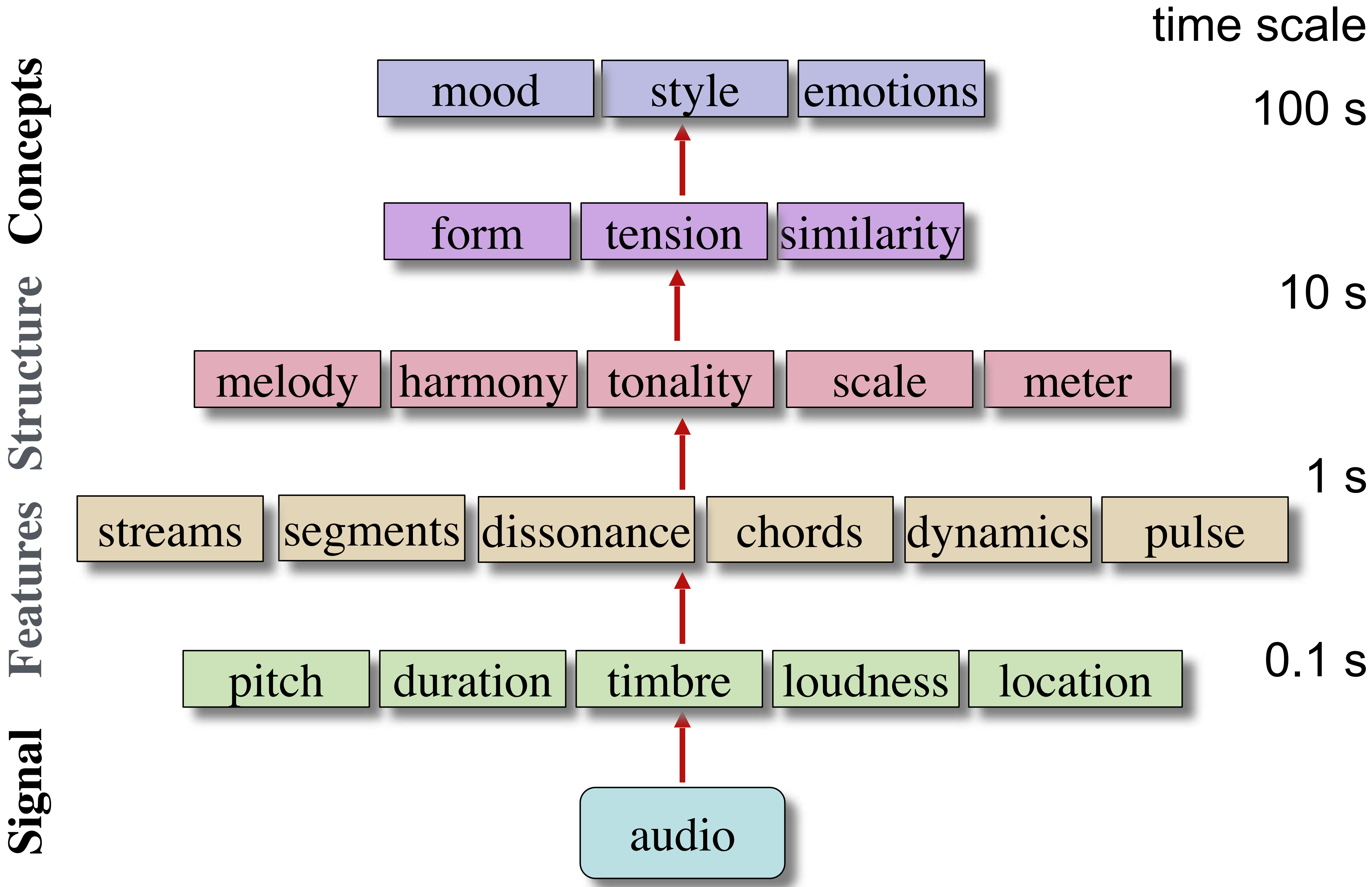
Why is window length important (perceptually)?

Levels of Music Processing

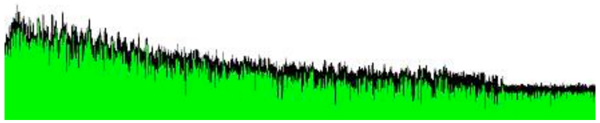


Musical features: Examples

Low-level / Timbral

brightness

spectrum



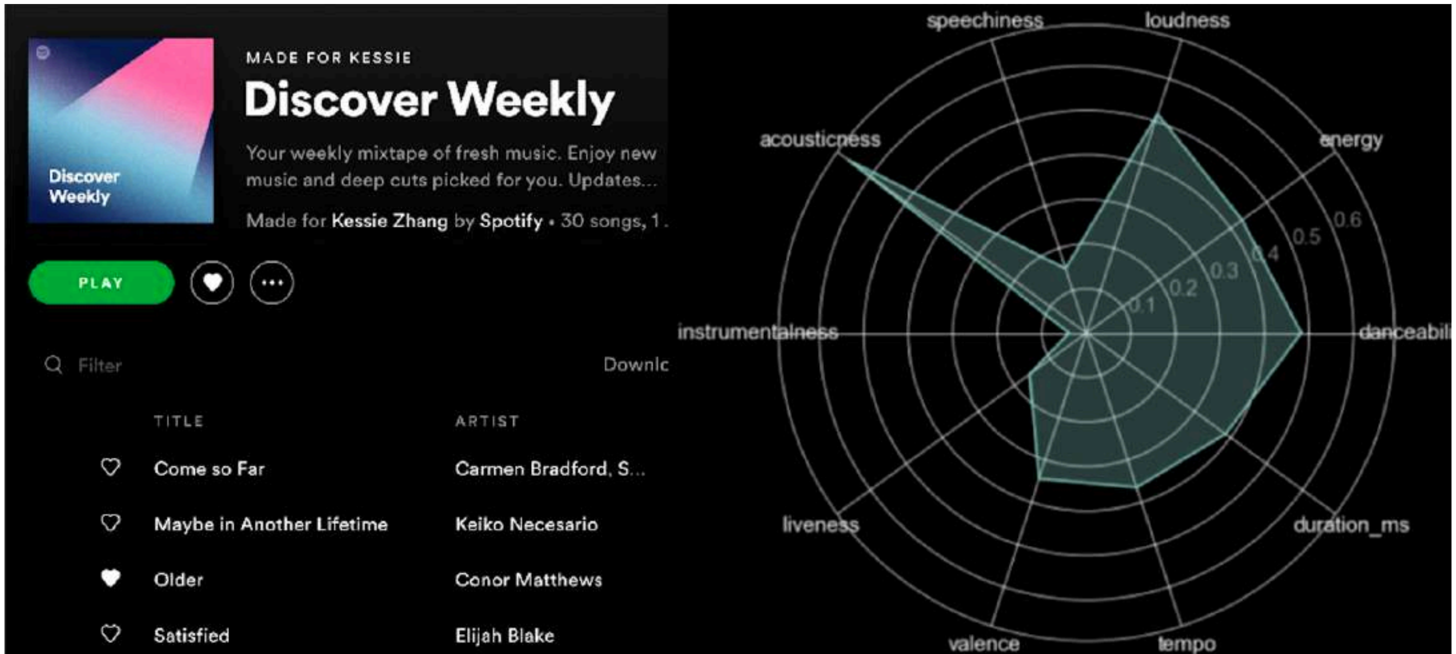
Mid/High-level / Rhythmic

pulse
clarity

envelope
autocorrelation

Feature Extraction from music

- features in music evolve continuously
- feature extraction relies on summarising this evolution (means, std)

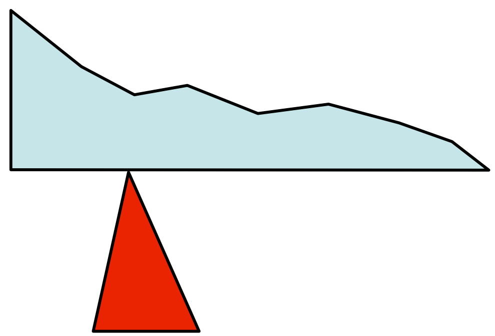


Which sounds brighter? (spectral centroid)

mean = 2167 Hz
std = 751 Hz

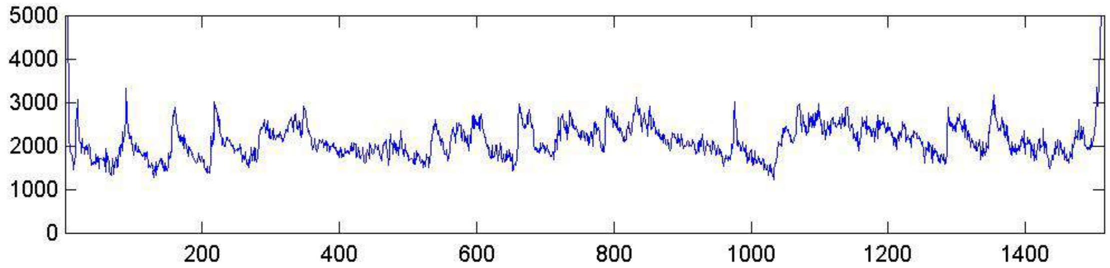
mean = 1953 Hz
std = 1534 Hz

mean = 1993 Hz
std = 706 Hz

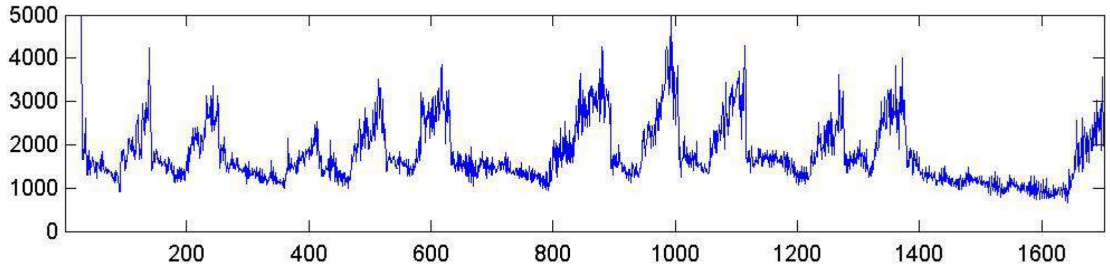


Example of frame-based analysis

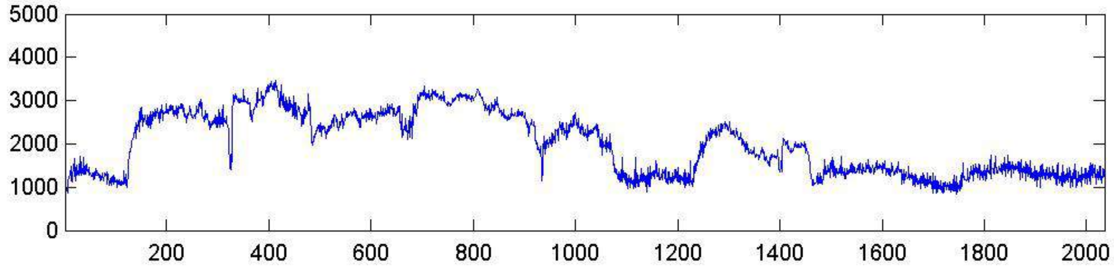
- spectral centroid of three excerpts



mean = 2167 Hz
std = 751 Hz



mean = 1953 Hz
std = 1534 Hz



mean = 1993 Hz
std = 706 Hz

Features Overview

- Dynamics
- Pitch
- Timbre
- Tempo/rhythm
- Tonality
- Structure

Acoustic features

Temporal

- zero-crossing rate
- low energy

Spectrotemporal

- spectral flux
- sub-band flux

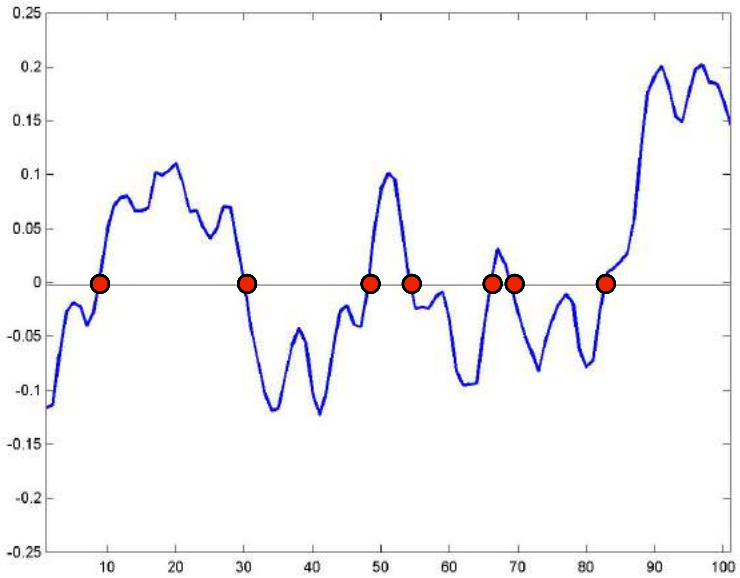
Spectral

- centroid
- high energy-low energy ratio
- entropy
- roll-off 85
- MFCC

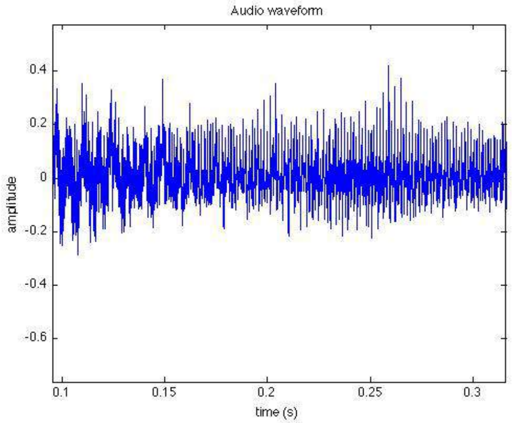
Identify features that might be useful for genre classification based on perceptual relevance

Zero-crossing rate

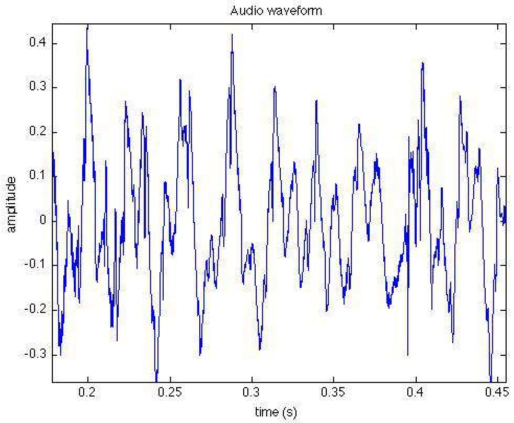
- number of time-domain zero-crossings of the signal per time unit



high:

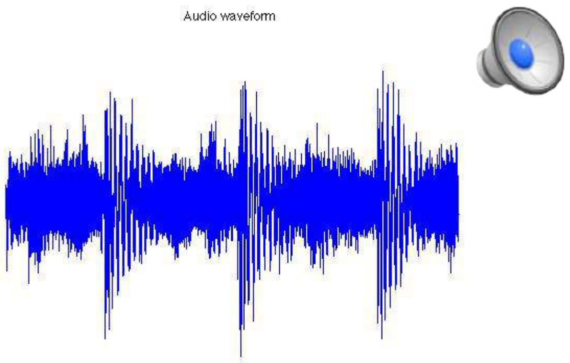


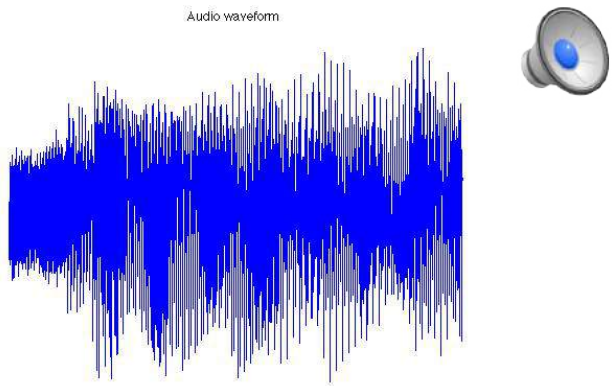
low:



Low Energy

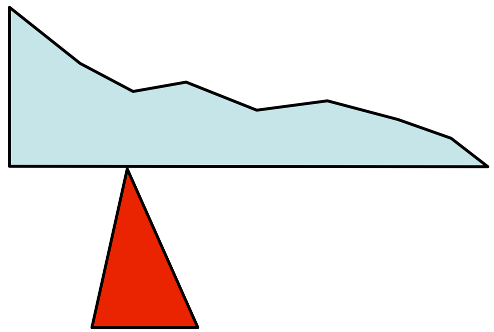
- proportion of signal frames whose energy is below average energy

high: 

low: 

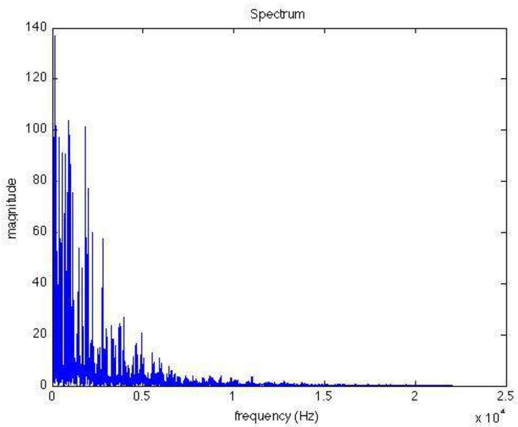
Spectral Centroid

- Center of mass of the spectrum

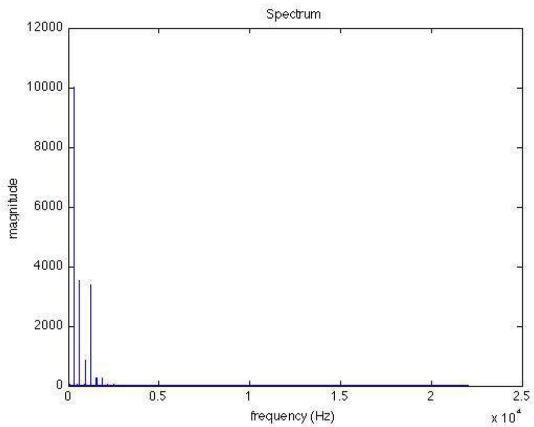


$$sc = \frac{\sum a_i f_i}{\sum a_i}$$

high:



low:



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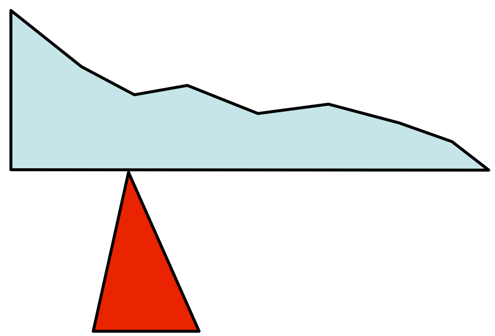

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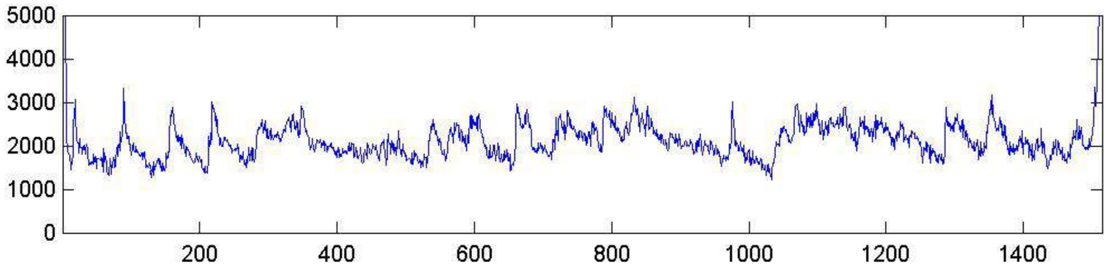
- spectral centroid of three excerpts



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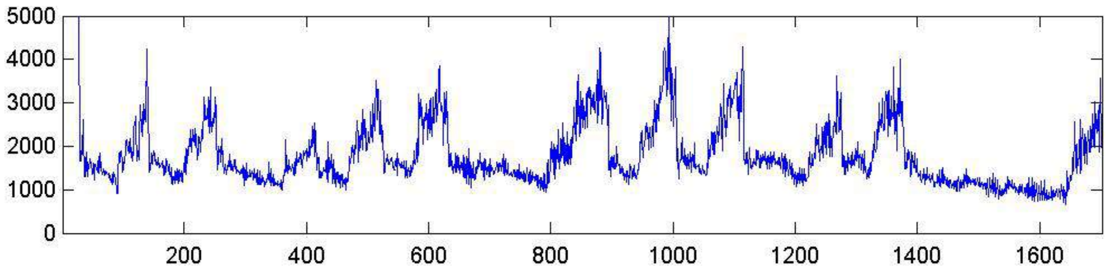

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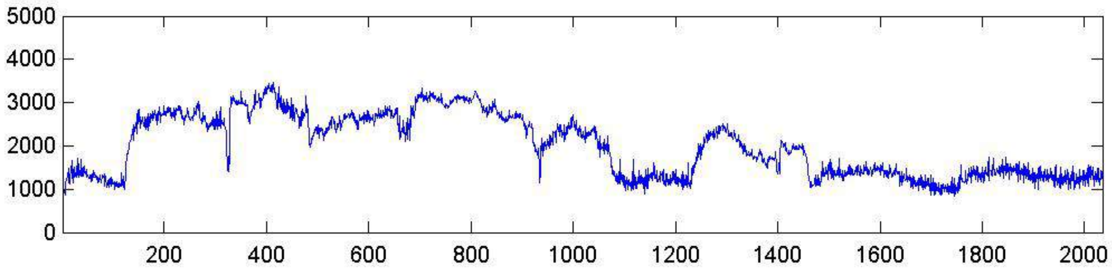
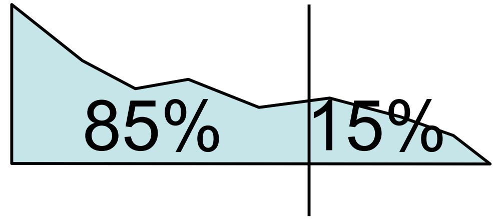


mean = 1993 Hz
std = 706 Hz

Spectral Roll-Off

- Frequency, below which a certain fraction (usually 85%) of spectral energy

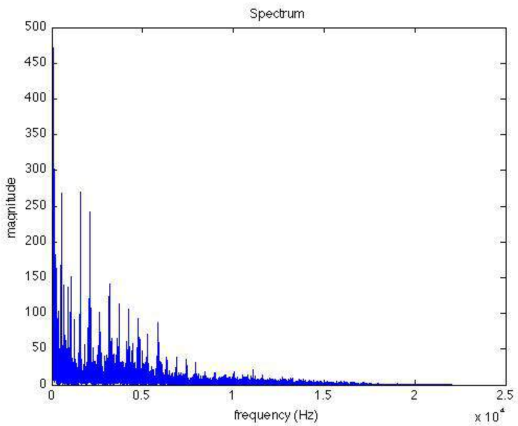


- R such that

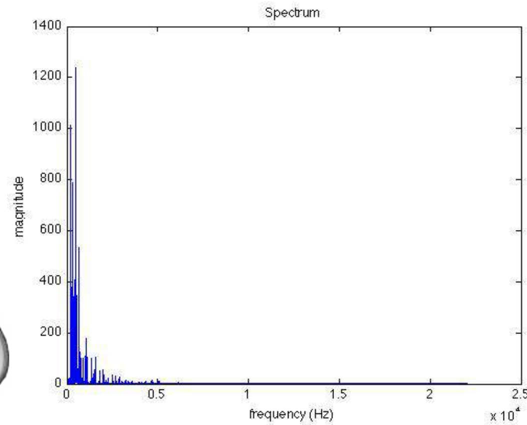
$$\sum_{1}^{R} a_i = 0.85 \sum_{1}^{N} a_i$$

- Measure of spectral shape

high:



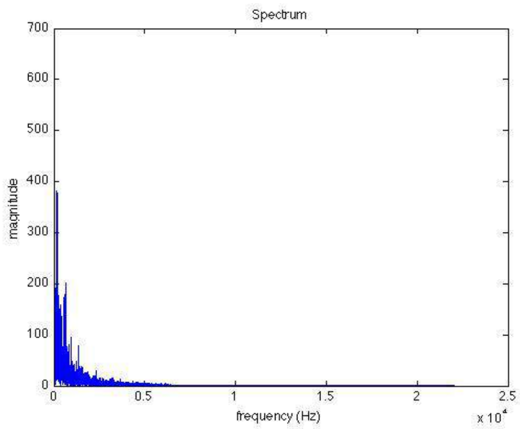
low:

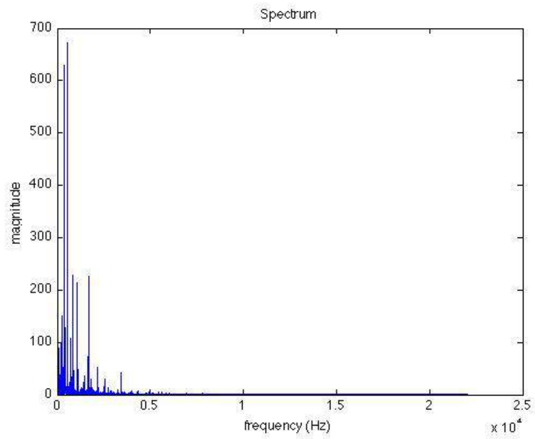


Spectral Irregularity

- measure of "jaggedness" of spectrum (Jensen, 1999)

$$irreg = \frac{\sum_{2}^{N}(a_i - a_{i-1})^2}{\sum_{1}^{N} a_i^2}$$

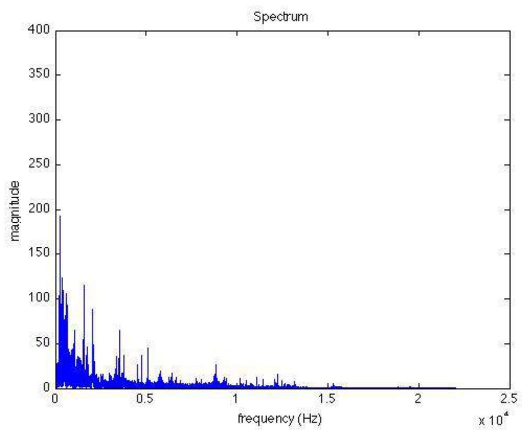
high: 

low: 

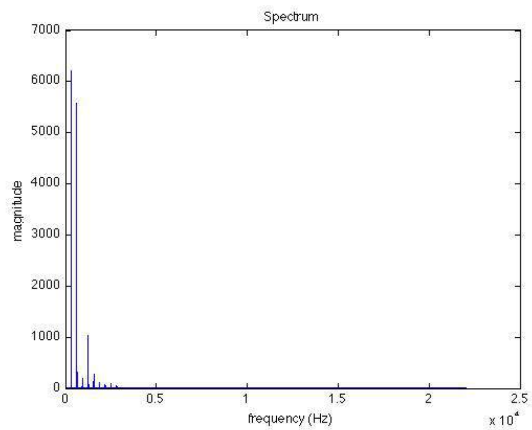
Spectral Entropy

- information-theoretic measure of spectral energy distribution
- high entropy = even distribution of spectral energy (more noise-like?)

high:

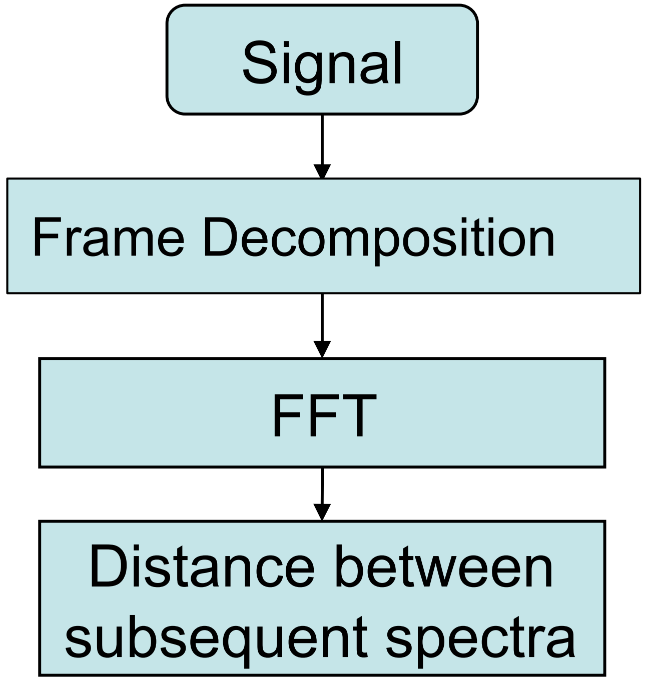


low:



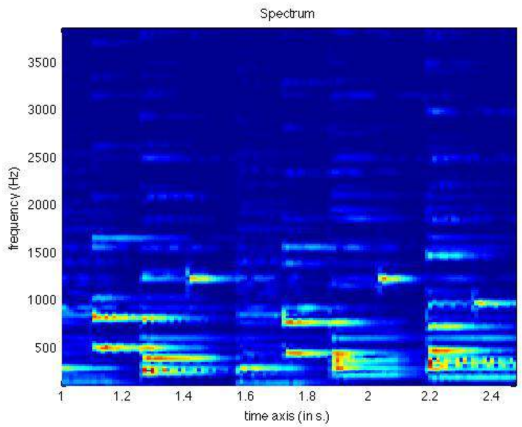
Spectral Flux

- Measure of change over time in spectrum
- Dissimilarity between subsequent spectral frames

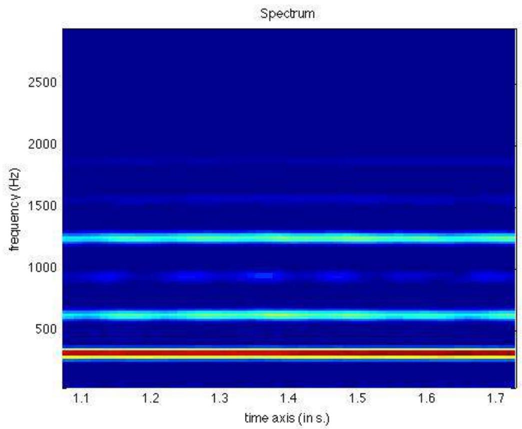


$$flux_i = \sum_{j=1}^{M} (a_{ij} - a_{(i-1)j})^2$$

high:

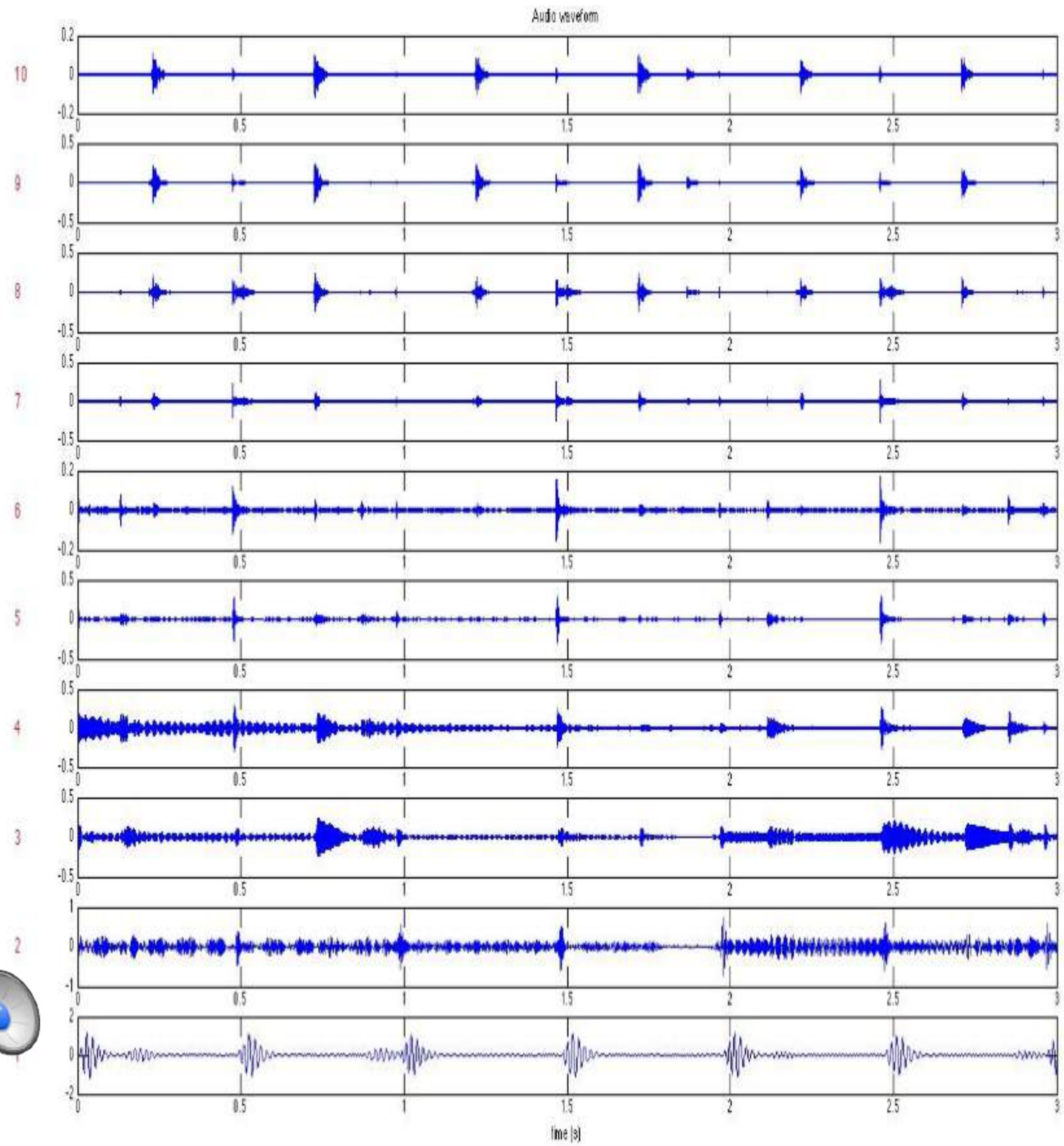


low:



Sub-band Flux

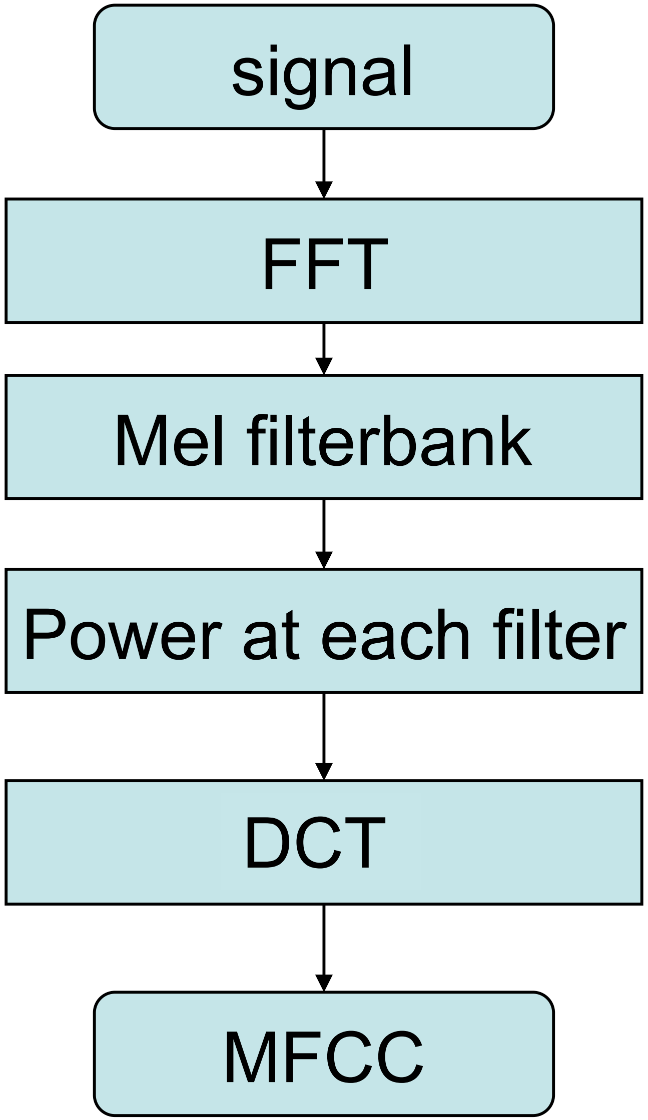
- Octave-scaled spectrum
    - 50 hz
    - 10 bands
- Spectral Flux in each band

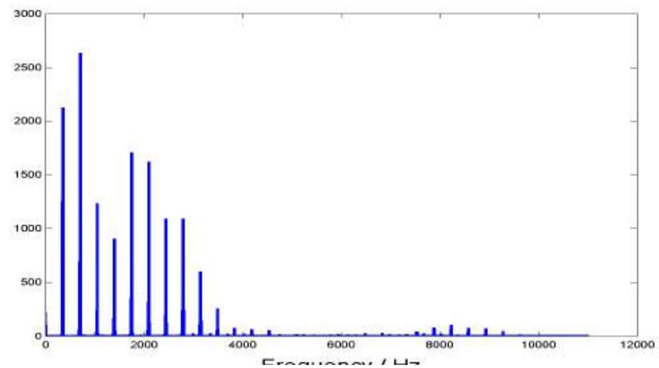


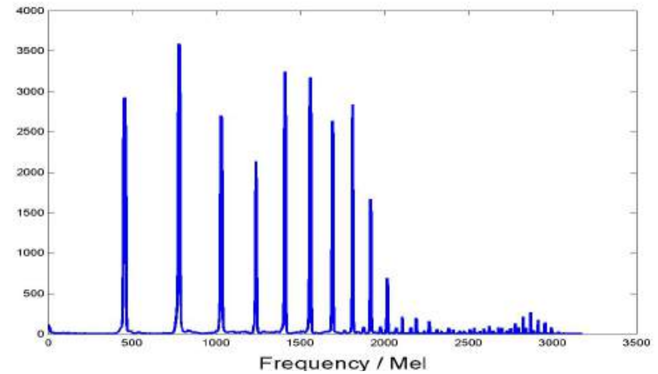
Mel-Frequency Cepstral Coefficients

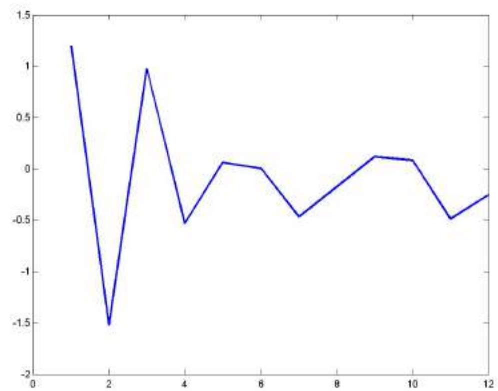
- Descriptor of spectral shape based on perception
- widely used in speech research (e.g. speech recognition)

Mel-frequency Cepstral Coefficients









Significance of MFCC

- provide a representation of the sound spectrum that closely corresponds to perceived distances between timbres (DePoli and Prandoni, 1997; Eronen, 2001; Terasawa et al., 2005)
- similarity in MFCC <-> similarity in perceived timbre
- important in classification of genre, mood, emotion, semantics

Genre Classification

Next class

Identify features that might be useful for genre classification based on perceptual relevance:

Temporal

- zero-crossing rate
- low energy

Spectrotemporal

- roughness
- sub-band flux

Spectral

- centroid
- high energy-low energy ratio
- entropy
- roll-off 85
- MFCC

Rhythm

Key/Tonality

Acoustic features

Rhythm

- tempo
- pulse clarity

Tonality

- chromagram
- mode
- keystrength/keyclarity

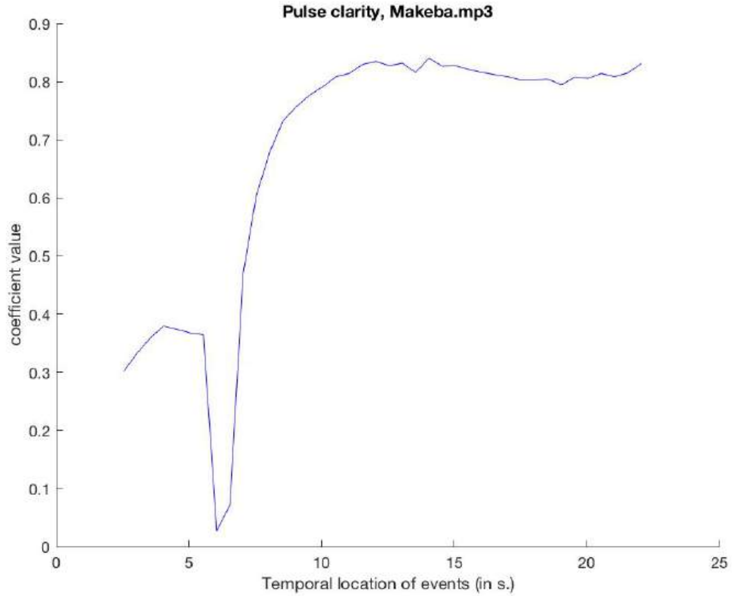
*typically extracted using longer time windows (context-dependent)

Rhythm

Tempo & Pulse Clarity

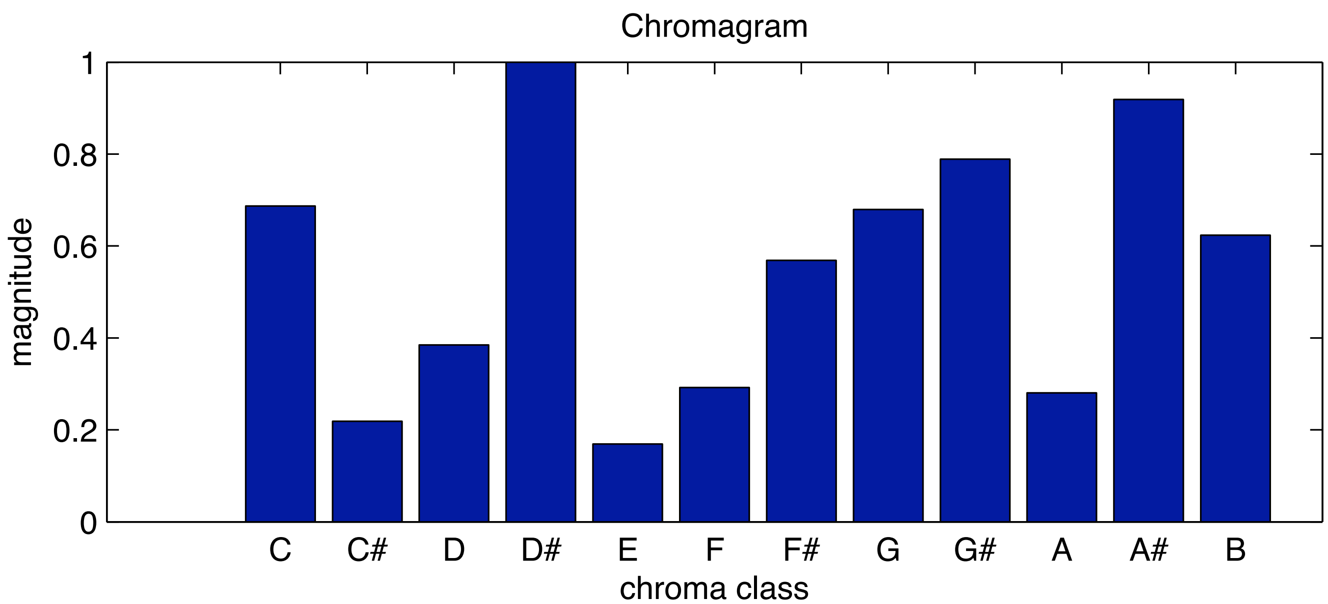
- tempo: estimate of how fast/slow the piece of music is

- pulse clarity/beat salience: how clear the beat is



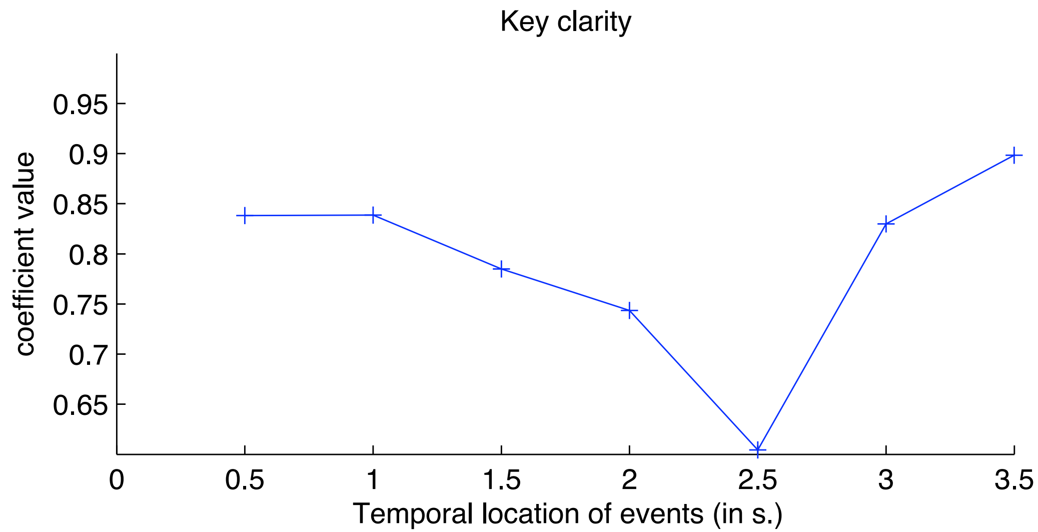
Acoustic features

- chromagram: Harmonic Pitch Class Profile, shows the distribution of energy along the pitches or pitch classes.



Acoustic features

- keystrength: measure of the tonal clarity



- mode: major or minor (roughly depicts “happy” or “sad”)

MIR Toolbox

MIR Toolbox

- Matlab toolbox for musical feature extraction from audio
- main developer Olivier Lartillot; Petri Toiviainen
- started within project Tuning the brain for music (EU FP7, 2006-9)

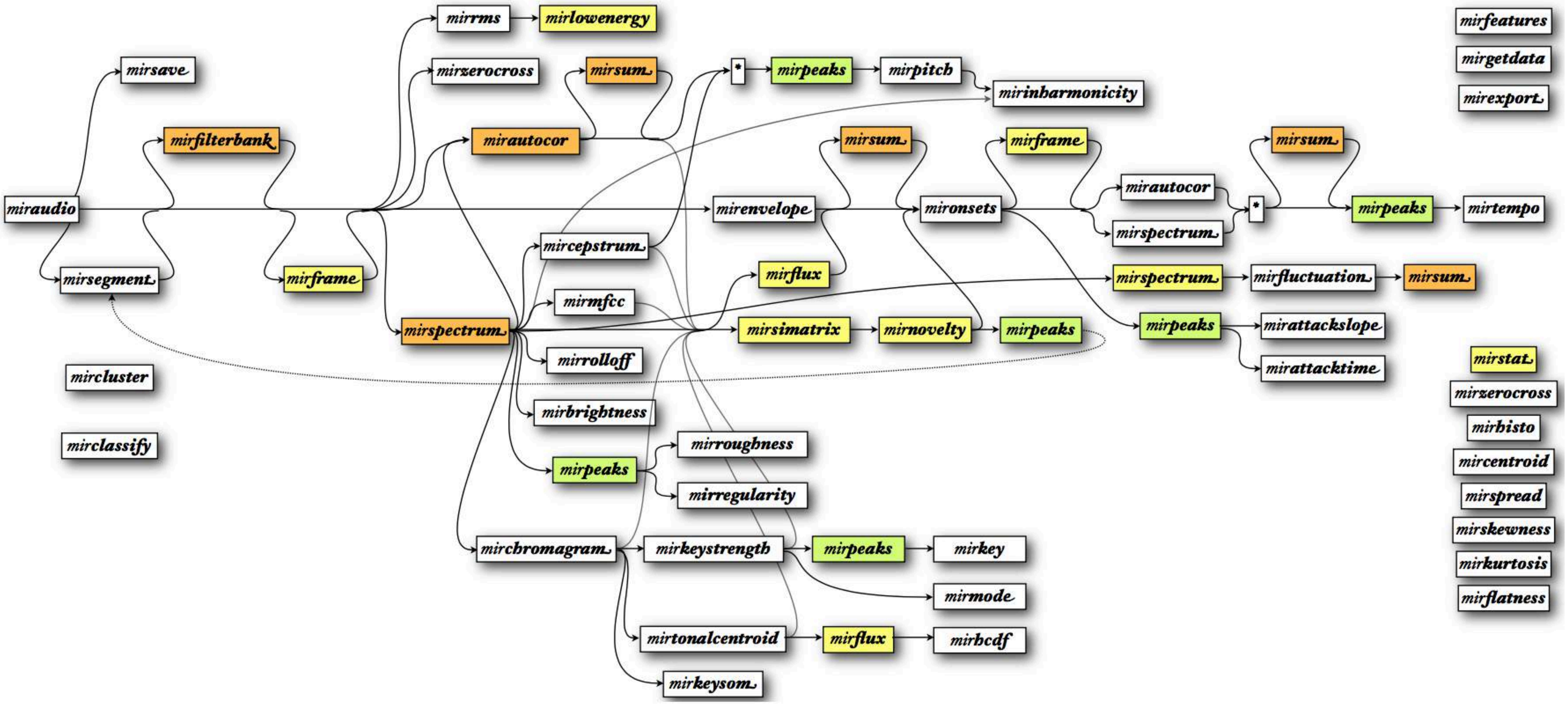
Overview

1. General Principles
2. Syntax & Basic Operations
3. Signal Processing Operators
4. Audio and Musical Descriptors
5. Statistical Analysis

General Principles

- **Modular framework**
  - Building blocks can be reused, reordered, ...
- **Simple and adaptive syntax**
  - User can focus on the general design.
  - MIRtoolbox takes care of the technical details.
- **Free software, open source**
  - Capitalized expertise of the research community, for everybody

General Principles

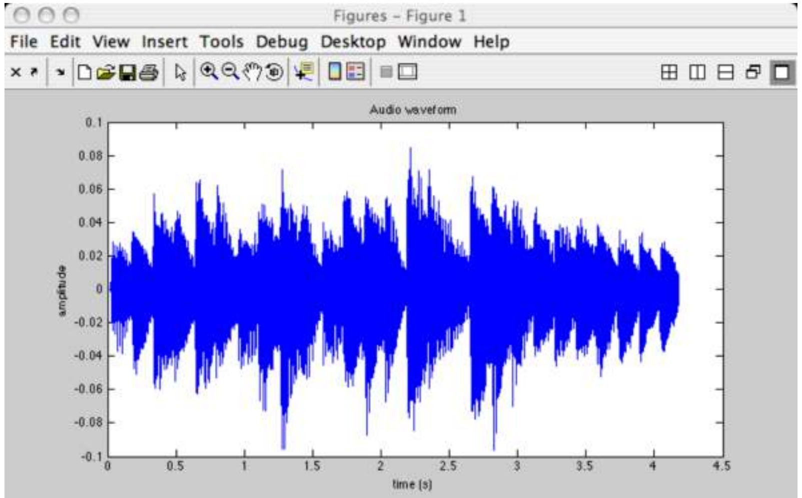


MIRtoolbox Reliances

- Requires:
  - Matlab, ≥ version 7
  - Signal Processing Toolbox (MathWorks)
- Distribution includes free softwares:
  - Auditory Toolbox, by Malcolm Slaney
  - Netlab toolbox, by Ian Nabney
  - SOM Toolbox, by Esa Alhoniemi et al.
- Code integrated from GPL project:
  - Music Analysis Toolbox by Elias Pampalk

Basic Operations

- *mir**audio**('**mysong.wav**')* *mir**audio**('**mysong.mp3**')*



- *mir**audio**('**Folder**')*
  - '*Folder*' = all files in Current Directory

Basic Operations

- *mir**audio**(... , ‘Center’)*

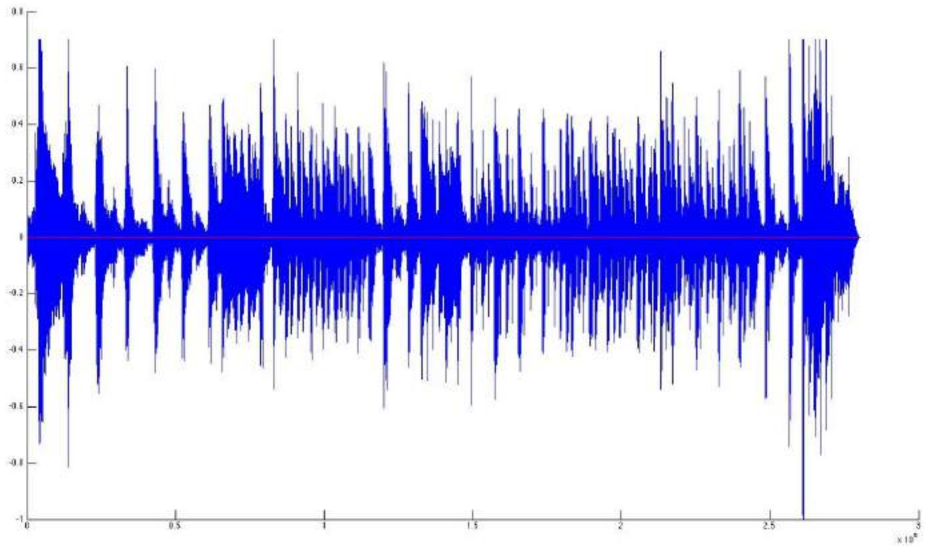
  (... , ‘Sampling’,r

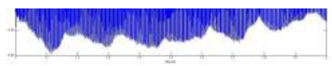
  (... , ‘Trim’)

  (... , ‘TrimStart’)

  (... , ‘TrimEnd’)

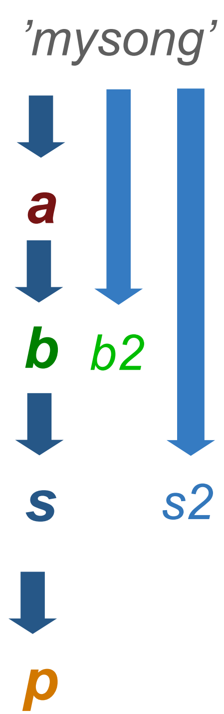
  (... , ‘Extract’, t1,



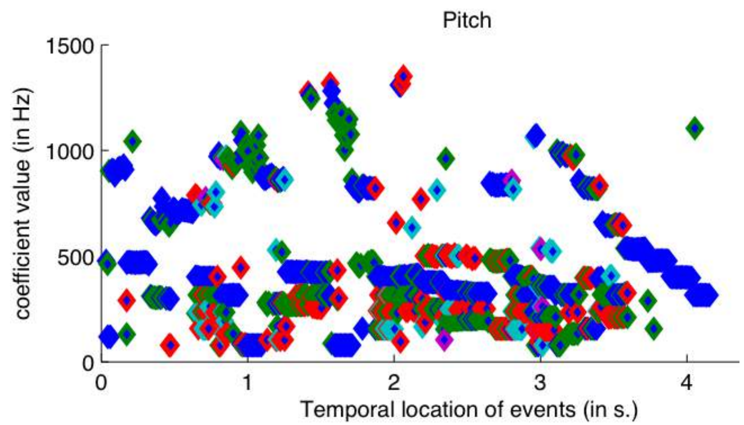


- *Audio Summation*
  - *a1 = mir**audio**(‘melody.wav’)*
  - *a2 = mir**audio**(‘accompaniment.wav’)*
  - *a = a1 + a2*

Flow of operators



- ***a*** = *mir**audio**('mysong')*
- ***b*** = *miraudio(**a**, **'Extract'**, 0, 4)*
    - *b2 = miraudio(**'mysong'**, **'Extract'**, 0, 4)*
    - *mir**play**(**b**)*
    - *mir**save**(**b**, 'excerpt.wav')*
- ***s*** = *mir**spectrum**(**b**)*
    - *s2 = mirspectrum(**'mysong'**)*
- ***p*** = *mir**pitch**(**s**, **'Frame'**)*
    - *mir**getdata**(**p**)*



*mir**spectrum***
Fourier Transform

- *mir**spectrum**(...*

  , ***'Min'***, 0 (in Hz)

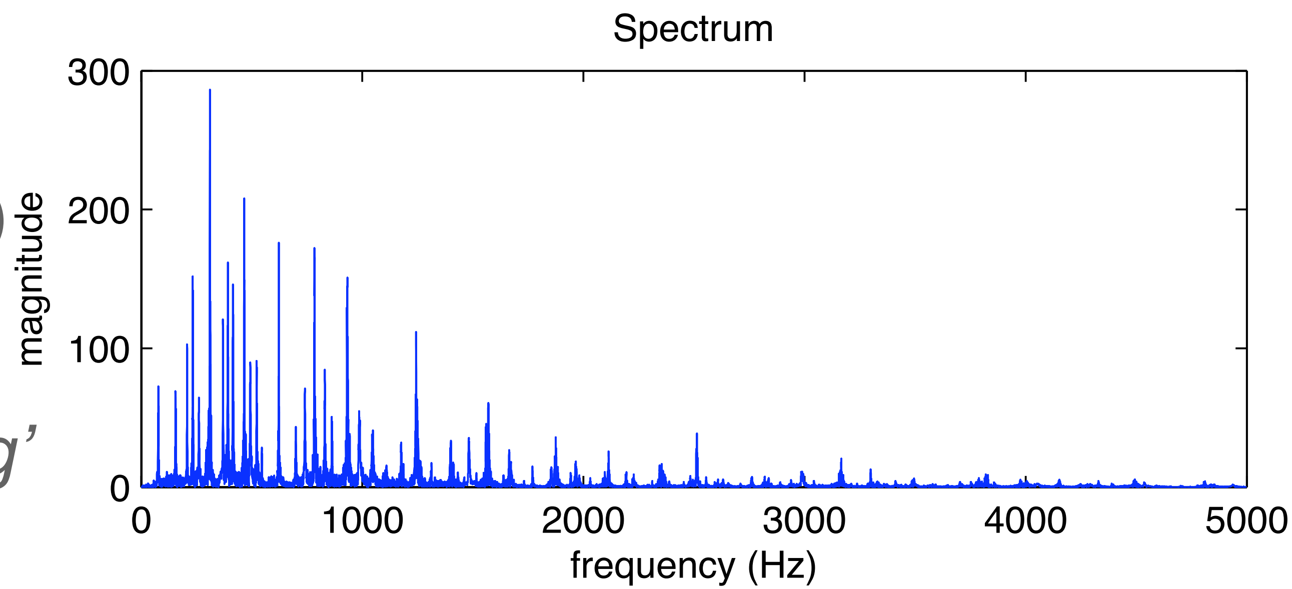
  , ***'Max'***, 5000 (in Hz)

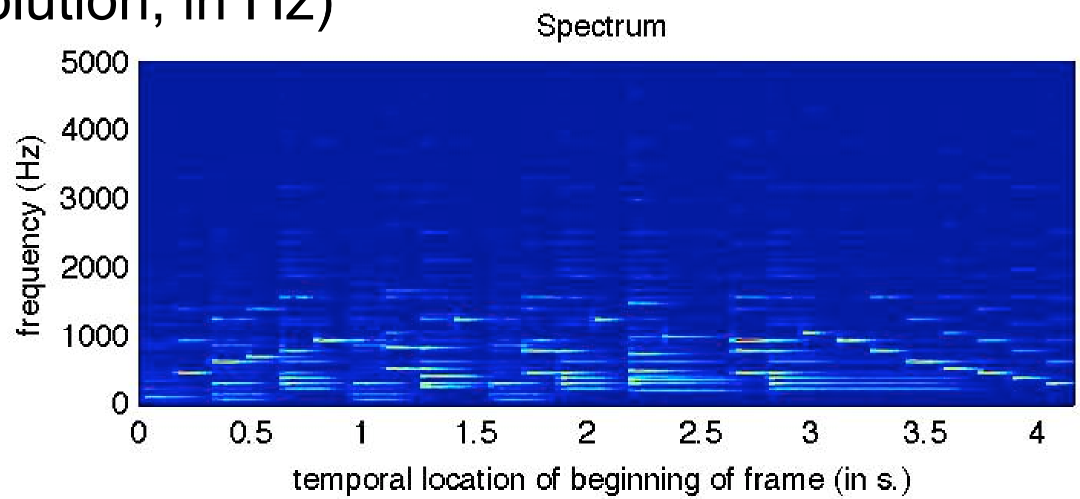
  , ***'Window'***, *'hamming'*

  , ***'MinRes'***, *r*

  (minimum frequency resolution, in Hz)

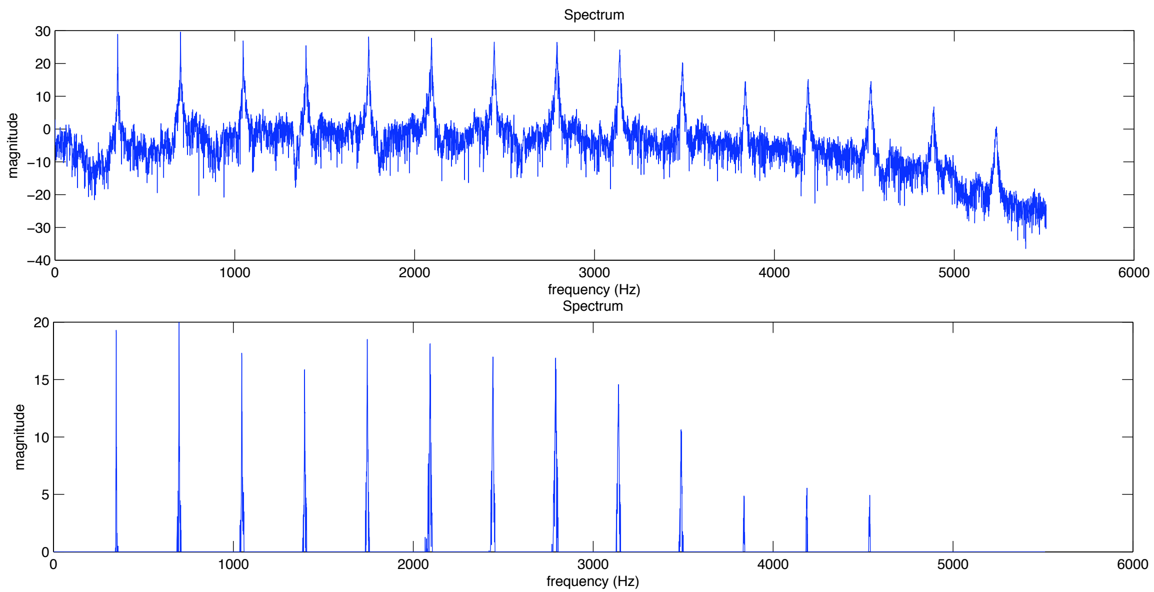
  , '***Frame***', *s*)





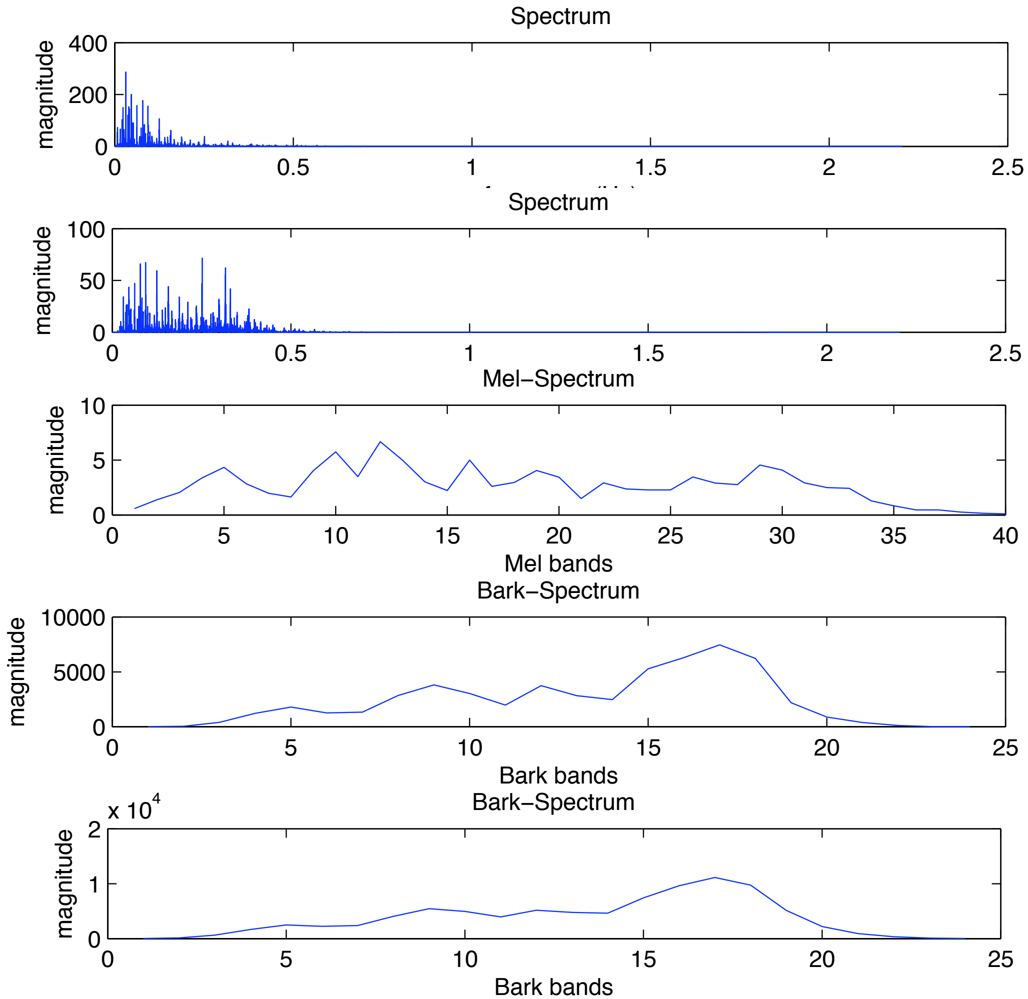
*mir**spectrum***
post-processing options

- *mir**spectrum**(..., ‘**Normal**’)* normalizes w.r.t. energy.
- *mir**spectrum**(..., ‘**Power**’)* squares the energy.
- *mir**spectrum**(..., ‘**dB**’)* in dB scale
- *mir**spectrum**(..., ‘dB’, th)* only highest energy, range of *th* dB



*mir***spectrum**
auditory models

- *mir***spectrum***(..., '***Terhardt***')*:
  Outer ear modeling
- *mir***spectrum***(..., '***Mel***')*:
  Mel-band spectrum
- *mir***spectrum***(..., '***Bark***')*:
  Bark-band spectrum
- *mir***spectrum***(..., '***Mask***')*:
  Masking effects along bands

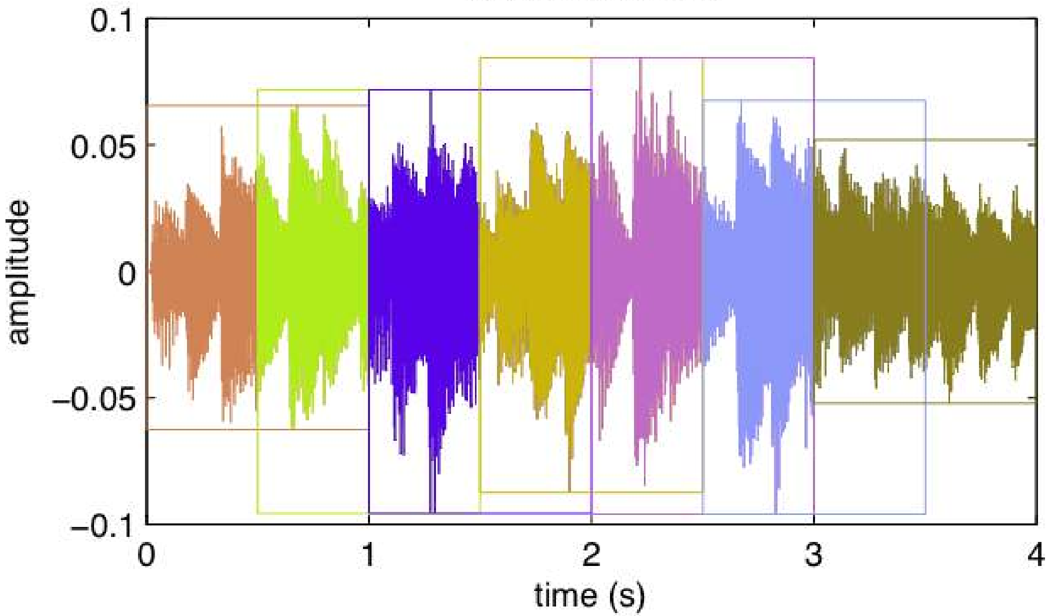


Frame decomposition

f *= mir**frame**('mysong', ...*
*'**Length**', .1, 's', '**Hop**', 20, '%')*

*mirplay(**f**)*

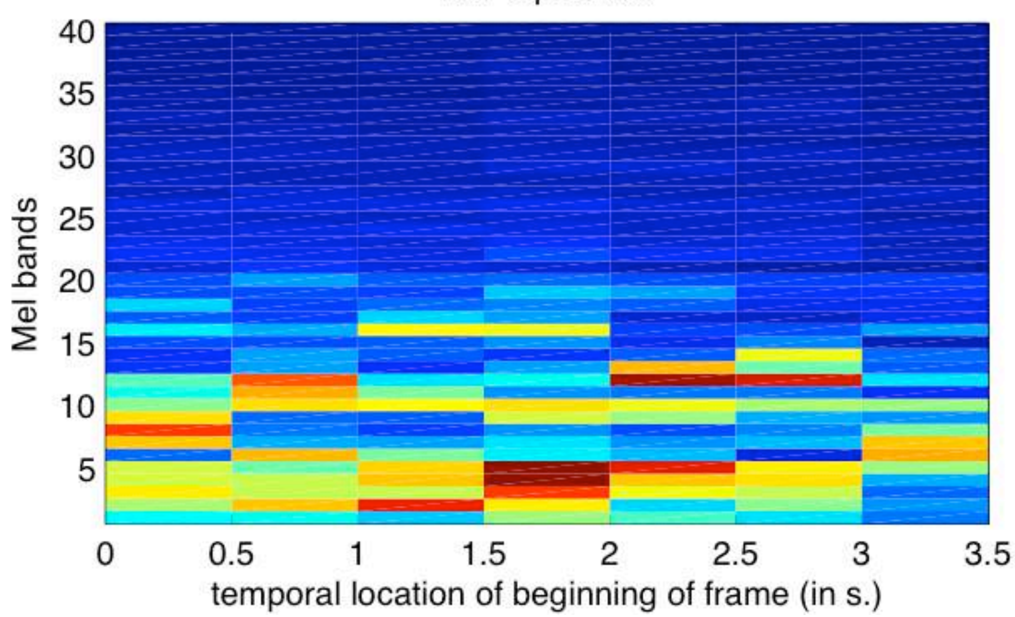
f



s *= mir**spectrum**(**f**, 'Mel')*

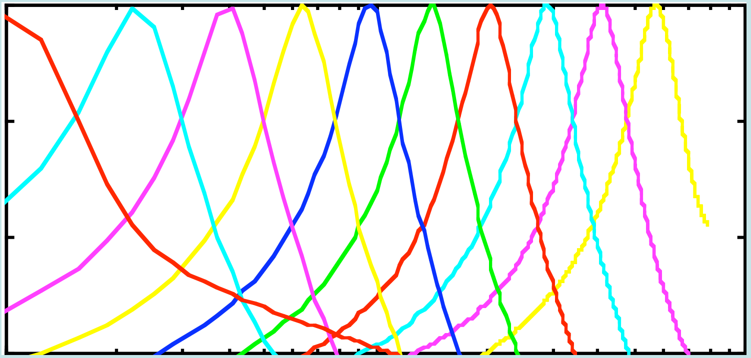
s *= mir**spectrum**('mysong', ...*
*'**Frame**', .1, .2, 'Mel')*

s

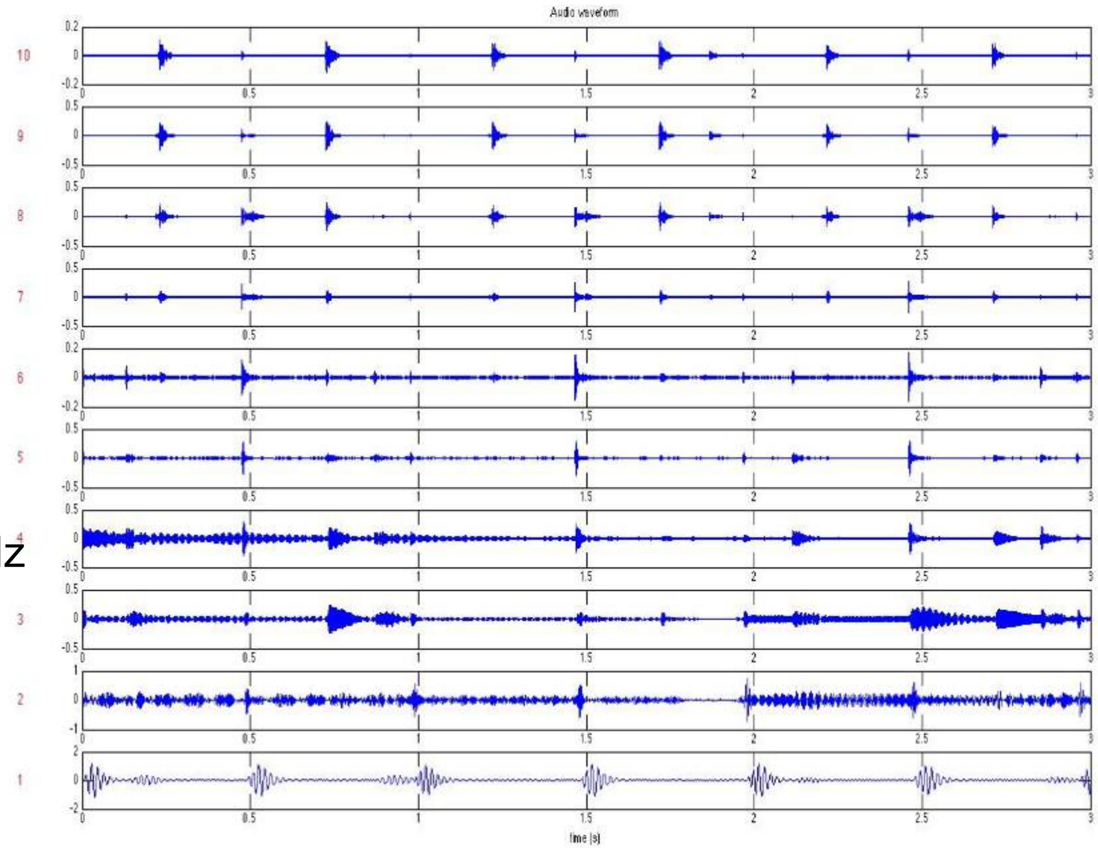


Filterbank decomposition

using Gammatone filterbank



100 Hz *Filter frequency responses* 10000 Hz

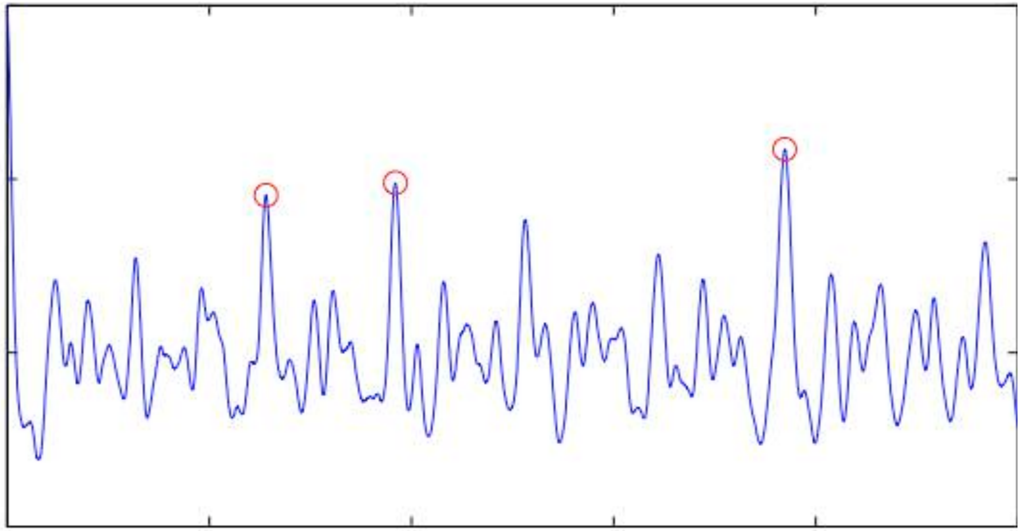


f = *mir**filterbank**('mysong', ...*
***'NbChannels'**, 10)*

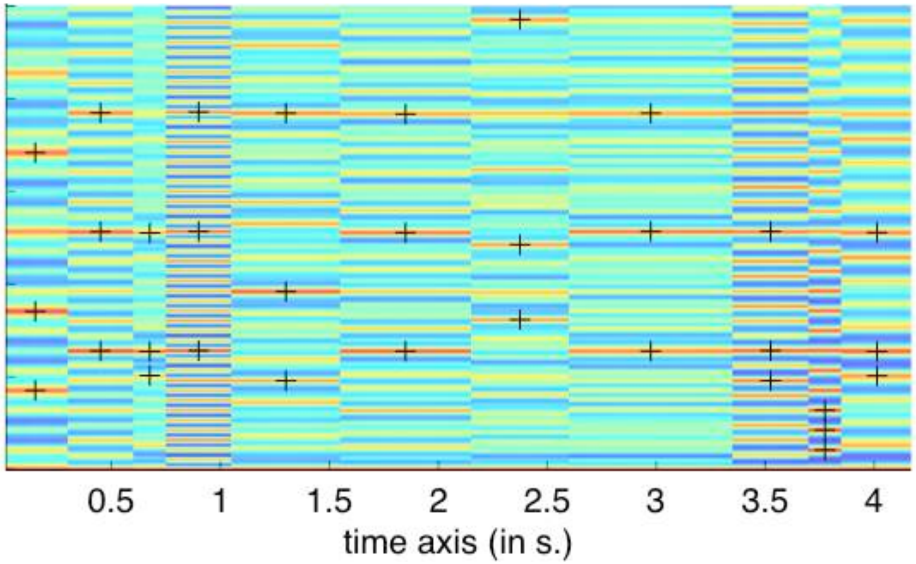
*mirplay(**f**)*

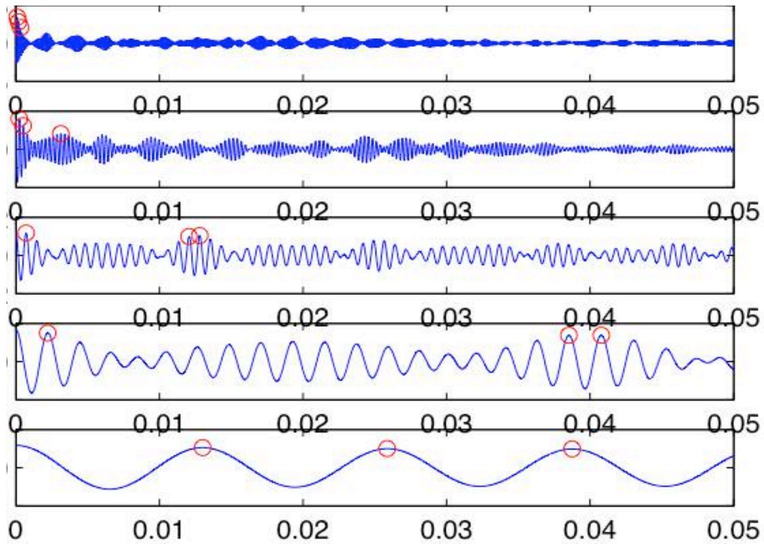
Peak picking
(for different kinds of data)

*mir**peaks**(...,*
*'**Total**', 3, '**NoBegin**')*



- Adapts to various input types:
  - Multi-frame, multi-segment:





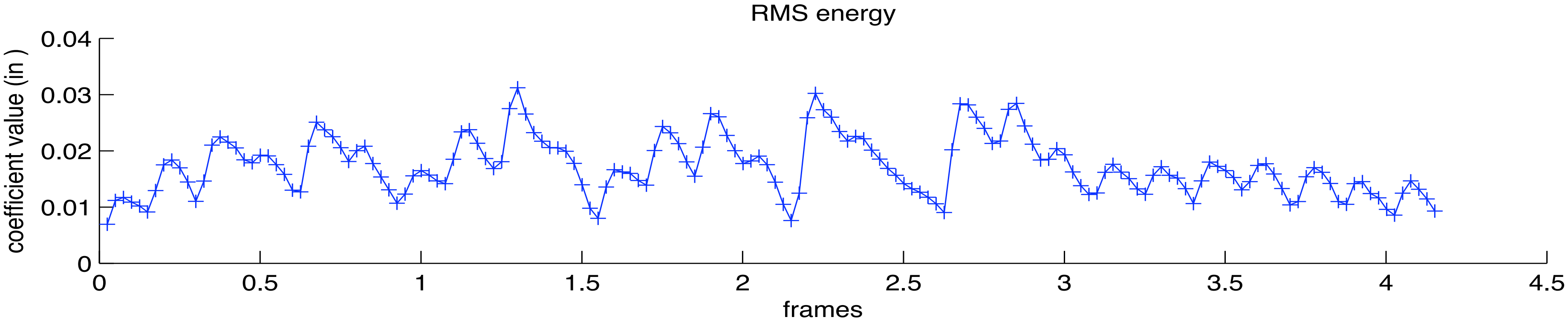
MIR Toolbox

Features Overview

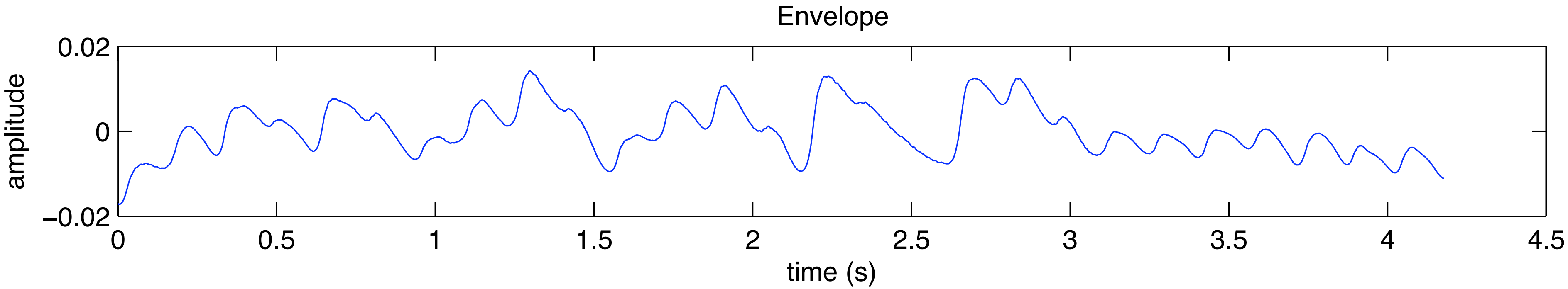
- Dynamics
- Tempo /rhythm
- Pitch
- Timbre
- Tonality
- Structure

(DYNAMICS)Energy / Envelope

- mirrms('mysong', 'Frame')

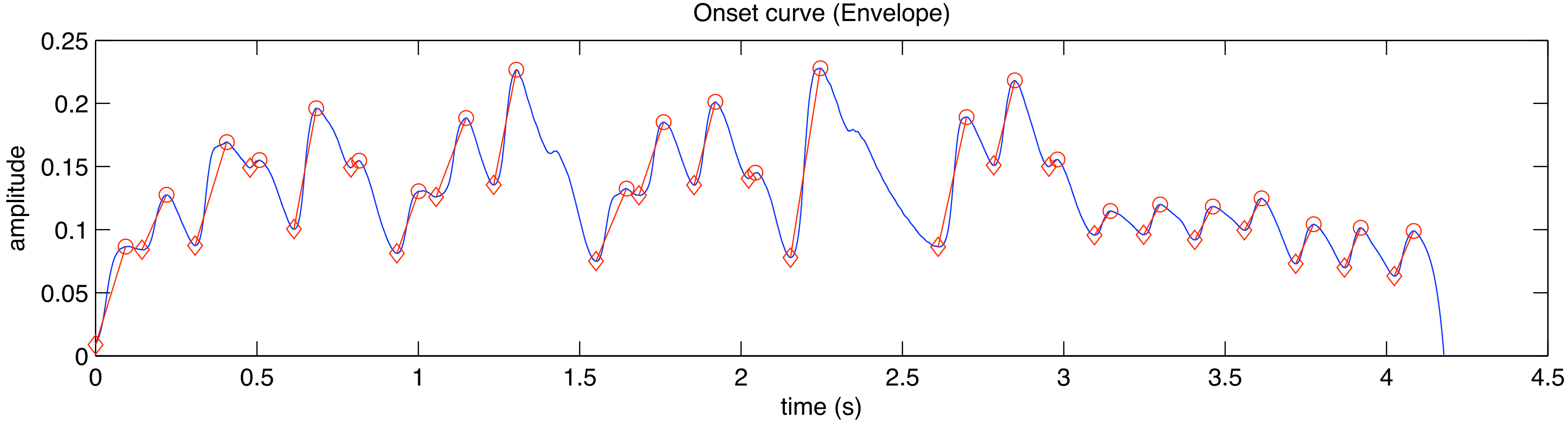


- mirenvelope('mysong')

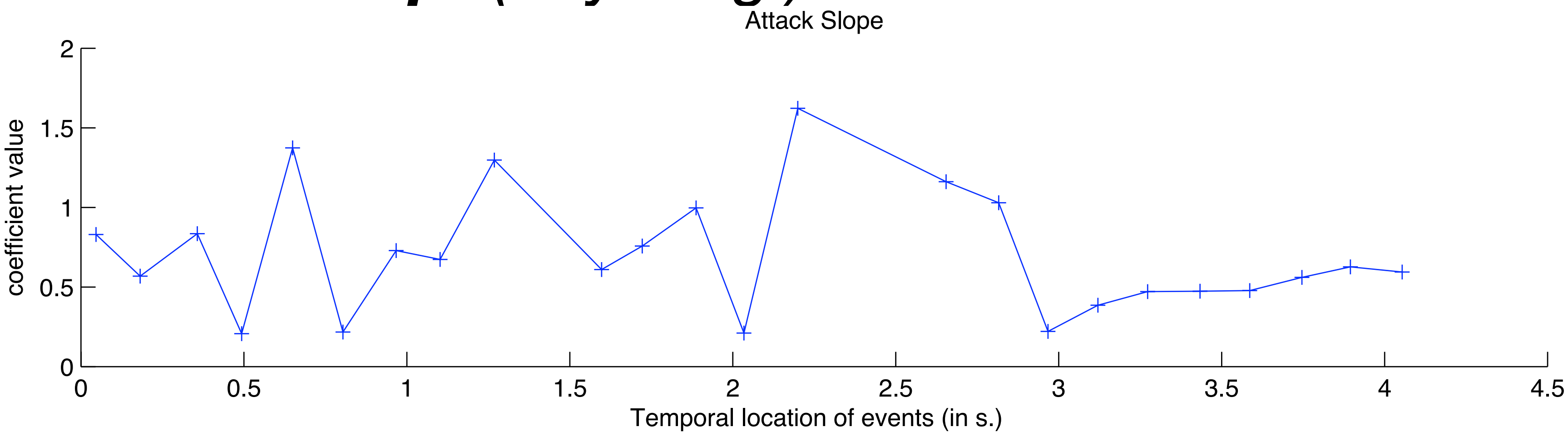


Onsets, attacks, etc.

- ***mir*onsets*('mysong', '*Attack*')***

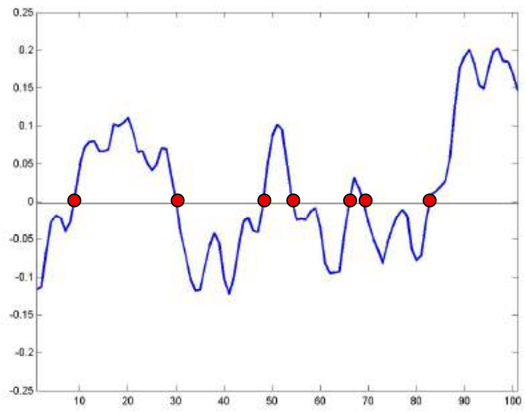


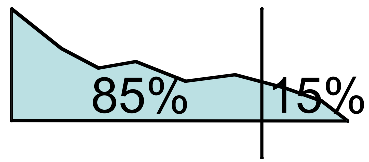
- ***mir*attackslope*('mysong')***

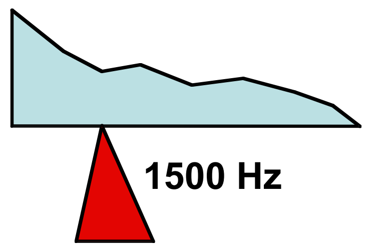


Timbre

- *mir**zerocross***
  - *Zero-crossing rate*
- *mir**rolloff***
  - *85% or 95%*
- *mir**brightness***
- *mir**mfcc***
  - *Mel*-Frequency Cepstral Coefficients
- *mir**roughness***
  - *Sensory Dissonance*
- *mir**regularity***







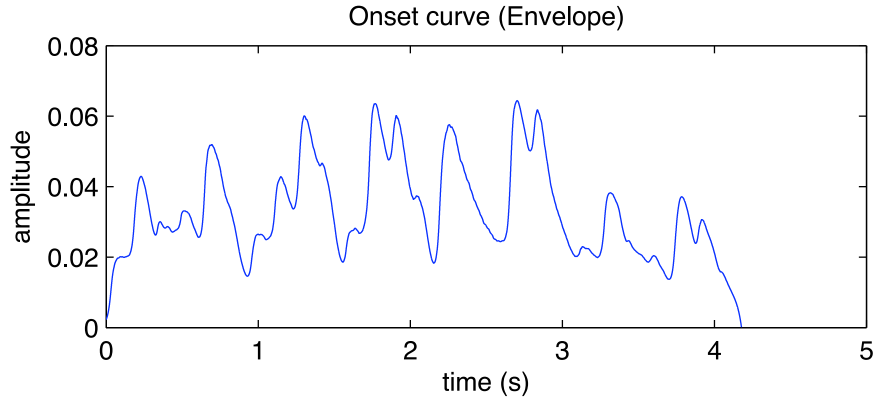
Tempo

- Roughly:
  - ***o*** = *mir**onsets**('mysong', 'Detect', 'No')*
  - ***do*** = *mironsets(**o**, '**Diff**')*
  - ***ac*** = *mir**autocor**(**do**)*
  - ***pa*** = *mir**peaks**(**ac**, 'Total', 1)*

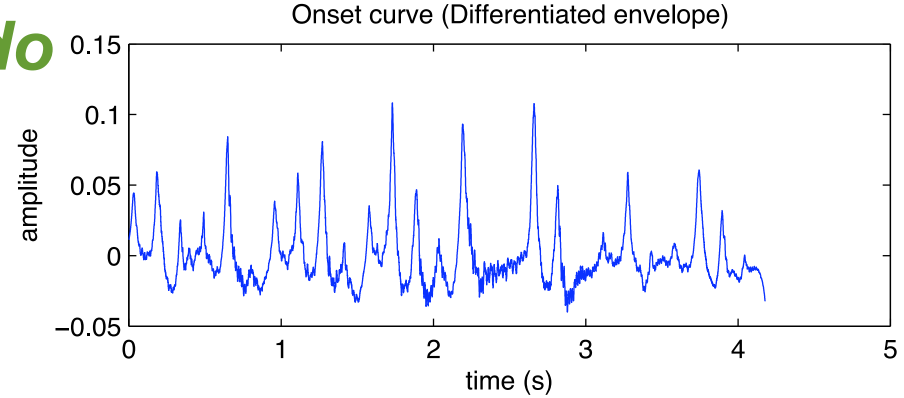
- In short:
  - *[**t**, pa] = mir**tempo**('mysong')*

```
t = 129.6333 bpm
```

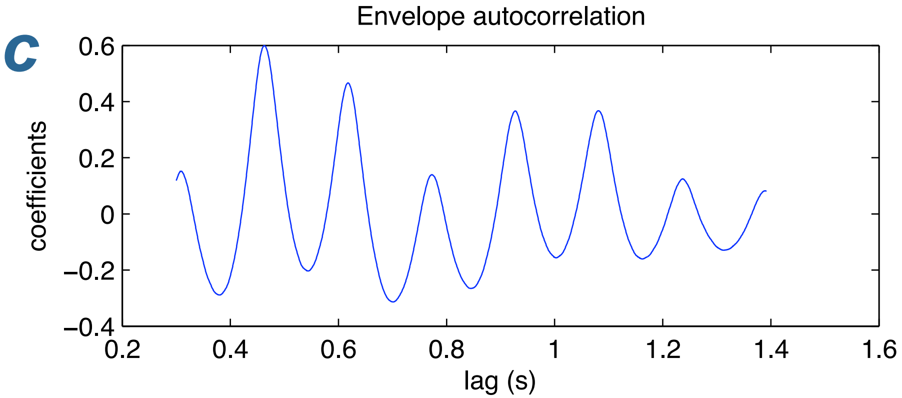
- ***o***



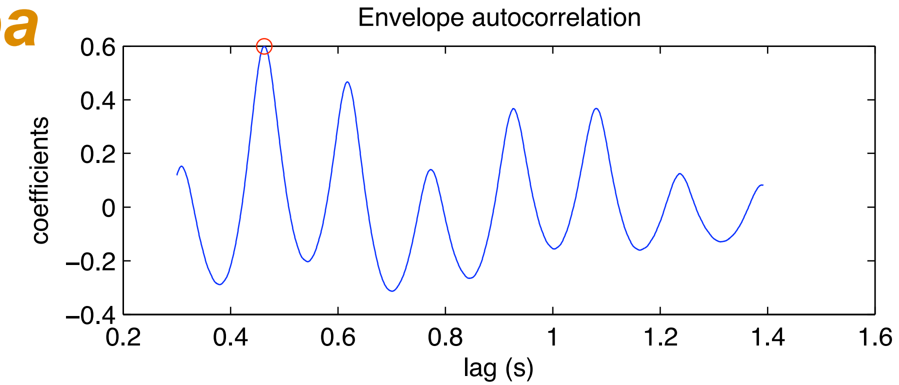
- ***do***



- ***ac***



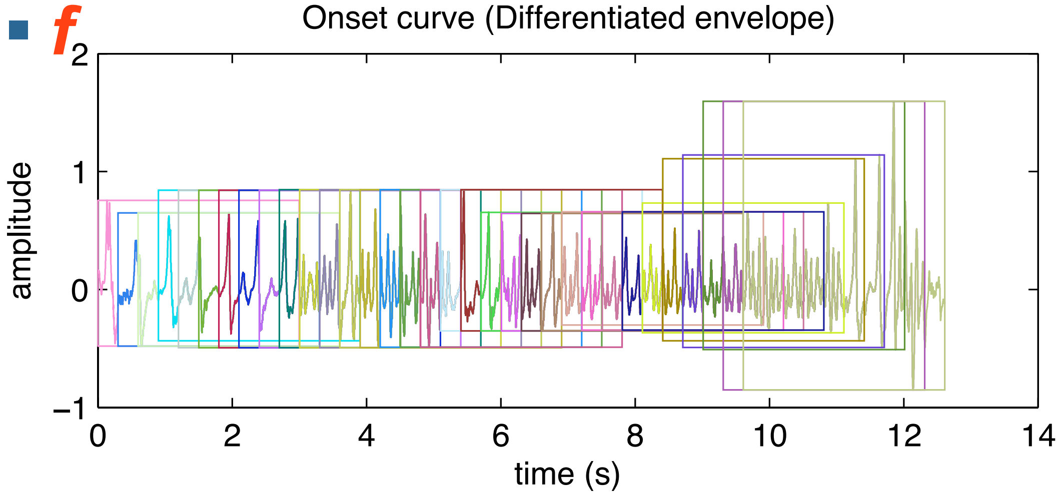
- ***pa***



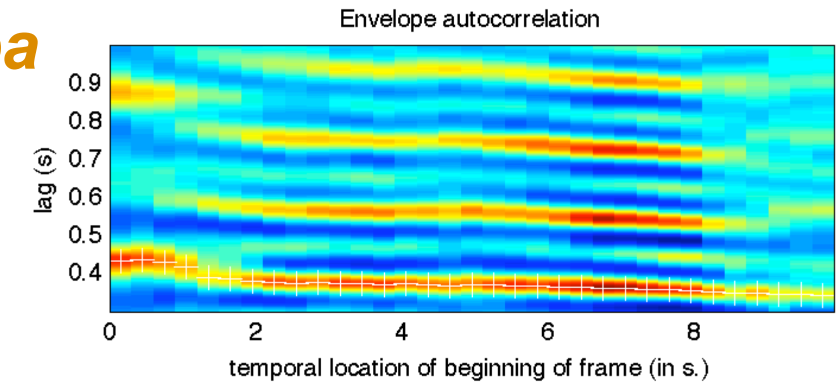
Tempo (temporal evolution)

- Roughly:
  - ***o*** = mir***onsets***(’mysong’, ‘Detect’, ‘No’)
  - ***do*** = mironsets(***o***, ‘***Diff***’)
  - ***f*** = mir***frame***(***do***)
  - ***ac*** = mir***autocor***(***f***)
  - ***pa*** = mir***peaks***(***ac***, ’Total’, 1)
- In short:
  - [***t***, ***pa***] = mir***tempo***(’mysong’, ‘***Frame***’)

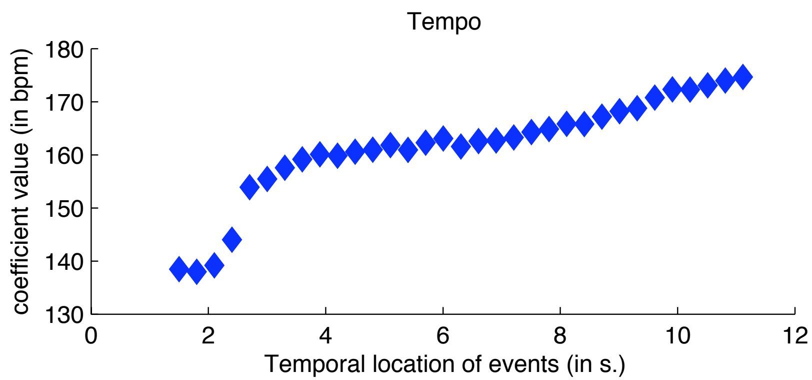
- ***f***



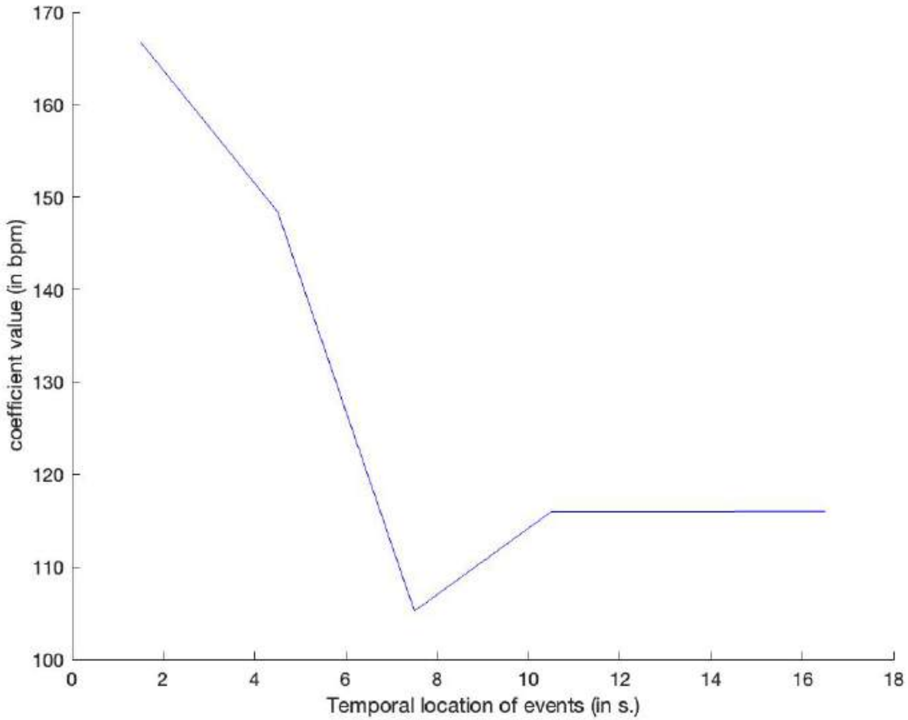
- ***pa***

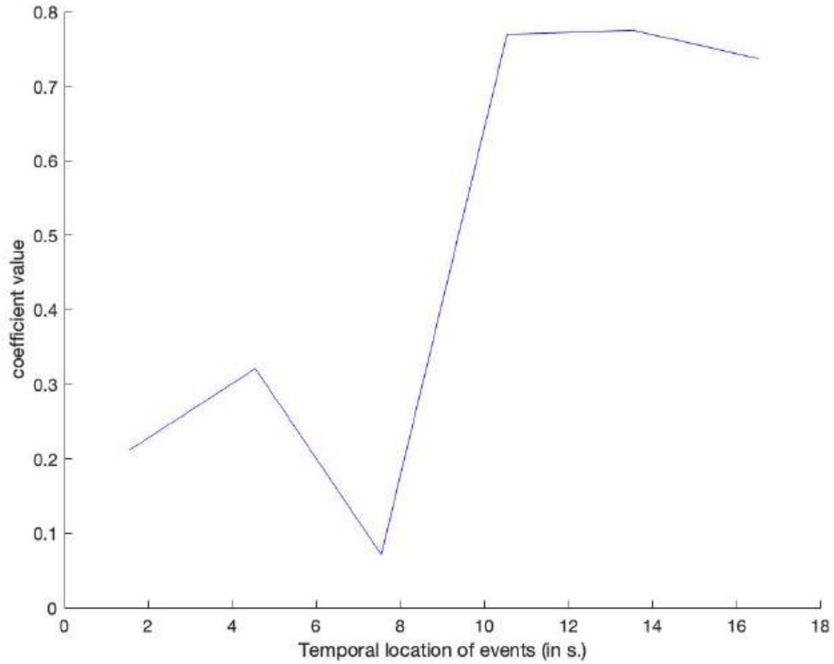


- ***t***



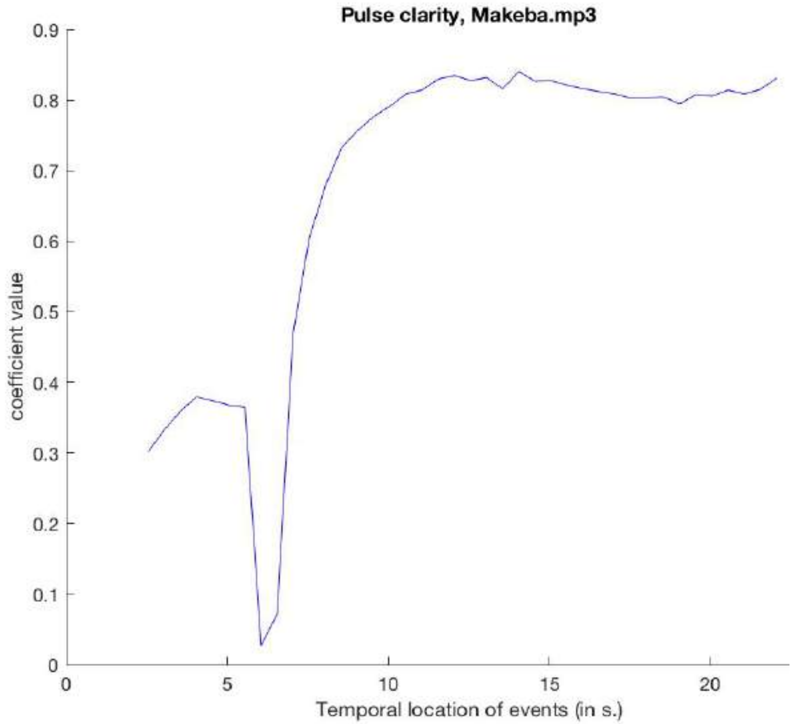
tempo vs pulse clarity





Pulse Clarity

- ***b***=mir**audio**(‘Makeba.mp3','Extract',5,25);
- *mir**pulseclarity**(**b**,’Frame')*

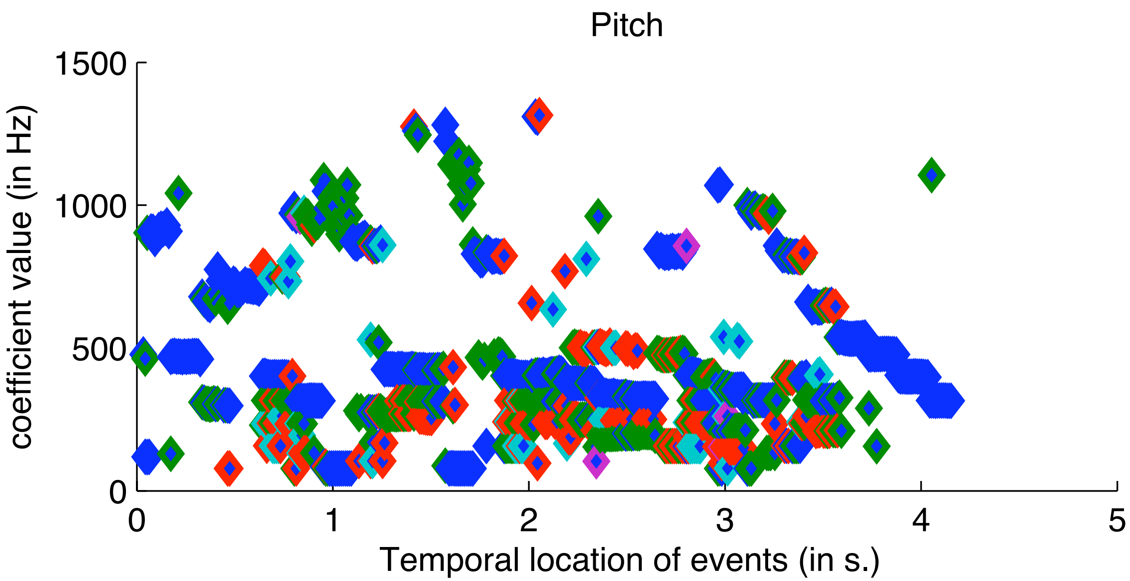


- *mir**pulseclarity**(miraudio('Makeba.mp3','Extract',5,25),'Frame')*

Pitch

- *[**p**, **pa**] = mir**pitch**('mysong', **'Frame'**)*
- *mirplay(**p**)*

- ***p***

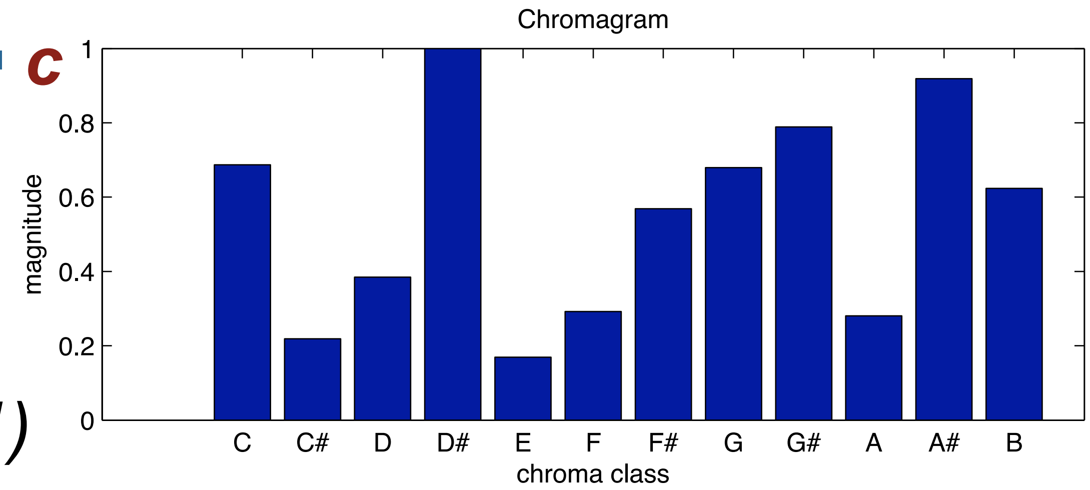


Tonal Analysis

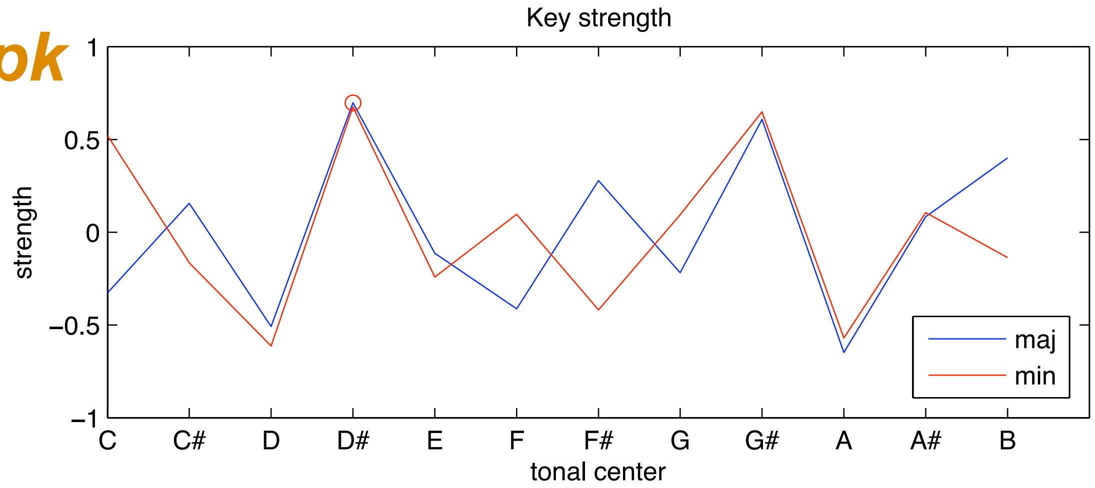
- Roughly:
  - ***c*** = mir***chromagram***('mysong')
  - ***ks*** = mir***keystrength***(***c***)
  - ***pk*** = mir***peaks***(***ks***, 'Total', 1)
- In short:
  - *[**k**, **kc**] = mir**key**('mysong')*

```
k = D# maj
kc = 0.69797
```

- ***c***



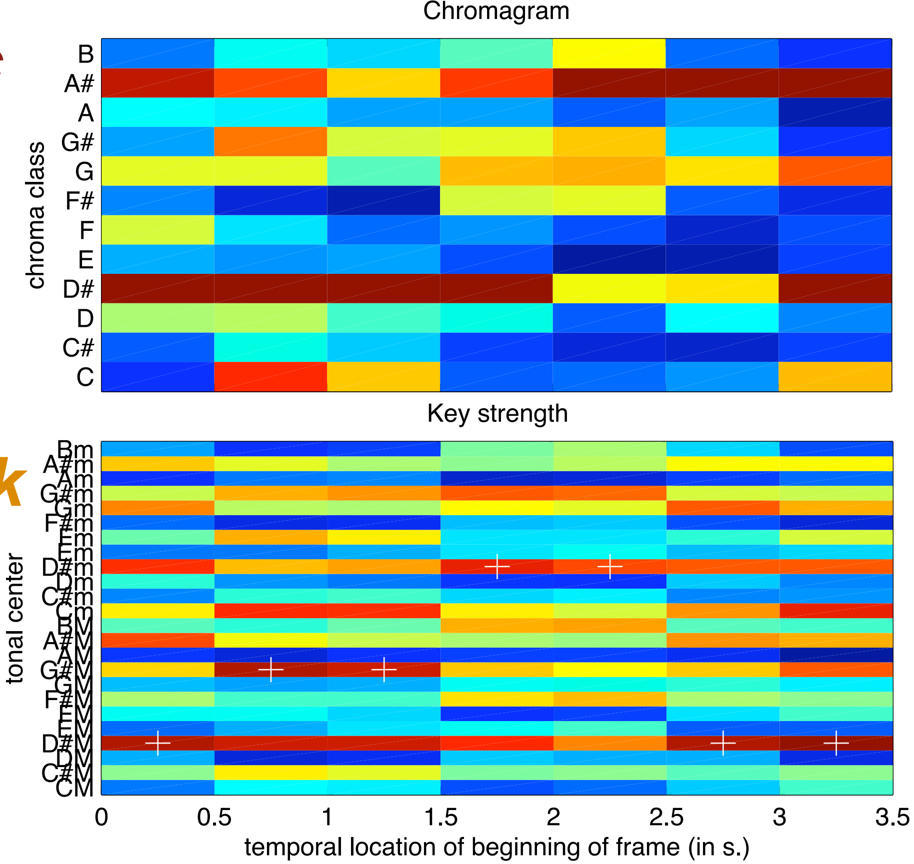
- ***pk***



Tonal Analysis (temporal evolution)

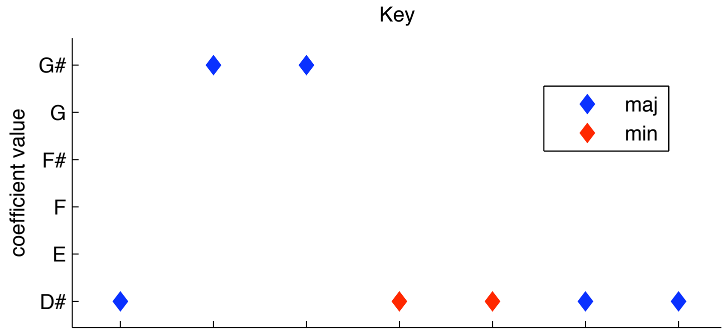
- Roughly:
  - ***c*** = *mir**chromagram**('mysong', '**Frame**')*
  - ***ks*** = *mir**keystrength**(**c**)*
  - ***pk*** = *mir**peaks**(**ks**, 'Total', 1)*
- In short:
  - *[**k**, **kc**] = mir**key**('mysong')*

- ***c***

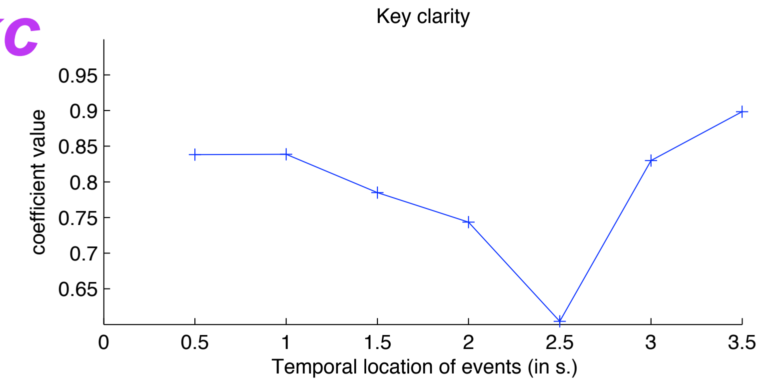


- ***pk***

- ***k***

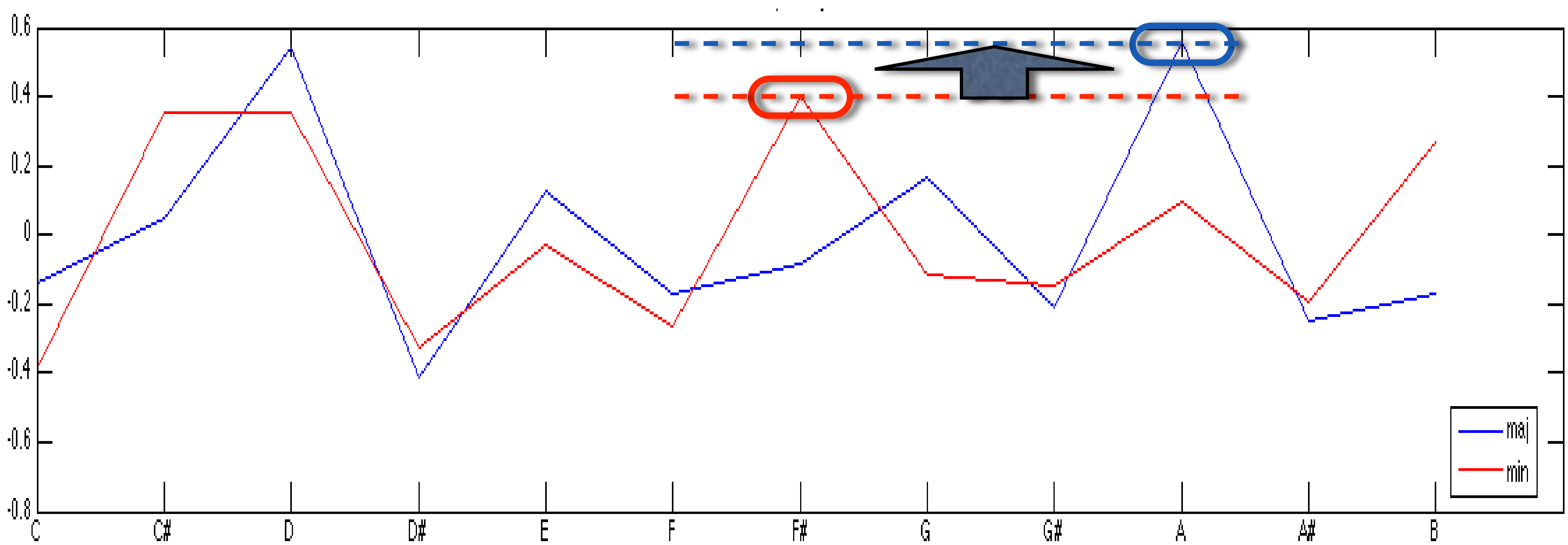


- ***kc***



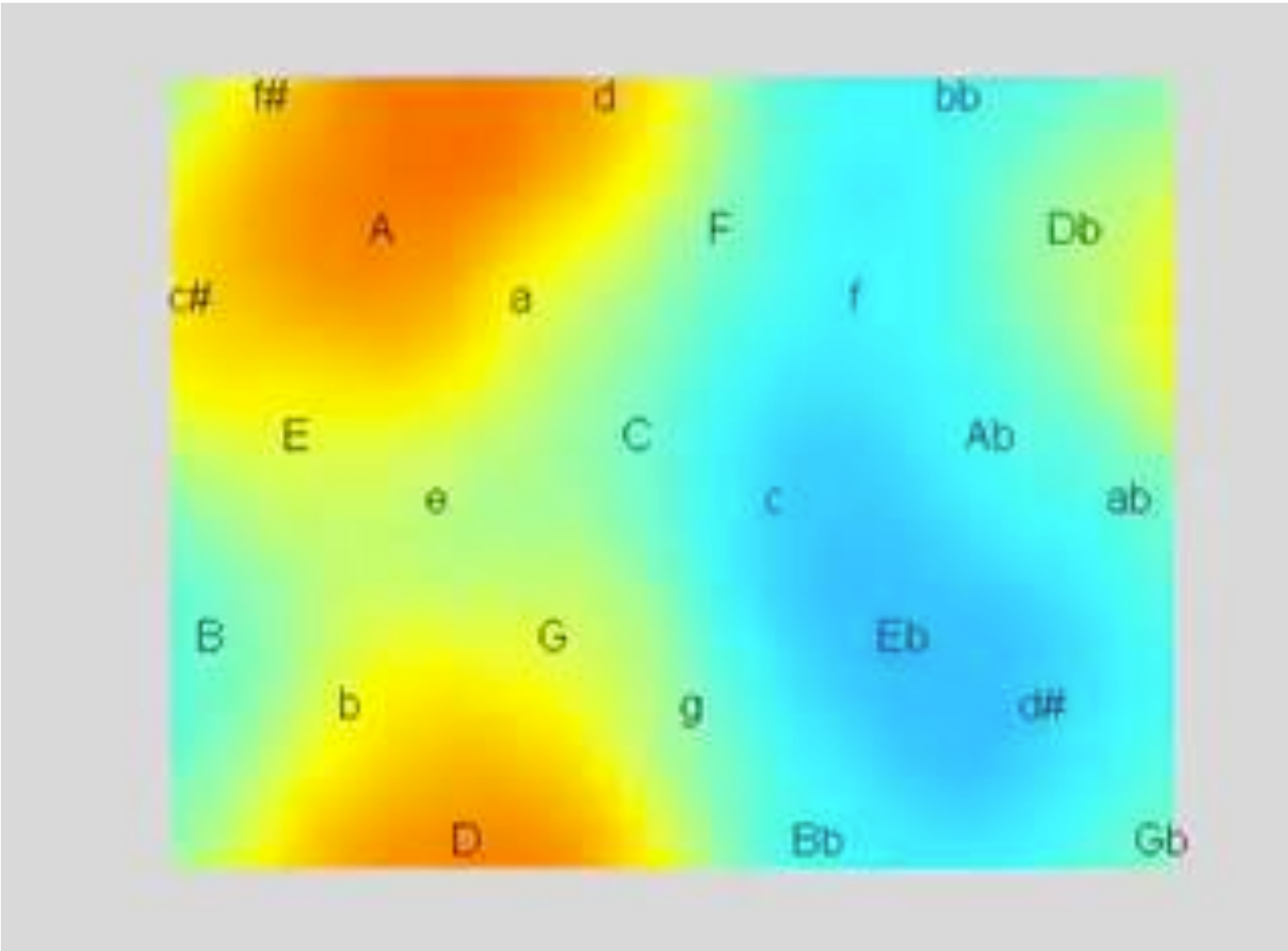
Modal Analysis

- ***mir*mode*('mysong')***



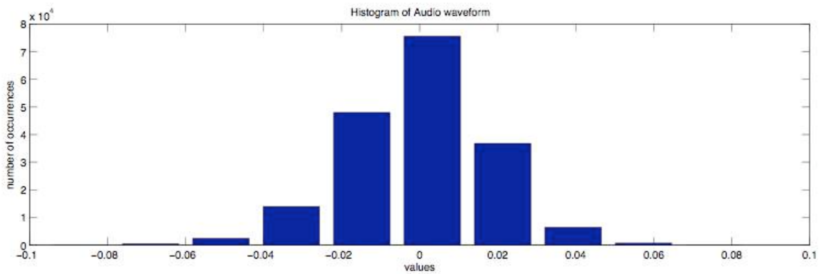
Tonal Analysis

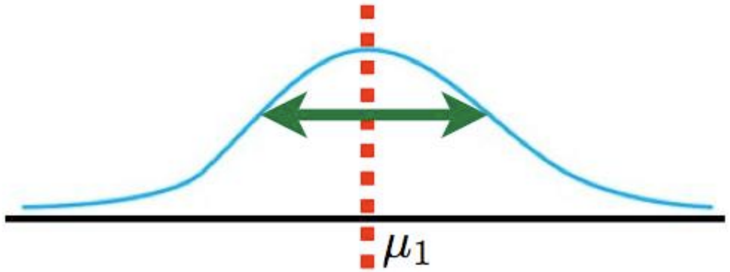
- *mir**keysom**('mysong', 'Frame')*



Statistics

- *mir**stat***
  - mean
  - standard deviation
  - slope
  - periodicity
- *mir**histo***
  - distribution histograms





- moments
  - *mir**centroid***
  - *mir**spread***
  - *mir**skewness***
  - *mir**kurtosis***

*mir**features***

- *mirzerocross*
- *mircentroid*
- *mirbrightness*
- *mirspread*
- *mirskewness*
- *mirkurtosis*
- *mirrolloff*
- *mirentropy*
- *mirflatness*
- *mirroughness*
- *mirregularity*
- *mirinharmonicity*
- *mirmfcc*
- *mirfluctuation*
- *mirattacktime*
- *mirattackslope*
- *mirlowenergy*
- *mirflux*
- *mirpitch*
- *mirchromagram*
- *mirkeystrength*
- *mirkey*
- *mirmode*
- *mirhcdf*
- *mirtempo*
- *mirpulseclarity*

Saving & Exporting

*a = mir**audio**('mysong','Extract',0,1)*

- *mir**save**(a, 'mysample')*

*p = mir**whatever**...*

- *mir**export**('res.**txt**', p, q, r, ...)*
    - *Excel, Word, etc..*

- *mir**export**('res.**arff**', p, q, r, ...)*
    - *Weka, etc..*

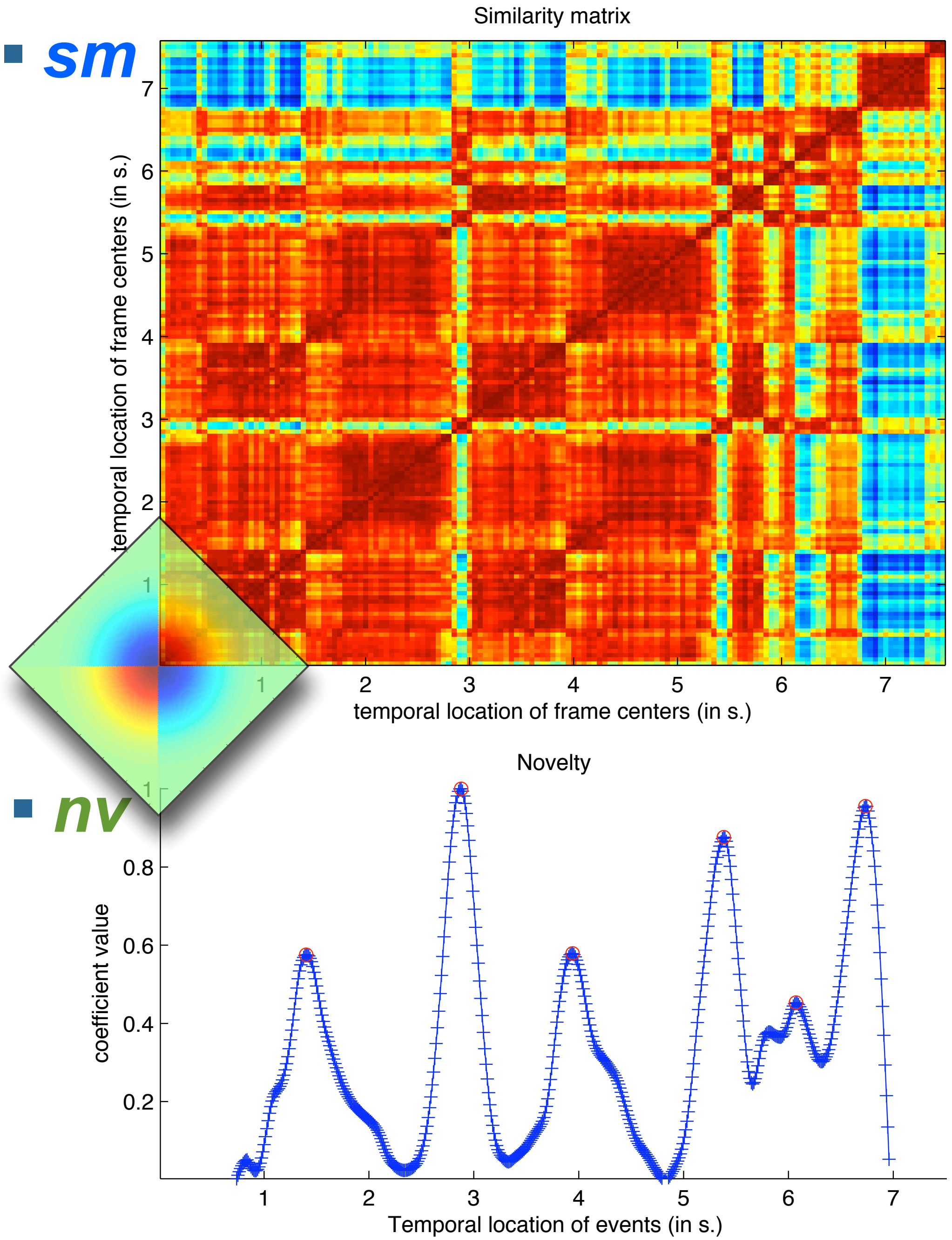
Musical Feature(s)
to
Musical Structure

Structural analysis

- ***x*** = *mir**spectrum**('mysong', '**Frame**')*
- = *mir**mfcc**('mysong', '**Frame**')*
- *whatever...*

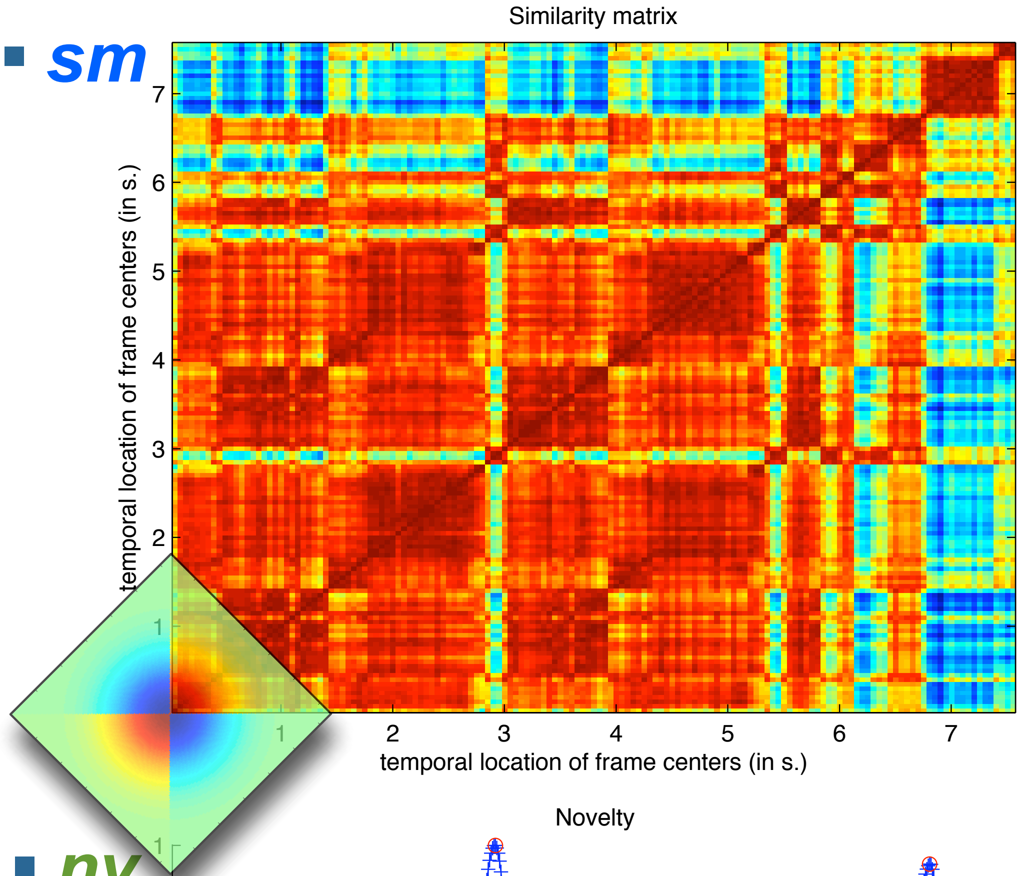
- ***sm*** = *mir**simatrix**(**x**)*
- ***nv*** = *mir**novelty**(**sm**)*

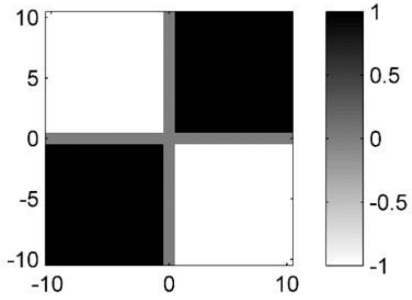
- ***sm***
- ***nv***



Structural analysis

- *sm*





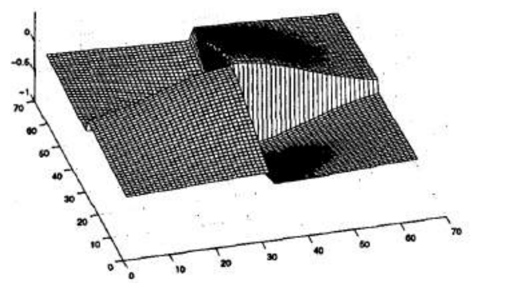
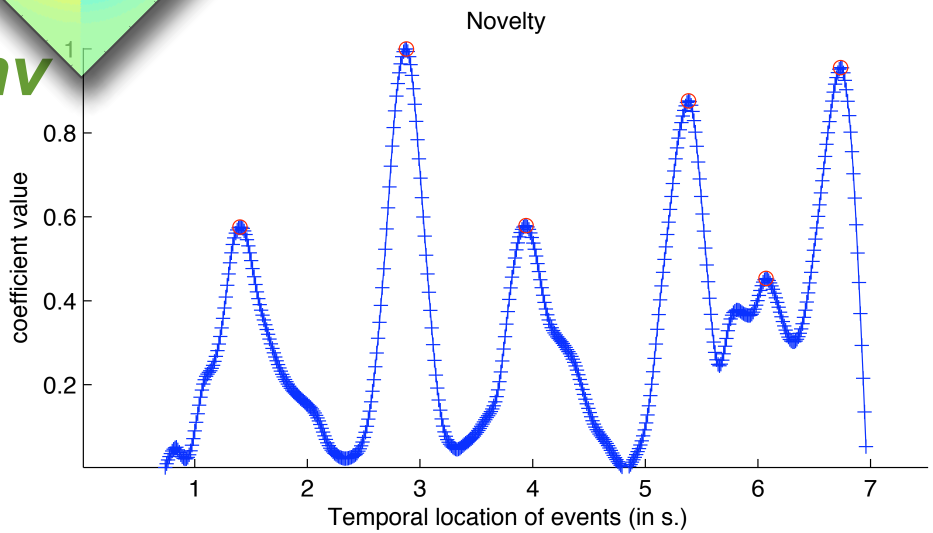


Figure 3. 64 x 64 checkerboard kernel with Gaussian taper

- *nv*



Tonal Analysis

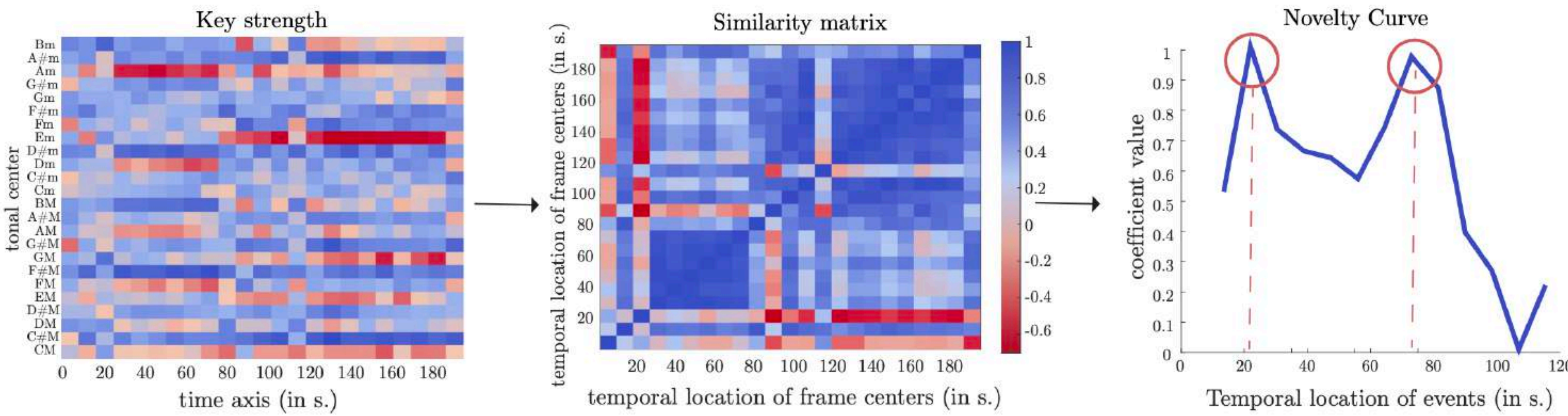
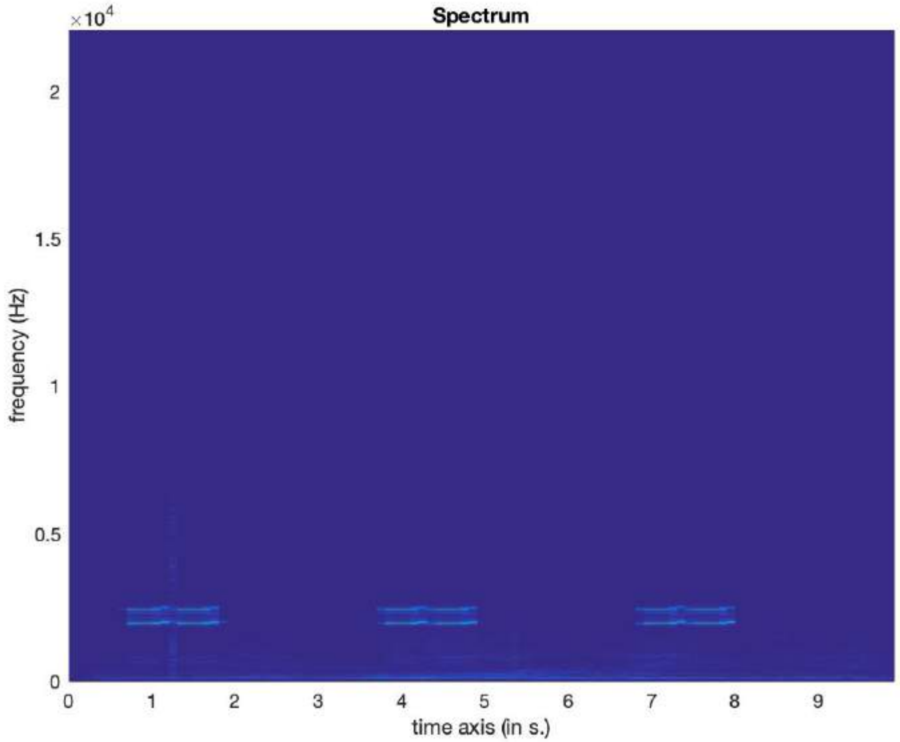


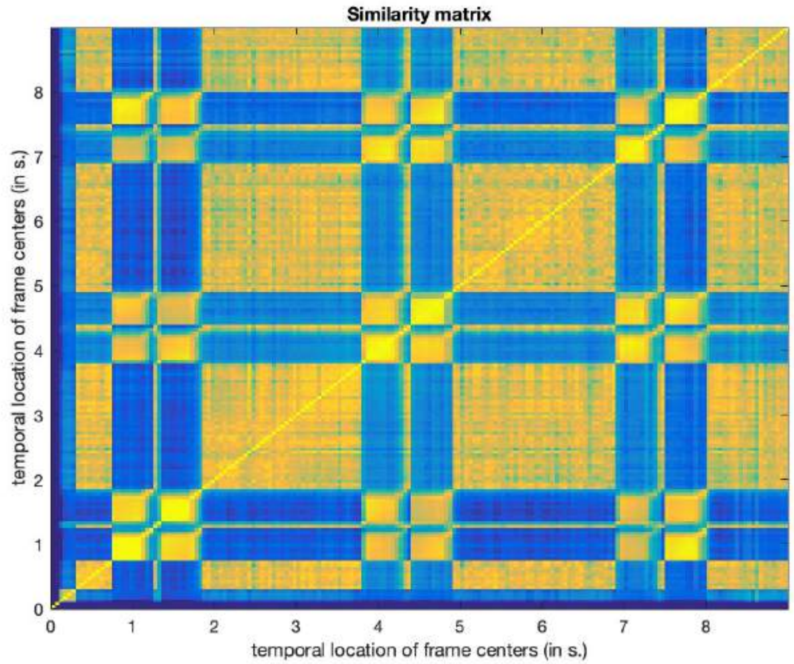
Figure 3. Music segmentation pipeline. We segment all tracks from the soundtrack to ensure a cohesive listening experience. We extract keystrength [21] that captures tonal properties of a soundtrack (left), compute the self-similarity matrix (center), and use that to calculate the novelty curve [24]. The peaks of this curve are used to segment the track.

SONUS TEXERE! AUTOMATED DENSE SOUNDTRACK CONSTRUCTION FOR BOOKS USING MOVIE ADAPTATIONS

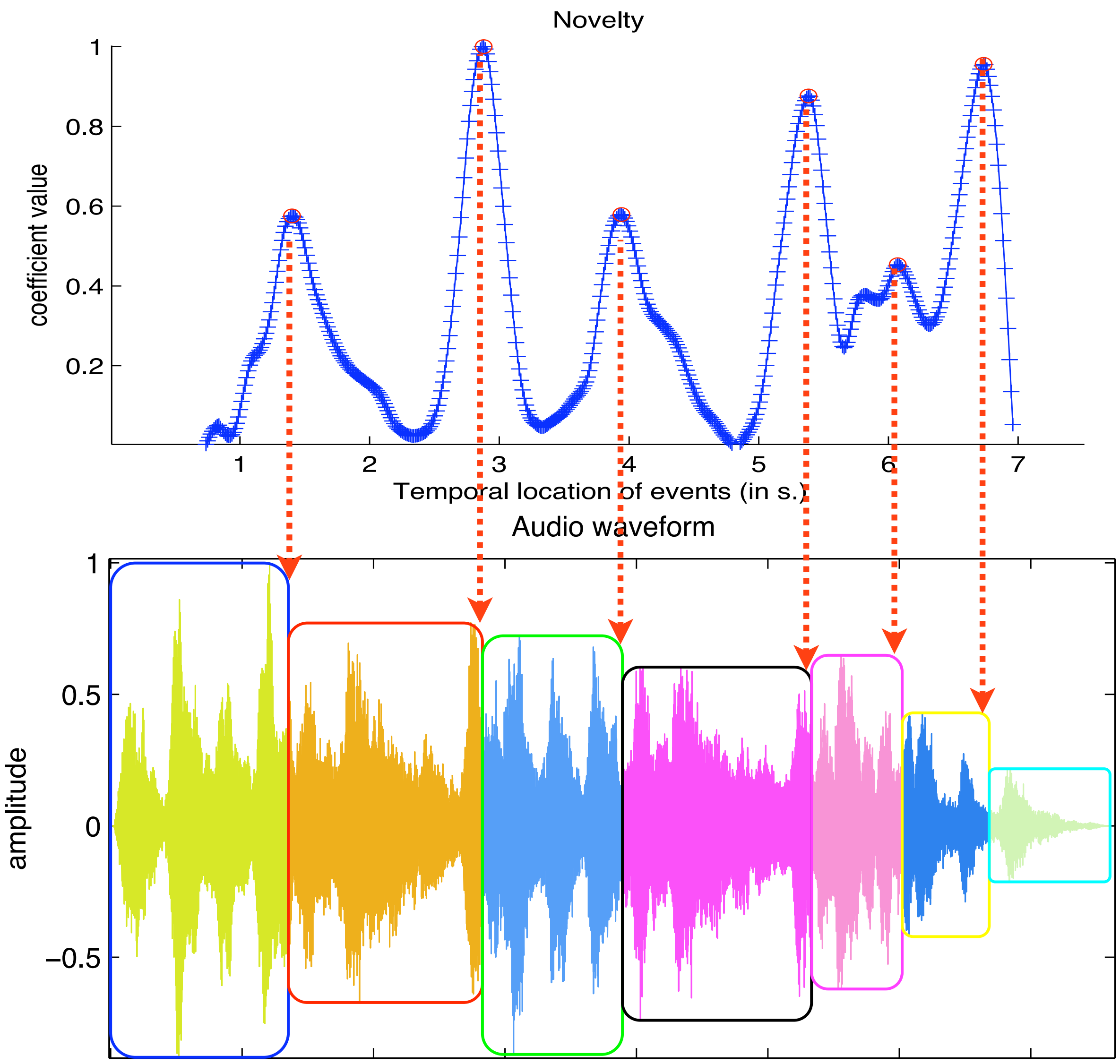
Jaidev Shriram Makarand Tapaswi Vinoo Alluri
International Institute of Information Technology, Hyderabad
https://auto-book-soundtrack.github.io/



How does the structure of this look like?



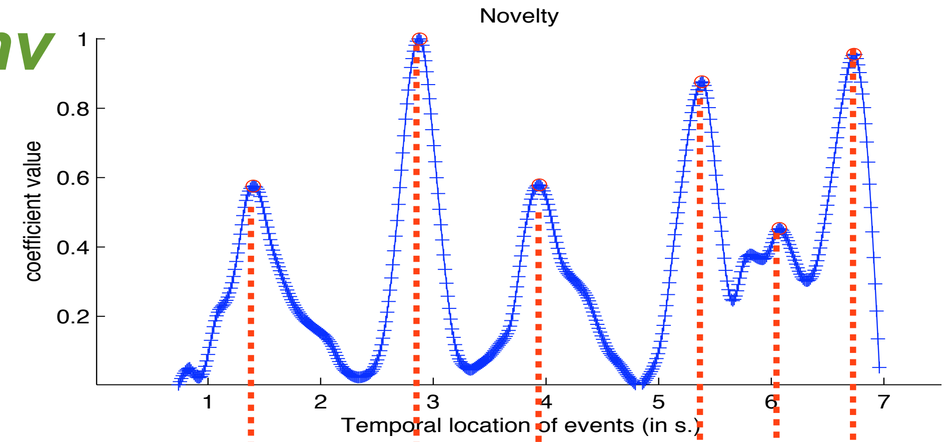
Segmentation



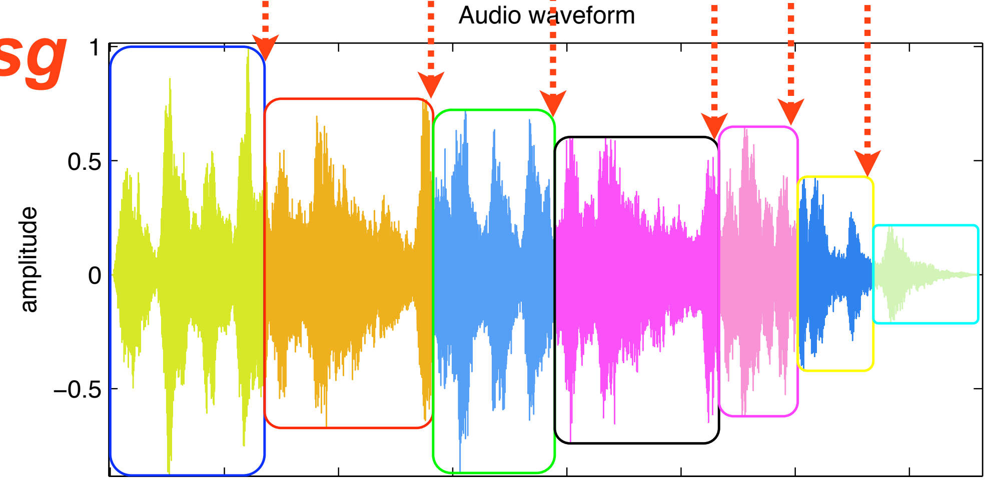
Segmentation

- *nv* = *mir**novelty**(sm)*
- *sg* = *mir**segment**('mysong', nv)*
- *sg* = *mir**segment**('mysong')*
  - *mirplay(sg)*
- *s* = *mirmfcc(sg)*
- *sm* = *mirsimatrix(s)*

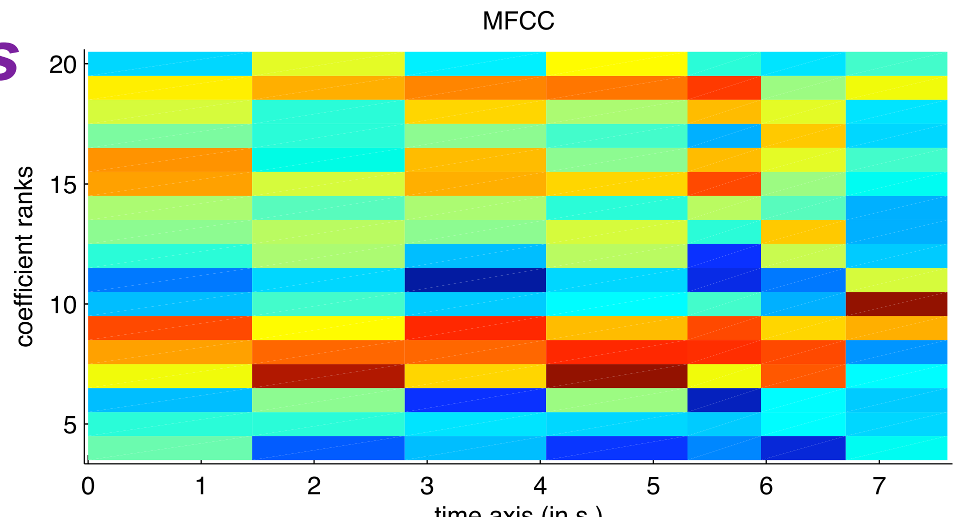
- *nv*



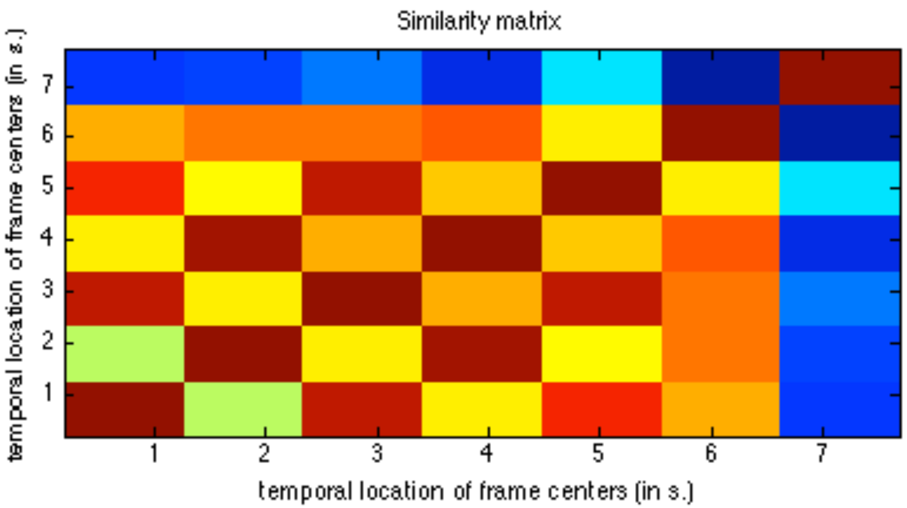
- *sg*



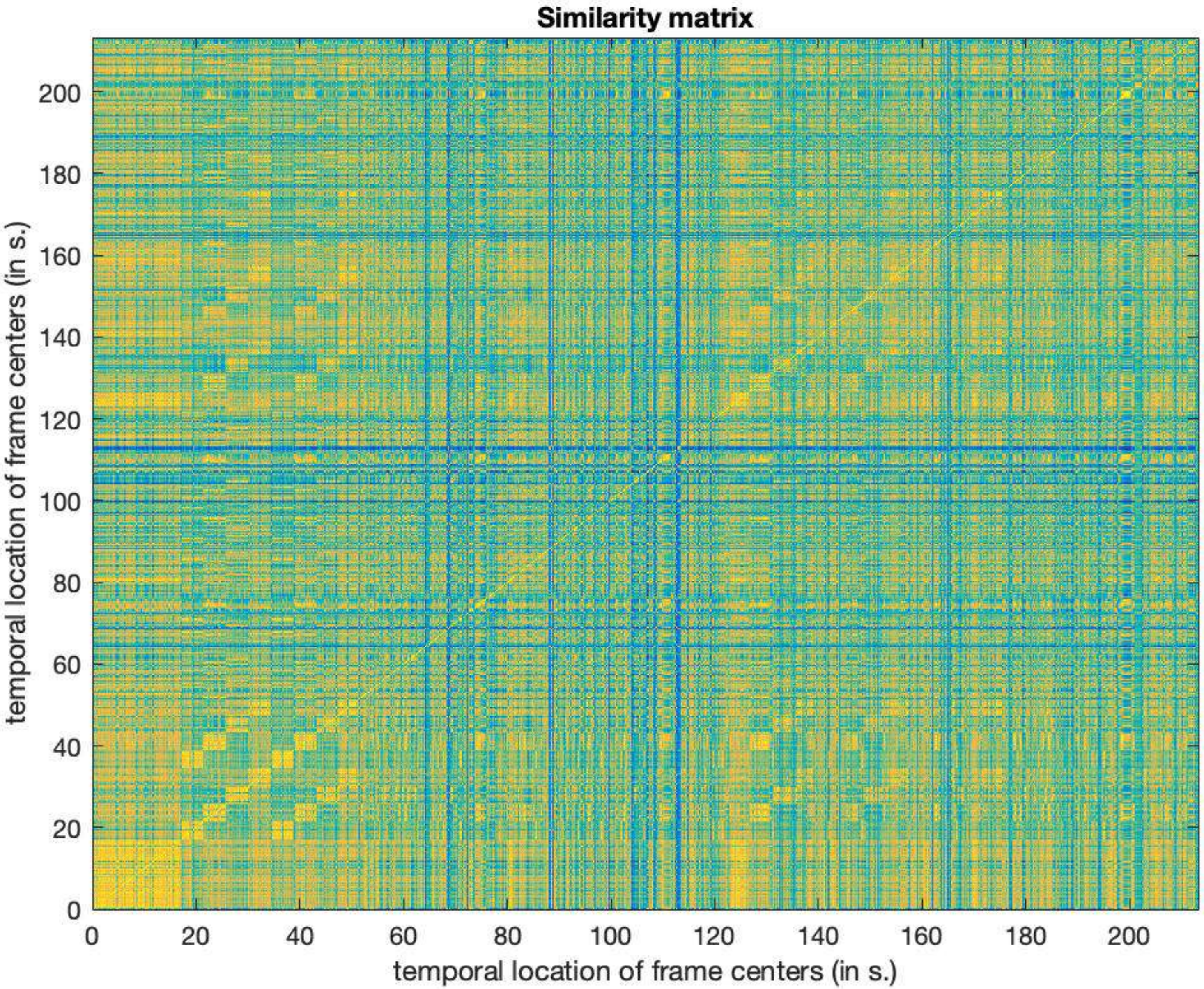
- *s*



- *sm*

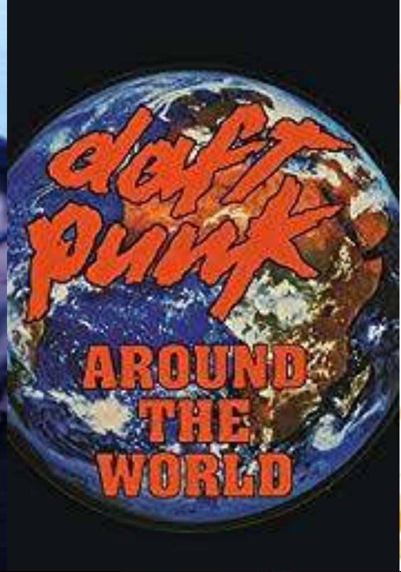


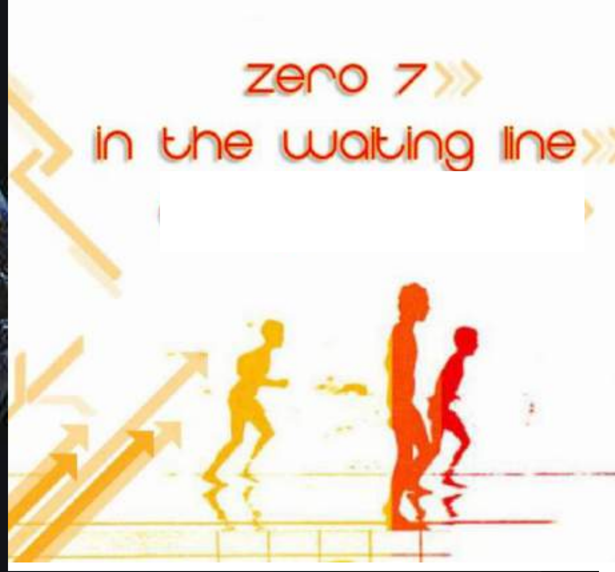
What can you say about the structure of this piece?



https://1drv.ms/u/s!AtoLT6JDyxo-iWSxEYJlLzdglJ3w?e=nbu6Fm


HOOVERPHONIC MAD ABOUT YOU

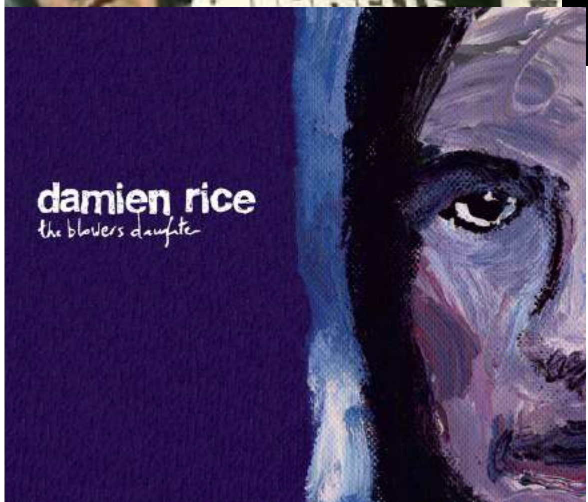

daft punk
AROUND THE WORLD


zero 7
in the waiting line


LED-ZEPPELIN

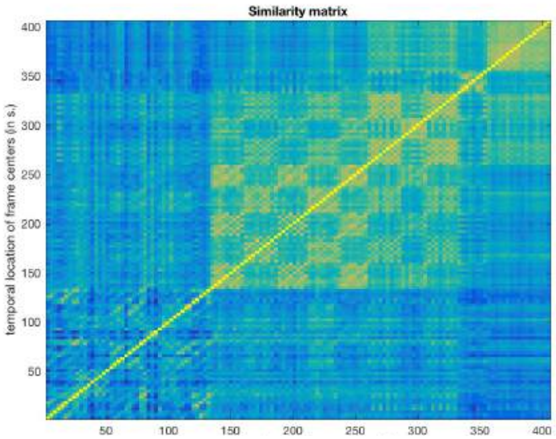

4
Stardust
"Music Sounds Better with You"

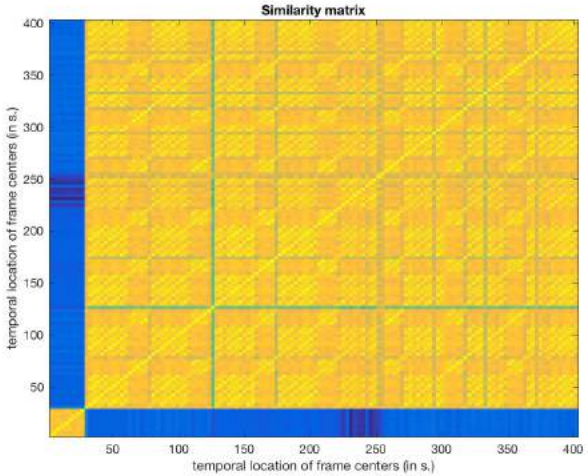

BRUNO MARS
TREASURE

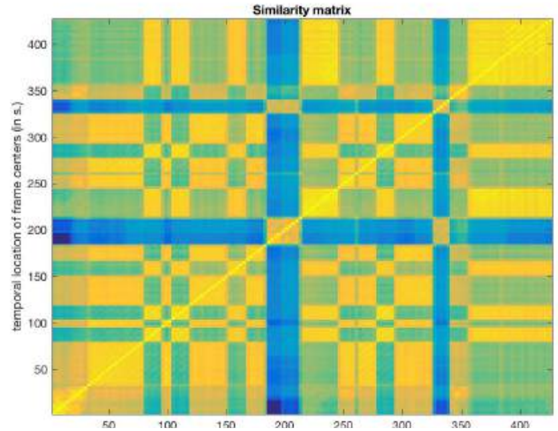

damien rice

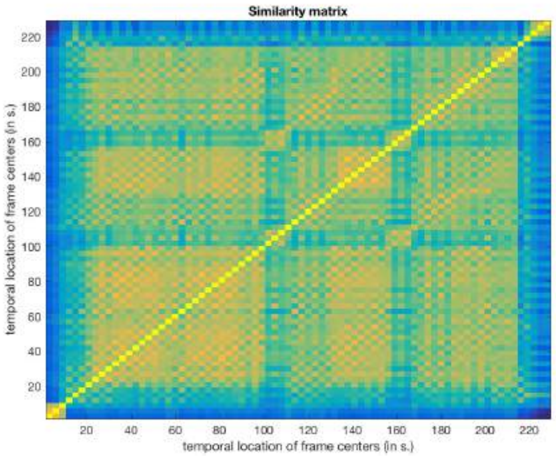
?

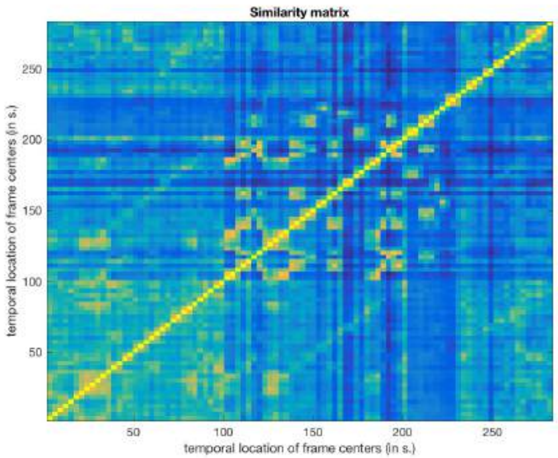

Purple Rain

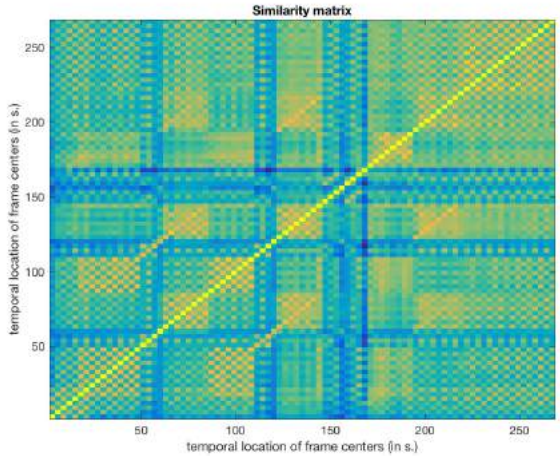




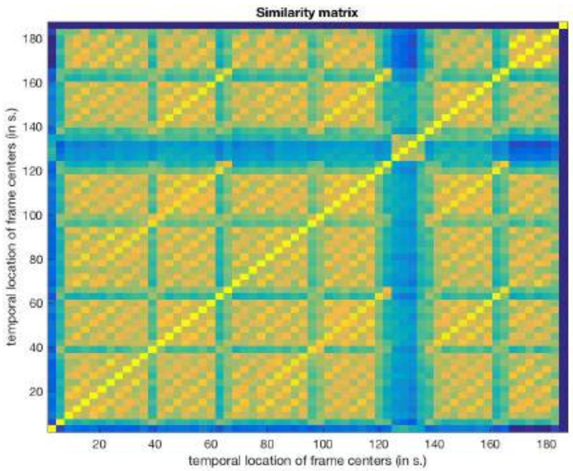


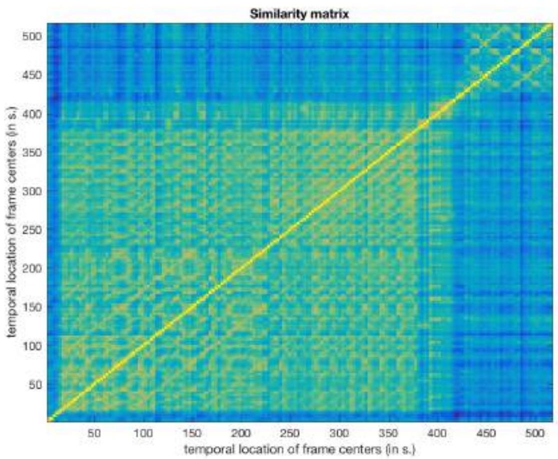


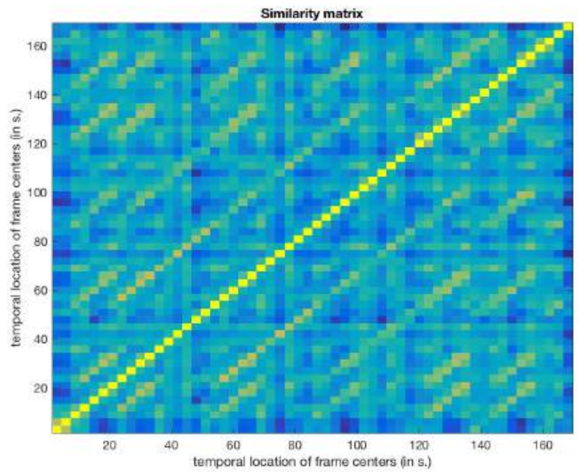




https://shorturl.at/bjz28





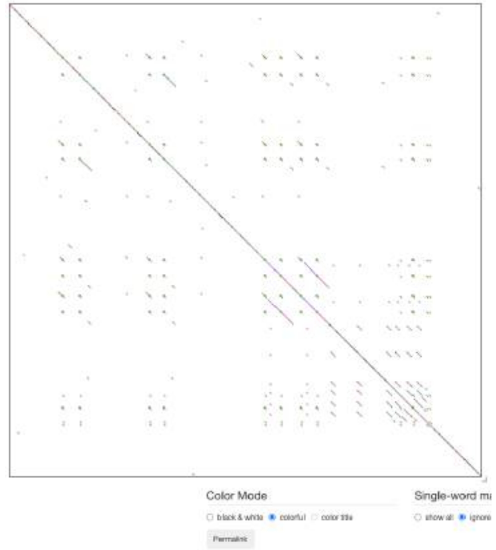


Visualizing Music(al Structure)

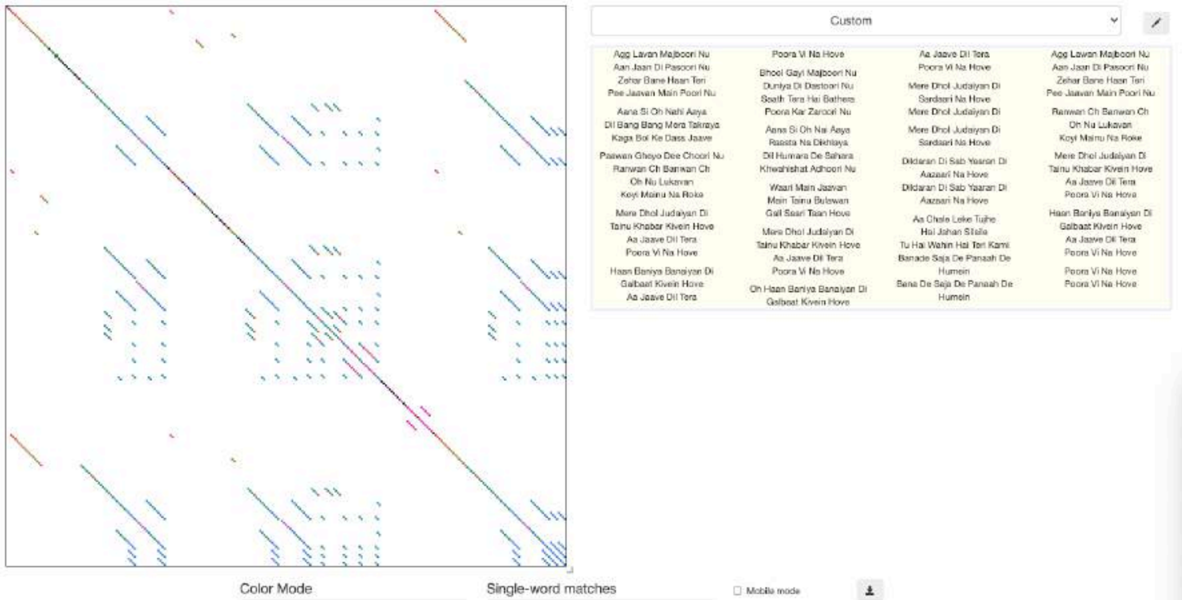
Lyrics


Vox

Carly Rae Jepsen - Call Me Maybe
I threw a wish in the well,
Don't ask me, I'll never tell
I looked to you as it fell,
And now you're in my way
I'd trade my soul for a wish,
Pennies and dimes for a kiss
I wasn't looking for this,
But now you're in my way
Your stare was holdin',
Ripped jeans, skin was showin'
Hot night, wind was blowin'
Where you think you're going, baby?
Hey, I just met you,
And this is crazy,
But here's my number,
So call me, maybe!
It's hard to look right
At you baby,
But here's my number,
So call me, maybe!
Hey, I just met you,
And this is crazy,
But here's my number,
So call me, maybe!
And all the other boys,
Try to chase me,
But here's my number,
So call me, maybe!
You took your time with the call,
I took no time with the fall
You gave me nothing at all,
But still, you're in my way
I beg, and borrow and steal
At first sight and it's real
I didn't know I would feel it,
But it's in my way
Your stare was holdin',
Ripped jeans, skin was showin'
Hot night, wind was blowin'
Where you think you're going, baby?
Hey, I just met you,
And this is crazy,
But here's my number,
So call me, maybe!
It's hard to look right
At you baby,
But here's my number,
So call me, maybe!
Hey, I just met you,
And this is crazy,
But here's my number,
So call me, maybe!
And all the other boys,
Try to chase me,
But here's my number,
So call me, maybe!
Before you came into my life
I missed you so bad
I missed you so bad
I missed you so, so bad
Before you came into my life
I missed you so bad
And you should know that
I missed you so, so bad (bad, bad)
It's hard to look right
At you baby,
But here's my number,
So call me, maybe!
Hey, I just met you,
And this is crazy,
But here's my number,
So call me, maybe!
And all the other boys,
Try to chase me,
But here's my number,
So call me, maybe!
Before you came into my life
I missed you so bad
I missed you so bad
I missed you so, so bad
Before you came into my life
I missed you so bad
And you should know that
So call me, maybe!
Color Mode
black & white
colorful
color title
Single-word matches
show all
ignore all
ignore stopwords
Mobile mode

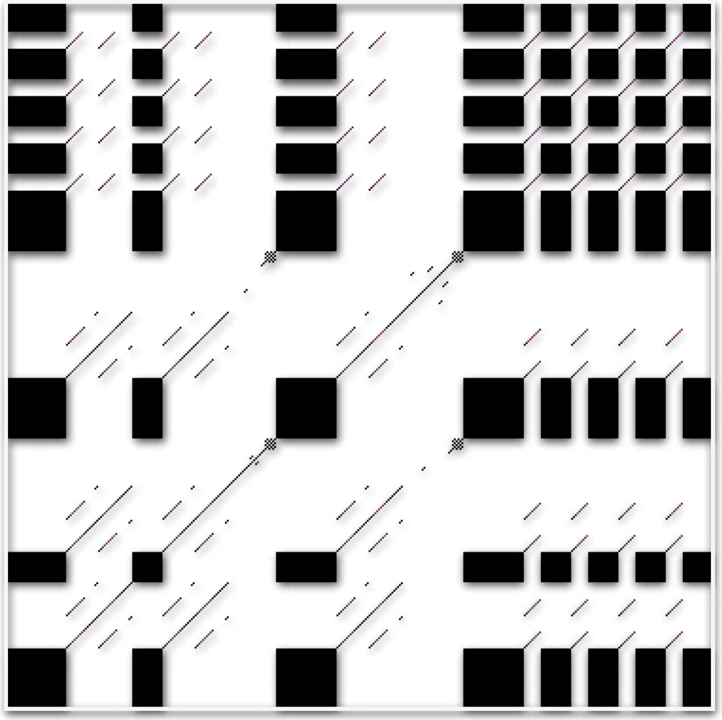


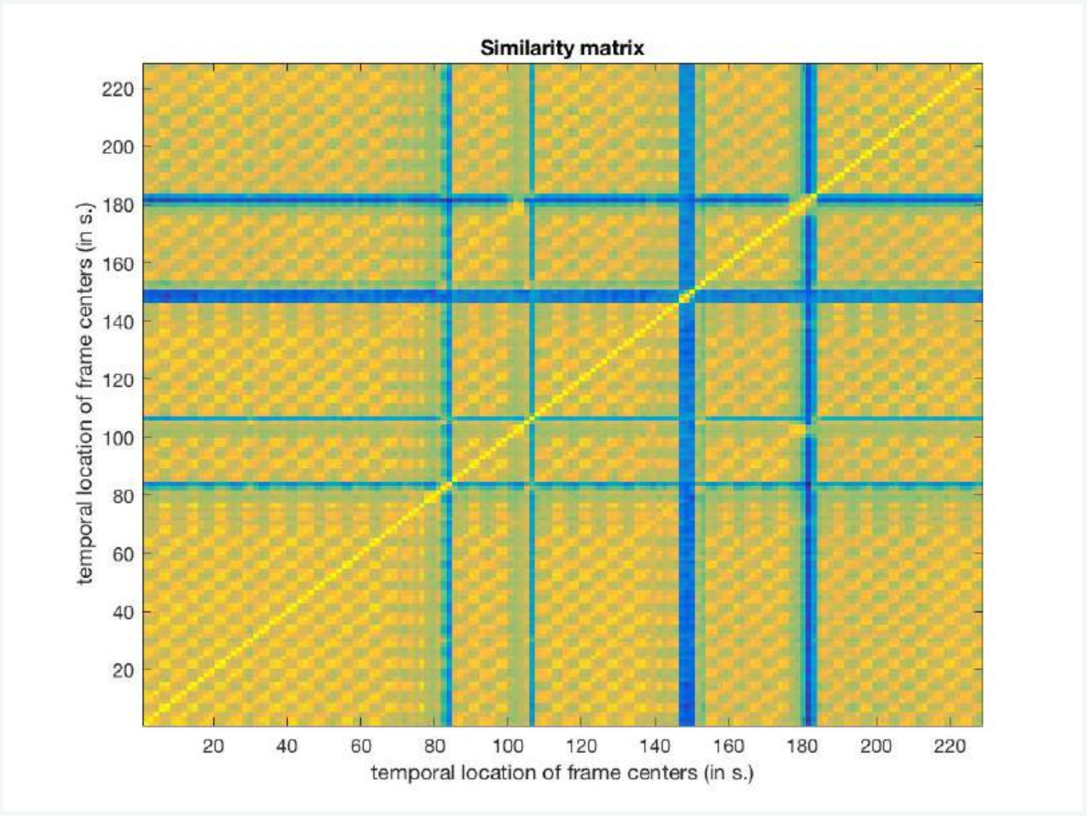
Color Mode
black & white
colorful
color title
Single-word m
show all
ignore
Permalink



Custom
Agg Lavan Majboori Nu
Aan Jaan Di Pasoori Nu
Zehar Bane Haan Teri
Pee Jaavan Main Poori Nu
Aana Si Oh Nahi Aaya
Dil Bang Bang Mera Takraya
Kaga Bol Ke Dass Jaave
Paawan Gheyo Dee Choori Nu
Ranwan Ch Banwan Ch
Oh Nu Lukavan
Koyi Mainu Na Roke
Mere Dhol Judaiyan Di
Tainu Khabar Kivein Hove
Aa Jaave Dil Tera
Poora Vi Na Hove
Haan Baniya Banaiyan Di
Galbaat Kivein Hove
Aa Jaave Dil Tera
Poora Vi Na Hove
Bhool Gayi Majboori Nu
Duniya Di Dastoori Nu
Saath Tera Hai Bathera
Poora Kar Zaroori Nu
Aana Si Oh Nai Aaya
Raasta Na Dikhlaya
Dil Humara De Sahara
Khwahishat Adhoori Nu
Waari Main Jaavan
Main Tainu Bulawan
Gall Saari Taan Hove
Mere Dhol Judaiyan Di
Tainu Khabar Kivein Hove
Aa Jaave Dil Tera
Poora Vi Na Hove
Oh Haan Baniya Banaiyan Di
Galbaat Kivein Hove
Aa Jaave Dil Tera
Poora Vi Na Hove
Mere Dhol Judaiyan Di
Sardaari Na Hove
Mere Dhol Judaiyan Di
Mere Dhol Judaiyan Di
Sardaari Na Hove
Dildaran Di Sab Yaaran Di
Aazaari Na Hove
Dildaran Di Sab Yaaran Di
Aazaari Na Hove
Aa Chale Leke Tujhe
Hai Jahan Silsile
Tu Hai Wahin Hai Teri Kami
Banade Saja De Panaah De Humein
Bana De Saja De Panaah De Humein
Agg Lavan Majboori Nu
Aan Jaan Di Pasoori Nu
Zehar Bane Haan Teri
Pee Jaavan Main Poori Nu
Ranwan Ch Banwan Ch
Oh Nu Lukavan
Koyi Mainu Na Roke
Mere Dhol Judaiyan Di
Tainu Khabar Kivein Hove
Aa Jaave Dil Tera
Poora Vi Na Hove
Haan Baniya Banaiyan Di
Galbaat Kivein Hove
Aa Jaave Dil Tera
Poora Vi Na Hove
Poora Vi Na Hove
Poora Vi Na Hove
Color Mode
Single-word matches
Mobile mode

Repetition in Music





Genre Classification

Where does one begin?

What does “genre” (musically) mean?

How do you describe “genre”?

Genre Classification

What assumptions do we make?

Classes are **acoustically** and **perceptually** separable

How do we go about selecting relevant acoustic features and parameters thereof?

Genre Classification

Assumption: **Classes are separable**

Perceptual

Genre 1

Genre 2

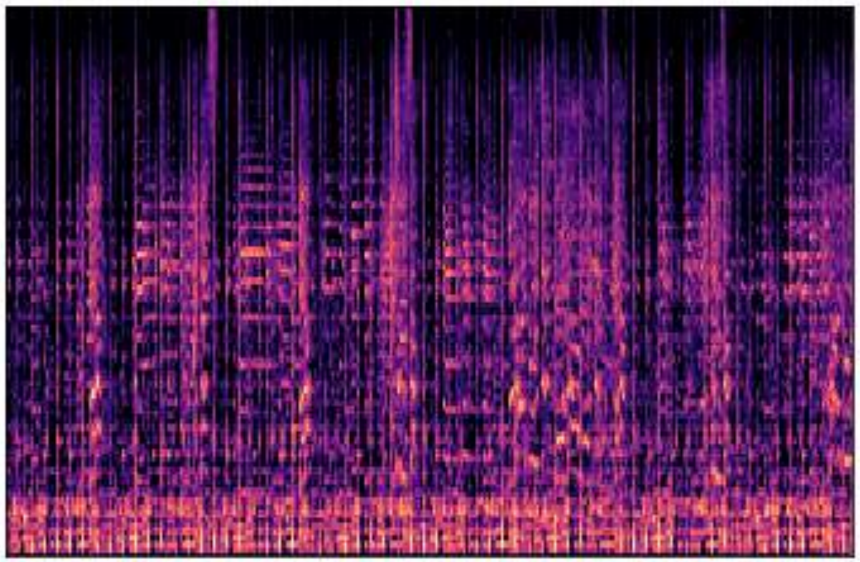
what are the perceptual features that distinguish these genres?

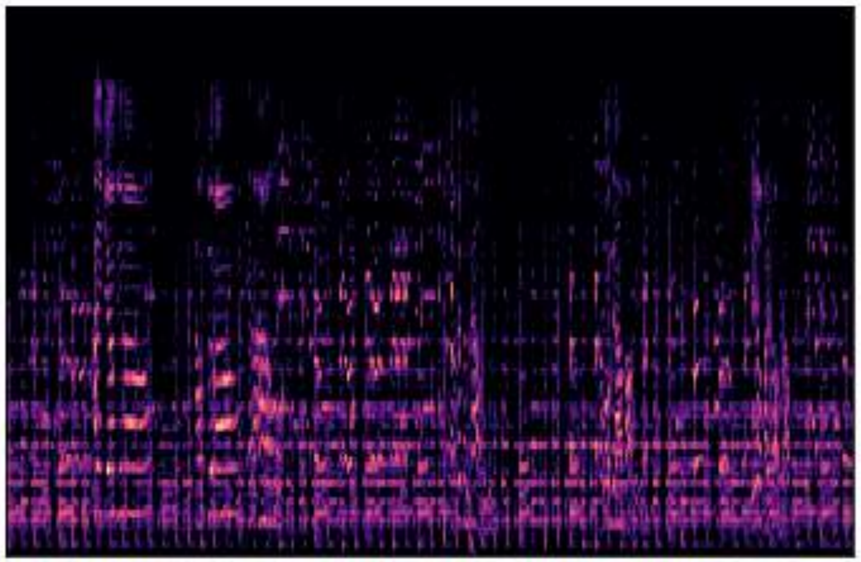
Genre Classification

Assumption: **Classes are separable**

Genre 1 Genre 2

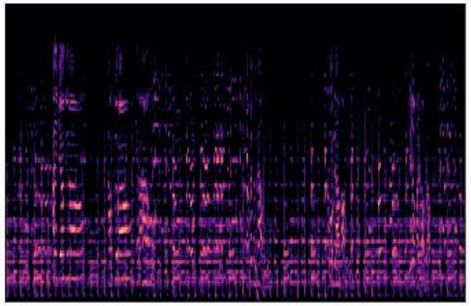
Acoustically



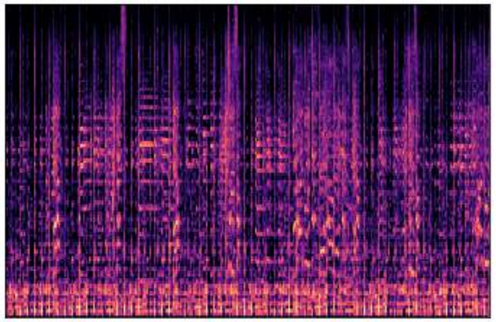


Genre Classification

based on perceptual features can you identify the acoustic features ?



Genre 1



Genre 2

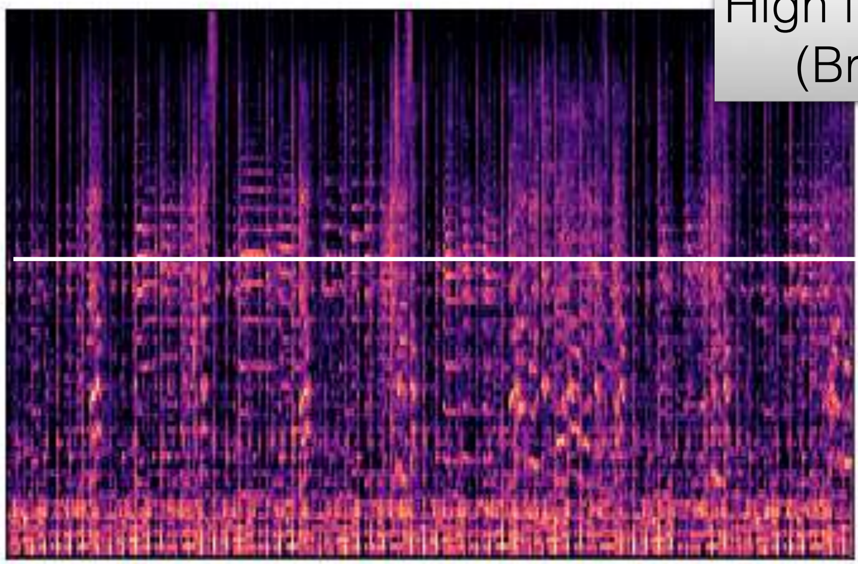
Genre Classification

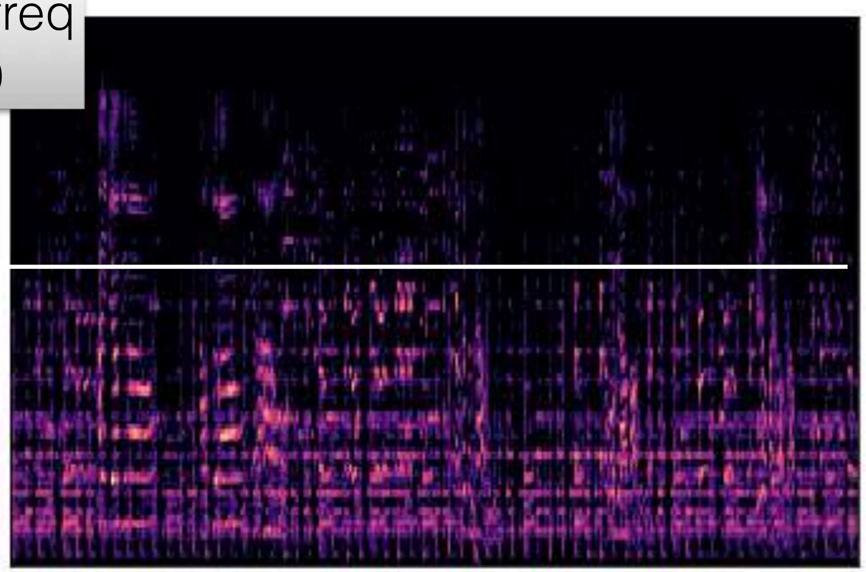
So what sort of features do i choose?

Timbre **Rhythm** **Key/Tonality**

Genre 2 **Genre 1**

High freq/Low freq
(Brightness)





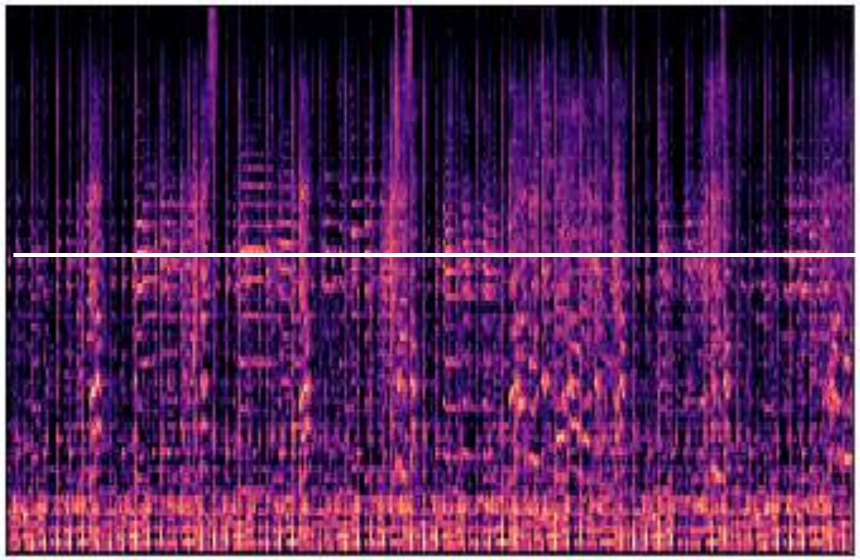
Spectral Centroid

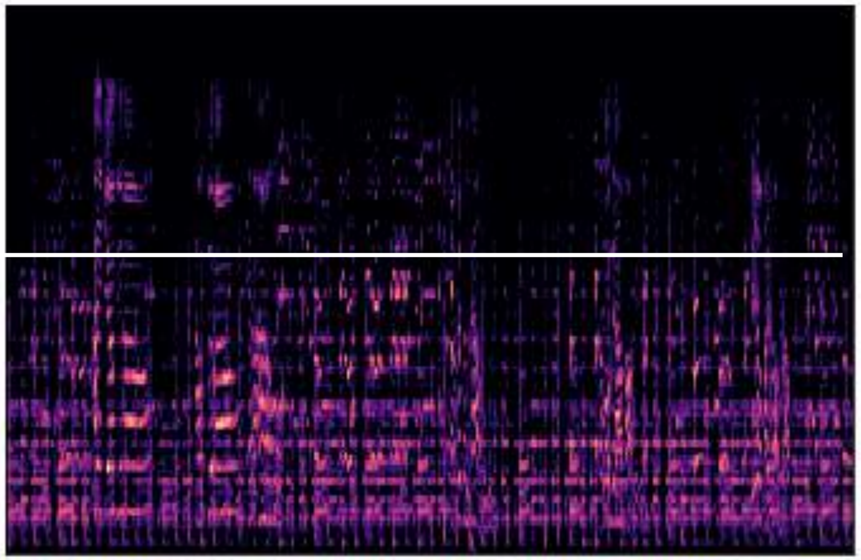
Genre Classification

So what sort of features do i choose?

Timbre **Rhythm** **Key/Tonality**

Genre 2 **Genre 1**

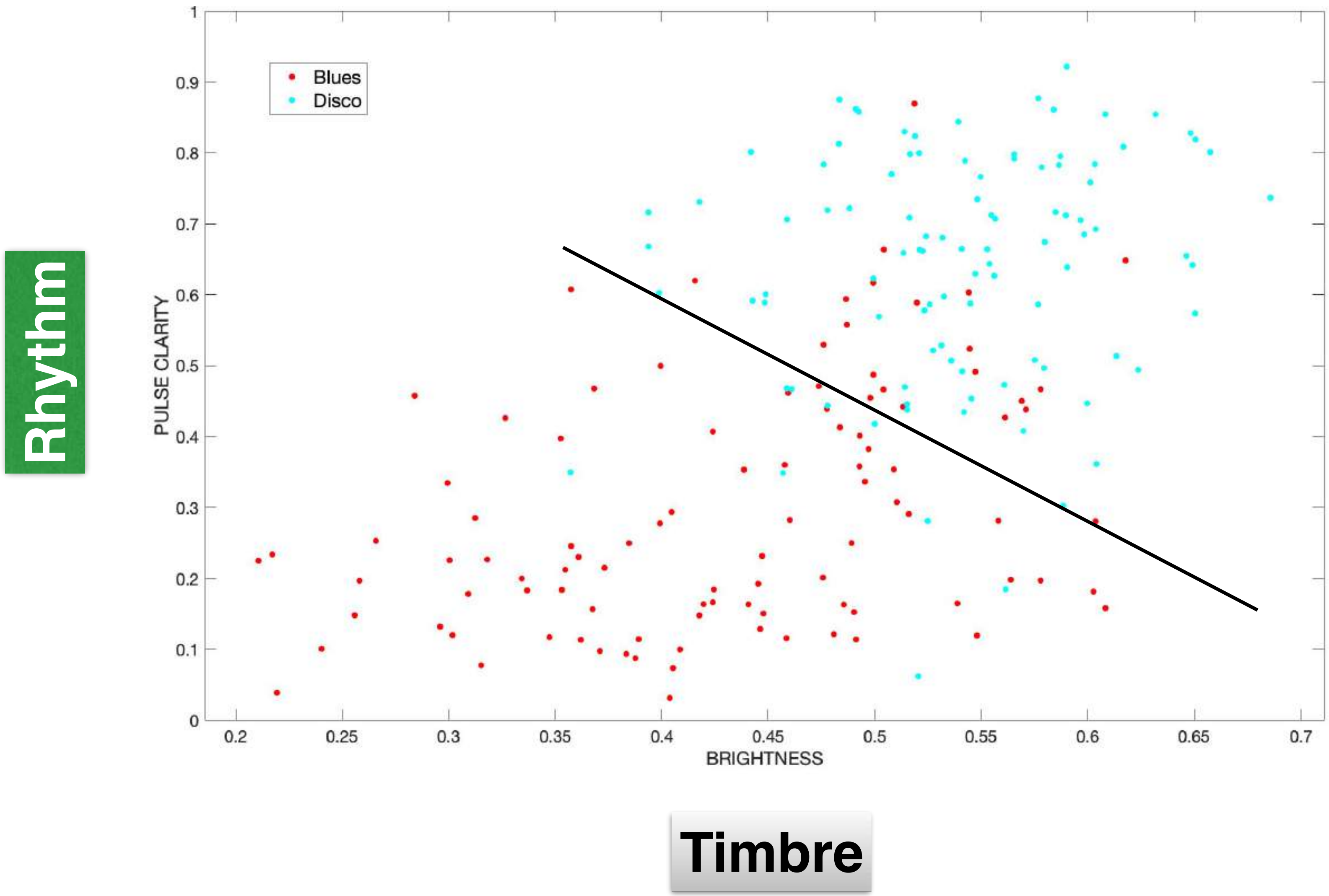




Tempo? Pulse Clarity?

Genre Classification

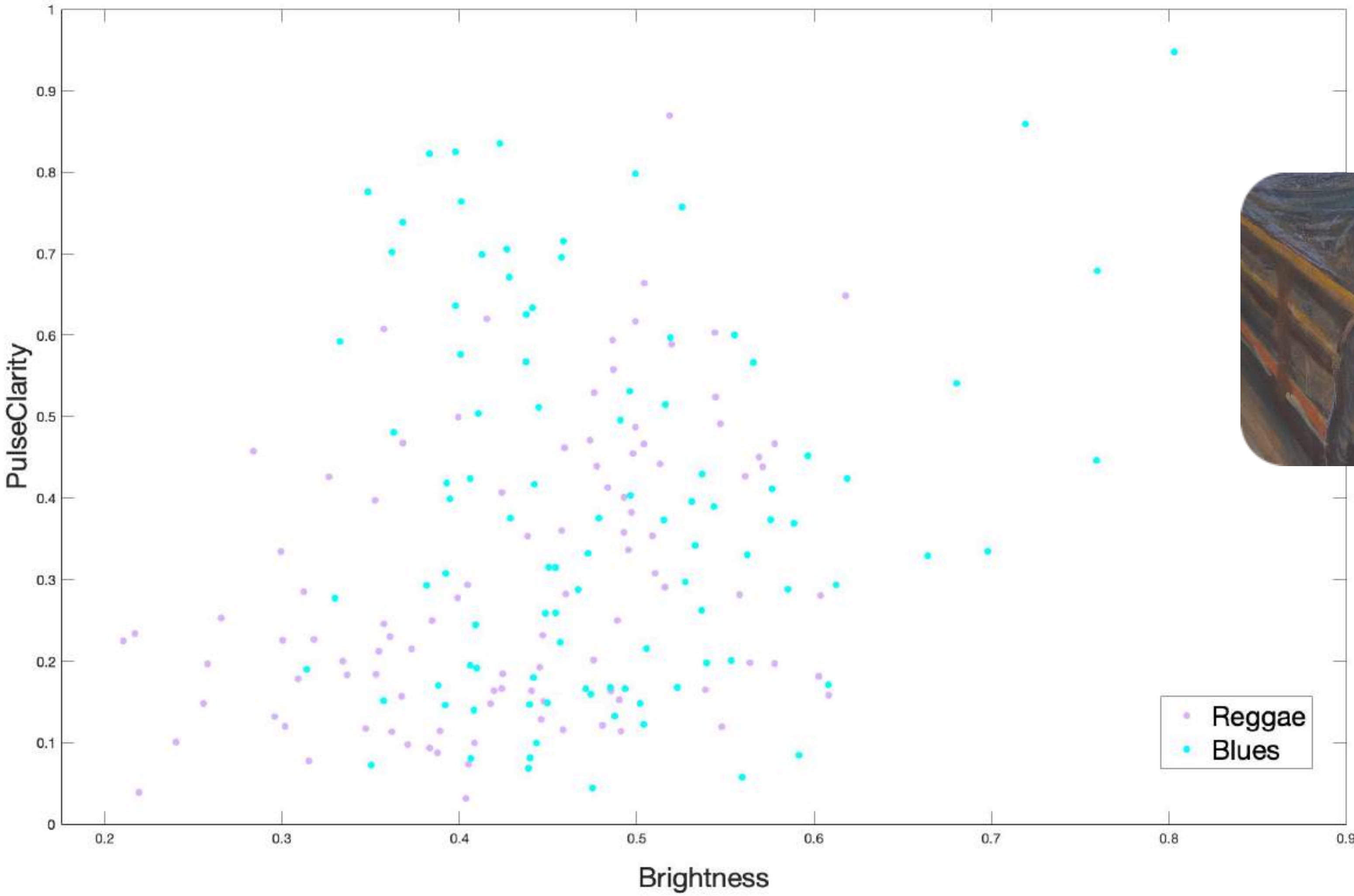
Acoustic feature selection



Genre Classification

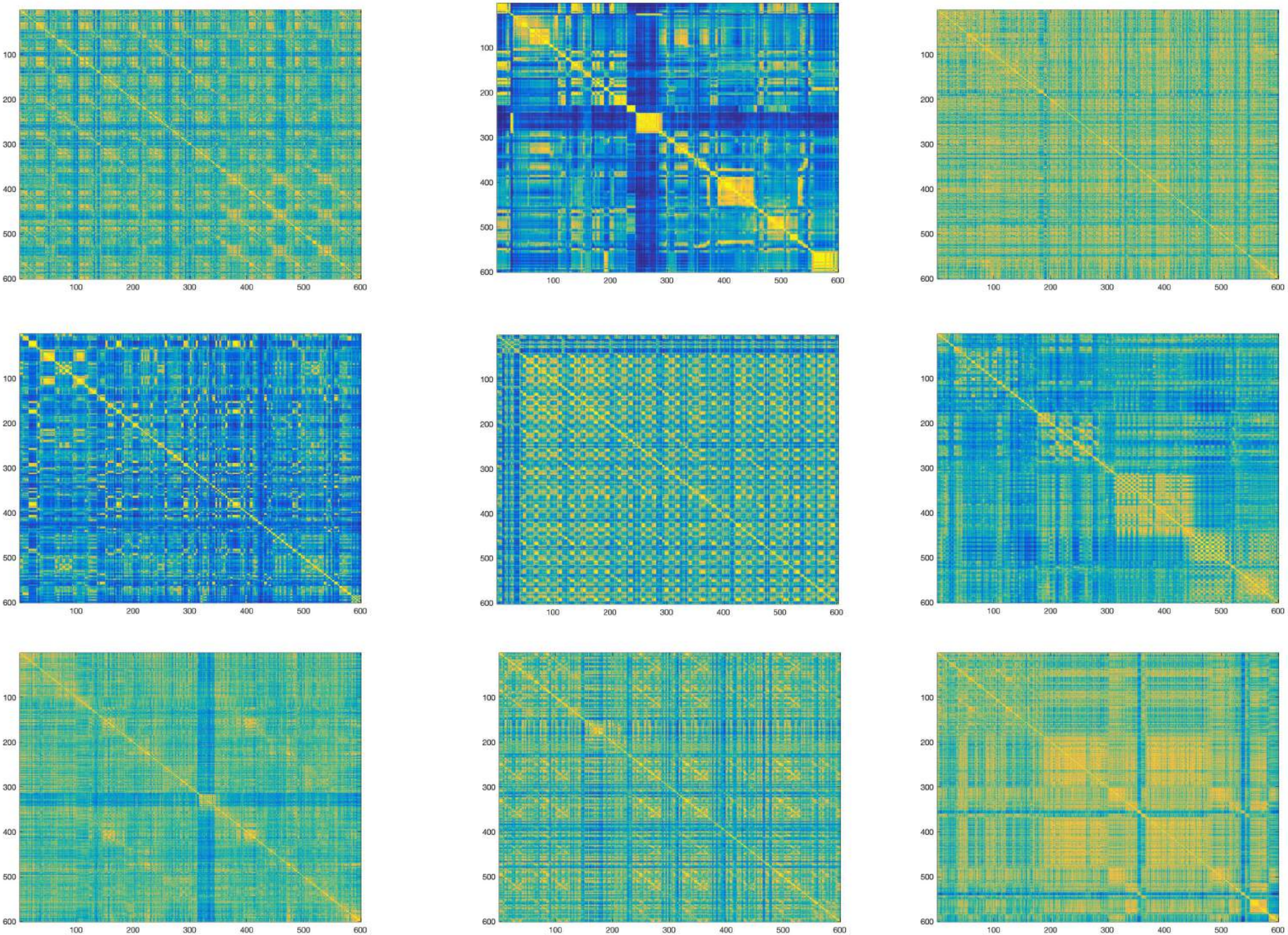
Genre 1 Acoustic feature selection **Genre 2**

Rhythm



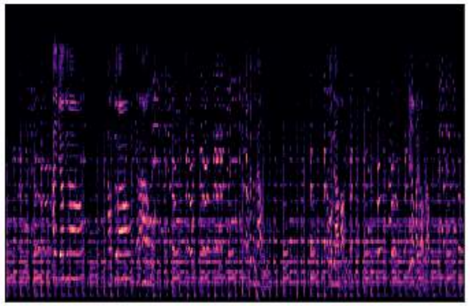
Timbre

Visualizing Genres (Structure) guess the genre?

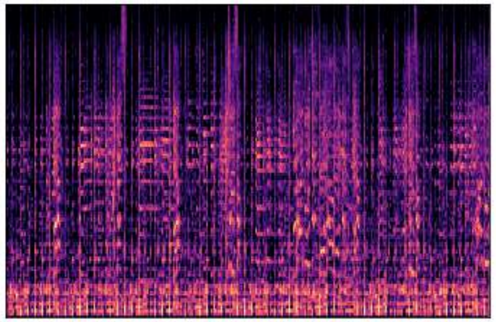

100
200
300
400
500
600
100
200
300
400
500
600

Genre Classification

can lyrics-based similarity matrices be used to identify genres ?

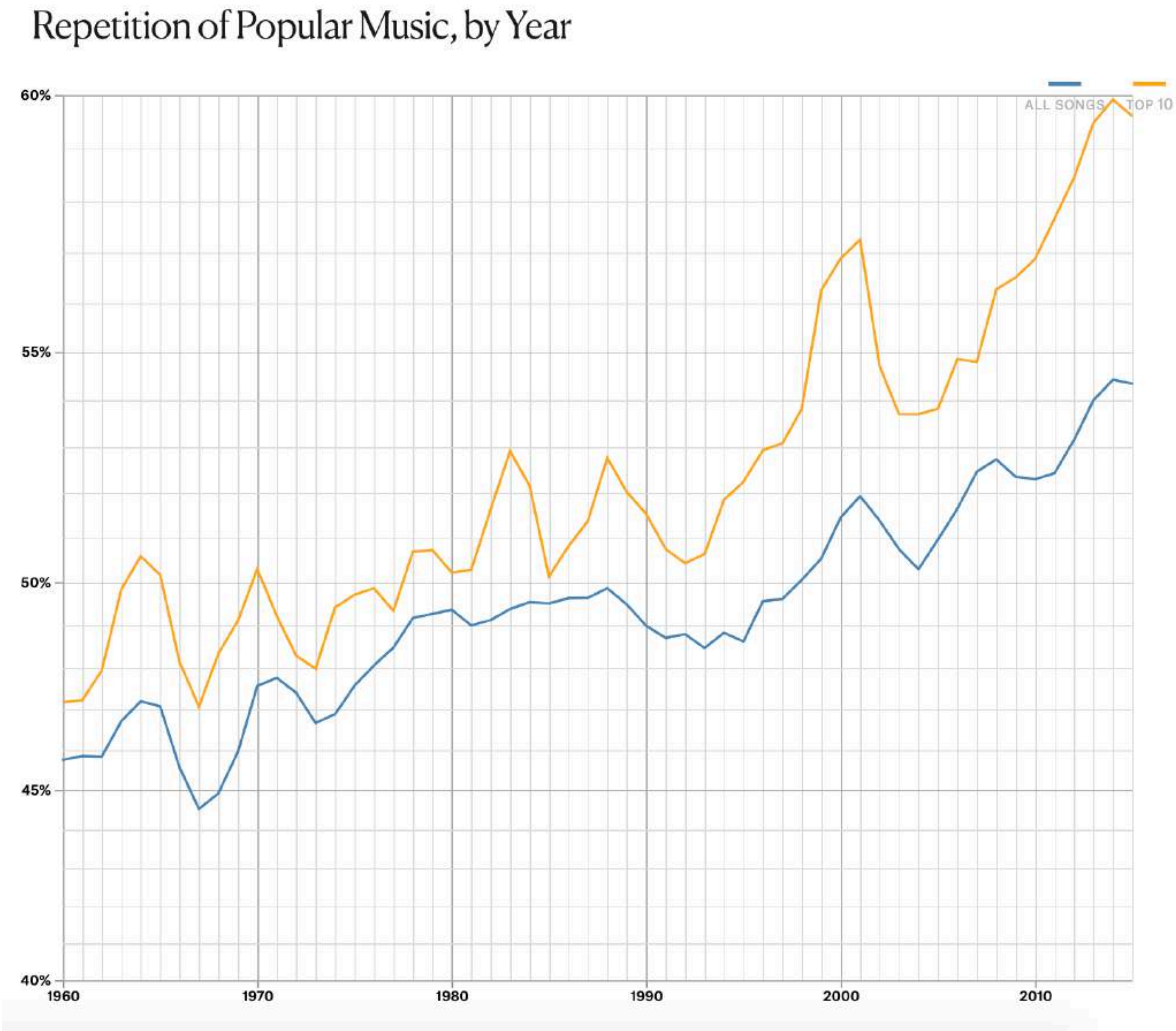


Genre 1



Genre 2

Repetition in Music



Compressibility in Music