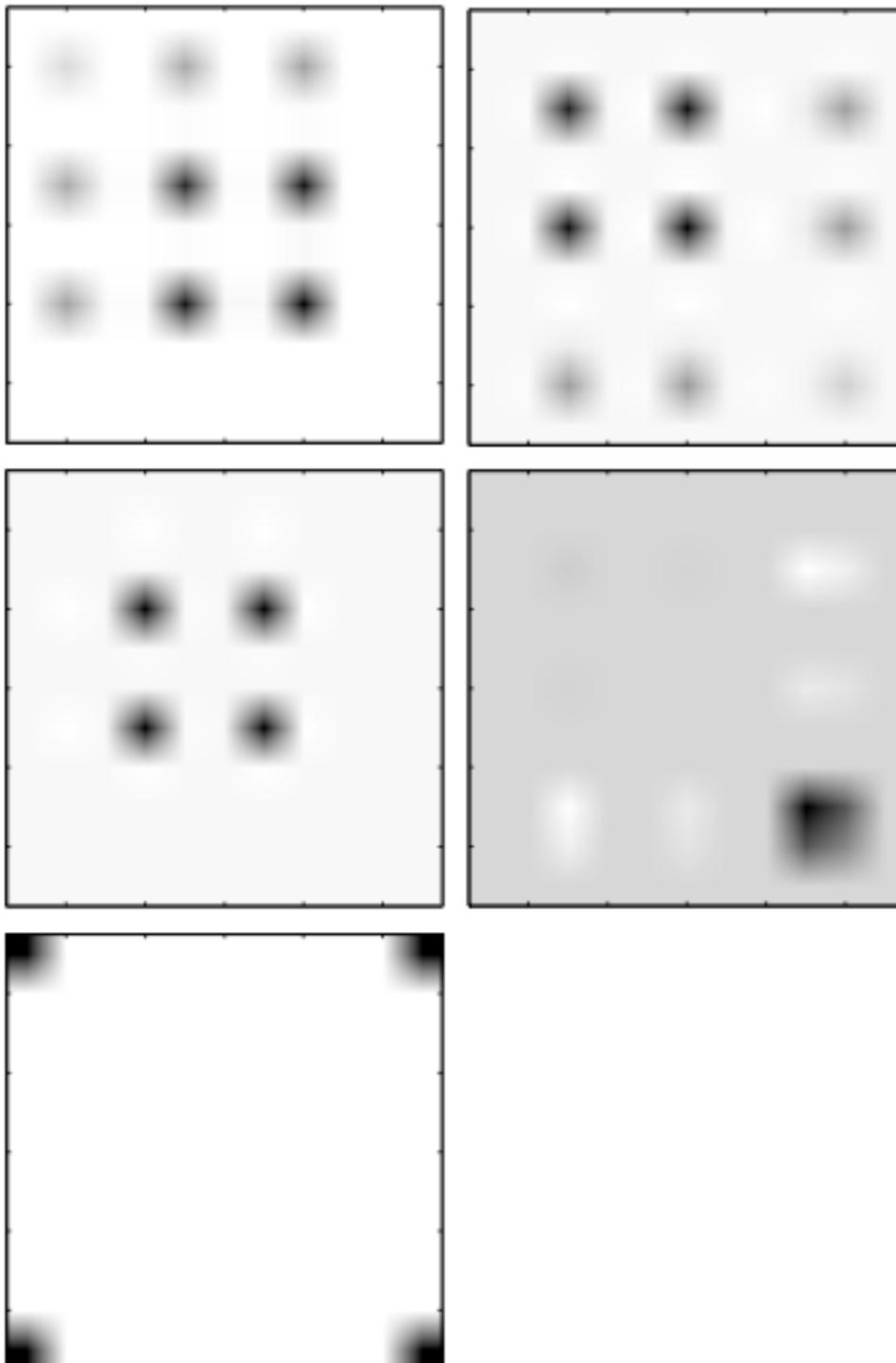
Structural Analysis



Segmentation Results: "Wild Honey" by U2			
Manual Segmentation		Automatic Segmentation	
Segment Label	Boundaries (Sec.)	Segment Label	Boundaries (Sec.)
Intro	0-9	Cluster 5	0 - 8.6275
Verse	10-40	Cluster 1	8.63 - 39.575
Chorus	41-55	Cluster 2	39.6 - 55.475
Intro	56-61	Cluster 3	55.5 - 62.075
Verse	62-93	Cluster 1	62.1 - 93.825
Chorus	94-124	Cluster 2	93.85 - 124.25
Intro	125-132	Cluster 3	124.275 - 131.325
Verse	133-162	Cluster 1	131.35 - 162.825
Bridge	163-178	Cluster 4	162.85 - 174.375
Chorus	179-208	Cluster 2	174.4 - 209.175
Intro	209-227	Cluster 5	209.20 - 227

images: Foote & Cooper 2003

Structural Analysis



Segmentation Results: "Wild Honey" by U2			
Manual Segmentation		Automatic Segmentation	
Segment Label	Boundaries (Sec.)	Segment Label	Boundaries (Sec.)
Intro	0 - 9	Cluster 5	0 - 8.6275
Verse	10-40	Cluster 1	8.63 - 39.575
Chorus	41-55	Cluster 2	39.6 - 55.475
Intro	56-61	Cluster 3	55.5 - 62.075
Verse	62-93	Cluster 1	62.1 - 93.825
Chorus	94-124	Cluster 2	93.85 - 124.25
Intro	125-132	Cluster 3	124.275 - 131.325
Verse	133-162	Cluster 1	131.35 - 162.825
Bridge	163-178	Cluster 4	162.85 - 174.375
Chorus	179-208	Cluster 2	174.4 - 209.175
Intro	209-227	Cluster 5	209.20 - 227

images: Foote & Cooper 2003

Aucouturier's Approach



Figure 2-1: Comparison of the classic MIDI track representation of music (A) and the texture representation (B)

Aucouturier's Approach



Figure 2-1: Comparison of the classic MIDI track representation of music (A) and the texture representation (B)

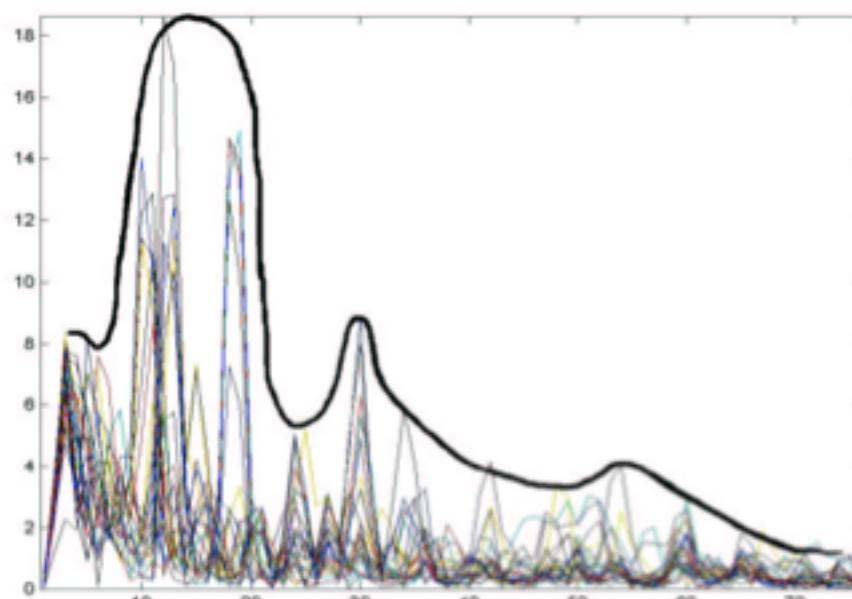


Figure 3-2: superposition of 50 successive STS (30 ms frames) for a polyphonic texture {guitar + bass + synthesizer}

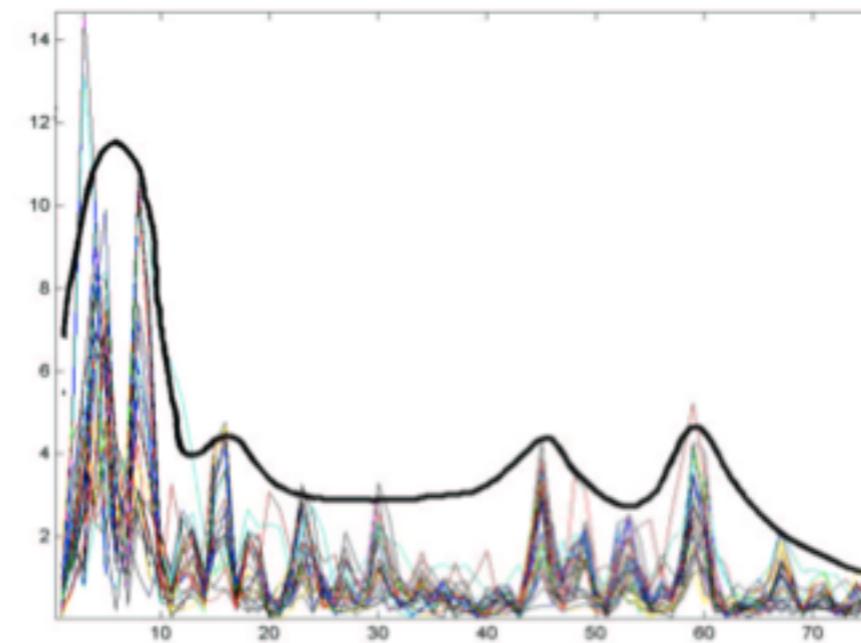


Figure 3-3: superposition of 50 successive STS (30ms frames) for a different polyphonic texture : {piano + bass + synthesizer}

images:Aucouturier 2001

Aucouturier's Approach

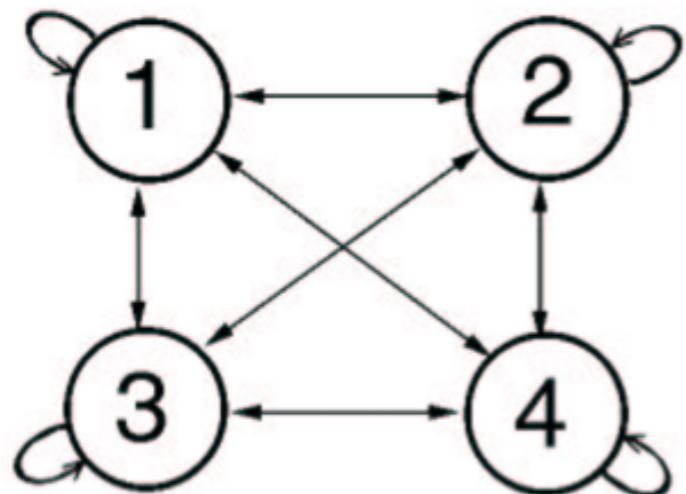


Figure 3-11: A 4-state ergodic HMM. Each state can generate a vector in the feature space according to some probability distribution

Aucouturier's Approach

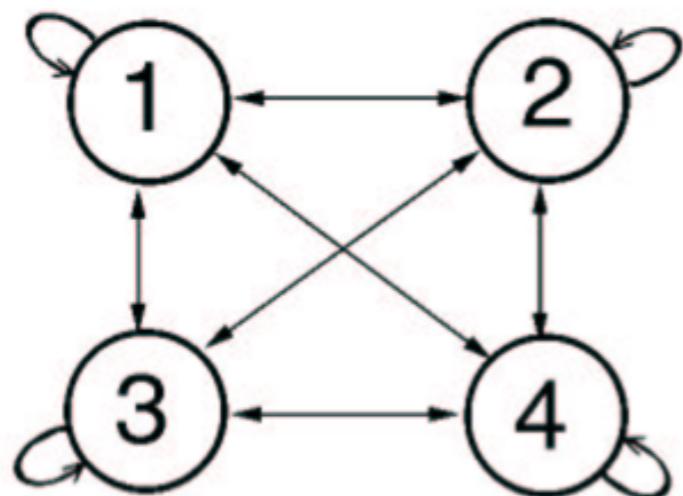


Figure 3-11: A 4-state ergodic HMM. Each state can generate a vector in the feature space according to some probability distribution

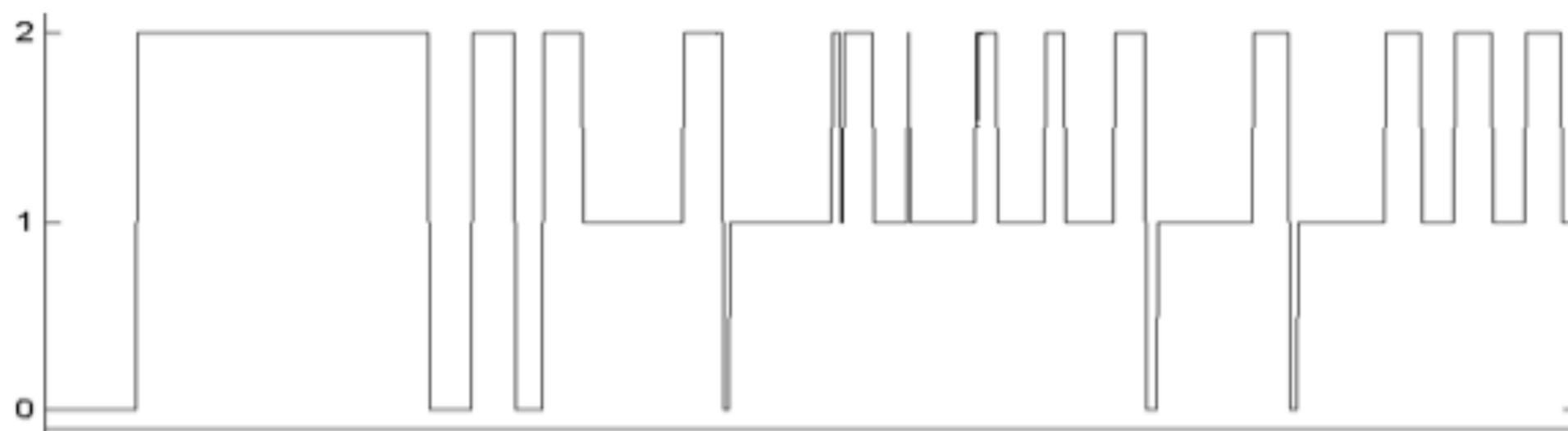


Figure 3-12: Segmentation of Bourvil's song. State 0 is {silence}, state 1 is {voice + accordion + accompaniment} and state 2 is {accordion + accompaniment}

Aucouturier's Approach

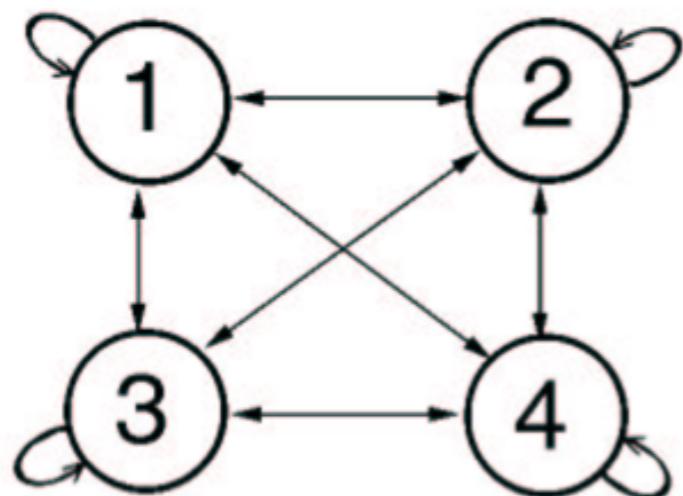


Figure 3-11: A 4-state ergodic HMM. Each state can generate a vector in the feature space according to some probability distribution

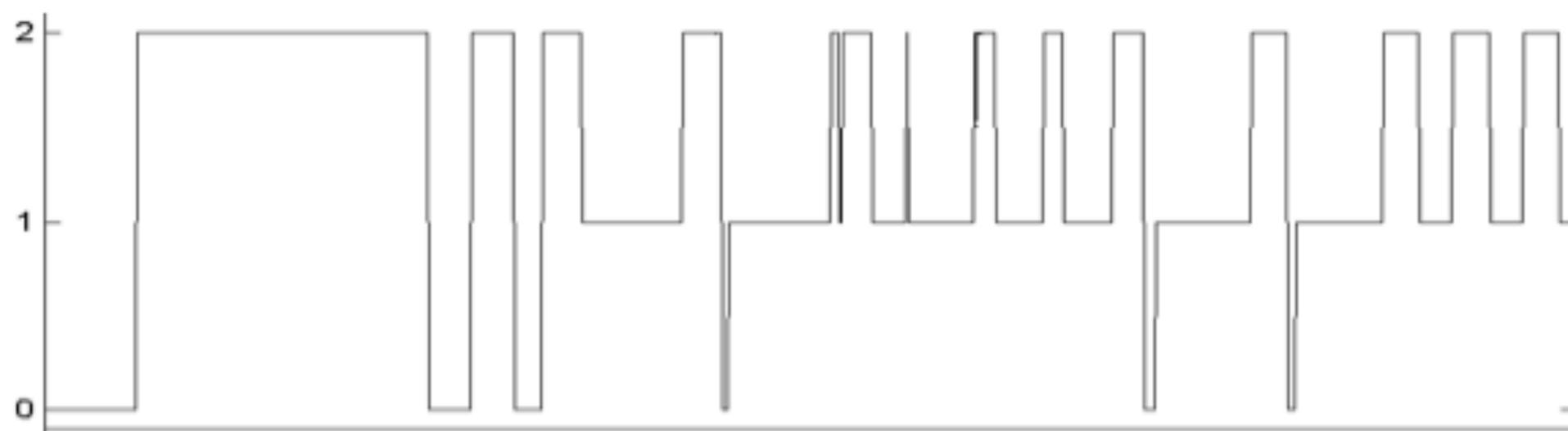
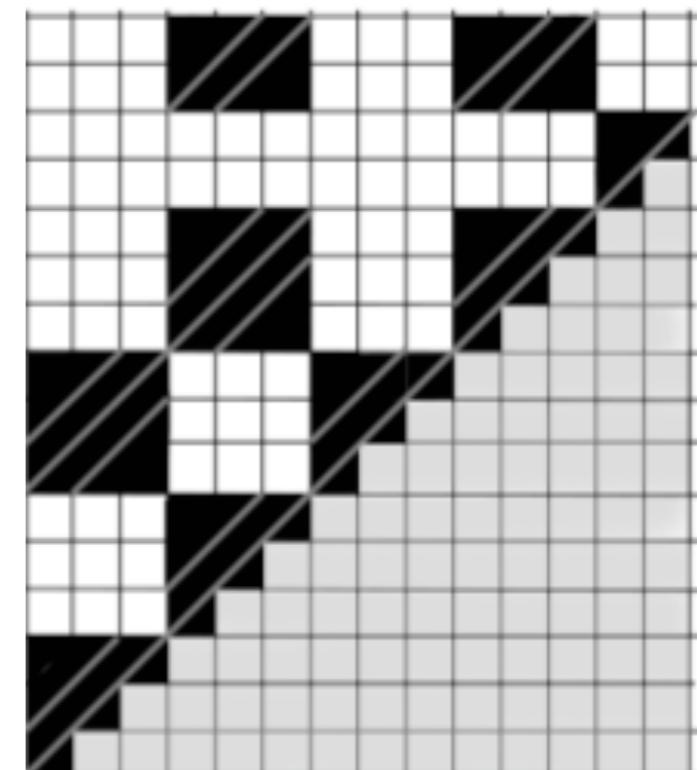
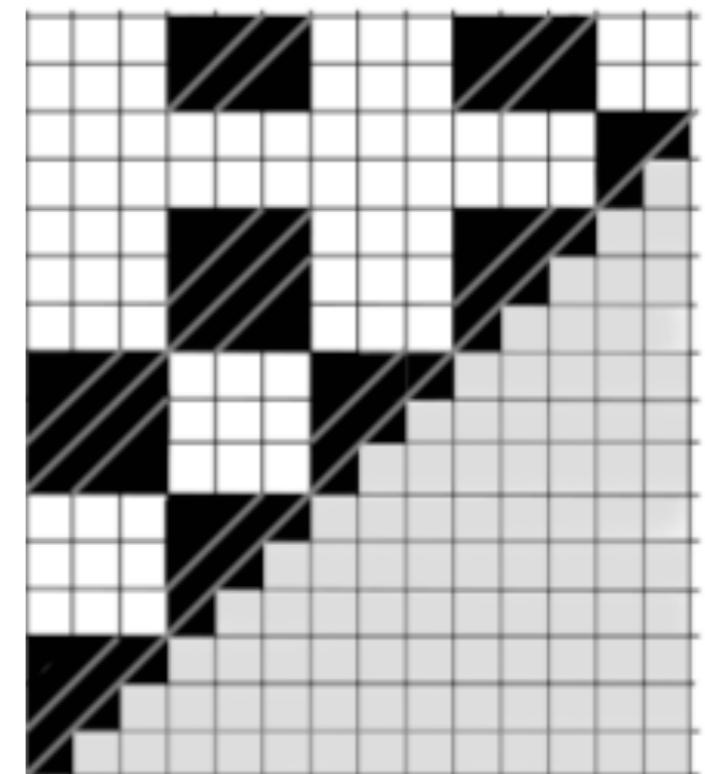


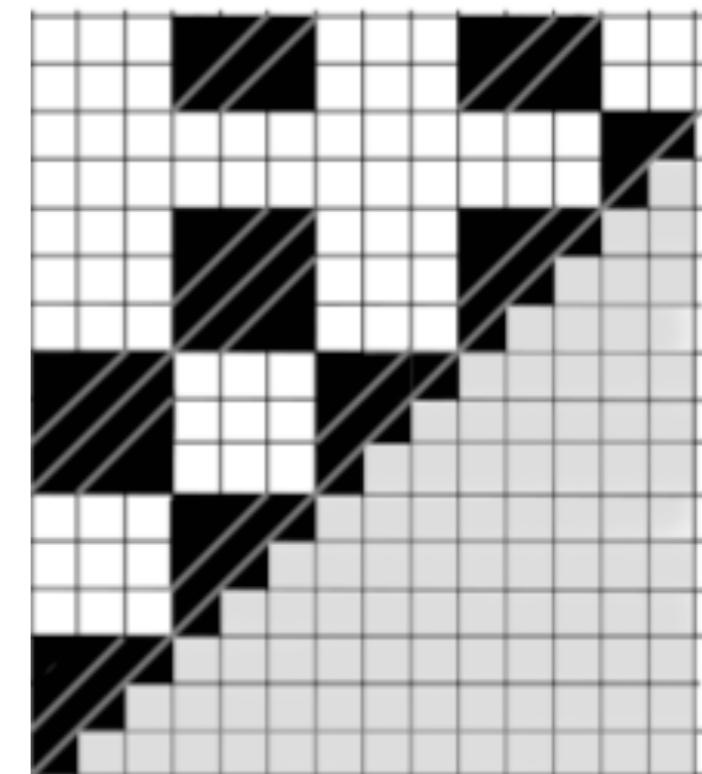
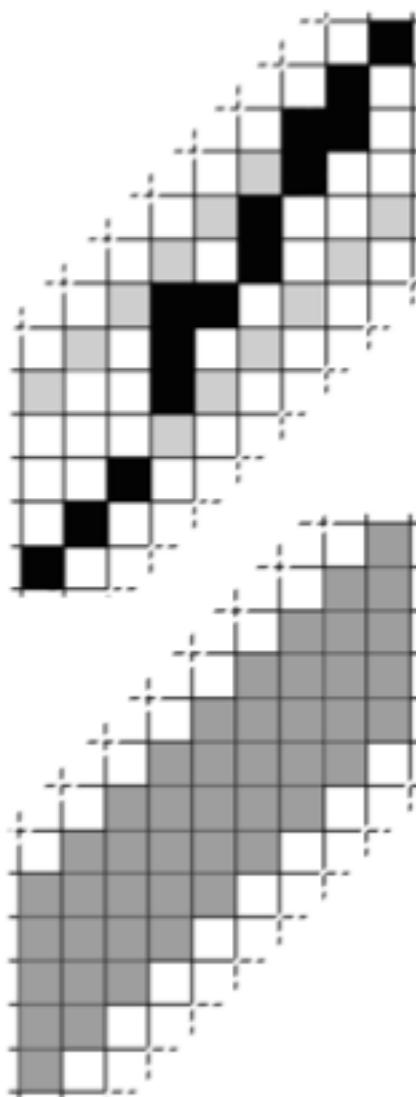
Figure 3-12: Segmentation of Bourvil's song. State 0 is {silence}, state 1 is {voice + accordion + accompaniment} and state 2 is {accordion + accompaniment}

Aucouturier's Approach



images: Aucouturier 2001

Aucouturier's Approach



images: Aucouturier 2001

Aucouturier's Approach

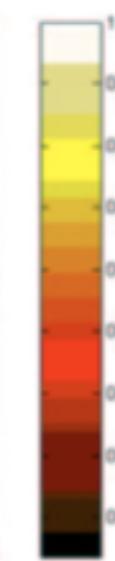
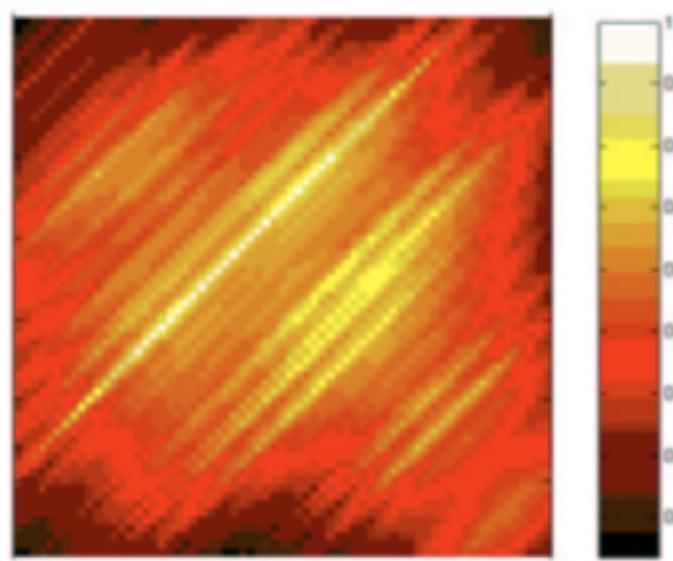
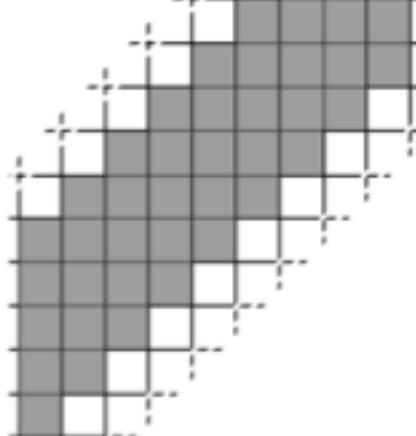
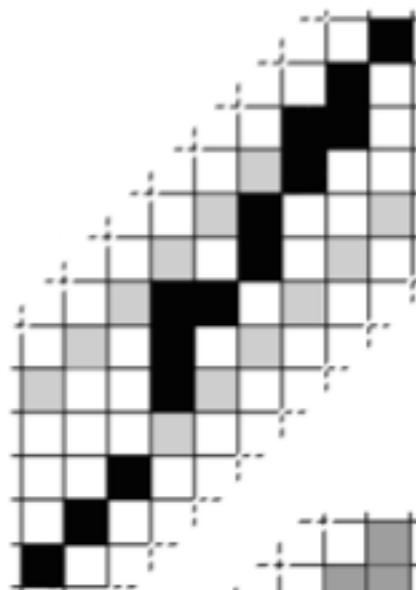


Figure 5-8: Detail of a correlation matrix with an approximate occurrence before (A) and after correlation with the diagonal kernel (B).

images:Aucouturier 2001

Aucouturier's Approach

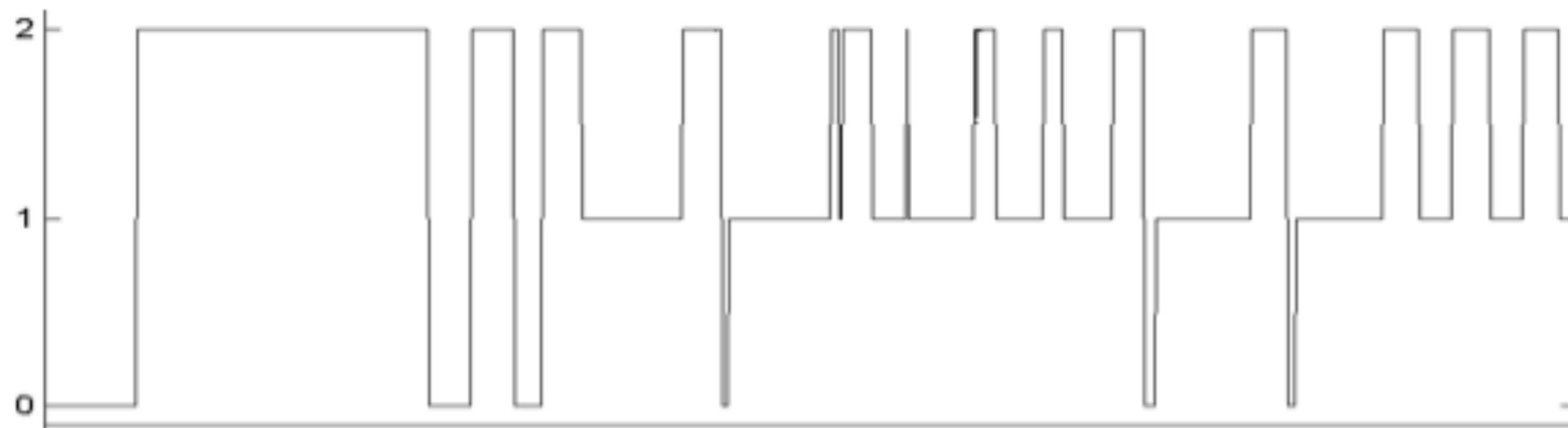


Figure 3-12: Segmentation of Bourvil's song. State 0 is {silence}, state 1 is {voice + accordion + accompaniment} and state 2 is {accordion + accompaniment}

Abdallah's Approach

Bjork:Its Oh So Quiet

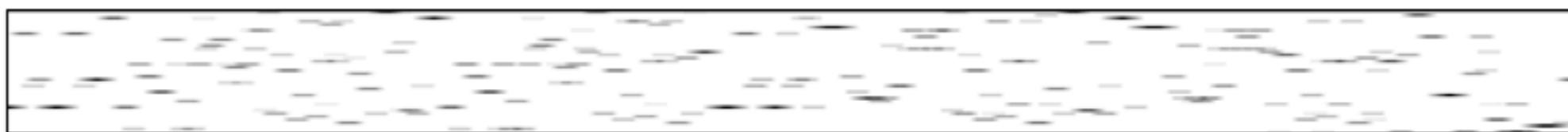


Abdallah's Approach

Bjork:Its Oh So Quiet



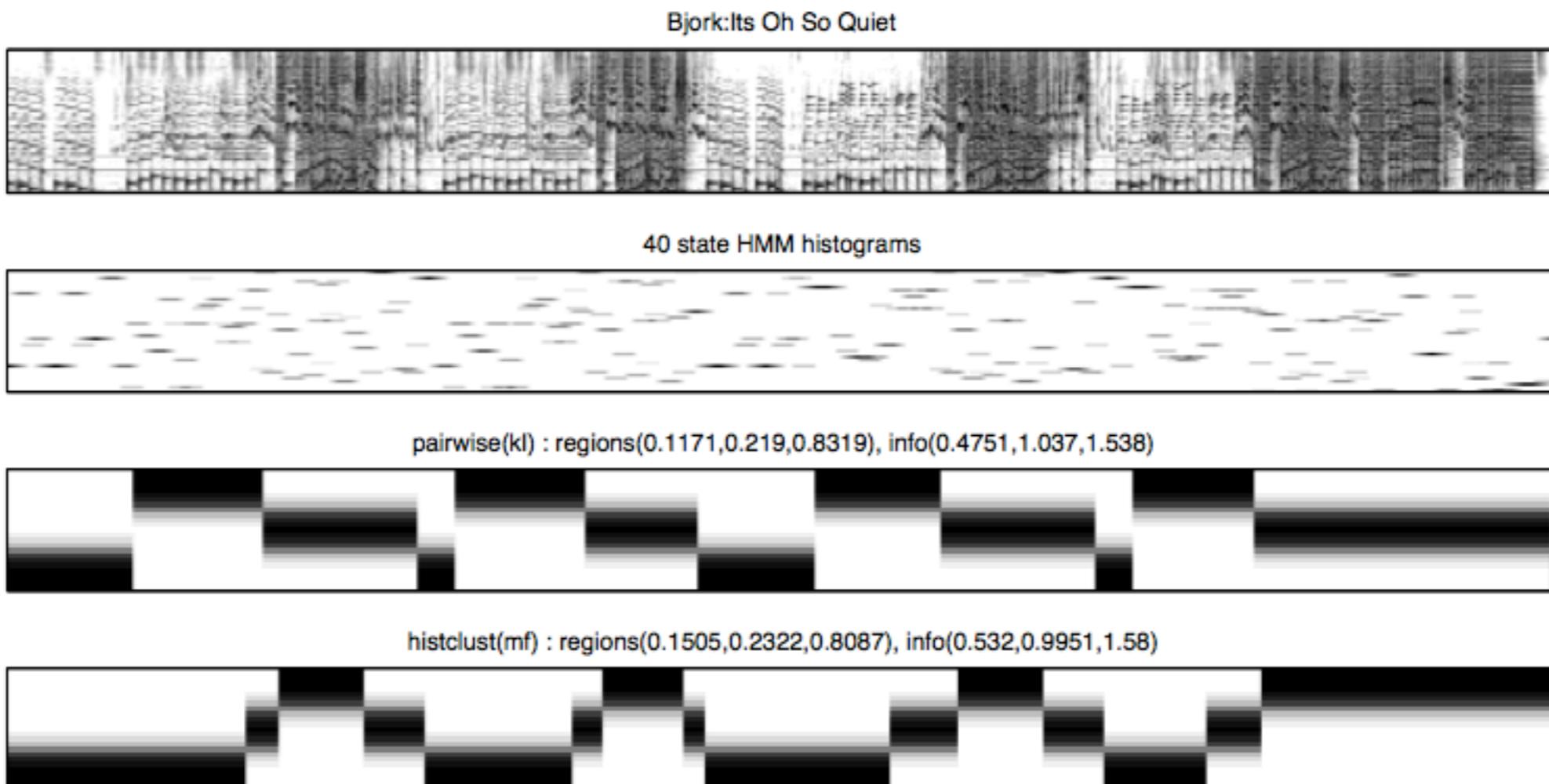
40 state HMM histograms



PCA +
HMM:

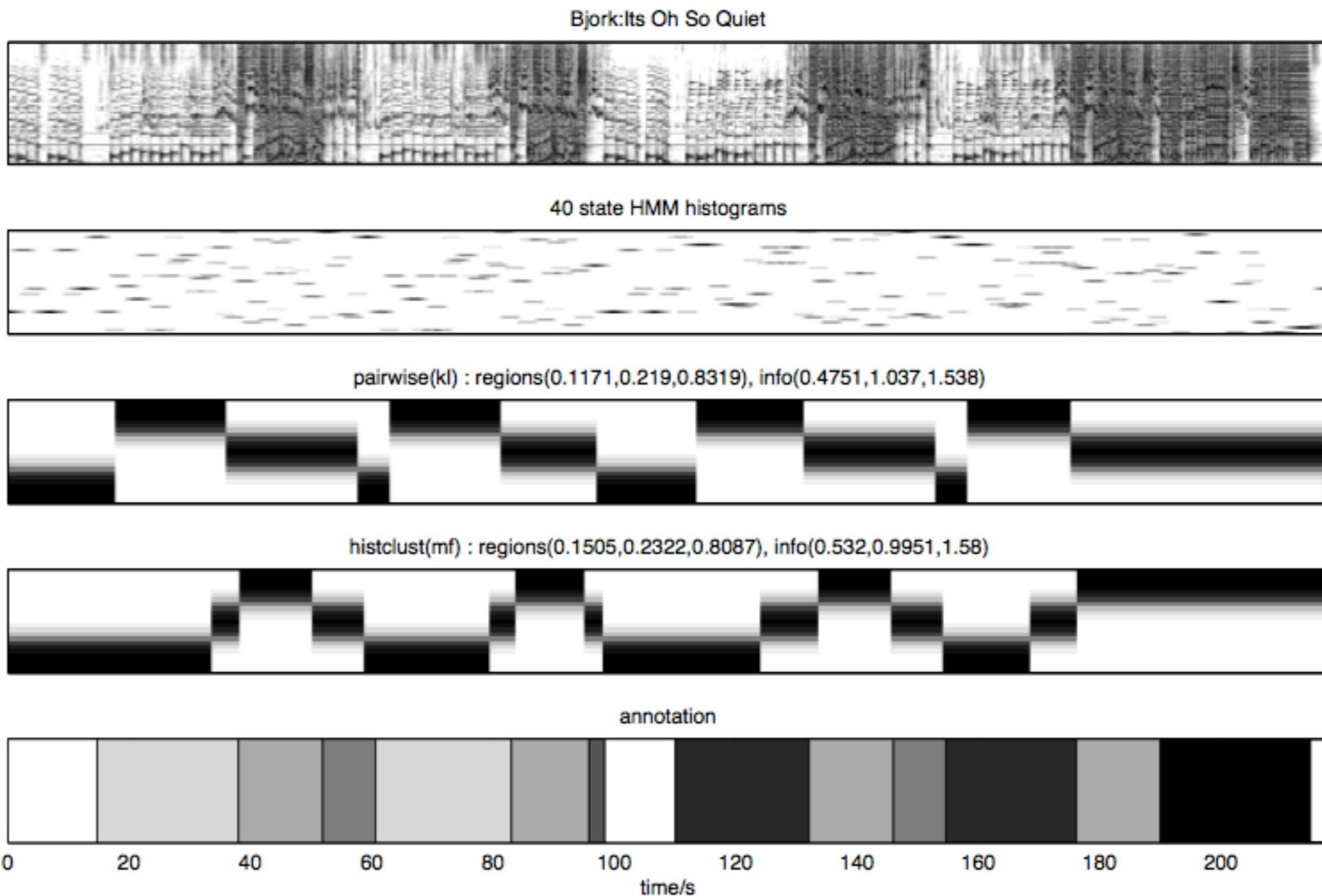
Abdallah's Approach

PCA +
HMM:
cluster:



Abdallah's Approach

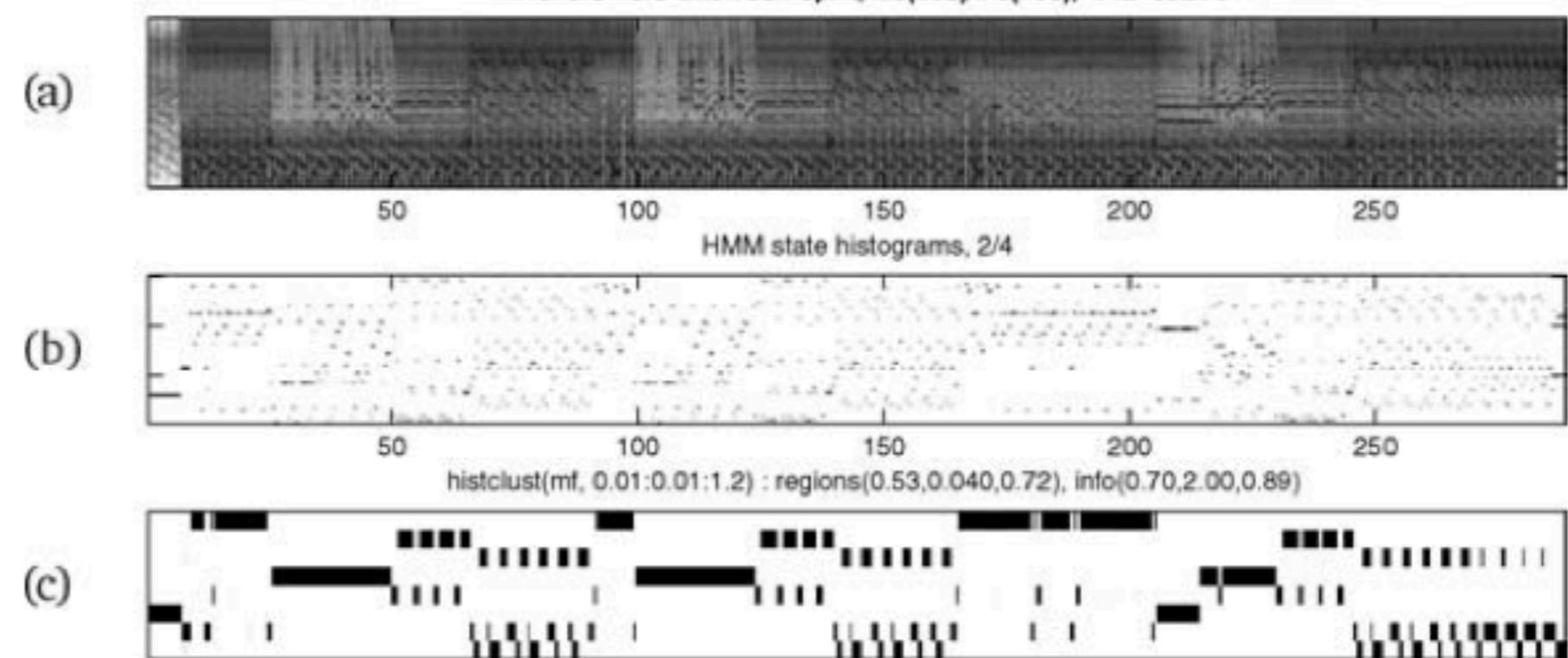
PCA +
HMM:
cluster:



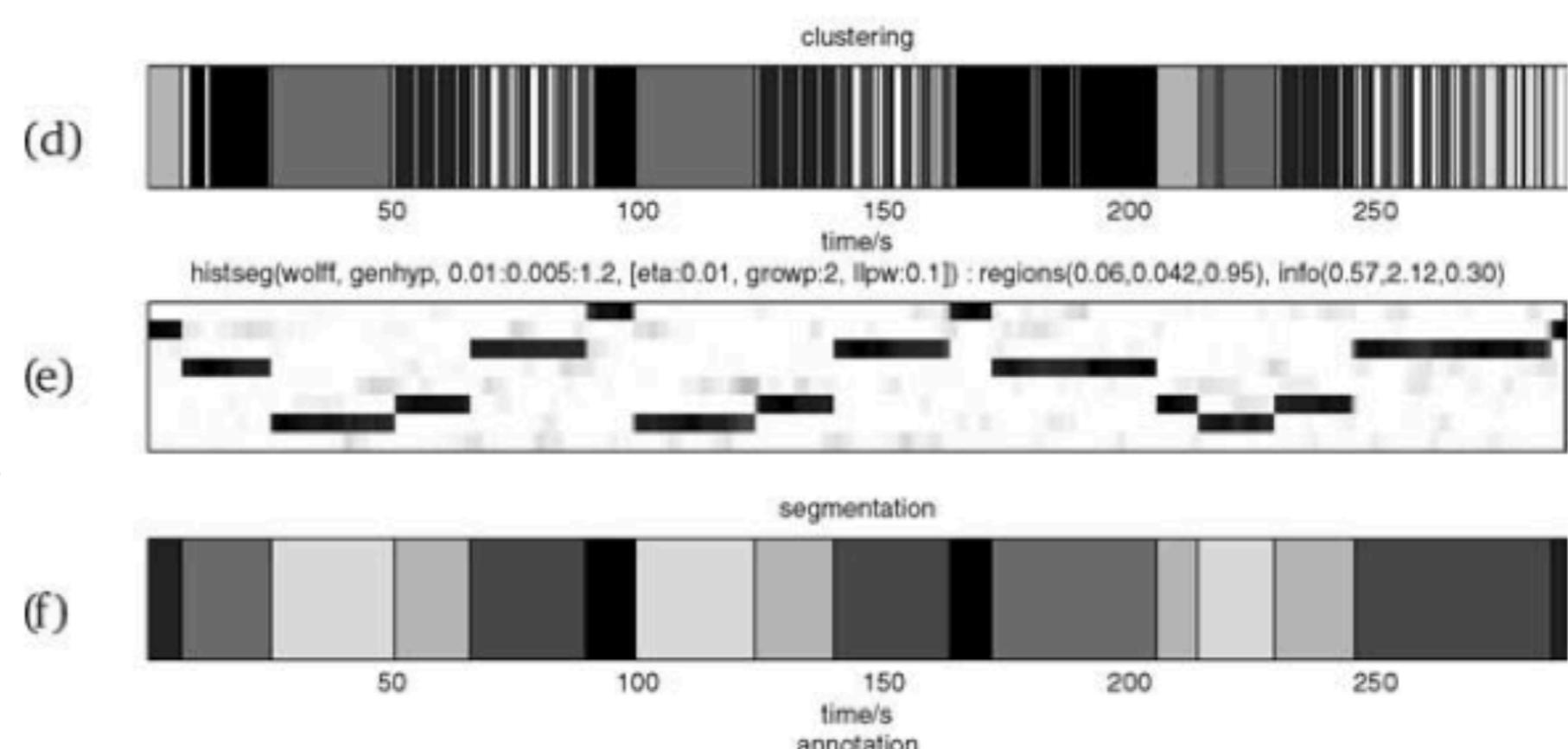
images:Abdallah et al. 2005

**PCA +
HMM:**

cluster 1:



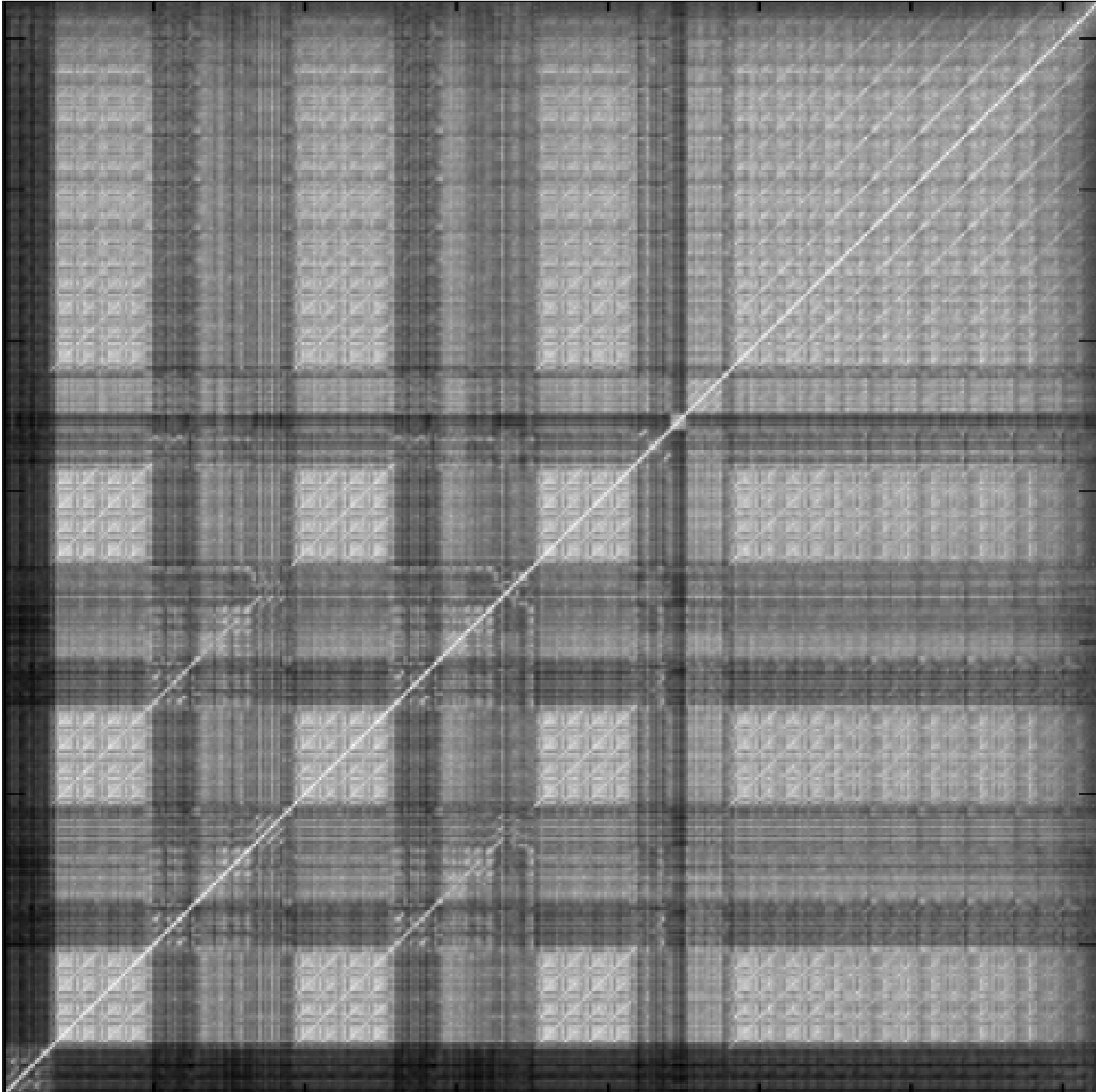
cluster 2:



annotation

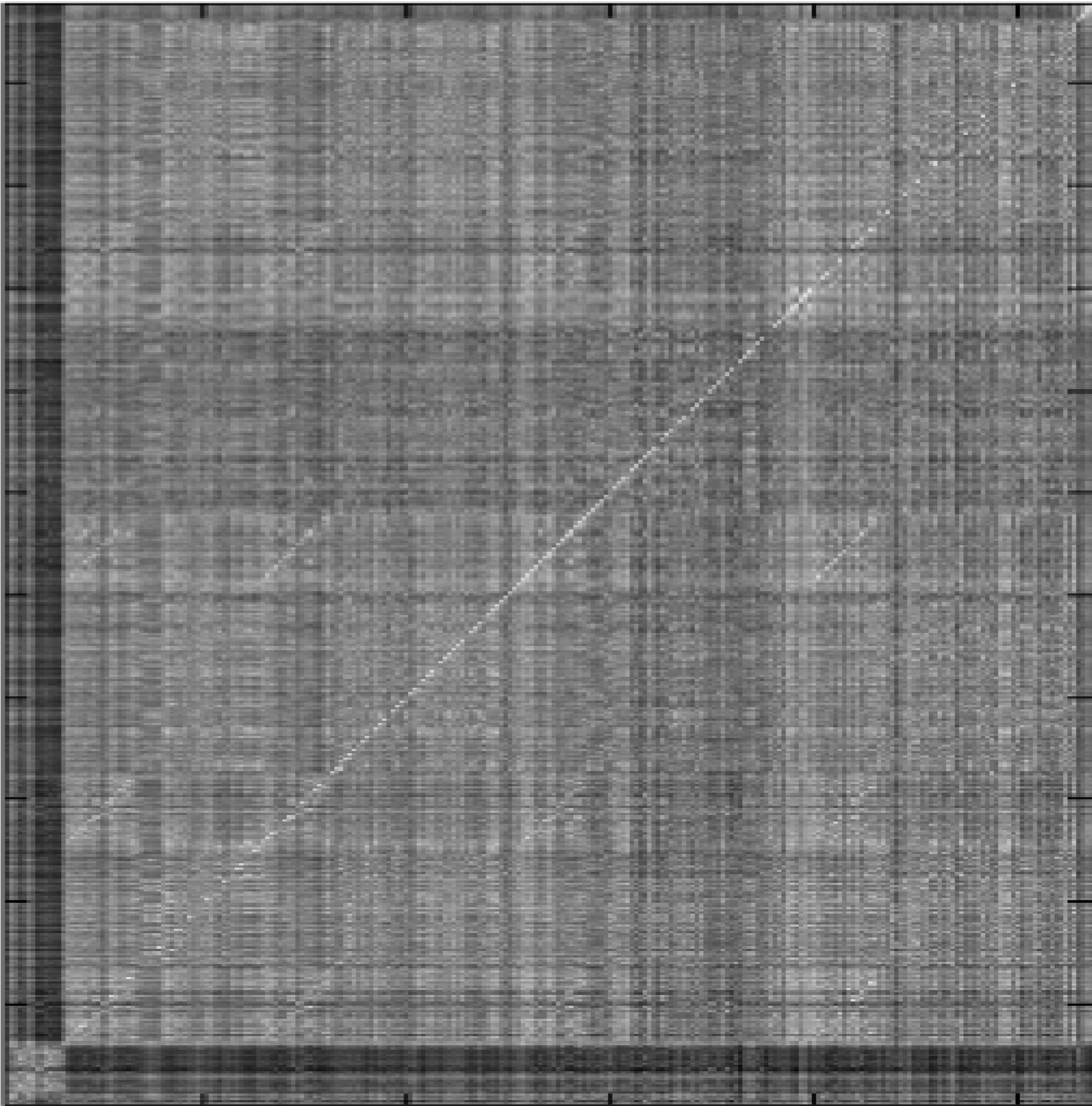


Which features?



song:
“Tubthumping” by
Chumbawamba

image:
Peiszer 2007

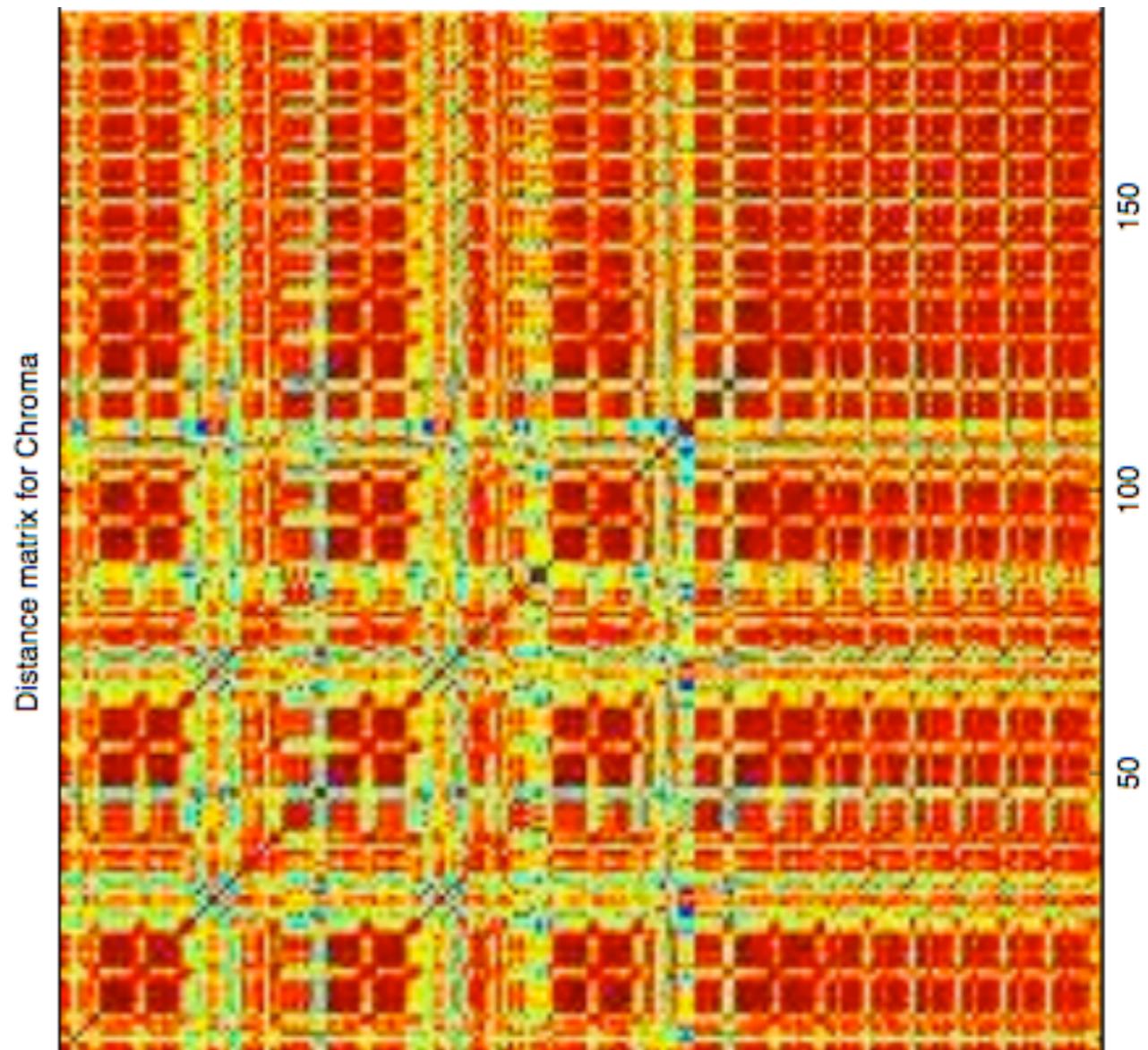


song: "Stan" by
Eminem

image:
Peiszer 2007

A note on features:

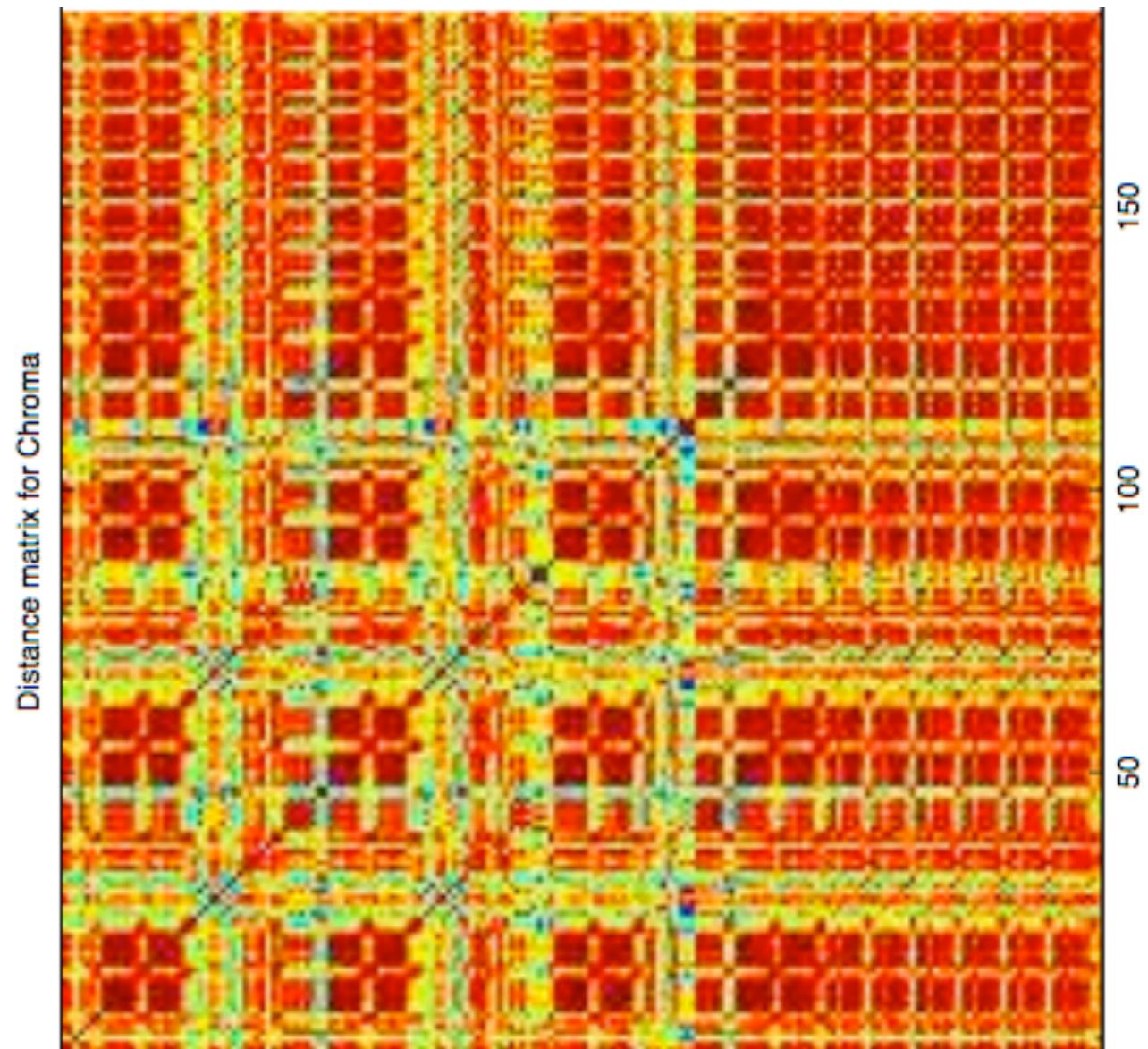
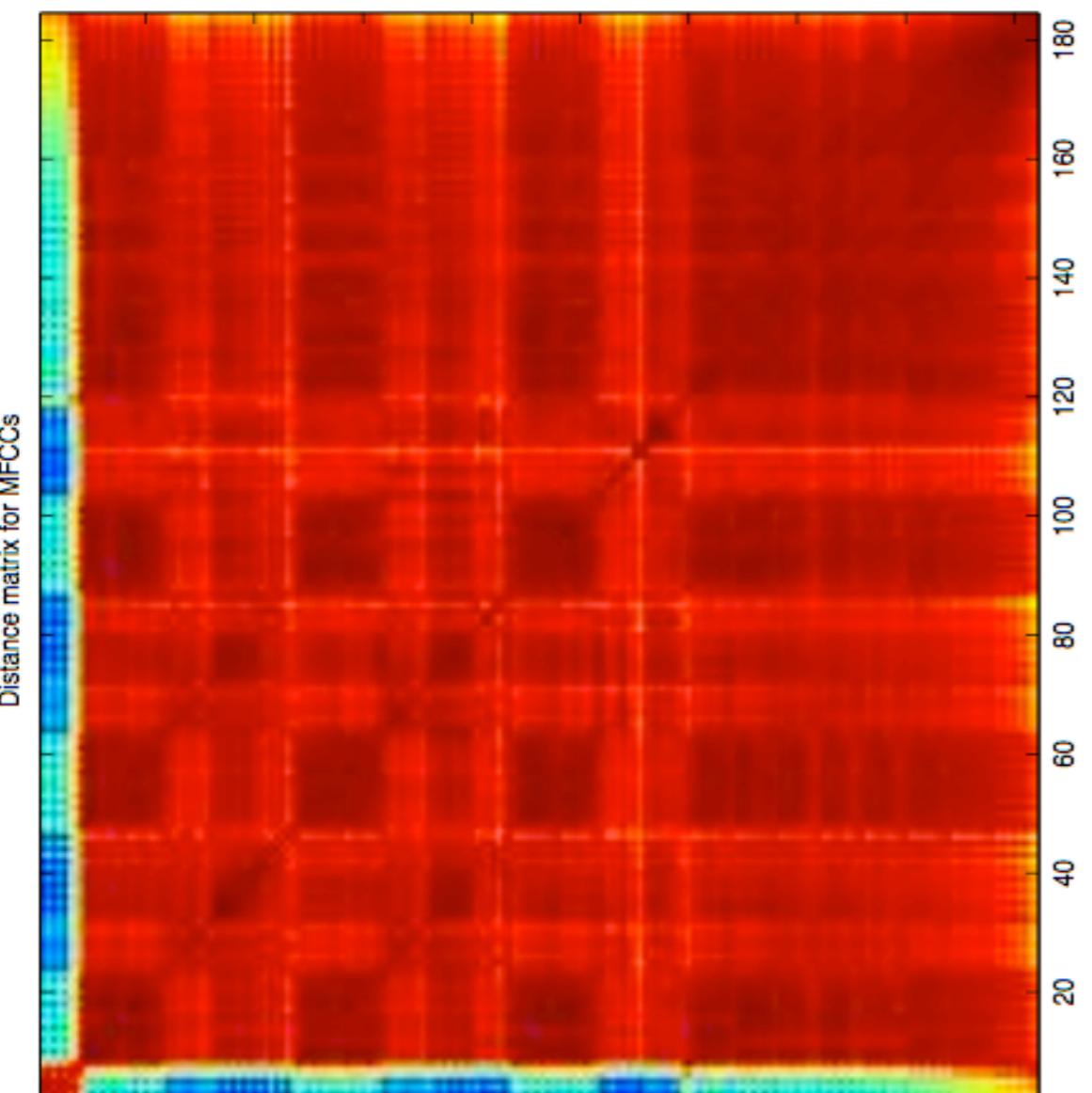
- States:
use MFCCs
- Sequences:
use pitch chroma



song: "Tubthumping" by Chumbawamba

A note on features:

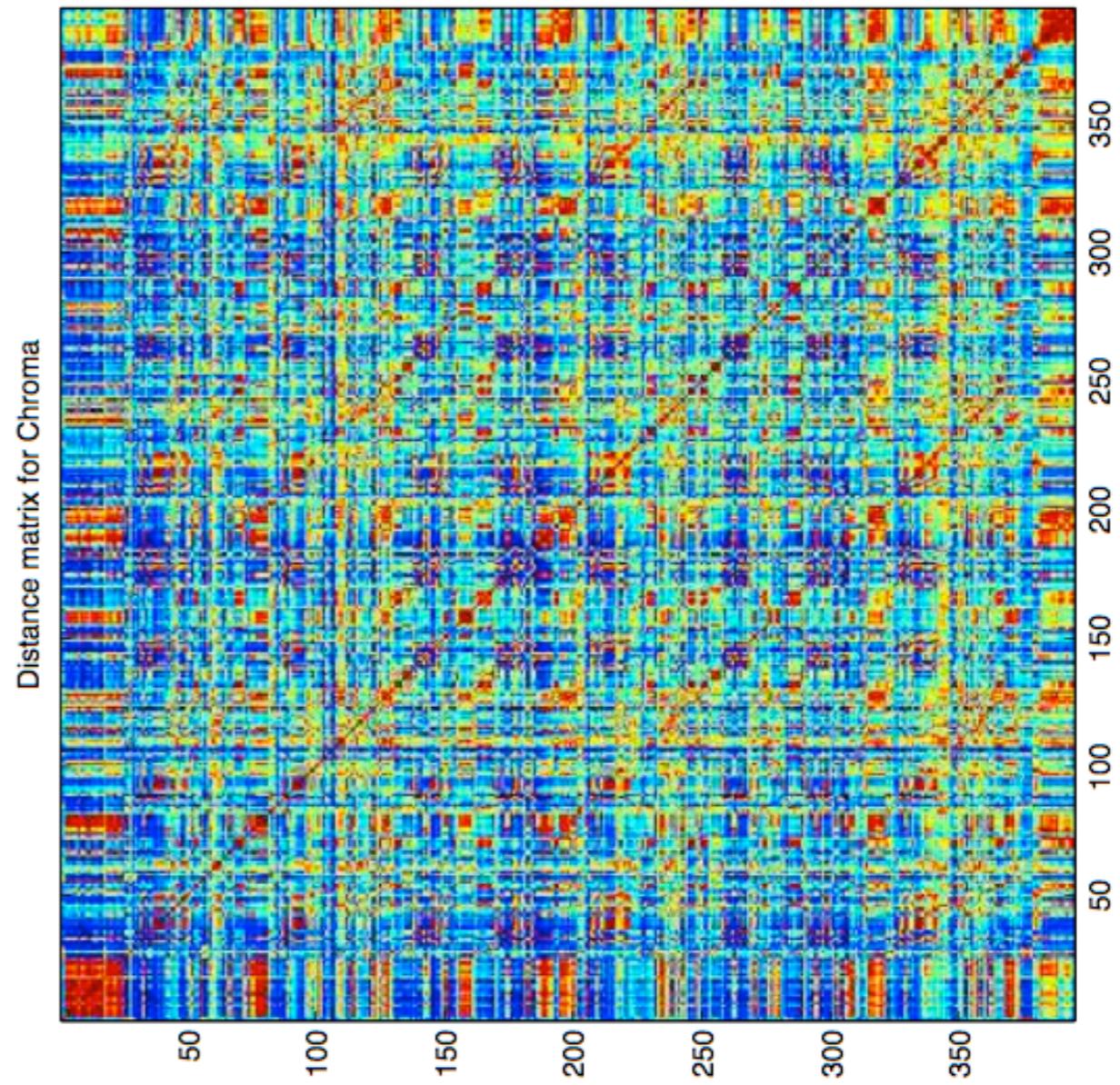
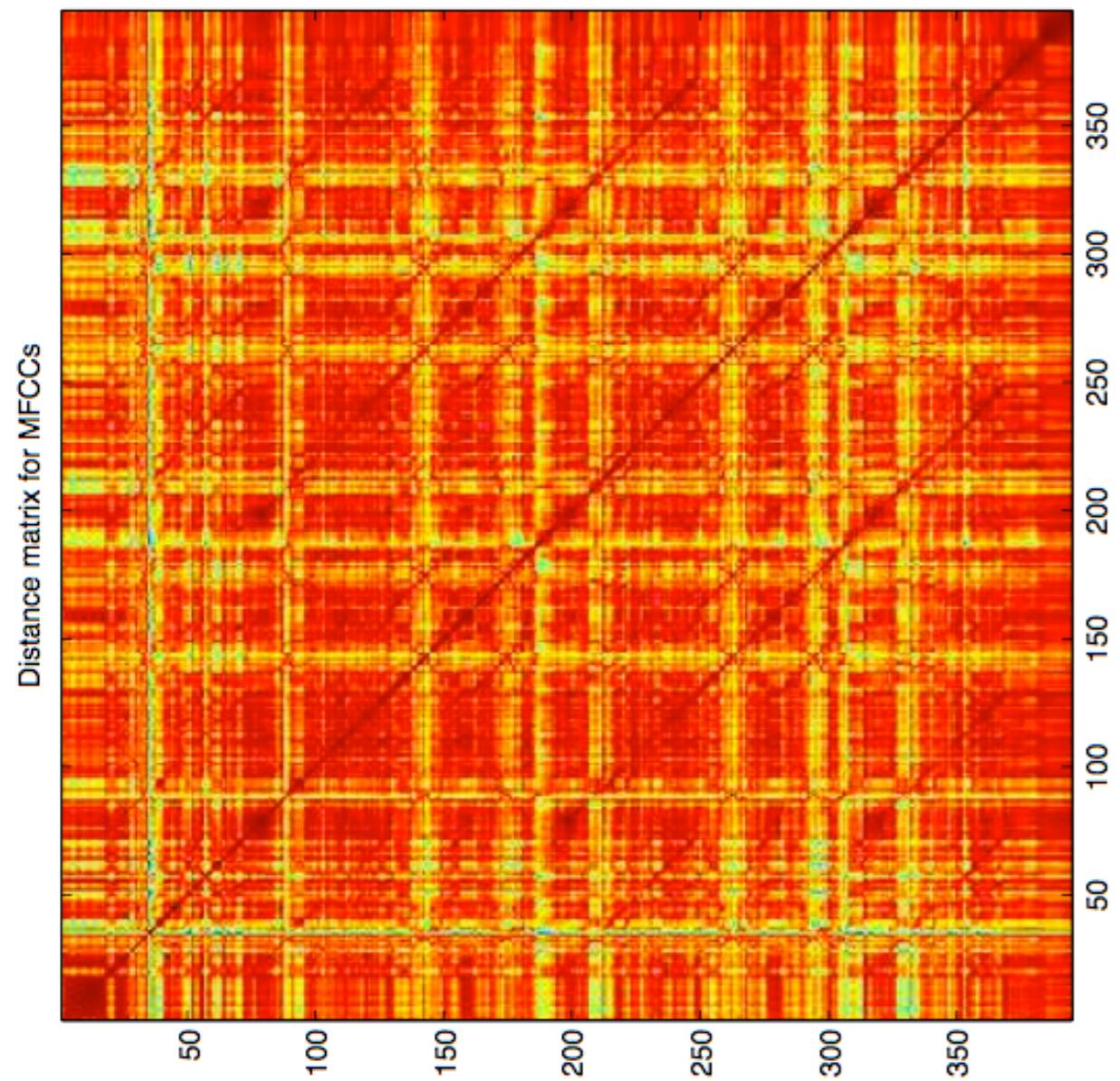
- States:
use MFCCs
- Sequences:
use pitch chroma



song: "Tubthumping" by Chumbawamba

A note on features:

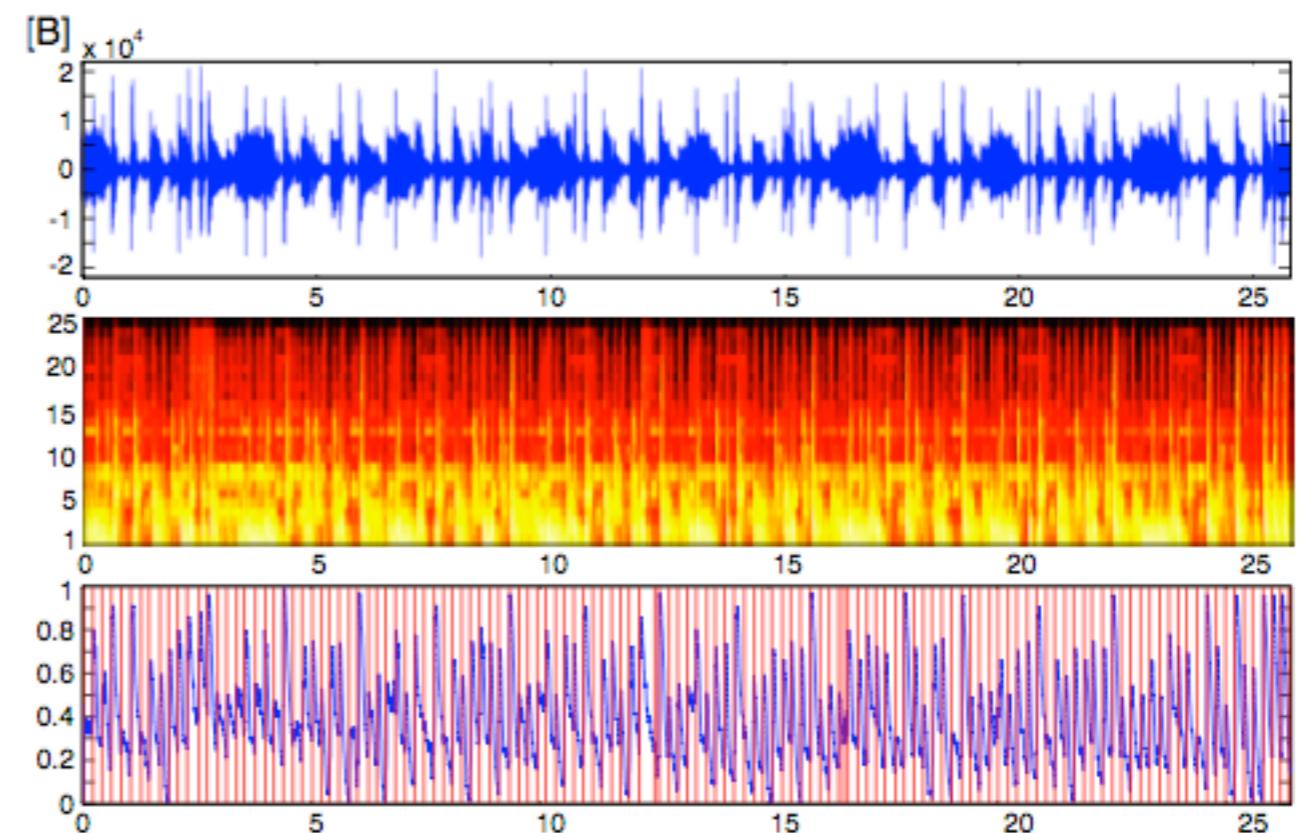
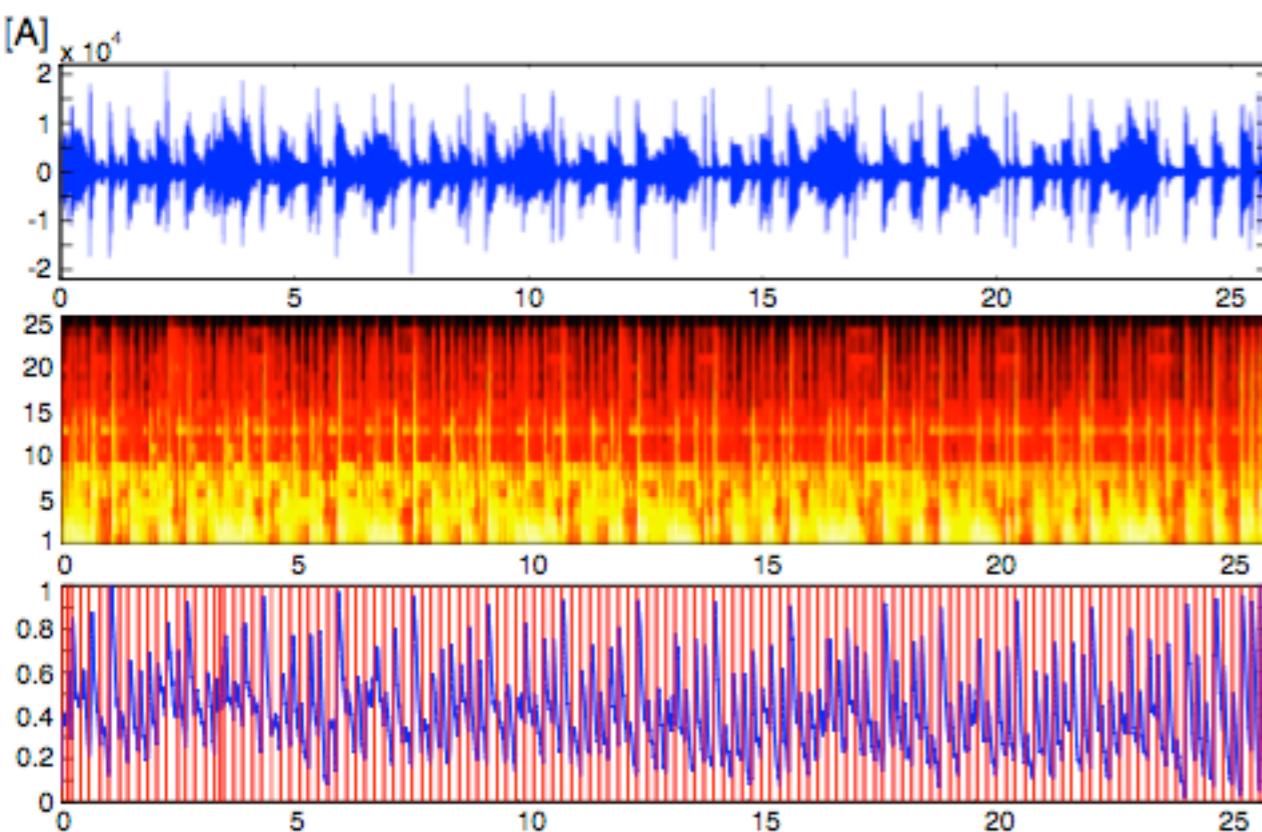
- States:
use MFCCs
- Sequences:
use pitch chroma



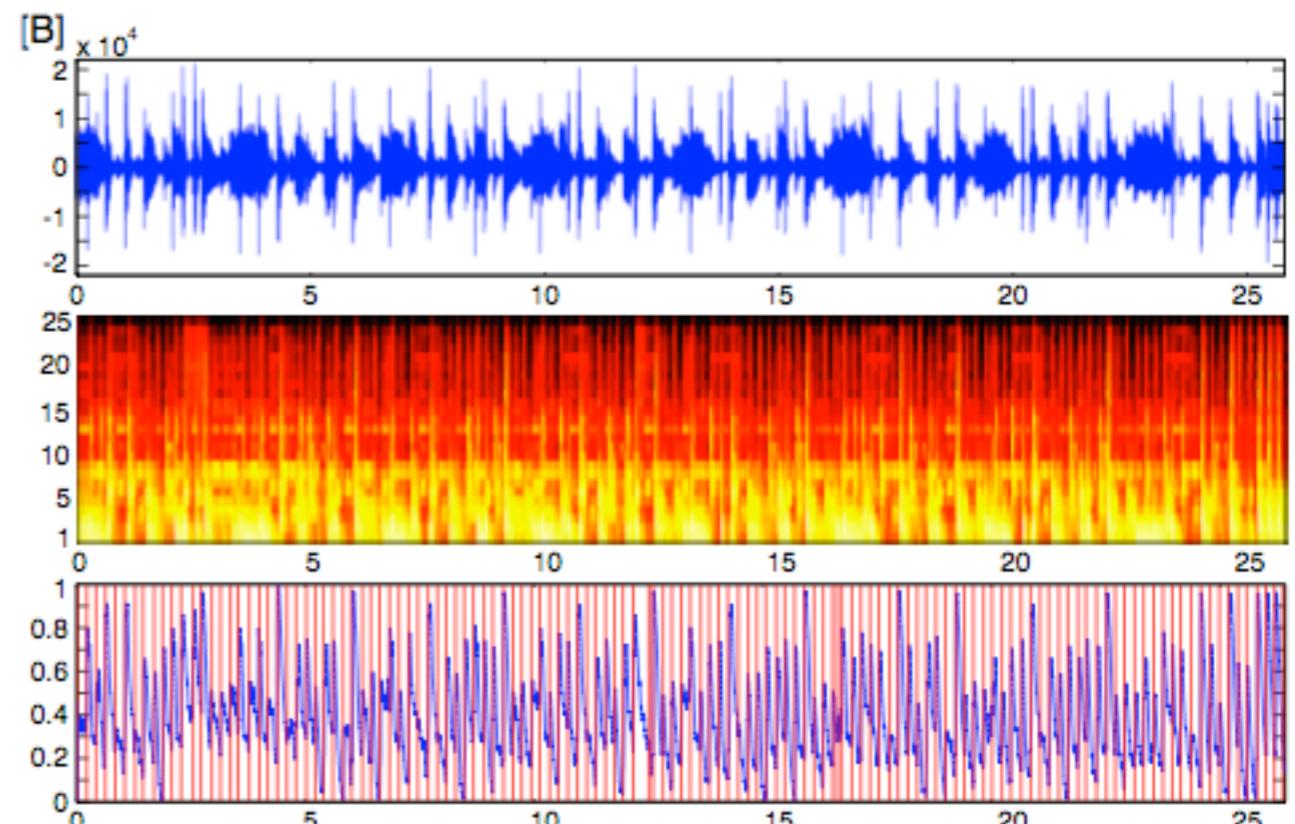
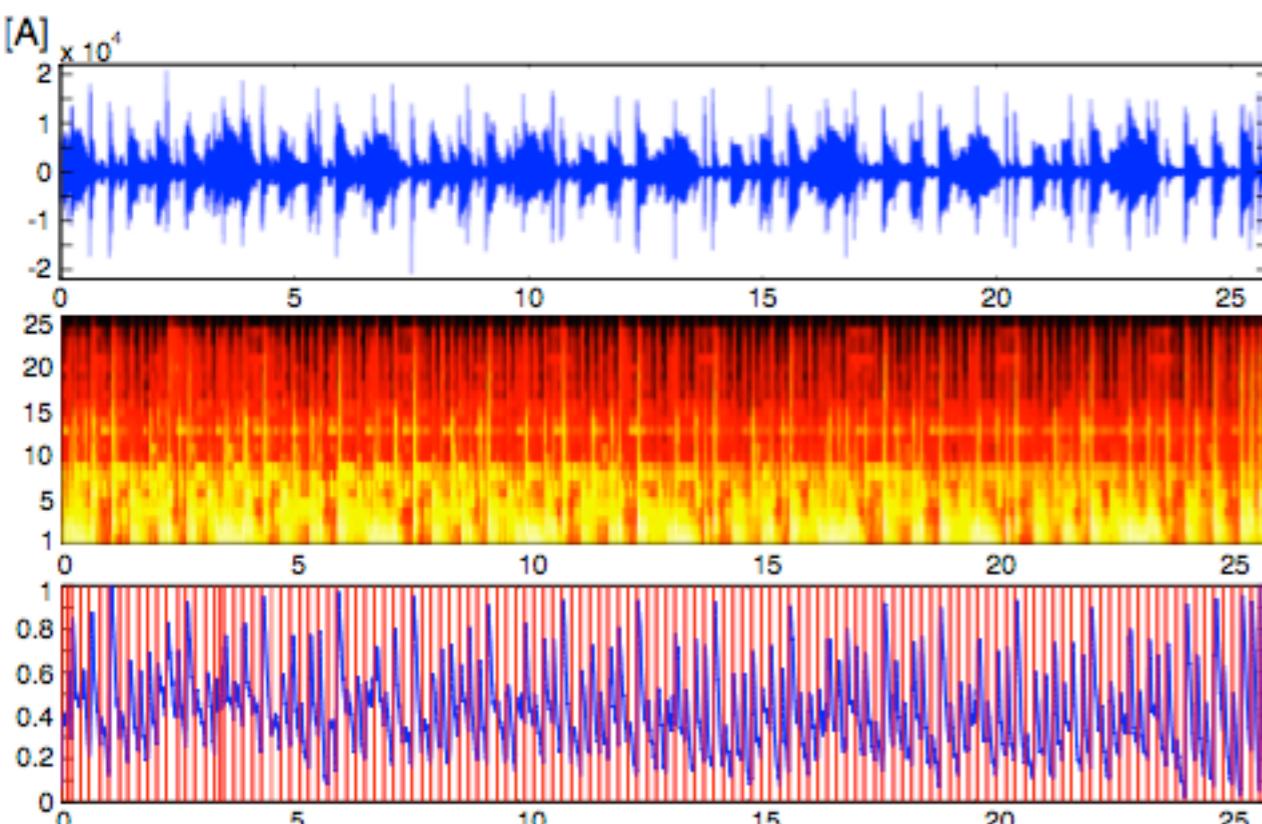
song: "Yesterday" by The Beatles

APPLICATIONS

Compression

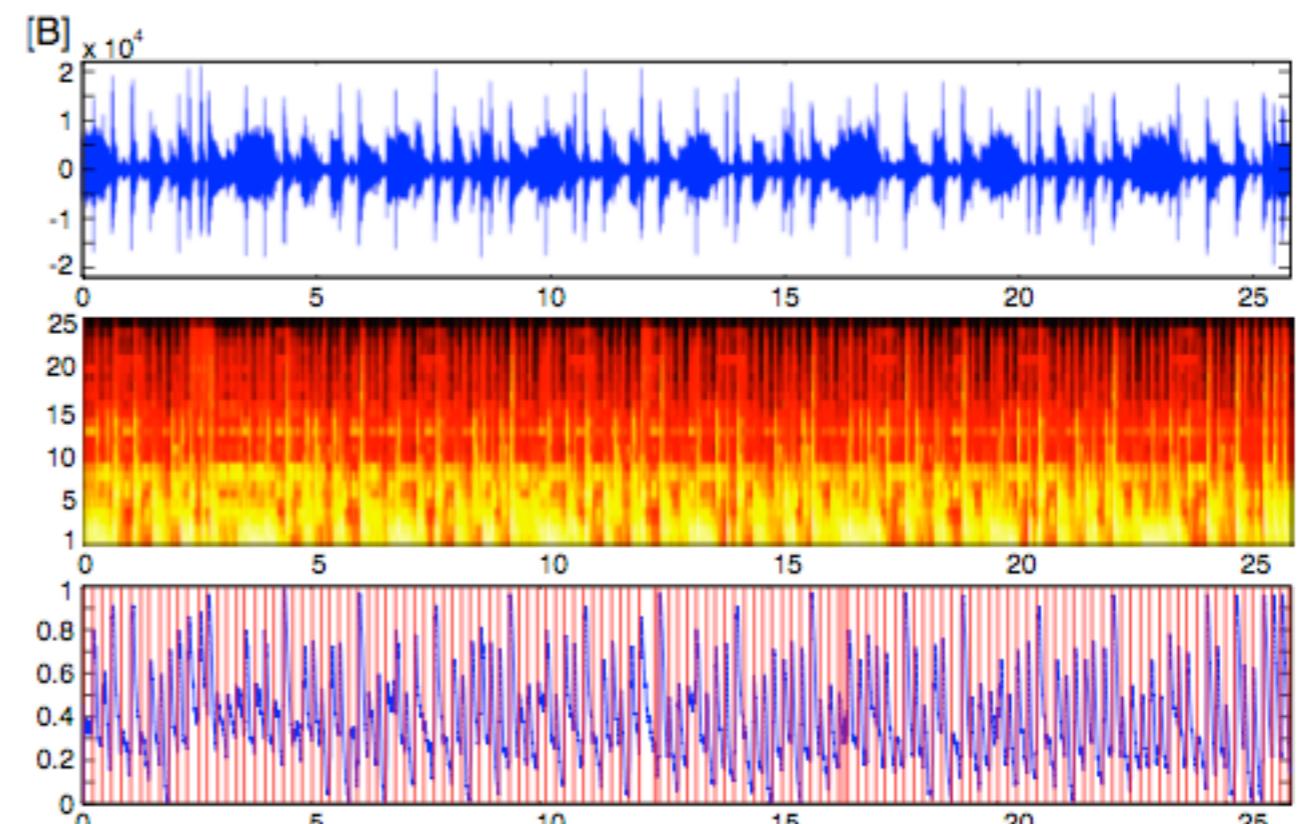
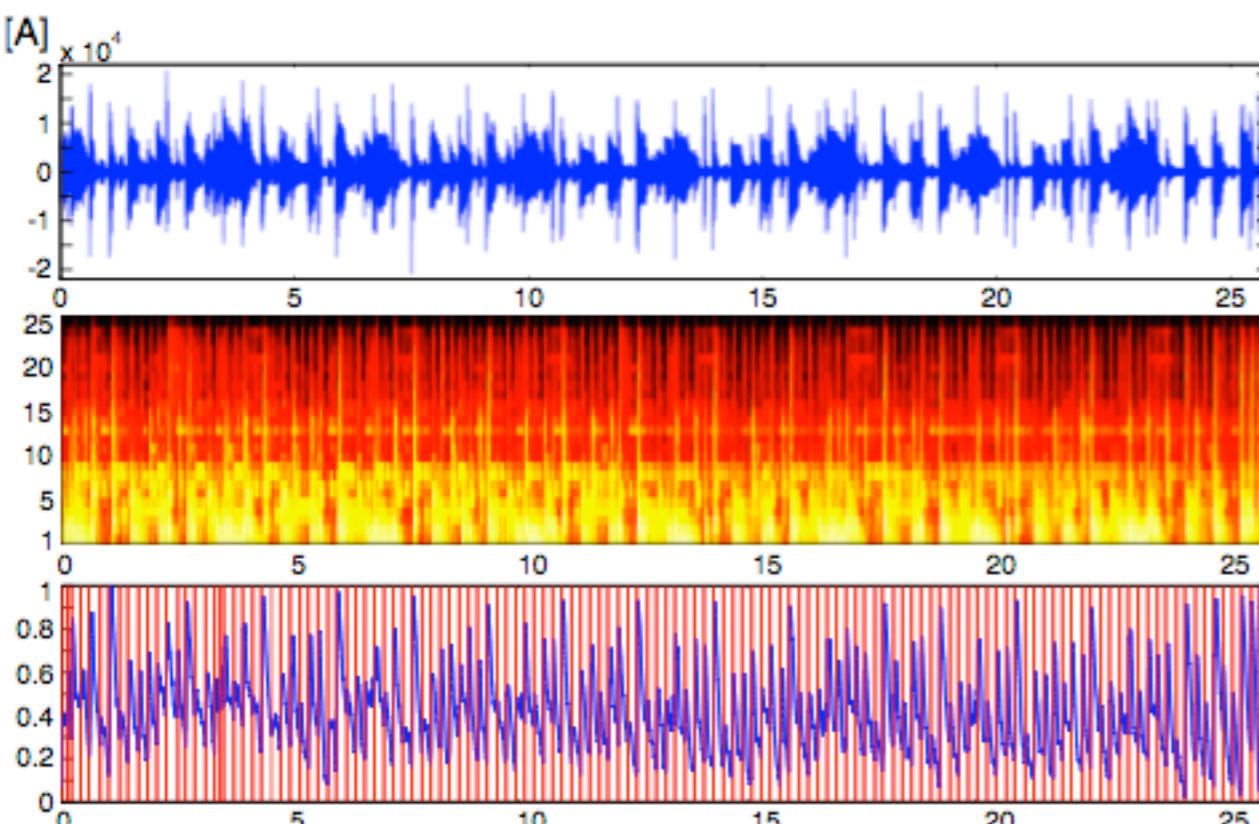


Compression



26 seconds
of audio

Compression



26 seconds
of audio

8 seconds
of audio



Advanced Music Navigation

<http://staff.aist.go.jp/m.goto/SmartMusicKIOSK/>



Last breakfast in K...



Dinner in Kyoto



Nijo Castle



Kyoto day 2



Hiroshima



Miyajima



Okonomiyaki



Desserts in Osaka



Downtown Osaka

Music thumbnailing



\$7.99 Buy Album ▾

Genre: Rock

Released: Dec 07, 2004

© 2004 Geffen Records



Customer Ratings

Rate this

We have not received enough ratings to display an average for this album.

Top Rufus Wainw...

Songs

Albums

1. Hallelujah

2. Across the Universe (r...

3. Give Me Your Heart Again

Want Two (Canadian Version)

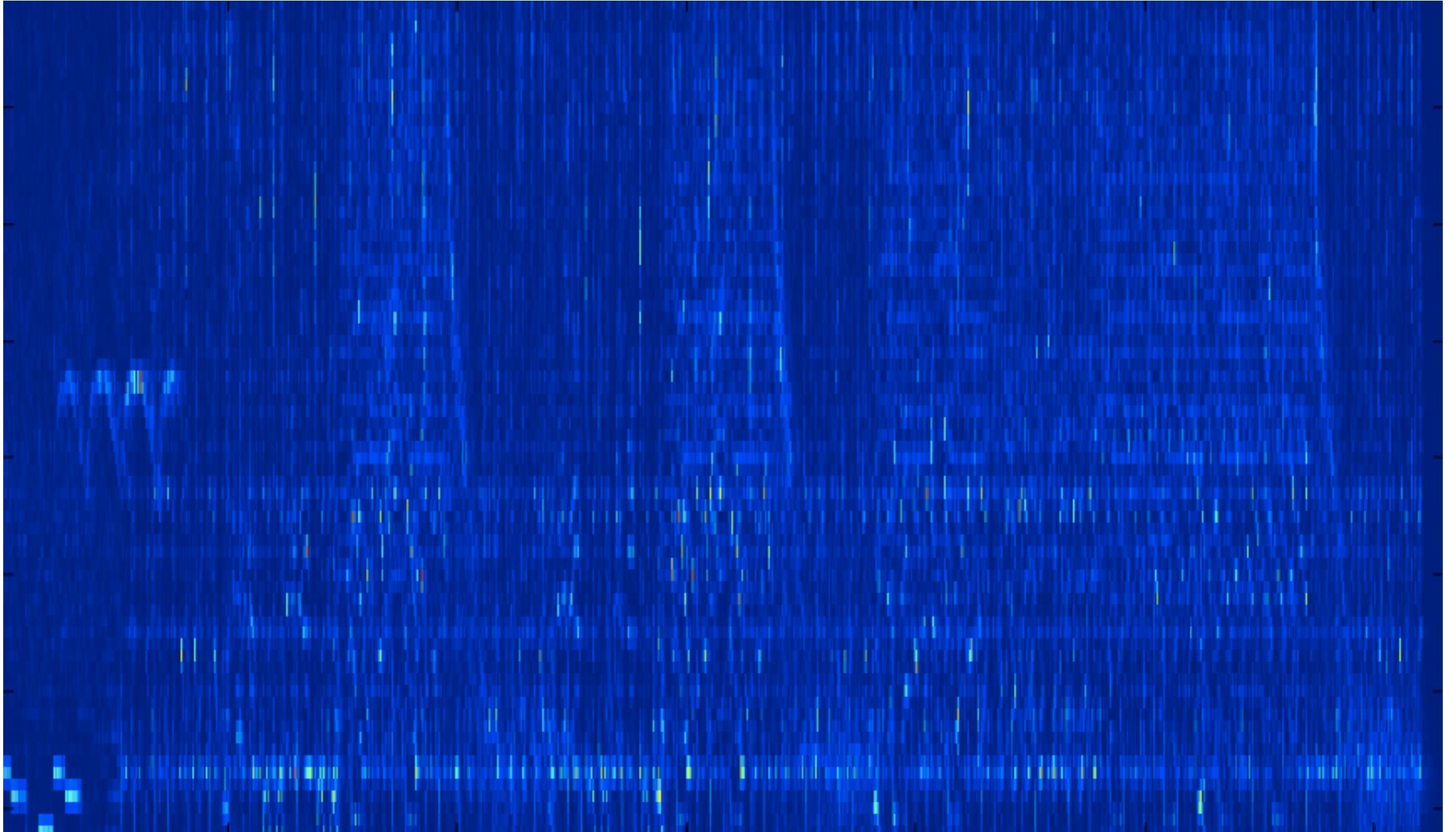
Album Review

Picking up where Want One left off, Rufus Wainwright's Want Two is a deeply introspective, sometimes kinky, personally critical set of mini-operettas that ruminate on his various relationships, drug abuse, and image in th

▲	Name	Artist	Time	Popularity
1.	Agnus Dei	Rufus Wainwright	5:45	
2.	The One You Love	Rufus Wainwright	3:42	
3.	Peach Trees	Rufus Wainwright	5:58	
4.	Little Sister	Rufus Wainwright	3:20	
5.	The Art Teacher	Rufus Wainwright	3:51	
6.	Hometown Waltz	Rufus Wainwright	2:31	
7.	This Love Affair	Rufus Wainwright	3:13	
8.	Gay Messiah	Rufus Wainwright	3:14	
9.	Memphis Skyline	Rufus Wainwright	4:51	
10.	Waiting for a Dream	Rufus Wainwright	4:14	
11.	Crumb By Crumb	Rufus Wainwright	4:11	
12.	Old W***e's Diet	Rufus Wainwright & Antony Hegarty	8:54	
13.	Couer de Parisienne - Reprise D'Ar...	Rufus Wainwright	2:46	
14.	Quand Vous Mourez de Nos Amou...	Rufus Wainwright	3:23	

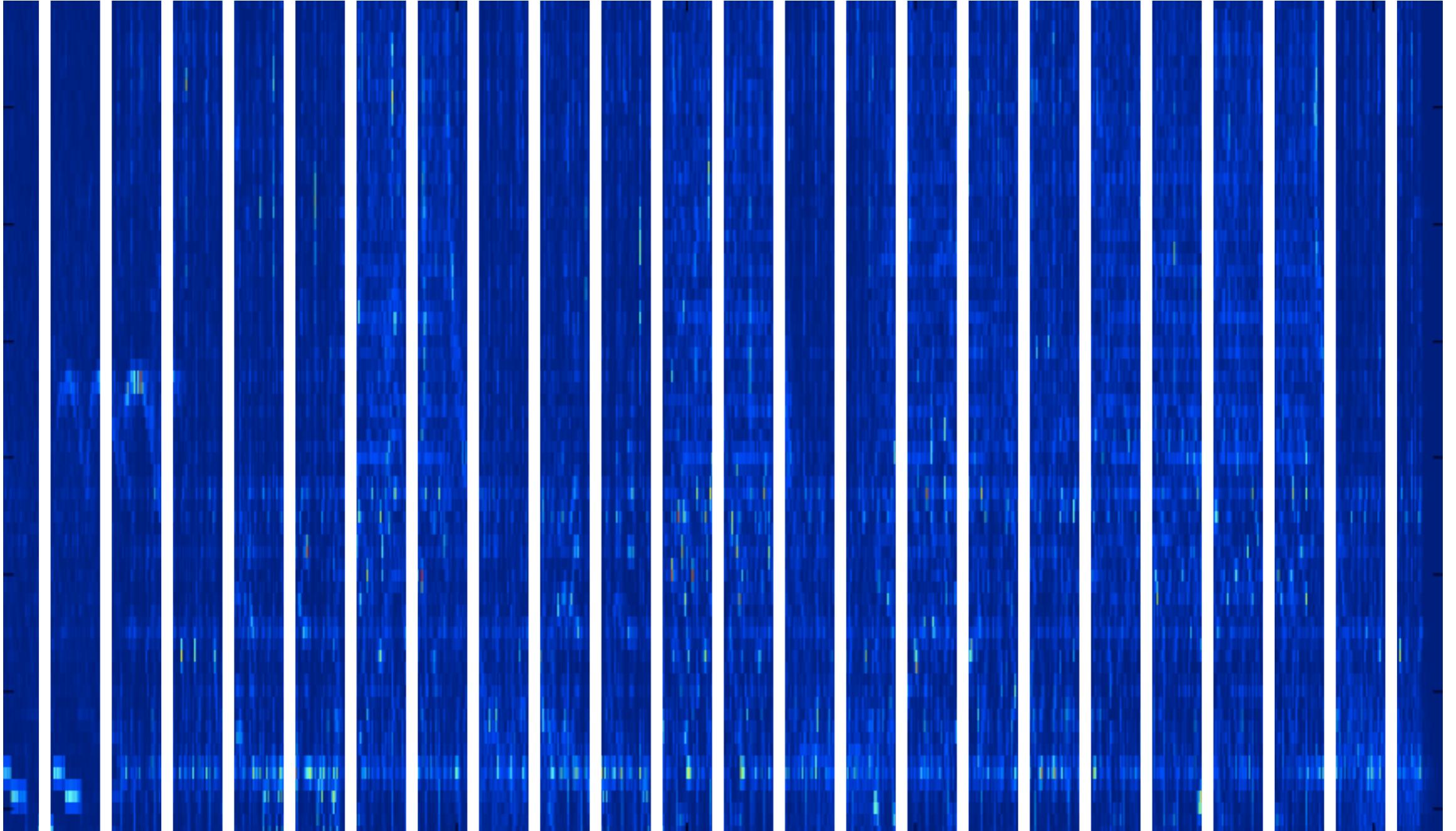
Preview All

Total: 14 Songs



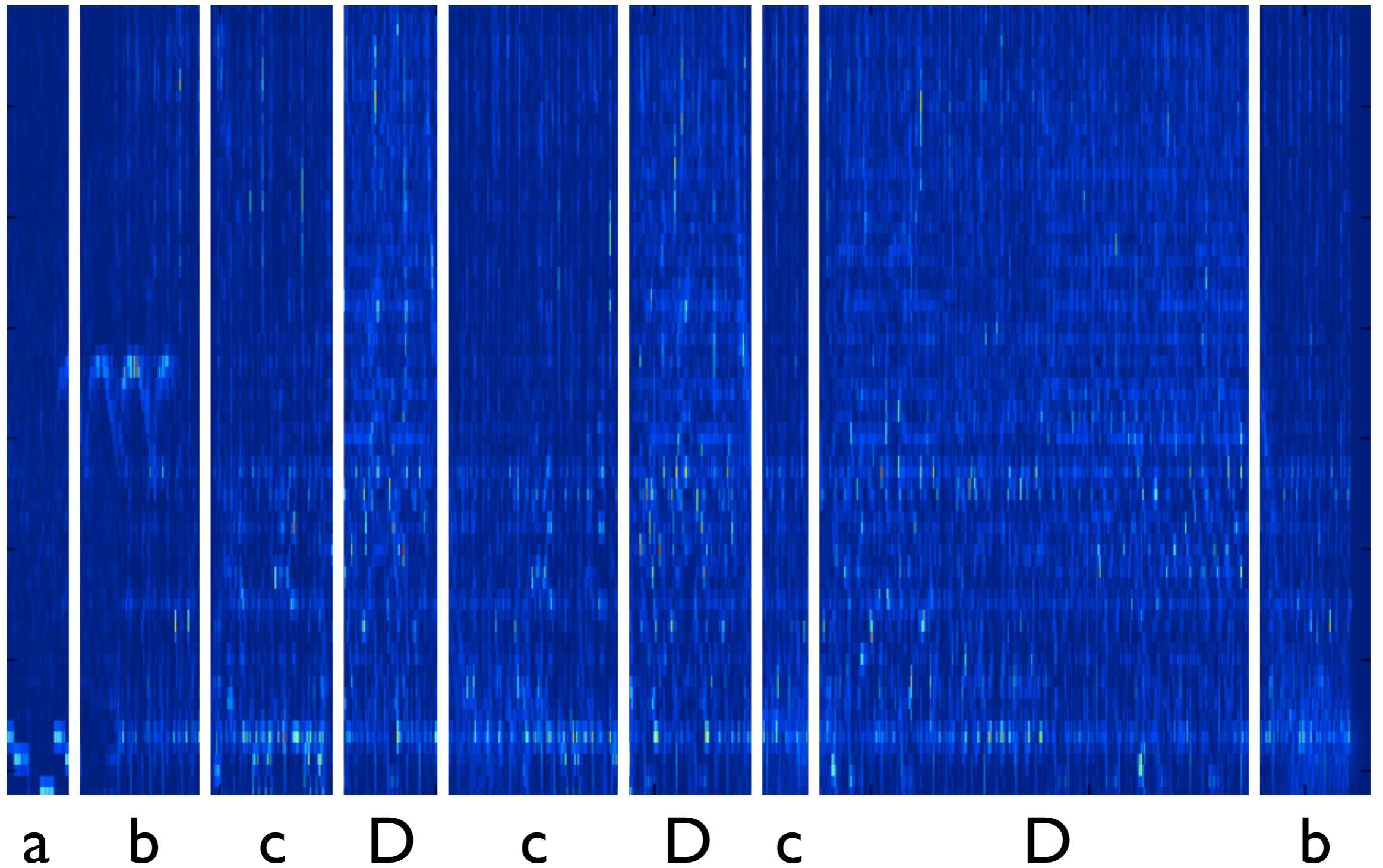
Music thumbnailing

song: "Fancy Footwork" by Chromeo



Music thumbnailing

song: "Fancy Footwork" by Chromeo



Music thumbnailing

song: "Fancy Footwork" by Chromeo

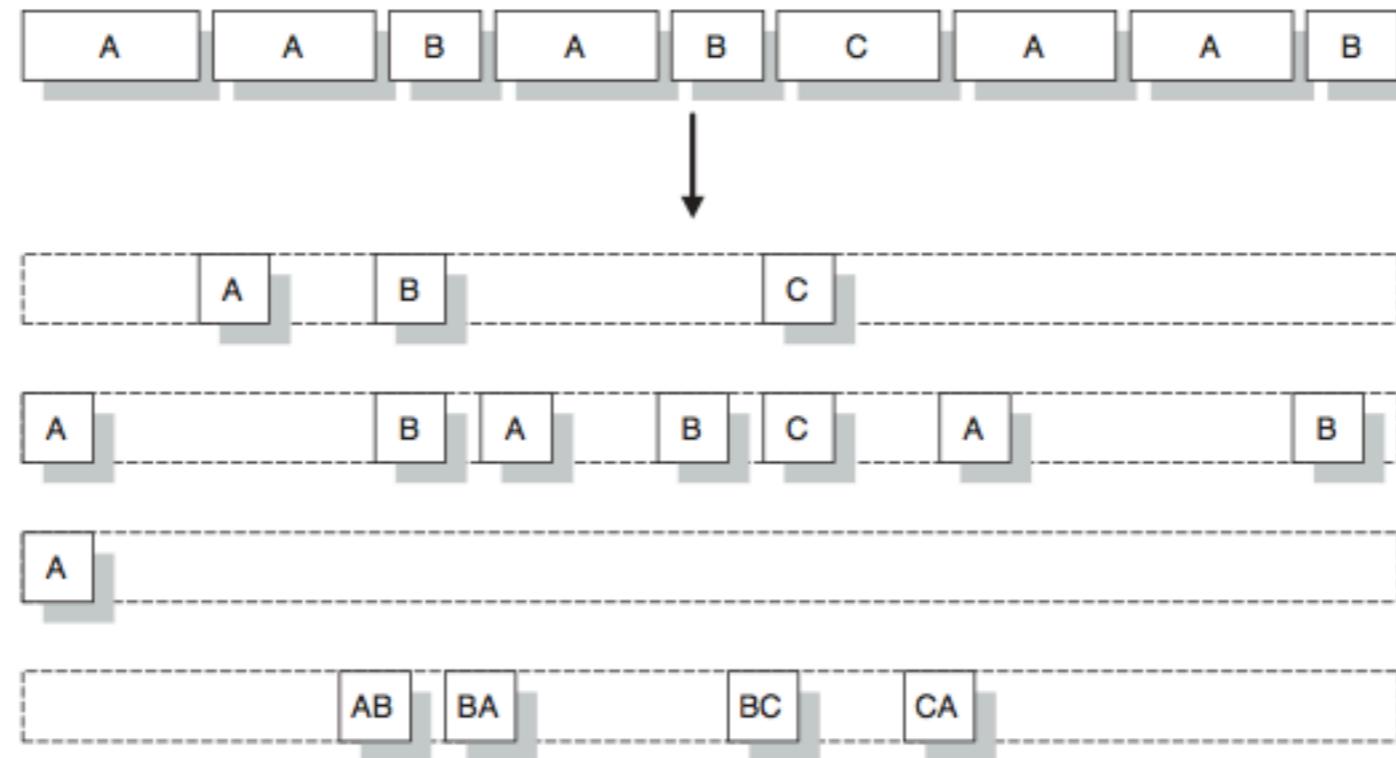
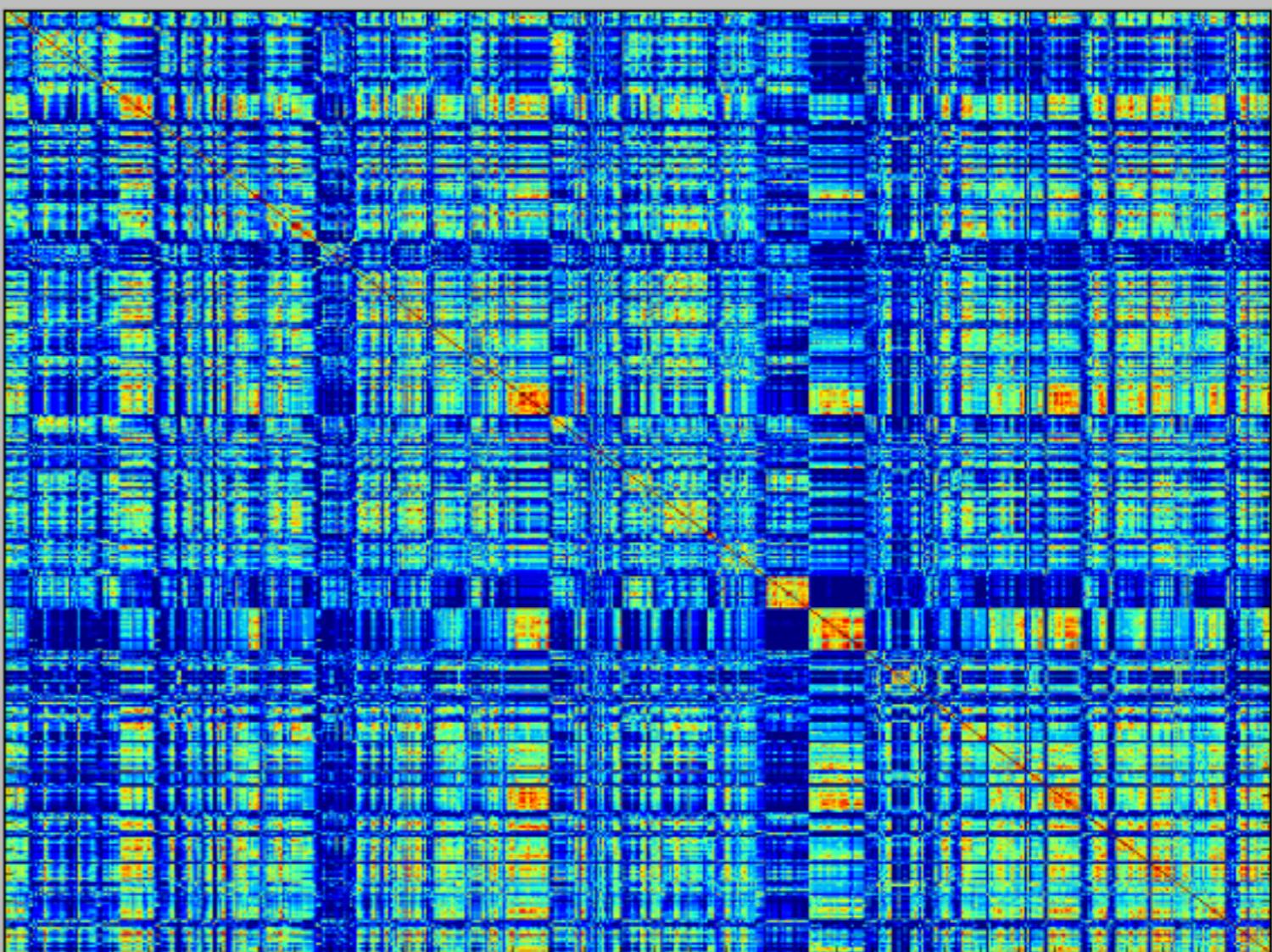


Fig. 25. Various possibilities for Audio Summary construction from sequence/state representation.

Music summarization

Figure 1

Hunky Dory/Queen Bitch/01.00
Hunky Dory/The Bewlay Brothers/00.40
Hunky Dory/The Bewlay Brothers/03.30
The Rise & Fall of Ziggy Stardust/Five Years/01.00
The Rise & Fall of Ziggy Stardust/Five Years/03.50
The Rise & Fall of Ziggy Stardust/Soul Love/02.00
e & Fall of Ziggy Stardust/Moonage Daydream/01.20
e & Fall of Ziggy Stardust/Moonage Daydream/04.20
The Rise & Fall of Ziggy Stardust/Starman/02.30
The Rise & Fall of Ziggy Stardust/It Ain't Easy/01.00
he Rise & Fall of Ziggy Stardust/Lady Stardust/00.50
The Rise & Fall of Ziggy Stardust/Star/00.20
se & Fall of Ziggy Stardust/Hang onto Yourself/00.20
e Rise & Fall of Ziggy Stardust/Ziggy Stardust/00.30
Rise & Fall of Ziggy Stardust/Suffragette City/00.20
Rise & Fall of Ziggy Stardust/Suffragette City/03.10
e & Fall of Ziggy Stardust/Rock 'n' Roll Suicide/02.30
Ziggy Stardust/John, I'm Only Dancing (Remix)/02.20
Rise & Fall of Ziggy Stardust/Velvet Goldmine/02.30
The Rise & Fall of Ziggy Stardust/Sweet Head/02.10
iggy Stardust/Ziggy Stardust (Original Demo)/00.40
Ziggy Stardust/Lady Stardust (Original Demo)/00.00
Ziggy Stardust/Lady Stardust (Original Demo)/02.50
Aladdin Sane/Watch That Man/02.10
Aladdin Sane/Aladdin Sane/00.30
Aladdin Sane/Aladdin Sane/03.20
Aladdin Sane/Drive in Saturday/01.00
Aladdin Sane/Drive in Saturday/03.50
Aladdin Sane/Panic in Detroit/02.20
Aladdin Sane/Cracked Actor/00.40
Aladdin Sane/Time/00.30
Aladdin Sane/Time/03.20
Aladdin Sane/The Prettiest Star/01.00
Aladdin Sane/Let's Spend the Night Together/00.20
Aladdin Sane/The Jean Genie/00.00



Hunky Dory/Queen Bitch/01.00
Hunky Dory/The Bewlay Brothers/00.40
Hunky Dory/The Bewlay Brothers/03.30
Fall of Ziggy Stardust/Five Years/01.00
Fall of Ziggy Stardust/Five Years/03.50
Fall of Ziggy Stardust/Soul Love/02.00
Iy Stardust/Moonage Daydream/01.20
Iy Stardust/Moonage Daydream/04.20
Fall of Ziggy Stardust/Starman/02.30
Fall of Ziggy Stardust/It Ain't Easy/01.00
of Ziggy Stardust/Lady Stardust/00.50
ise & Fall of Ziggy Stardust/Ziggy Stardust/Star/00.20
iggy Stardust/Hang onto Yourself/00.20
f Ziggy Stardust/Suffragette City/00.20
Ziggy Stardust/Rock 'n' Roll Suicide/00.30
Ziggy Stardust/Suffragette City/03.10
John, I'm Only Dancing (Remix)/02.20
Ziggy Stardust/Velvet Goldmine/02.30
ll of Ziggy Stardust/Sweet Head/02.10
Ziggy Stardust (Original Demo)/00.40
-/Lady Stardust (Original Demo)/00.00
-/Lady Stardust (Original Demo)/02.50
Aladdin Sane/Watch That Man/02.10
Aladdin Sane/Aladdin Sane/00.30
Aladdin Sane/Panic in Detroit/02.20
Aladdin Sane/Drive in Saturday/01.00
Aladdin Sane/Drive in Saturday/03.50
Aladdin Sane/Aladdin Sane/03.20
Aladdin Sane/Time/00.30
Aladdin Sane/Time/03.20
Aladdin Sane/The Prettiest Star/01.00
/Let's Spend the Night Together/00.20
Aladdin Sane/The Jean Genie/00.00

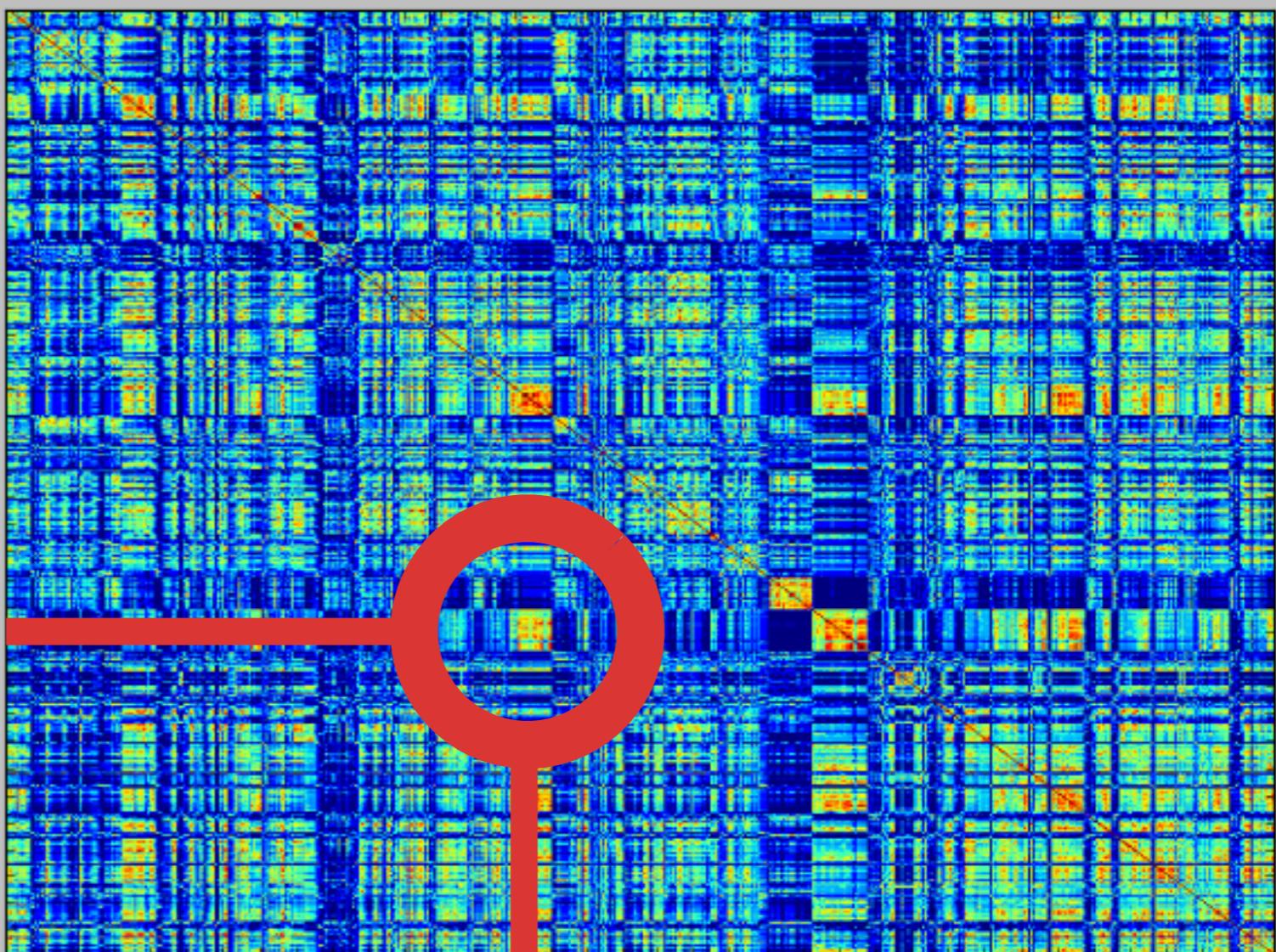
by Mike Mandel

<http://mr-pc.org/bowie/>



Figure 1

Hunky Dory/Queen Bitch/01.00
Hunky Dory/The Bewlay Brothers/00.40
Hunky Dory/The Bewlay Brothers/03.30
The Rise & Fall of Ziggy Stardust/Five Years/01.00
The Rise & Fall of Ziggy Stardust/Five Years/03.50
The Rise & Fall of Ziggy Stardust/Soul Love/02.00
e & Fall of Ziggy Stardust/Moonage Daydream/01.20
e & Fall of Ziggy Stardust/Moonage Daydream/04.20
The Rise & Fall of Ziggy Stardust/Starman/02.30
The Rise & Fall of Ziggy Stardust/It Ain't Easy/01.00
he Rise & Fall of Ziggy Stardust/Lady Stardust/00.50
The Rise & Fall of Ziggy Stardust/Star/00.20
se & Fall of Ziggy Stardust/Hang onto Yourself/00.20
e Rise & Fall of Ziggy Stardust/Ziggy Stardust/00.30
Rise & Fall of Ziggy Stardust/Suffragette City/00.20
Rise & Fall of Ziggy Stardust/Suffragette City/03.10
e & Fall of Ziggy Stardust/Rock 'n' Roll Suicide/02.30
Ziggy Stardust/John, I'm Only Dancing (Remix)/02.20
Rise & Fall of Ziggy Stardust/Velvet Goldmine/02.30
The Rise & Fall of Ziggy Stardust/Sweet Head/02.10
iggy Stardust/Ziggy Stardust (Original Demo)/00.40
Ziggy Stardust/Lady Stardust (Original Demo)/00.00
Ziggy Stardust/Lady Stardust (Original Demo)/02.50
Aladdin Sane/Watch That Man/02.10
Aladdin Sane/Aladdin Sane/00.30
Aladdin Sane/Aladdin Sane/03.20
Aladdin Sane/Drive in Saturday/01.00
Aladdin Sane/Drive in Saturday/03.50
Aladdin Sane/Panic in Detroit/02.20
Aladdin Sane/Cracked Actor/00.40
Aladdin Sane/Time/00.30
Aladdin Sane/Time/03.20
Aladdin Sane/The Prettiest Star/01.00
Aladdin Sane/Let's Spend the Night Together/00.20
Aladdin Sane/The Jean Genie/00.00



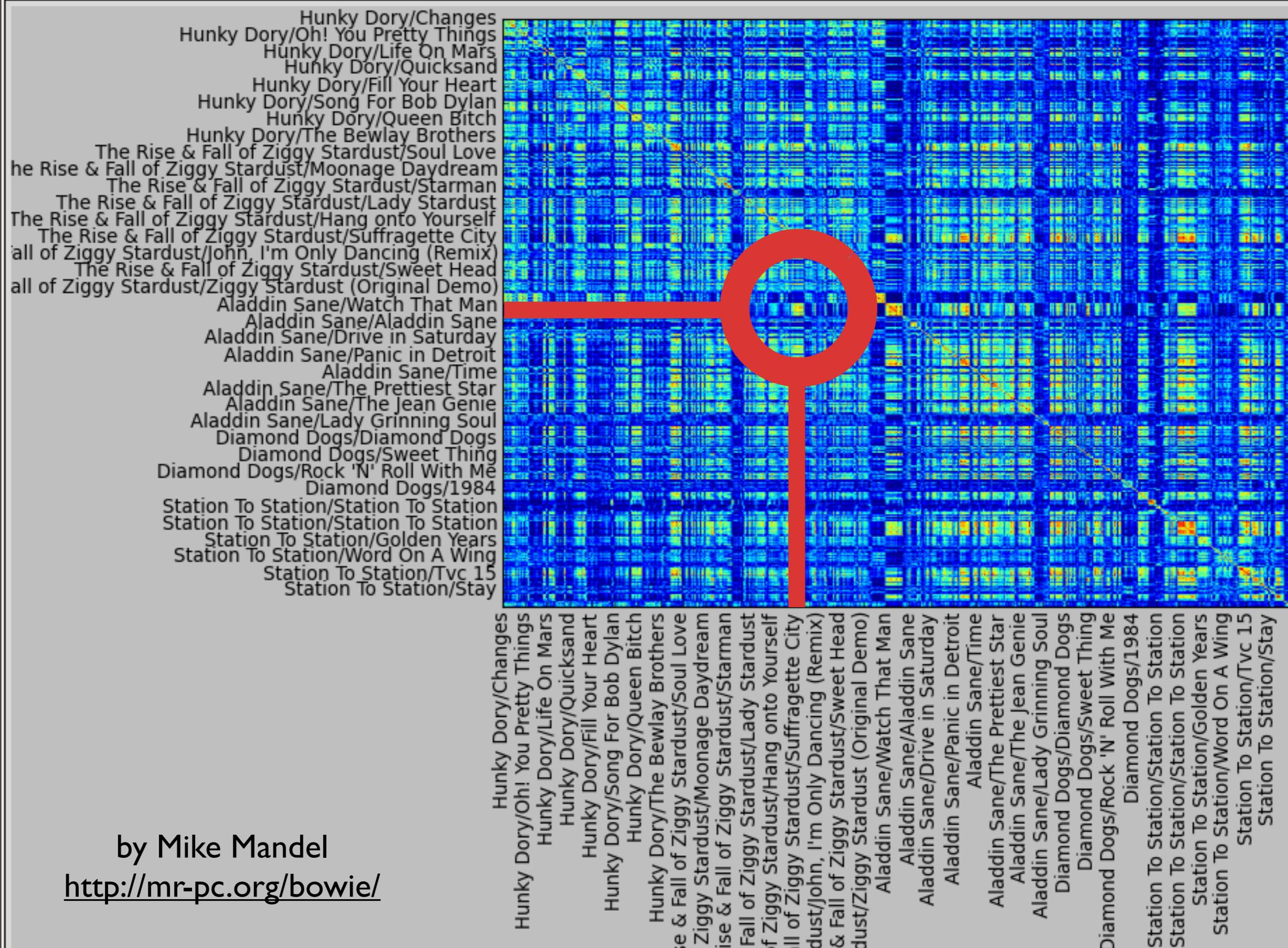
Hunky Dory/Queen Bitch/01.00
Hunky Dory/The Bewlay Brothers/00.40
Hunky Dory/The Bewlay Brothers/03.30
Fall of Ziggy Stardust/Five Years/01.00
Fall of Ziggy Stardust/Five Years/03.50
Fall of Ziggy Stardust/Soul Love/02.00
Iy Stardust/Moonage Daydream/01.20
Iy Stardust/Moonage Daydream/04.20
Fall of Ziggy Stardust/Starman/02.30
II of Ziggy Stardust/It Ain't Easy/01.00
of Ziggy Stardust/Lady Stardust/00.50
ise & Fall of Ziggy Stardust/Star/00.20
iggy Stardust/Hang onto Yourself/00.20
f Ziggy Stardust/Ziggy Stardust/00.30
Ziggy Stardust/Suffragette City/00.20
Ziggy Stardust/Suffragette City/03.10
y Stardust/Rock 'n' Roll Suicide/02.30
John, I'm Only Dancing (Remix)/02.20
Ziggy Stardust/Velvet Goldmine/02.30
II of Ziggy Stardust/Sweet Head/02.10
Ziggy Stardust (Original Demo)/00.40
/Lady Stardust (Original Demo)/00.00
/Lady Stardust (Original Demo)/02.50
Aladdin Sane/Watch That Man/02.10
Aladdin Sane/Aladdin Sane/00.30
Aladdin Sane/Panic in Detroit/02.20
Aladdin Sane/Drive in Saturday/01.00
Aladdin Sane/Drive in Saturday/03.50
Aladdin Sane/Aladdin Sane/03.20
Aladdin Sane/Cracked Actor/00.40
Aladdin Sane/Time/00.30
Aladdin Sane/The Prettiest Star/01.00
/Let's Spend the Night Together/00.20
Aladdin Sane/The Jean Genie/00.00

by Mike Mandel

<http://mr-pc.org/bowie/>



Figure 1

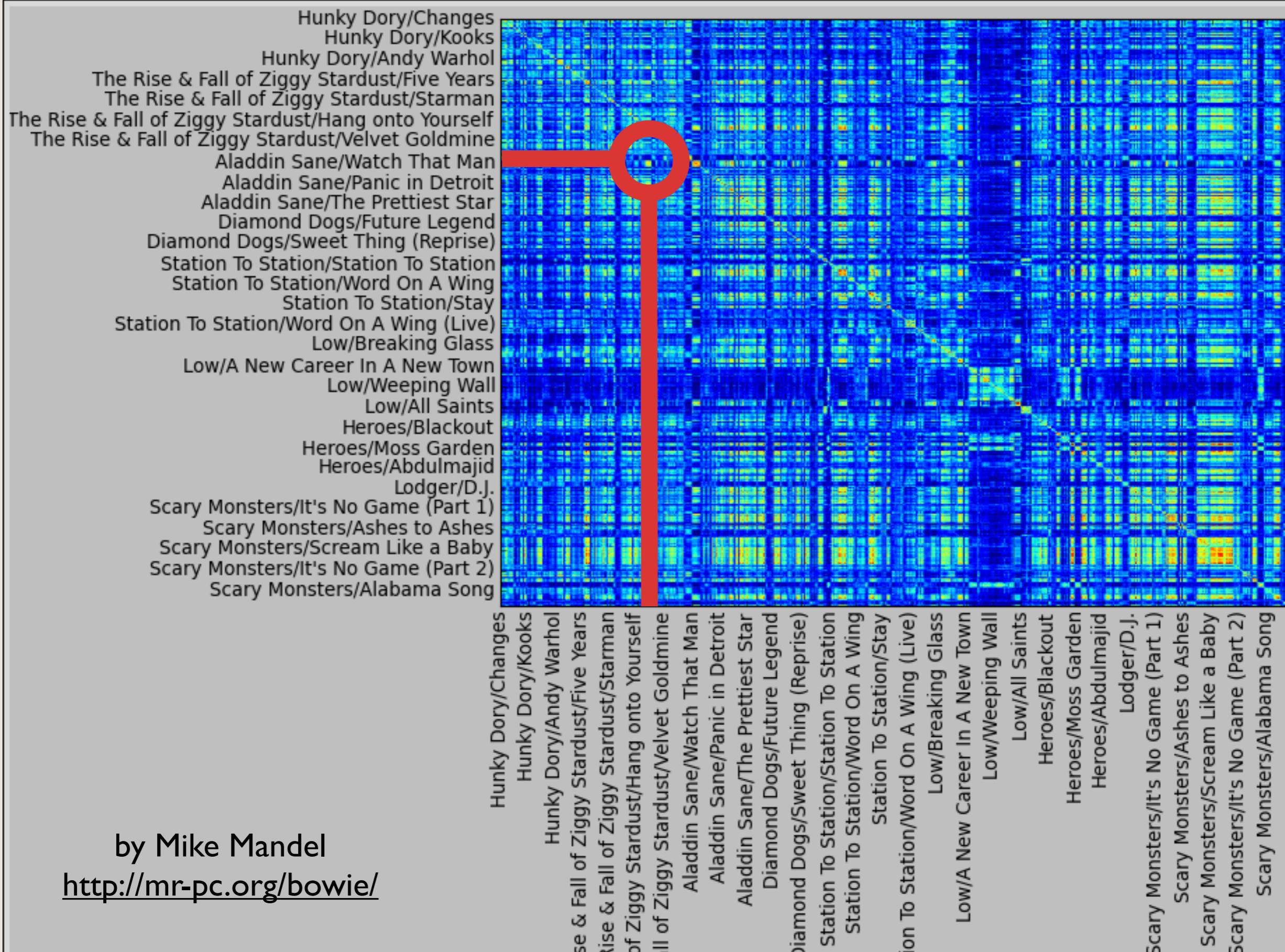


by Mike Mandel

<http://mr-pc.org/bowie/>



Figure 1

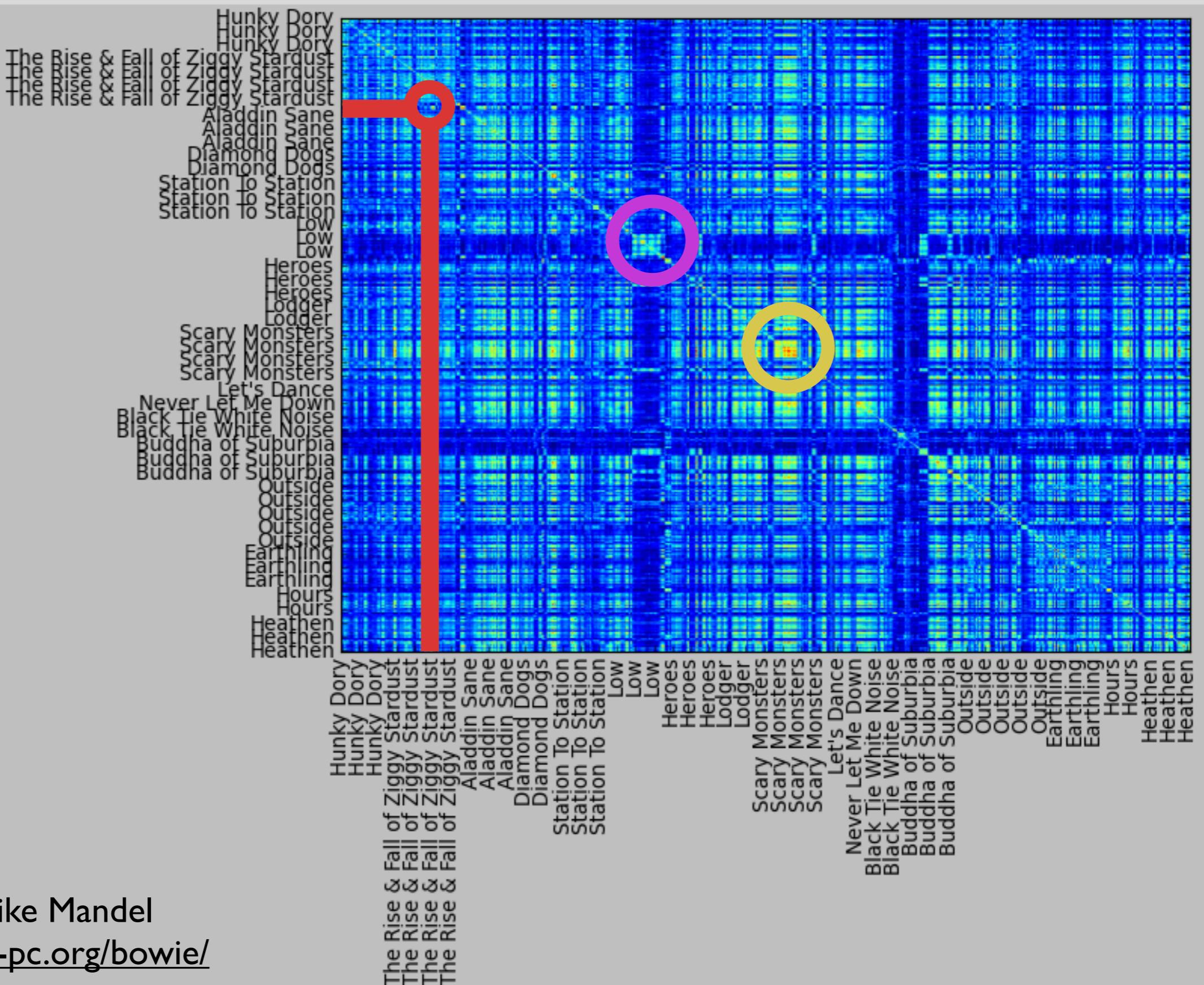


by Mike Mandel

<http://mr-pc.org/bowie/>



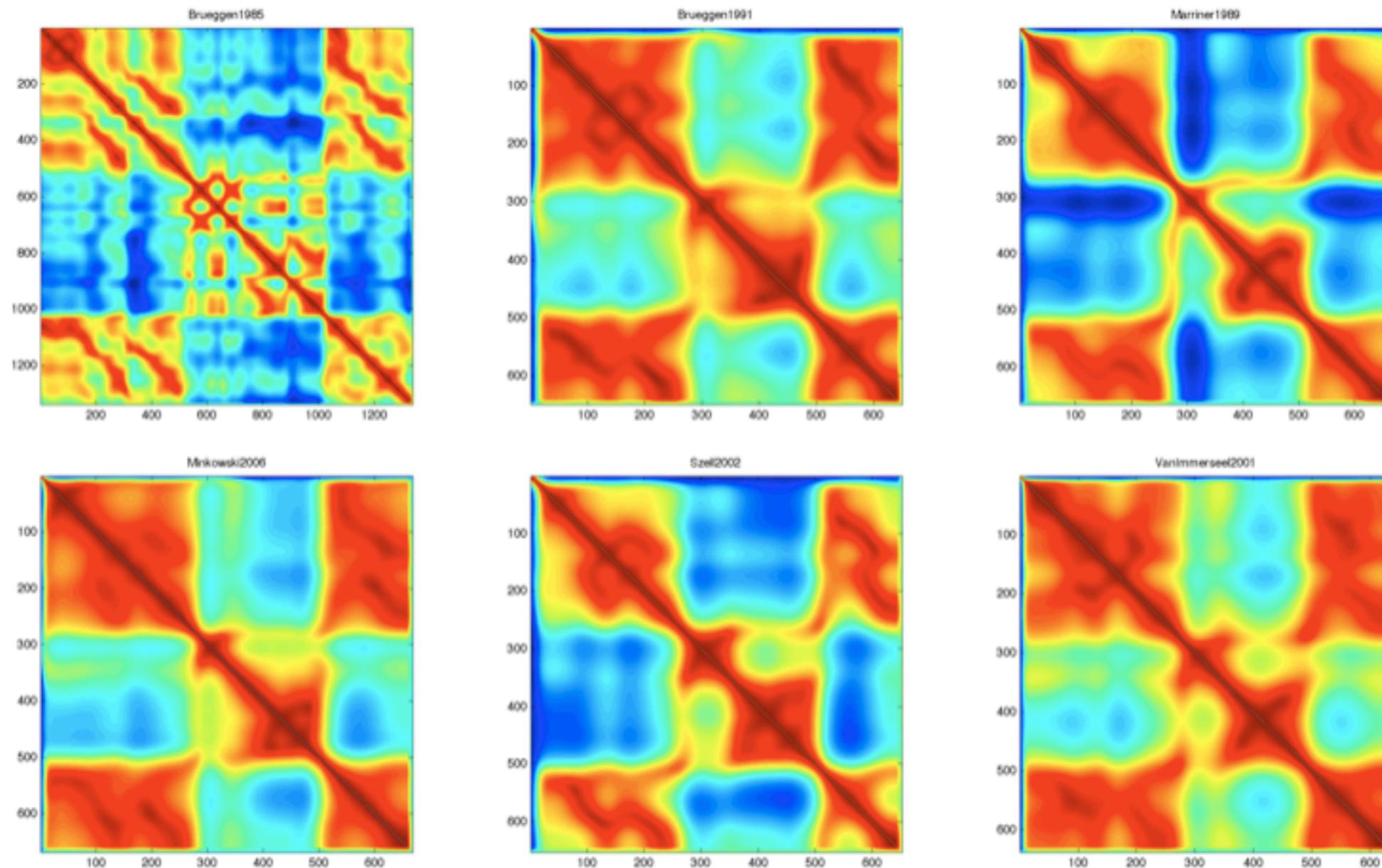
Figure 1



by Mike Mandel

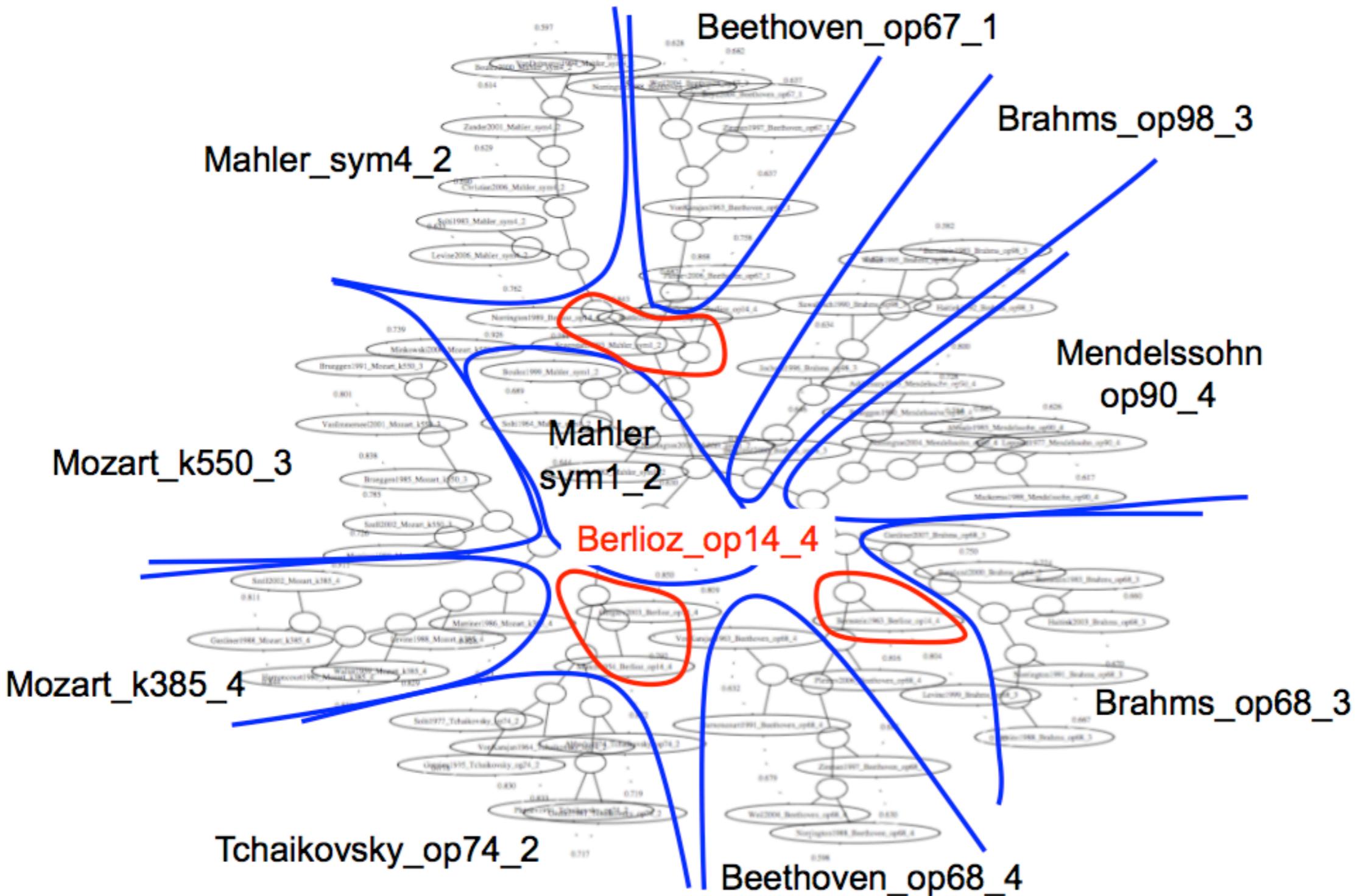
<http://mr-pc.org/bowie/>





Retrieval by structural similarity

image: Bello 2009



Retrieval by structural similarity

image: Bello 2009

Bootstrapping other tasks

Bootstrapping other tasks

Use for onset detection

Use for lyric-audio alignment

Use to improve chord labels

Bootstrapping other tasks

Use for onset detection

Onsets helps analysis

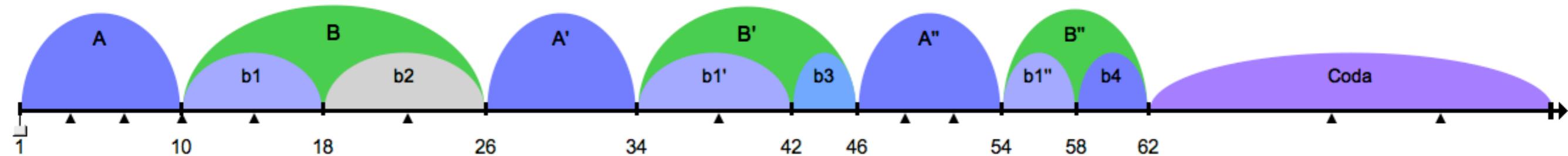
Use for lyric-audio alignment

Lyrics help analysis

Use to improve chord labels

We use chroma already

 Timeline: Chopin, Nocturne in D-Flat Major, Op. 27 no. 2



Automatic annotations

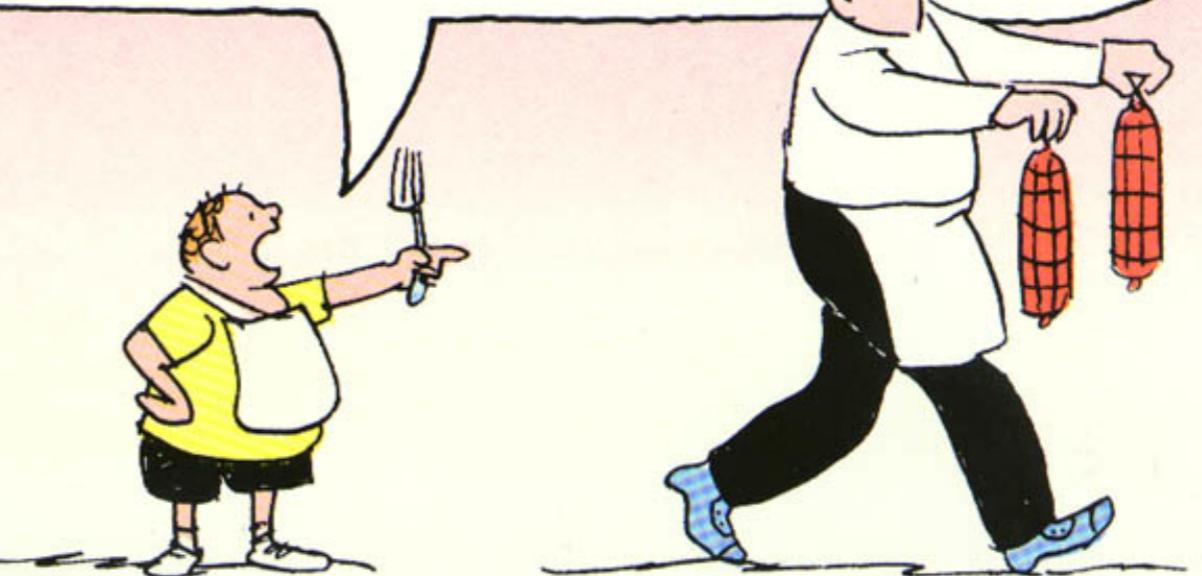
image: <http://variations.sourceforge.net/vat/>

FUTURE WORK

- I.** Annotate more music
- 2.** Do more evaluation
- 3.** Analyze music more deeply

**GO HANG A SALAMI!
I'M A LASAGNA HOG!**

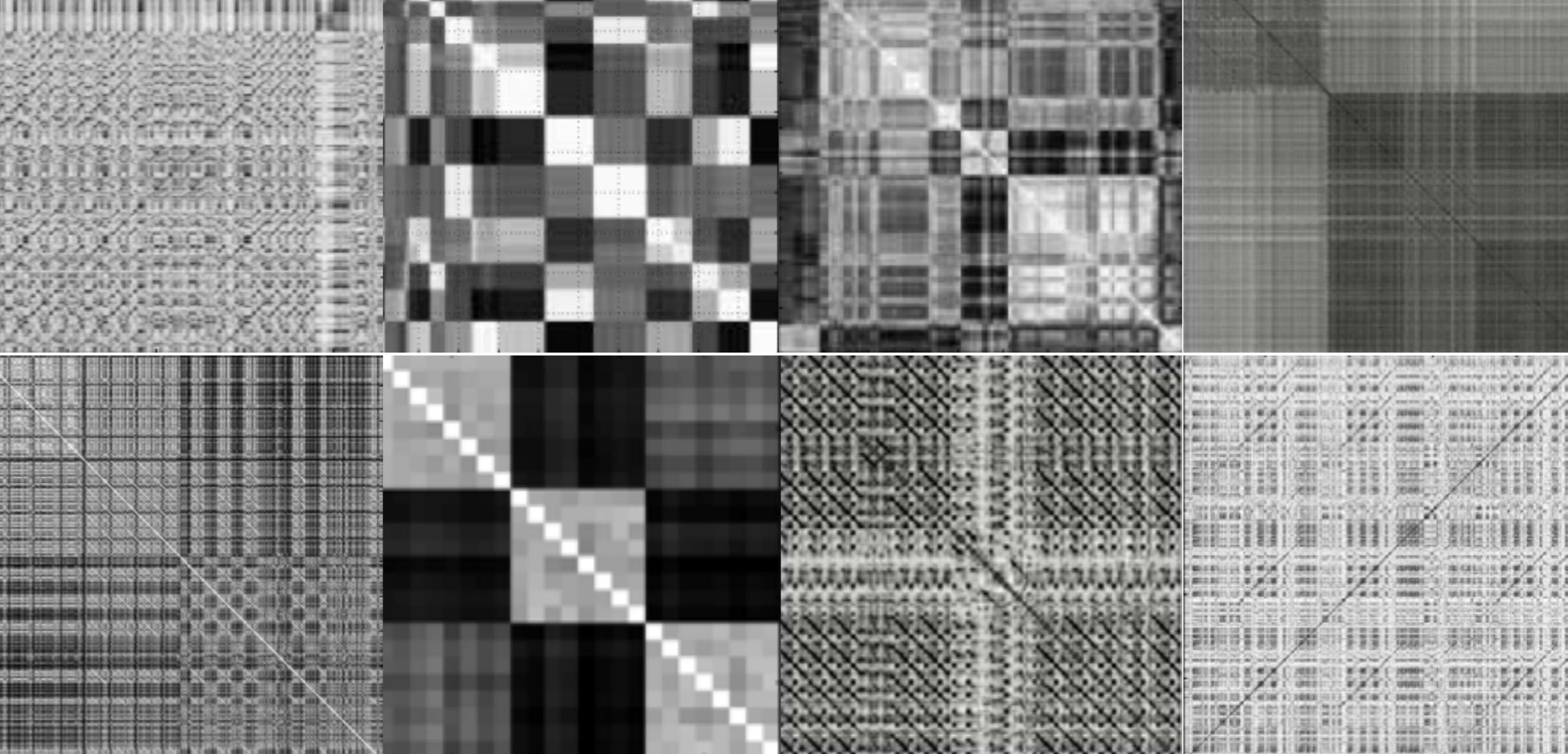
and Other
Palindromes
by JON AGEET



I. Analyze more music:

SALAMI:
Structural Analysis of Large
Amounts of Music Information

23,000 hours of music



Large-scale evaluations aren't very common...

Paper	Corpus; annotation	Evaluation
[ANS ⁺ 05, LSC06, LS06, RCAS06]	14 songs; start, end time and label for each segment	performance measure from image segmentation (adapted); information-theoretic measure
[AS01]	20 songs of various genres (folk to rock, pop, blues and orchestral music); no annotation	empirically: “The better the segmentation, the more coherent the different textures sound.”
[BW01, BW05]	93 songs; annotated chorus section; genres include dance, country-western, Christian hymns)	no evaluation of segmentation
[CS06]	7 music tracks; start times of melodic repetitions	mean query rank
[Cha05]	21 classical piano solo pieces, 26 Beatles songs; start, end time and label for each segment	roll-up procedure, edit distance
[CF03]	seven songs; number of verses and choruses	number of verses and choruses
[Got03]	100 songs from music database RWC [GHNO02]; start and end times of choruses	length of chorus sections
[LC00]	50 Beatles songs	user tests (ten subjects)
[LWZ04]	100 songs; annotated: repetitions, music structure	edit distance
[MXKS04, Mad06]	50 songs; vocal/instrumental boundaries, chord transitions, key, song structure	number and length of segments
[Ong05]	54 Beatles songs; start, end time and label for each segment	intersection of boundaries, allowing 3 s deviation
[PK06]	50 songs (subset of MUSIC [Hei03] and RWC databases [GHNO02], Beatles songs); start, end time and label for each segment	adapted roll-up procedure [Cha05]
[Pei07]	94+15 songs (subset of [PK06]’s and [LS07]’s corpus, a few additional songs); start, end time and label for each segment, 2-level-hierarchy, alternative labels	weighted, normalized edit distance, independent evaluation of boundaries and form

and there's little concensus on evaluation methods.

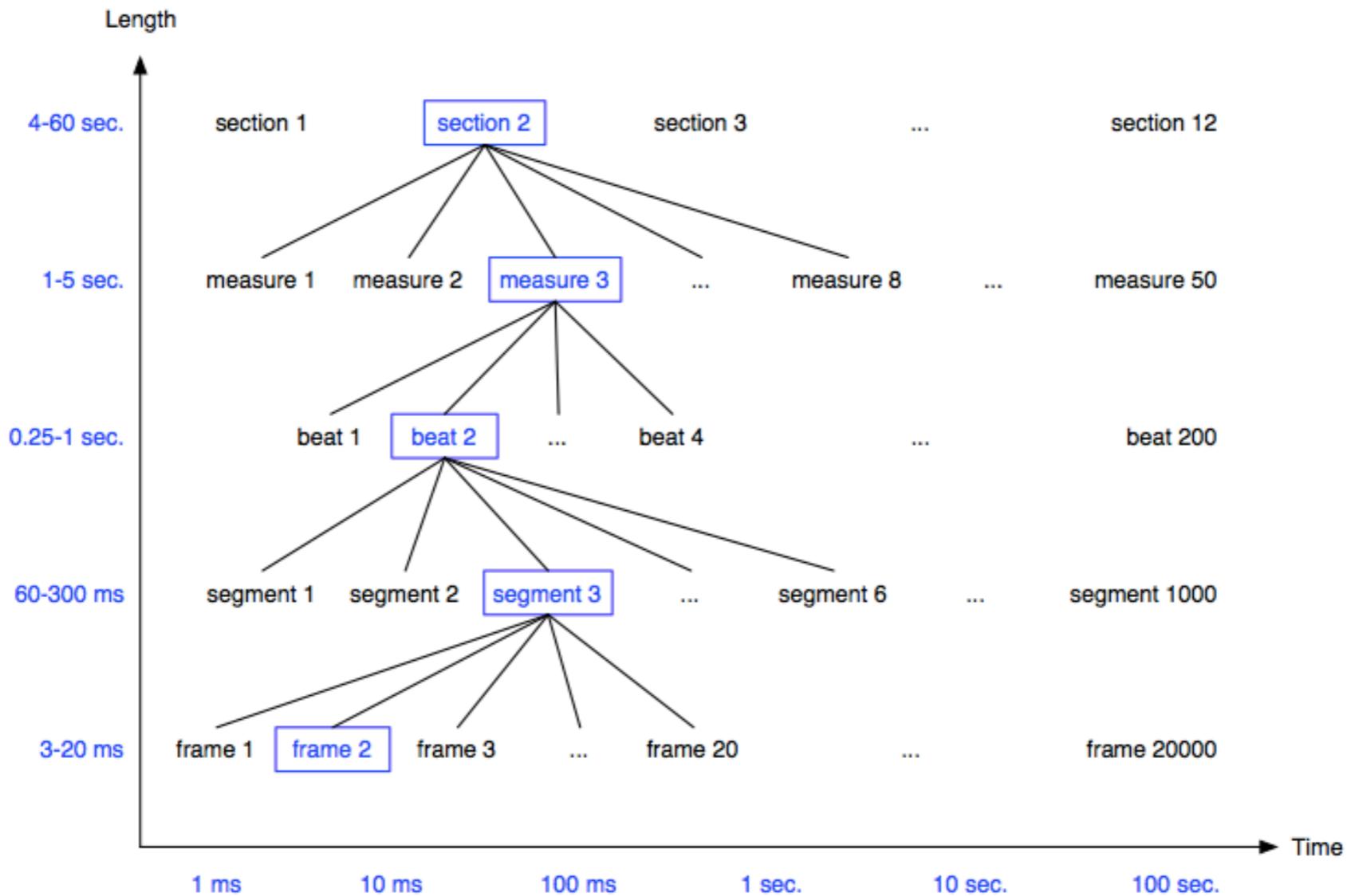


Figure 2-5: Example of a song decomposition in a tree structure.

Structure is hierarchical...
analysis should be too!

Thank you!

References

- Abdallah, S., K. Noland, M. Sandler, M. Casey, and C. Rhodes. 2005. Theory and evaluation of a Bayesian music structure extractor. In *Proceedings of the International Conference on Music Information Retrieval (ISMIR)*, London, 420-5.
- Abdallah, S., M. Sandler, C. Rhodes, and M. Casey. 2006. Using duration models to reduce fragmentation in audio segmentation. *Machine Learning* 65 (2-3): 485-515.
- Aucouturier, J.-J. 2001, July. *Segmentation of musical signals, and applications to the analysis of musical structure*. Master's thesis, Kings College, University of London.
- Bello, J. P. 2009. Grouping recorded music by structural similarity. In *Proceedings of the International Society for Music Information Retrieval Conference (ISMIR)*, 531-6.
- Chai, W. 2005. *Automated analysis of musical structure*. Ph. D. thesis, Massachusetts Institute of Technology, MA, USA.
- Foote, J. 1999. Visualizing music and audio using self-similarity. In *Proceedings of the ACM International Conference on Multimedia*, New York, NY, USA, 77-80.
- Foote, J. 2000. Arthur: Retrieving orchestral music by long-term structure. In *Proceedings of the International Symposium on Music Information Retrieval (ISMIR)*, Plymouth, MA, USA.
- Foote, J., and M. Cooper. 2003. Media segmentation using self-similarity decomposition. In M. Yeung, R. Lienhart, and C.-S. Li (Eds.), *Proceedings of the SPIE: Storage and Retrieval for Media Databases*, Volume 5021, Santa Clara, CA, USA, 167-75. SPIE.
- Goto, M. 2003. Smartmusickiosk: Music listening station with chorus-search function. In *Proceedings of the ACM Symposium on User Interface Software and Technology (UIST)*, 31-40. ACM.
- Jehan, T. 2004. Perceptual segment clustering for music description and time-axis redundancy cancellation. In *Proceedings of the International Conference on Music Information Retrieval (ISMIR)*, Barcelona, Spain, 124-7.
- Jehan, T. 2005. *Creating music by listening*. Ph. D. thesis, Massachusetts Institute of Technology, Cambridge, MA.
- Paulus, J. 2009. *Signal processing methods for drum transcription and music structure analysis*. Ph. D. thesis, Tampere University of Technology, Tampere, Finland.
- Peeters, G. 2004. Deriving musical structures from signal analysis for music audio summary generation: “sequence” and “state” approach. In G. Goos, J. Hartmanis, and J. van Leeuwen (Eds.), *Computer Music Modeling and Retrieval*, Volume 2771, 169-85. Springer Berlin / Heidelberg.
- Peiszer, E. 2007. *Automatic audio segmentation: Segment boundary and structure detection in popular music*. Master's thesis, Technische Universität Wien.