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TUTORIAL 4


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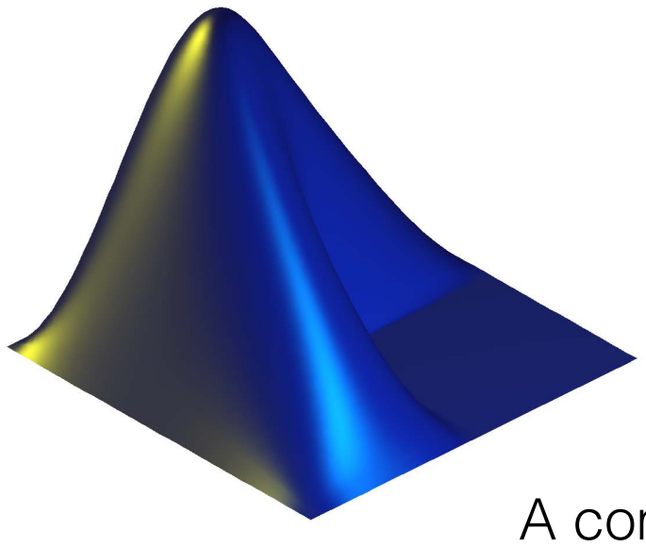
MiningSuite, a comprehensive framework for music analysis, articulating audio (MIRtoolbox 2.0) and symbolic approaches
Olivier Lartillo

ISMIR 2014 Tutorial, 27.10.2014

https://code.google.com/p/miningsuite/



MiningSuite

A comprehensive framework for music analysis, articulating audio (MIRtoolbox 2.0) and symbolic approaches

Olivier Lartillot
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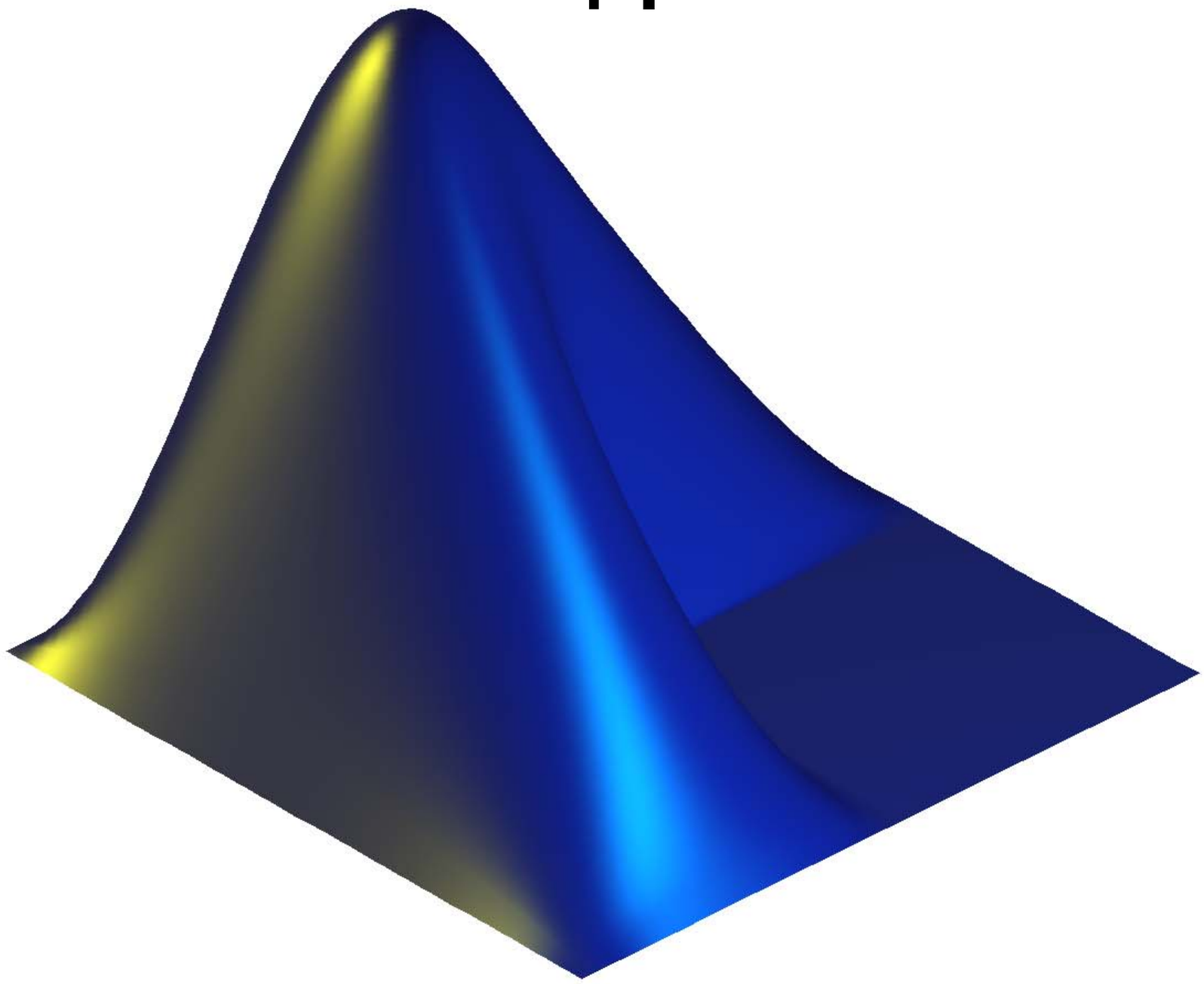
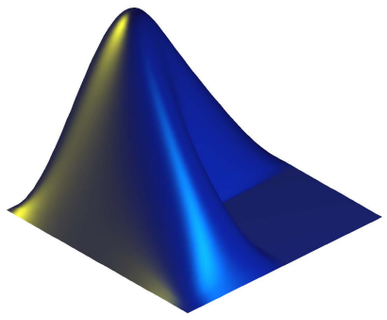
Tutorial overview

1. General description: Aims, architecture, syntax, …
2. Audio-based approaches (*MIRtoolbox* 2.0)
3. Symbolic approaches: "*MIDItoolbox* 2.0" and new musicological models
4. How it works
5. How you can contribute: open-source community

1.



General description



MiningSuite

- Matlab framework
- Large range of audio and music analysis tools
- Both audio and symbolic representations
- Highly adaptive syntactic layer on top of Matlab
- Syntactic layer within the operators' Matlab code, simplifying and clarifying the code
- Memory management mechanisms

MIRtoolbox

- Matlab framework ✔ (but intricate, non-optimized)
- Large range of audio and music analysis tools ✔
- Both audio and symbolic representations ✘
- Highly adaptive syntactic layer on top of Matlab ✔
- Syntactic layer within the operators' Matlab code, simplifying and clarifying the code ✘
- Memory management mechanisms ✔

What's new in MiningSuite

- Code & architecture entirely rebuilt
    - More efficient, more readable, better organised, better generalisable
- Integration audio / symbolic representations
- Innovative and integrative set of symbolic-based musicological tools and pattern mining
- Syntactic layer within the operators' Matlab code, simplifying and clarifying the code
- Open-source collaborative environment

Aim of this tutorial

- Overview of audio and symbolic approaches to computational audio/music analysis
- Take benefit of the capabilities of the environment, of the user-friendly syntax and architecture
- Understand how the framework works
- Understand about the choices in the toolbox architecture, and maybe discuss about that?
- Add new codes and new features in the project

MIRtoolbox history

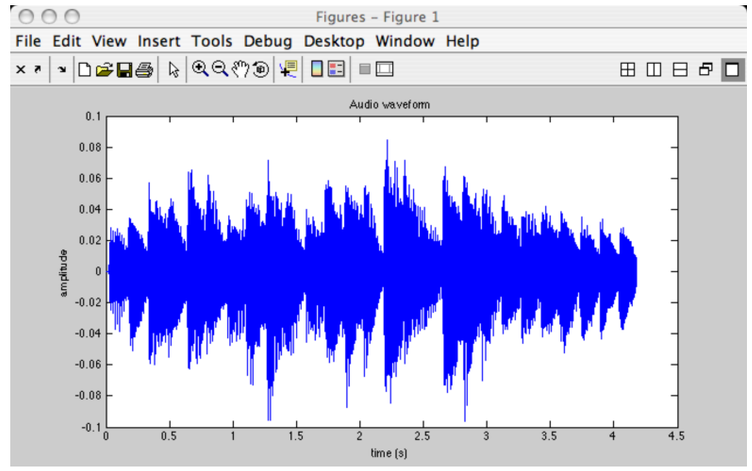
- Matlab toolboxes @ University of Jyväskylä:
  - *MIDItoolbox* (Eerola & Toiviainen, 2004)
  - *Music Therapy Toolbox* (Lartillot, Toiviainen, Erkkilä, 2005)
- European project *Tuning the Brain for Music* (NEST, FP6, 2006–08)
  - **Large range of audio/musical features** extracted from large databases, linked to emotional ratings (Eerola et al., ISMIR 2009)
- Master program @ University of Jyväskylä, MIR course (2005–)
  - Toolbox **easy to use**, no Matlab expertise required
- version 1.0 in 2007, current version 1.5.

MIRtoolbox advantages

- Highly modular framework:
  - building blocks can be reused, reordered
  - no need to recode processes, to reinvent the wheel
- Adaptive syntax: users can focus on design, *MIRtoolbox* takes care of technical details
- Free software, open source: Capitalized expertise of the research community, for everybody
- 10000s download, 500+ citations, reference tool in MIR

MIRtoolbox syntax

- ***mir****audio('ragtime.wav')* outputs a figure:



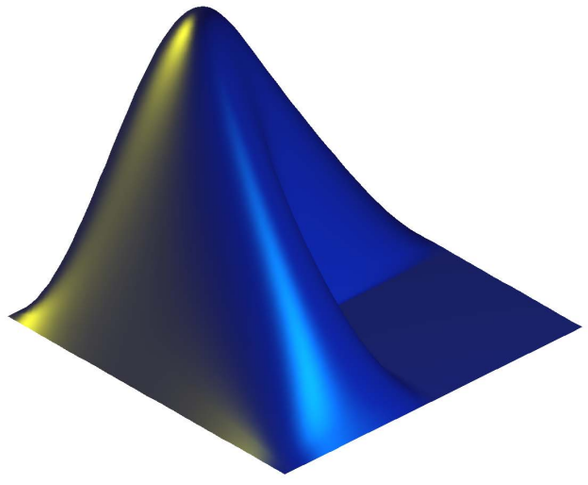
- *miraudio('ragtime.wav')****;*** blocks figure display
- ***mir****tempo('ragtime.wav')*
- *mirtempo('****Folder****')* operates on all files in the Current Directory
- ***a =*** *miraudio('ragtime.wav'****, 'Extract', 0, 60, 's'****)*
- ***a*** *= miraudio(****a****, 'Center');*
- *t = mirtempo(a)*
- *d =* ***mirgetdata****(t)* returns the result in *Matlab* array
- ***get****(t, '****Sampling****')* returns additional data stored in *MIRtoolbox* object

MiningSuite syntax

- ***sig.****input('ragtime.wav')* outputs a figure
- *sig.input('ragtime.wav')****;*** **postpone any computation**
- ***mus.****tempo('ragtime.wav')*
- *mus.tempo('Folder')* operates on all files in the Current Directory
- *a = sig.input('ragtime.wav', 'Extract', 0, 60, 's')*
- *a = sig.input(a, 'Center');*
- *t = mus.tempo(a)*
- *d =* ***t.getdata*** returns the result in *Matlab* array
- ***t.show*** returns additional data stored in *MIRtoolbox* object

MiningSuite history

- Academy of Finland research fellowship, 2009-14
  - Integrating audio and symbolic into common framework, higher-level music analysis
- *MIRtoolbox*: a “Rube Goldberg machine”
  - Obscure architecture, obscure code, highly inefficient in speed and memory → rewrite
- *MIRtoolbox* innovative framework draws interest outside MIR
  - Reorganize framework into discipline-focused packages
- *MIDItoolbox* did not evolve since 1.0 (2004)



MiningSuite

- SIGMINR: signal processing
- AUDMINR: audio, auditory modelling
- MUSMINR: music analysis
- PATMINR: pattern mining
- SEQMINR: sequence processing
- VOCMINR: voice analysis?

Packages

- In *MIRtoolbox*, all operators start with *mir…* prefix (***mir****audio*, ***mir****spectrum*, etc.)
    - to avoid conflicts with other Matlab functions

- In *MiningSuite*, each module (*SigMinr*, *AudMinr*, etc.) is a *package*: its operators are called using a particular prefix (***sig.****spectrum*, ***aud.****spectrum*, etc.)

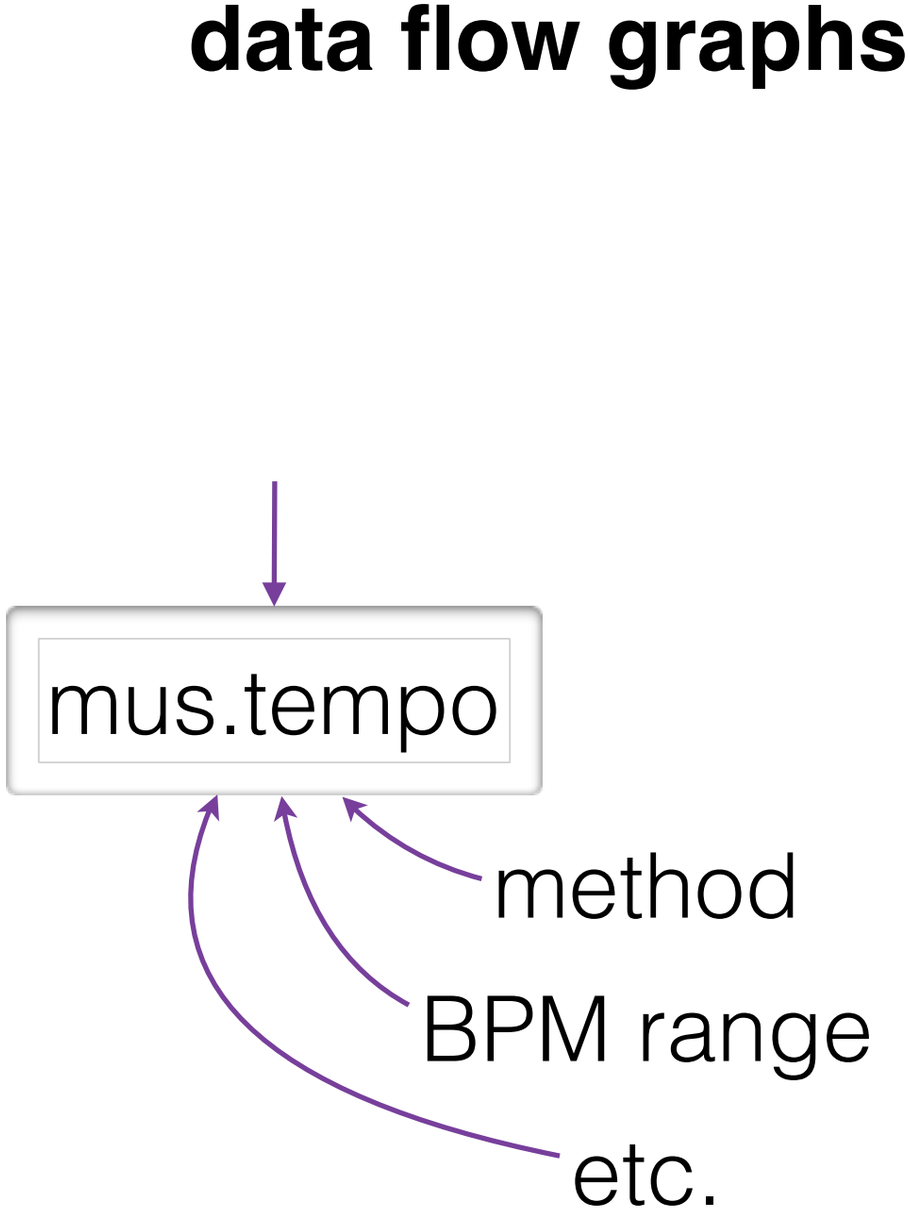
Signal domain

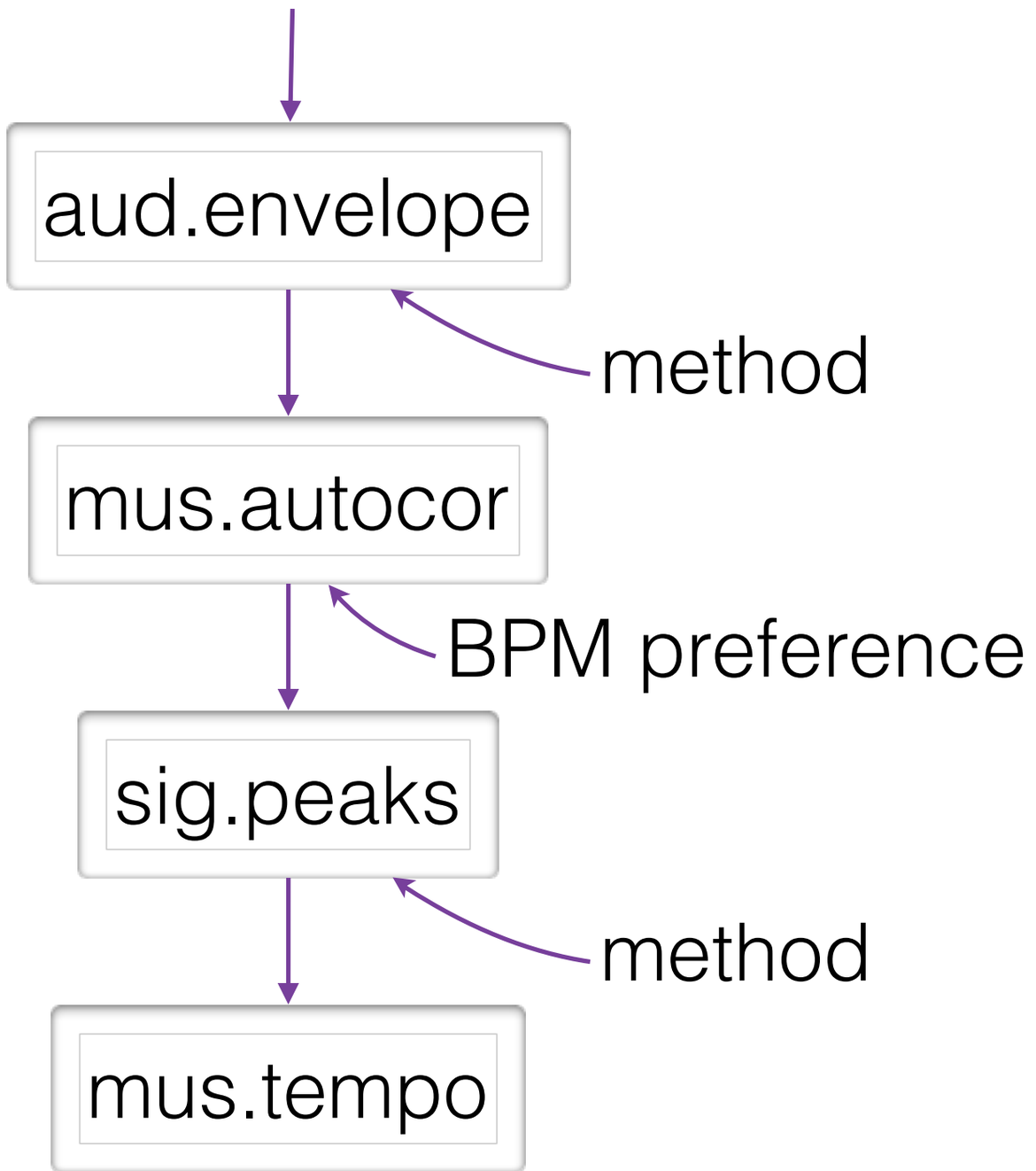
- SIGMINR
  - sig.input, sig.spectrum, …
- AUDMINR
  - aud.spectrum, …
  - aud.mfcc, aud.brightness, …
- MUSMINR
  - mus.spectrum, …
  - mus.tempo, mus.key, …

- Sets of operators related to signal processing operations, audio and musical features
- Versions specific to particular domains
- Each operator can be tuned with a set of options

Signal domain: Modular

data flow graphs





Symbolic domain

- MUSMINR

- ~~*Succession* of operations applied to input signal?~~

- Several types of analysis applied *together for each successive note* of the symbolic sequence

- One single operator: ***mus.score***

- Types of analysis selected as options of *mus.score*

Symbolic domain

- AUDMINR: *aud.score* (auditory scene transcription)
- MUSMINR: *mus.score*
- SEQMINR: sequence management
- PATMINR: sequential pattern mining

Software dependencies

- *MathWorks*' *Matlab* 7.6 (r2008a) or newer versions.
    - But *Matlab* 8.2 (r2013b) or newer is strongly recommended, because *MiningSuite* easily crashes on previous versions*.
        - MiningSuite based on new object oriented paradigm introduced in Matlab 7.6
- *MathWorks*' *Signal Processing Toolbox*
- Included in the distribution: code from *Auditory Toolbox* (Slaney), *Music Analysis Toolbox* (Pampalk), *MIDI Toolbox* (Eerola et al.)

* versions 7.6 to 8.2: there exists a workaround based on debug mode. Cf. README.txt.

How to start

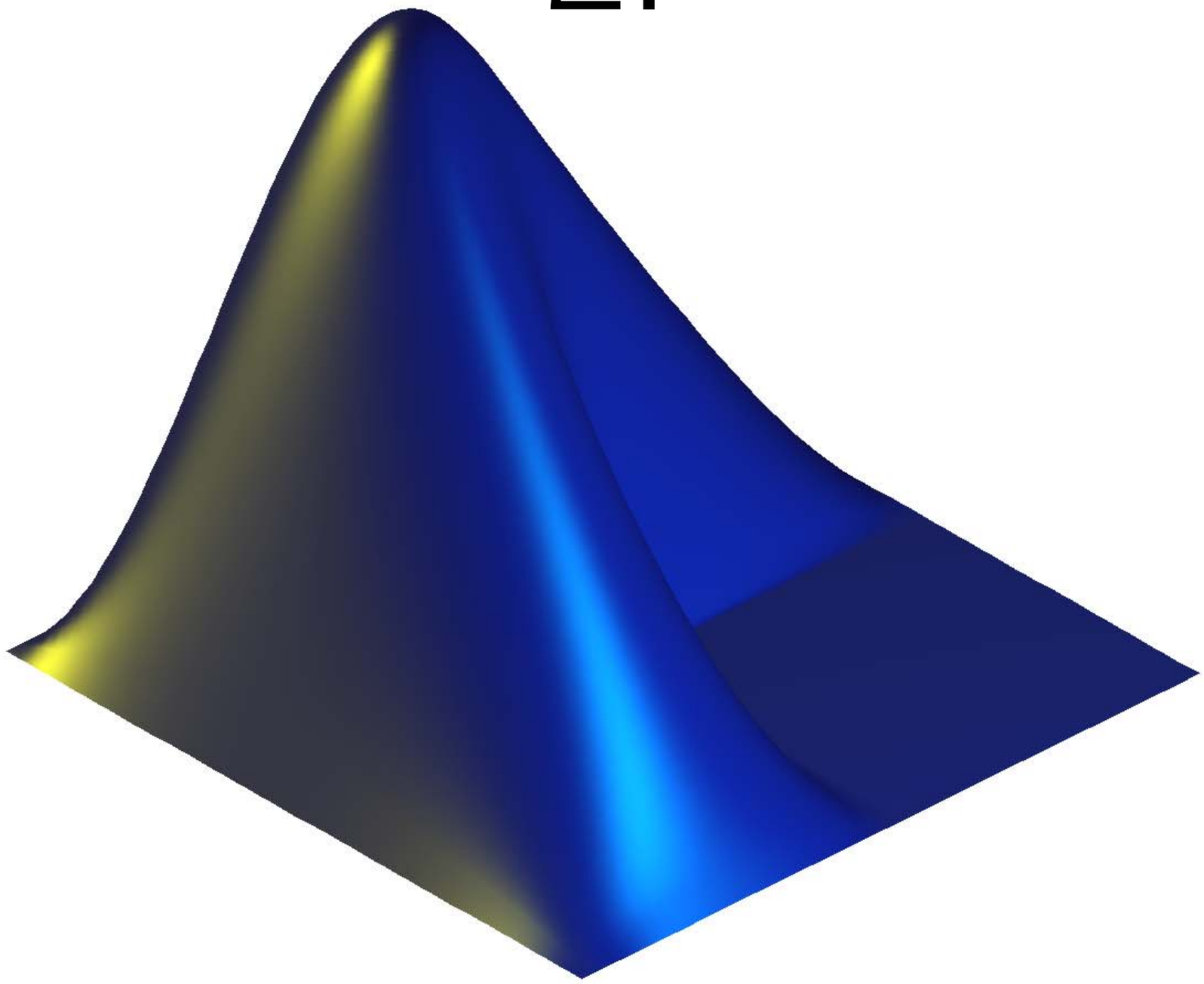
- Download version 0.8 on *MiningSuite* website: https://code.google.com/p/miningsuite/
- Read the README.txt file:
  - Add the folder "miningsuite" to your Matlab path.
  - *help miningsuite*
  - Check the examples in USAGE.m (unfinished…)

MiningSuite development

- Started in 2010
- Sneak Peek version 0.6 released in January 2014 for AES Semantic Audio. Proof of concept, basic architecture
- Alpha version 0.8 released now for ISMIR 2014. **Focus on the architecture**, not on the exact feature implementation. **Not everything implemented. Results cannot be trusted!**
- Beta version 0.9 with more complete implementation, user's guide (in wiki) and code documentation.
- Version 1.0 with complete bench test. We need you..
- Further versions: We definitely need you!


Tutor
1. General descript
2. Audio-based app
3. Symbolic approa
musicological me
4. How it works
5. How you can

2.



Audio-based approaches

SIGMINR

signal processing

sig.input

sig.frame

sig.flux

sig.peaks

sig.segment

sig.rms

sig.autocor

sig.zerocross

sig.spectrum

sig.cepstrum

sig.rolloff

sig.stat…

sig.filterbank

sig.simatrix

sig.cluster

sig.envelope

AUDMINR

audio, auditory modeling

aud.spectrum

aud.filterbank

aud.envelope

aud.brightness

aud.attacktime

aud.roughness

aud.pitch

aud.attackslope

aud.mfcc

aud.score

aud.fluctuation

aud.novelty

aud.segment

aud.eventdensity

MUSMINR

music theory

mus.spectrum

mus.pitch

mus.tempo

mus.chromagram

mus.pulseclarity

mus.keystrength

mus.metre

mus.key

mus.keysom

mus.mode

mus.score

sig.input

- In *MIRtoolbox*: *miraudio*. But *SigMinr* is not restricted to audio only, but any kind of signal.

- *sig.signal* is the actual signal object (cf. part IV)

- *sig.input* takes care of the transformations of the signal representation before further processing

- *sig.input(v, sr)* converts a *Matlab* vector *v* into a signal of sampling rate *sr*

sig.input

- *sig.input('myfile')**
- Formats: .wav, .flac, .ogg, .au, .mp3, .mp4, .m4a
- Using *Matlab*'s *audioread*

* Indicate the file extension as well (because *audioread* requires that).

(*sig.input* actually calls routine from *AudMinr* for the processing of audio files.)

sig.input: transformations

- By default, multi-tracks are summed into mono.
  - *sig.input('mysong', '**Mix**', 'no')* keeps the multitrack decomposition.
- *sig.input(..., '**Center**')* centers the signal.
- *sig.input(..., '**Sampling**', r)* resamples at rate *r* (in Hz.), using *resample* from *Signal Processing Toolbox*
- *sig.input(..., '**Normal**')* normalizes with respect to RMS

sig.input: extraction

- *sig.input(…, '**Extract**', 1, 2, 's', '**Start**')*
  - extracts signal from 1 s to 2 s after the start

- *sig.input(..., 'Extract', 44100, 88200, '**sp**')*
  - from samples #44100 to 88200 after the start

- *sig.input(..., 'Extract', -1, +1, '**Middle**')*
  - from 1 s before to 1 s after the middle of the signal

- *sig.input(..., 'Extract', -10000, 0, 'sp', '**End**')*
  - the last 10000 samples in the signal

sig.input: trimming silence

- *sig.input(…, '**Trim**')* trims (pseudo-)silence at start and end

- *sig.input(..., '**Trim**', '**JustStart**')* at start only

- *sig.input(..., '**TrimEnd**', '**JustEnd**')* at end only

- *sig.input(..., '**Trim**', **TrimThreshold**', thr)* specifies the silence threshold. Default *thr = .06*

- Silent frames have RMS energy below *thr* times the medium RMS energy of the whole audio file.

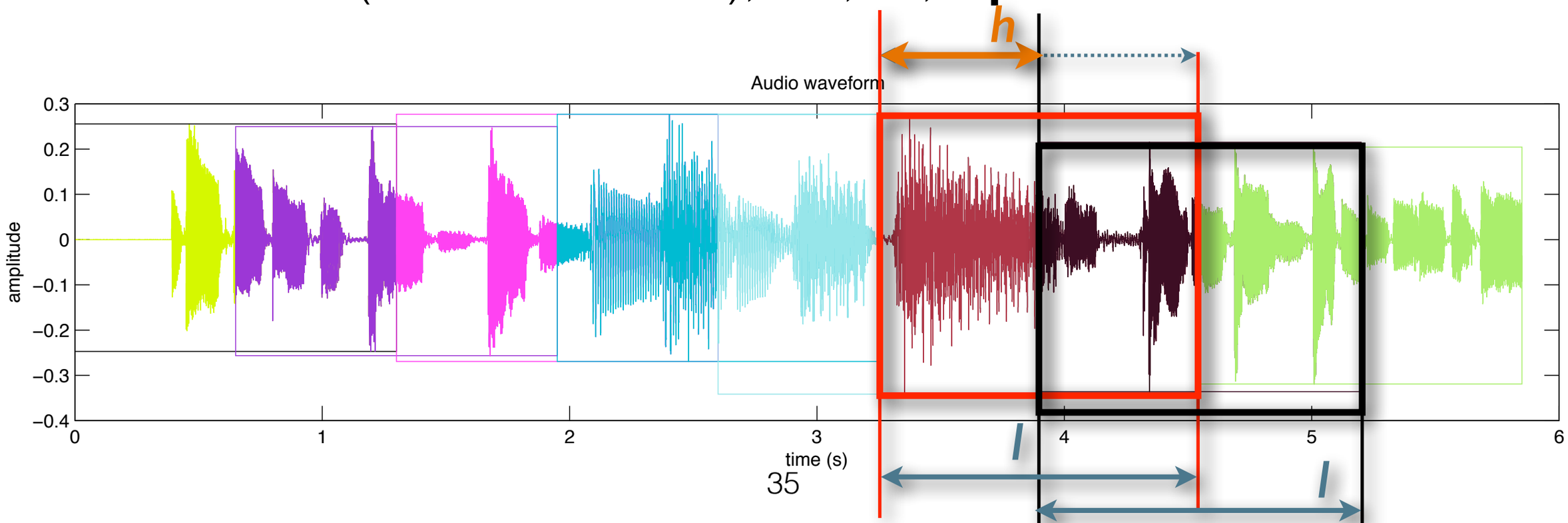
.play, .save
sonification

- a = sig.input(…, ‘Trim’)
- a.play
- a.save(‘newfile.mp3’)

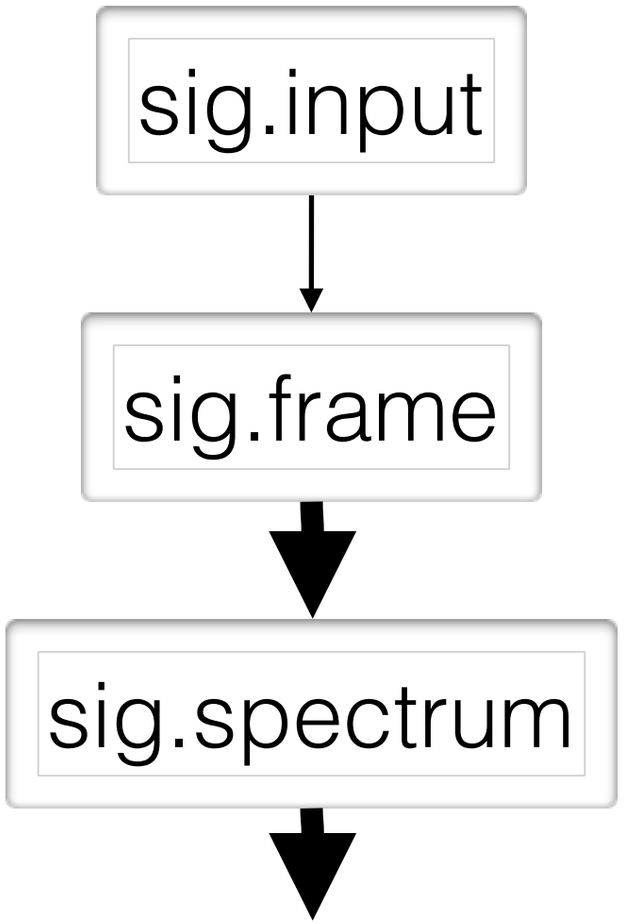
sig.frame
frame decomposition

- *f = sig.frame(…, '**FrameSize**', l, 's')*
  - unit: '**s**' (seconds), '**sp**' (samples)
- *f = sig.frame(..., '**FrameHop**', h, '/1')*
  - unit: '**/1**' (ratio from 0 to 1),'**Hz**', '**s**', '**sp**'

f.play
f.save



sig.frame
frame decomposition



- *a = sig.input(…*
- *f = sig.frame(a)*
- *s = sig.spectrum(f)*

Or: *s = sig.spectrum(…, ‘Frame’)*

‘*Frame*’ option frame decomposition

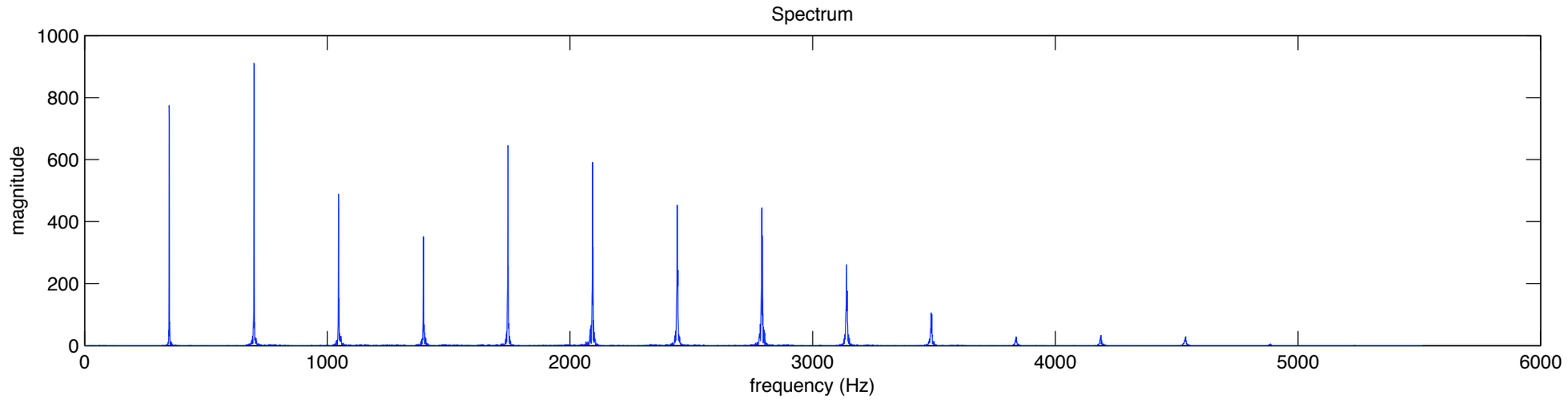
- *sig.input(…, ‘FrameSize’, …, ‘FrameHop’, …)*
- *sig.spectrum(…, ‘FrameSize’, …, ‘FrameHop’, …)*
- *sig.spectrum(…, ‘Frame’)* (default frame configuration)
- ‘*Frame*’ option available to most operators, each with its own default frame configuration
- Each operator can perform the frame decomposition where it is most suitable.

sig.spectrum
frequency spectrum

Discrete Fourier Transform of audio signal x:

$$X_k = \sum_{n=0}^{N-1} x_n e^{-\frac{2\pi i}{N} kn} \qquad k = 0, \ldots, N-1$$

Amplitude spectrum: *s = sig.spectrum(…)*



Phase spectrum: *s.phase*

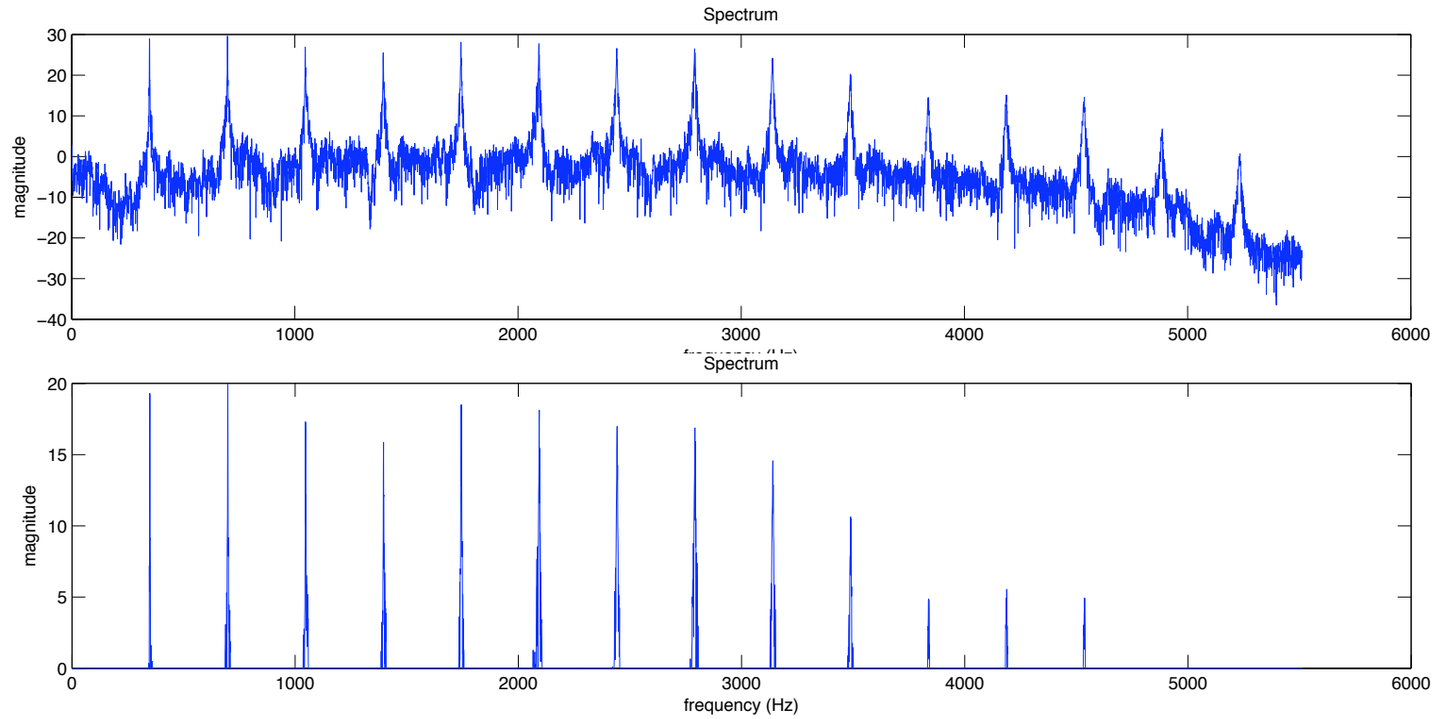
Fast Fourier Transform using *Matlab's fft* function.

sig.spectrum parameter specification

- *sig.spectrum(…, 'Min',* 0*)* in Hz
- *sig.spectrum(…, 'Max',* sampling rate/2*)* in Hz
- *sig.spectrum(…, 'Window', 'hamming')*
- frequency resolution r, in Hz:
  - *sig.spectrum(…, 'Res',* r*)*: exact resolution specification
  - *sig.spectrum(…, 'MinRes',* r*)*: minimal resolution (less precise constraint, but more efficient)
- *sig.spectrum(…, 'Phase', 'No')*

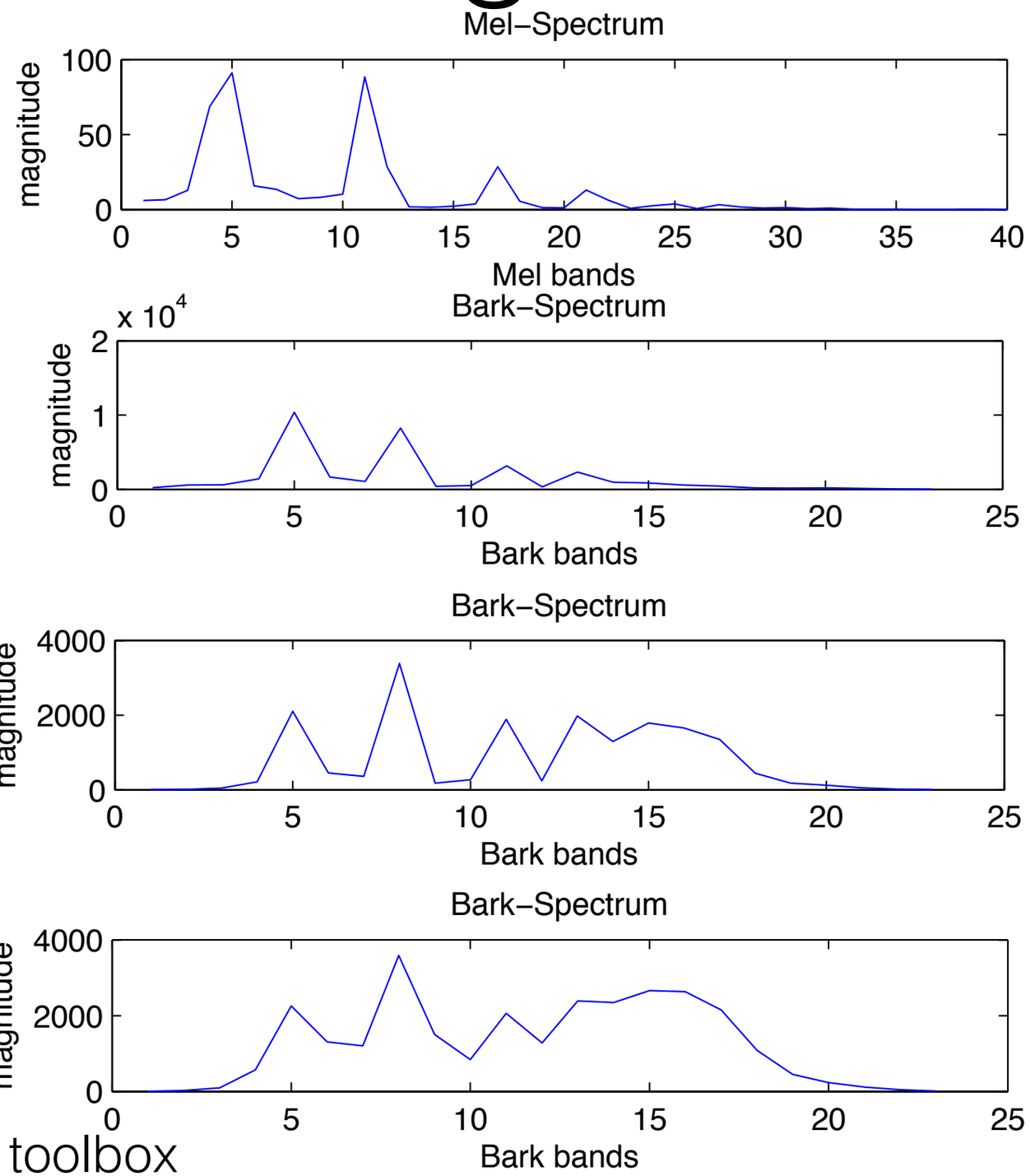
sig.spectrum post-processing

- *mirspectrum(..., 'Normal')* normalizes w.r.t. energy.
- *mirspectrum (..., 'Power')* squares the energy.
- *mirspectrum(..., 'dB')*
  - in dB scale
- *mirspectrum(..., 'dB'*, th*)*
  - th highest dB
- *mirspectrum(..., 'Smooth'*, o*)*
- *mirspectrum(..., 'Gauss'*, o*)*



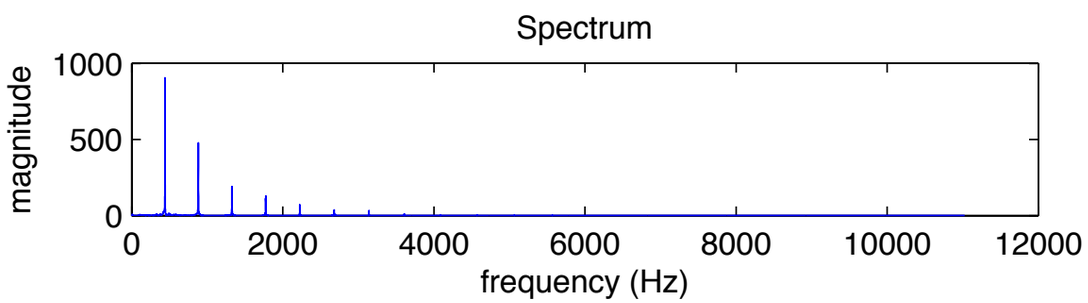
aud*.spectrum*
auditory modeling

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

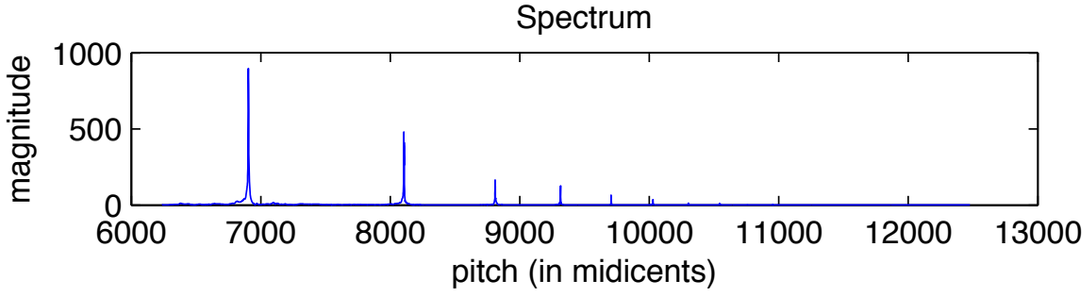


based on *Auditory toolbox* and *Music Analysis* toolbox

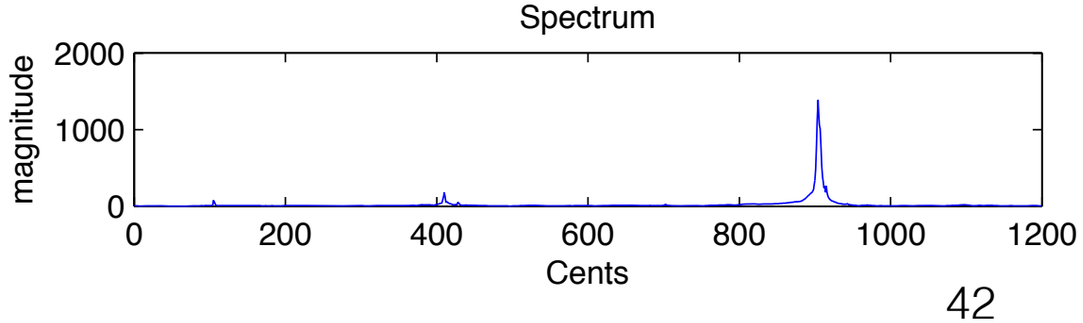
mus.*spectrum*
pitch-based distribution



- *mus.spectrum(…, '**Cents**')*

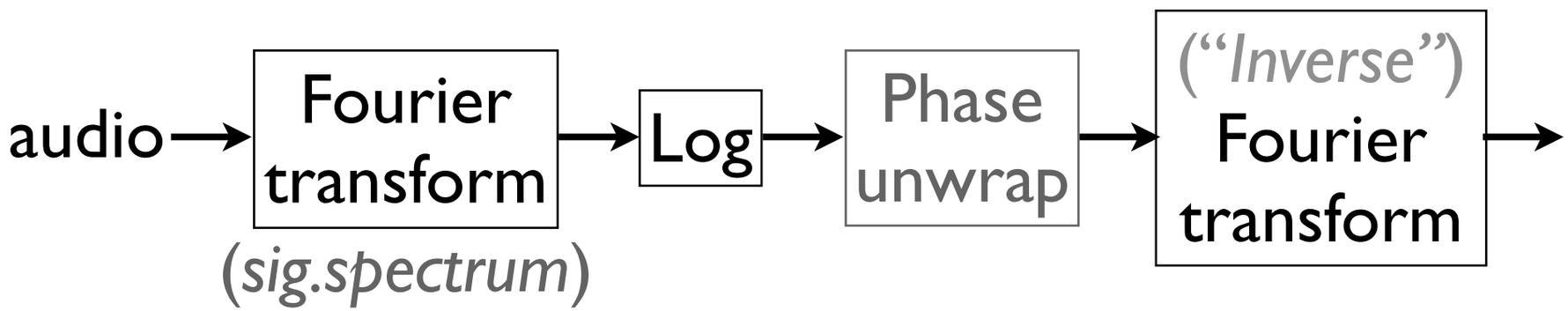


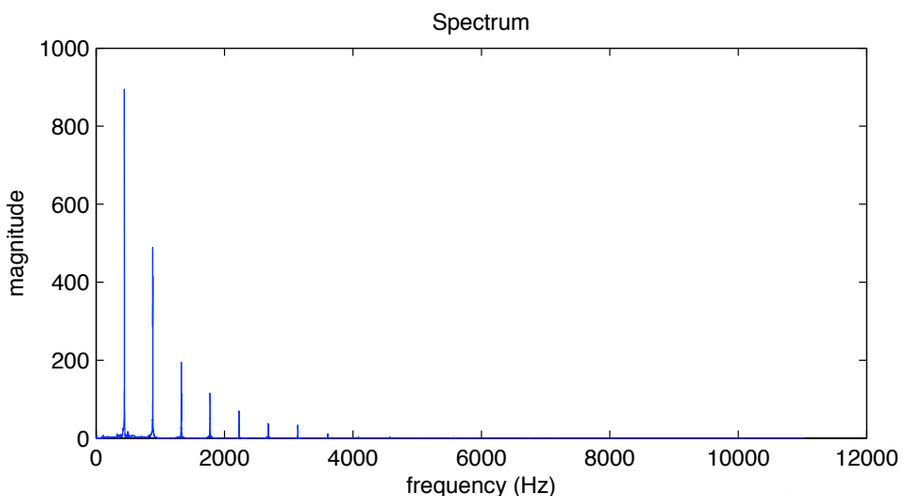
- *aud.spectrum(..., '**Collapsed**'):* into one octave, divided into 1200 cents

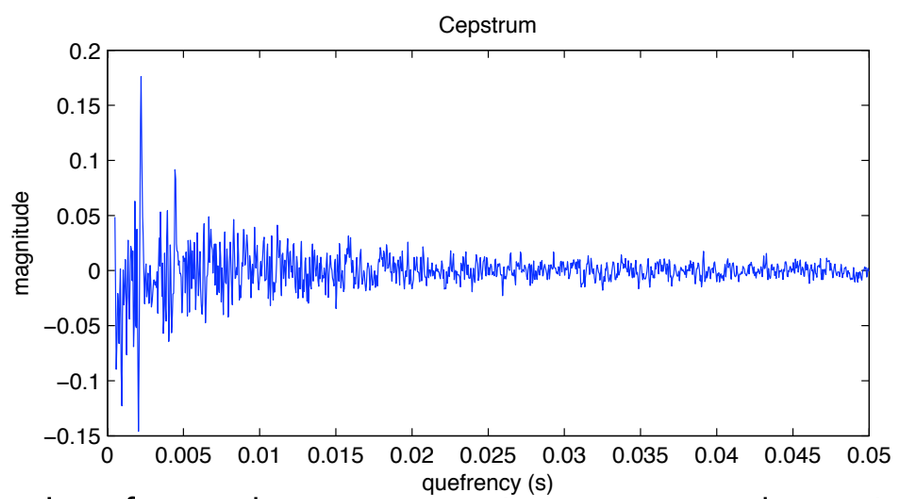


sig.cepstrum
cepstral analysis

*sig.cepstrum(…, '**Complex**')*: complex cepstrum



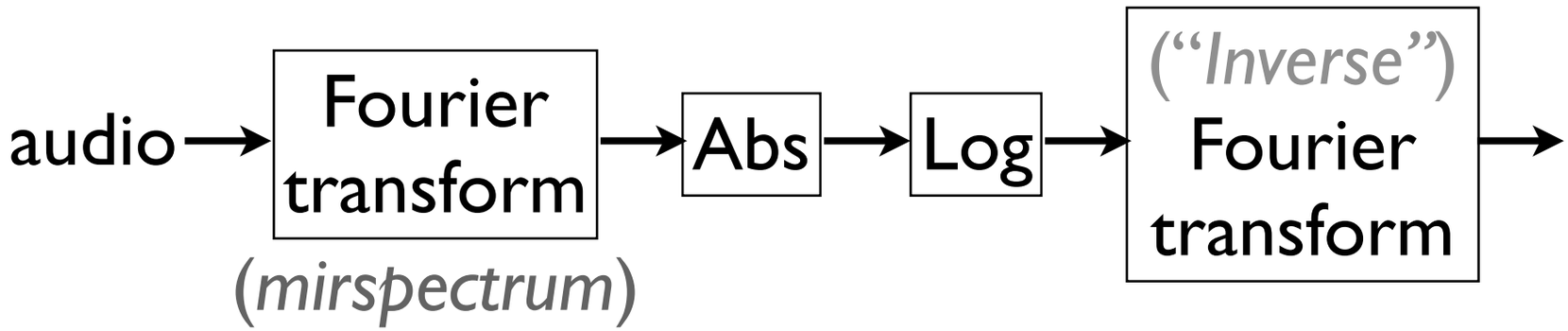


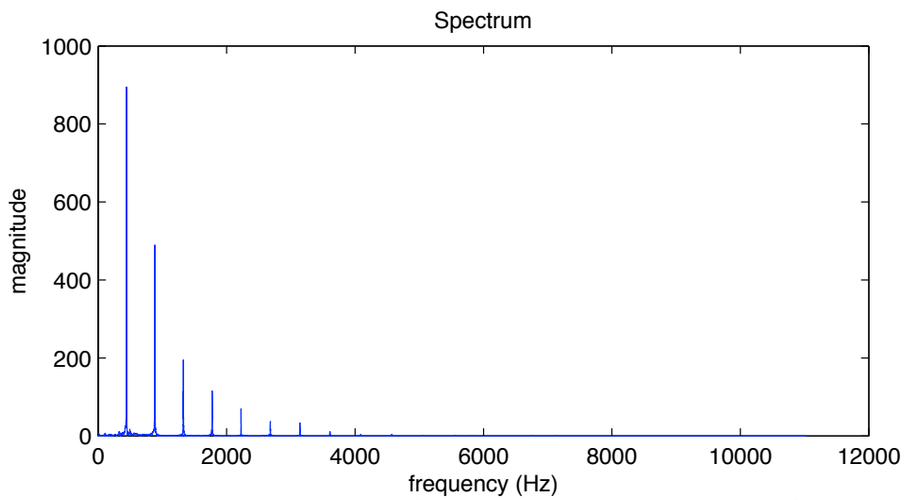


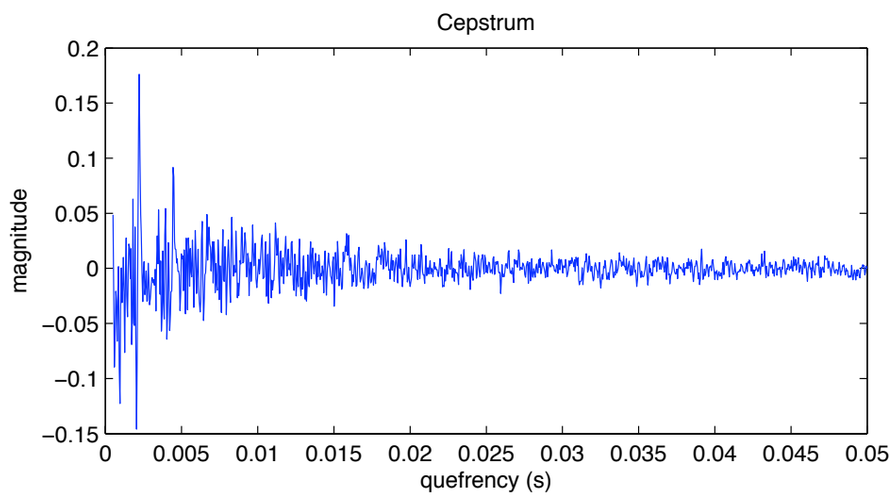
Bogert, Healy, Tukey. The quefrency alanysis of time series for echoes: cepstrum, pseudo-autocovariance, cross-cepstrum, and saphe cracking. Symposium on Time Series Analysis, Chapter 15, 209-243, Wiley, 1963.

sig.cepstrum
cepstral analysis

*sig.cepstrum(…, '**Real**')*: real cepstrum







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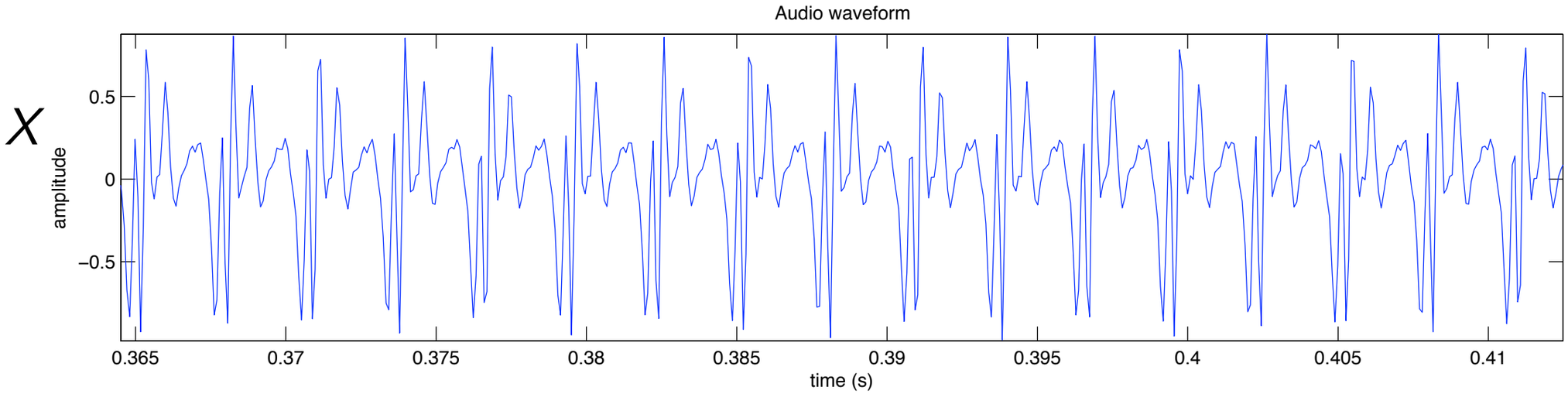
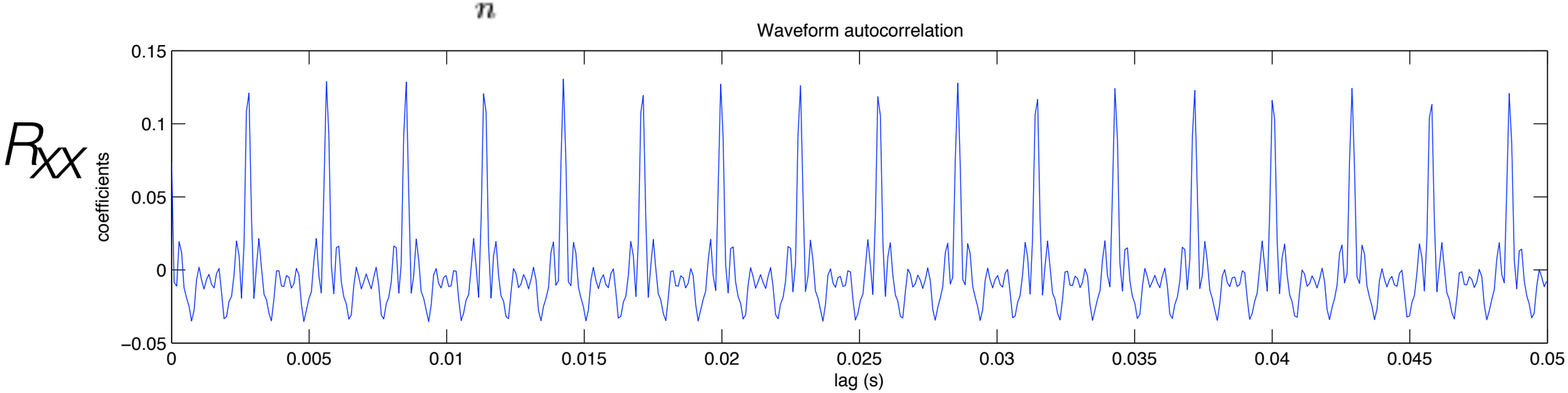
sig.cepstrum
cepstral analysis

- *sig.cepstrum(…, '**Freq**')*
  - represented in the frequency domain
- *sig.cepstrum(..., 'Min', 0, 's')*
- *sig.cepstrum(..., 'Max', .05, 's')*

sig.autocor
autocorrelation function



$$R_{xx}(j) = \sum_n x_n \overline{x}_{n-j} \ .$$



sig.autocor
autocorrelation function

- *sig.autocor(…, '**Min**', t1, 's') t1=0 s*
- *sig.autocor(…, '**Max**', t2, 's') t2=.05 s (audio) or t2=2 s (envelope)*
- *sig.autocor(…, '**Freq**') lags in Hz.*
- *sig.autocor(…, '**Window**',w) w='hanning'*
  specifies a windowing method
- *sig.autocor(…, '**NormalWindow**',f)* f='on'='yes'=1
  divides by autocorrelation of the window*
- *sig.autocor(…, 'Halfwave')* half-wave rectification

*Boersma. Accurate short-term analysis of the fundamental frequency and the harmonics-to-noise ratio of a sampled sound, IFA Proceedings 17: 97-110, 1993.

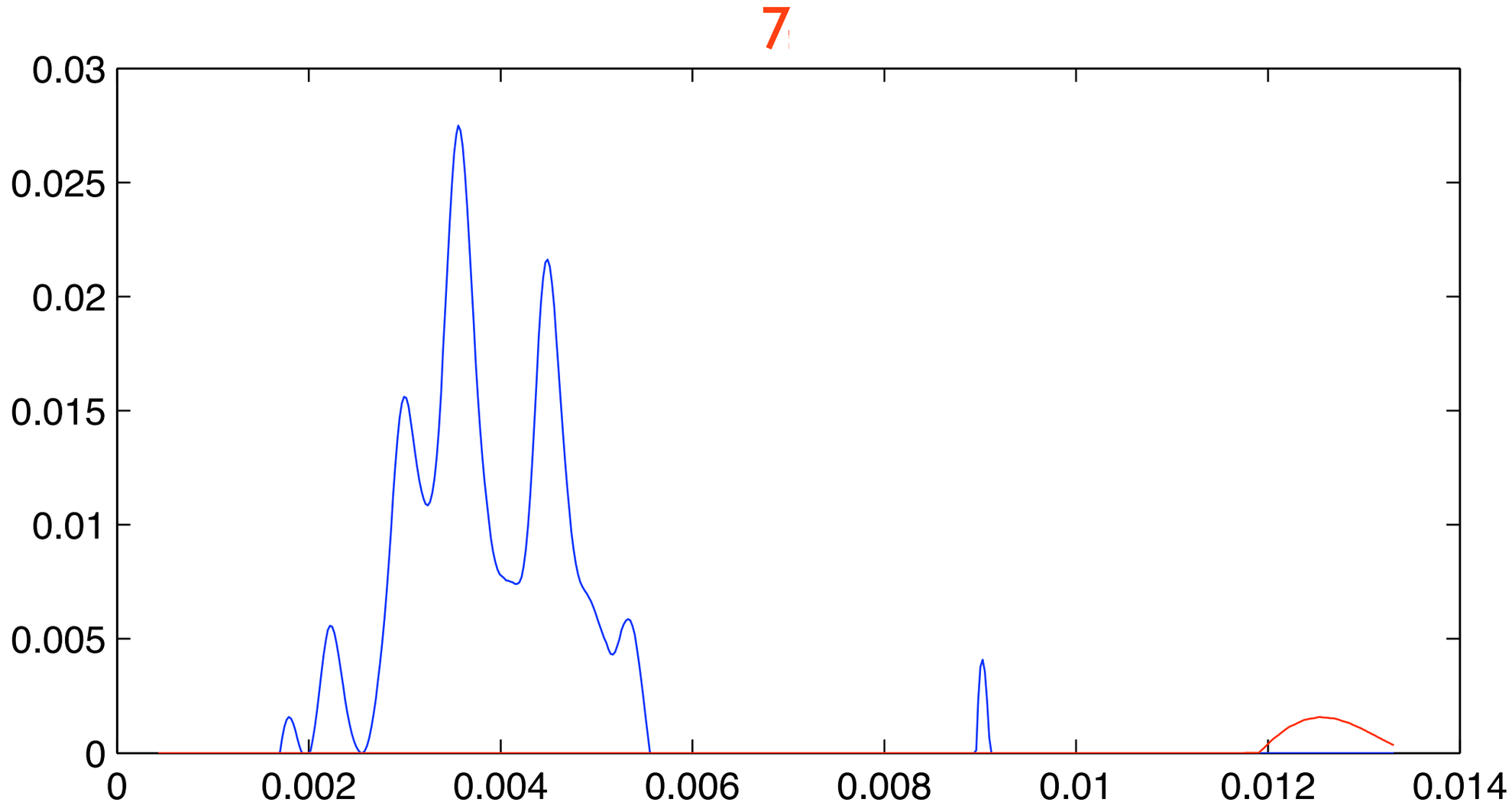
sig.autocor
generalized autocorrelation

- Autocorrelation (by default):
  - $y = IDFT(|DFT(x)|^2)$
- Generalized autocorrelation:
  - $y = IDFT(|DFT(x)|^{\boldsymbol{k}})$
- *sig.autocor(…, '**Compress**', k)* k=.67

Tolonen, Karjalainen. A Computationally Efficient Multipitch Analysis Model, IEEE Transactions on Speech and Audio Processing, 8(6), 2000.

sig.autocor
generalized autocorrelation

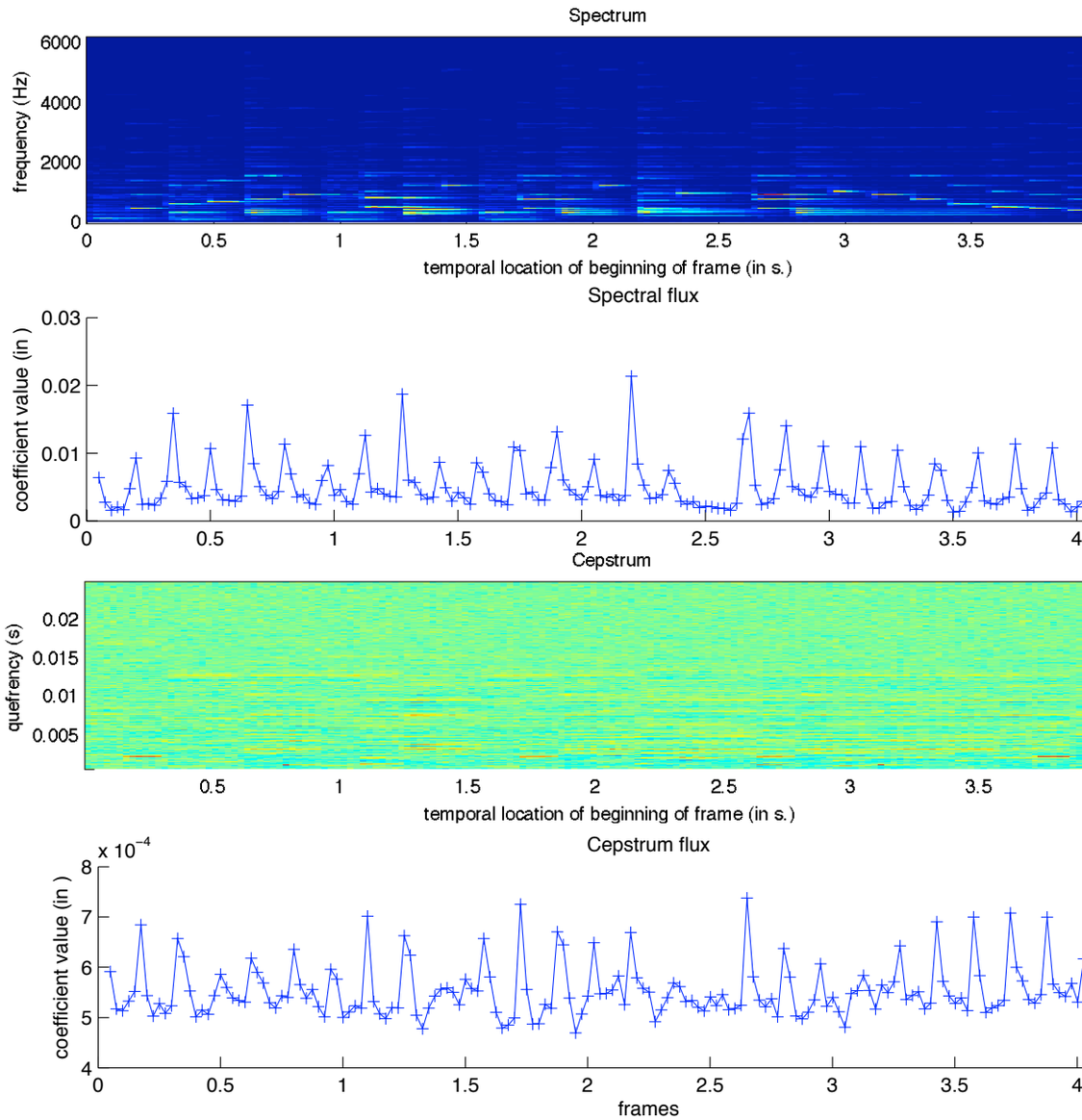
- *sig.autocor('Amin3', 'Enhanced', 2:10)*



Tolonen, Karjalainen. A Computationally Efficient Multipitch Analysis Model, IEEE Transactions on Speech and Audio Processing, 8(6), 2000.

sig.flux: distance between successive frames

- *s = sig.spectrum(a, 'Frame')*
- *sig.flux(s) = sig.flux(a)*
- *c = sig.cepstrum(a, 'Frame')*
- *sig.flux(c)*



sig.flux: distance between successive frames

- *sig.flux(…, '**Dist**',* d*)* d = *'Euclidian', 'City', 'Cosine'* specifies the distance measure.
- *sig.flux(..., '**Inc**')* positive differences
- *sig.flux(..., '**Complex**')* complex flux
- *sig.flux(..., '**Median**', l, C)*
- *sig.flux(..., '**Median**', l, C, '**Halfwave**')*

Audio level

Sound

Dynamics

sig.rms
root-mean square

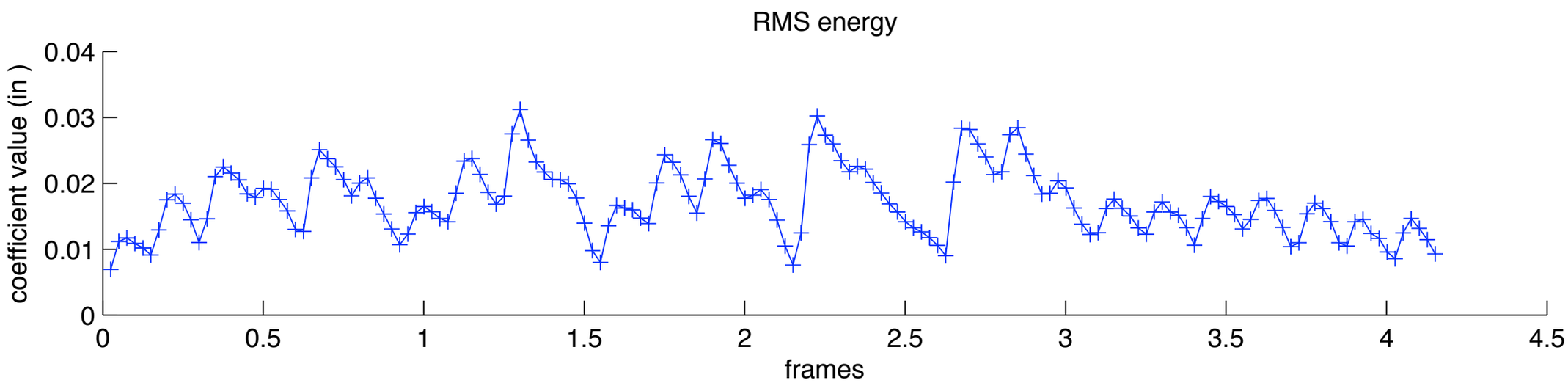
$$x_{\mathrm{rms}} = \sqrt{\frac{1}{n}\sum_{i=1}^{n} x_i^2} = \sqrt{\frac{x_1^2 + x_2^2 + \cdots + x_n^2}{n}}$$

- *sig.rms('ragtime')*

```
The RMS energy related to file ragtime is 0.017932
```

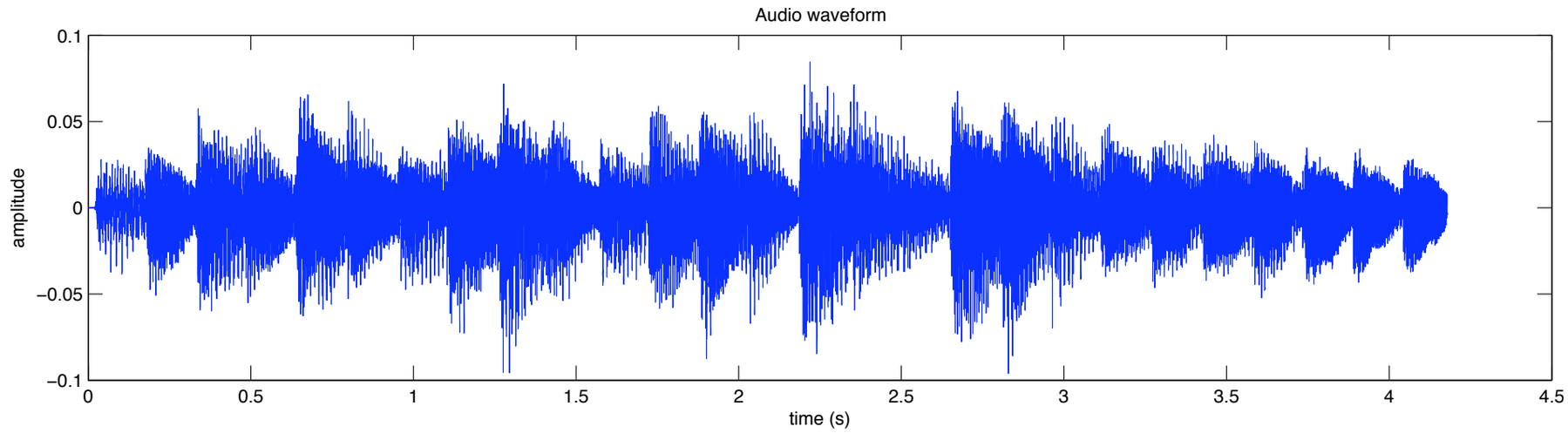
- *sig.rms('ragtime', 'Frame')*

Default frame size .05 s, frame hop = .5

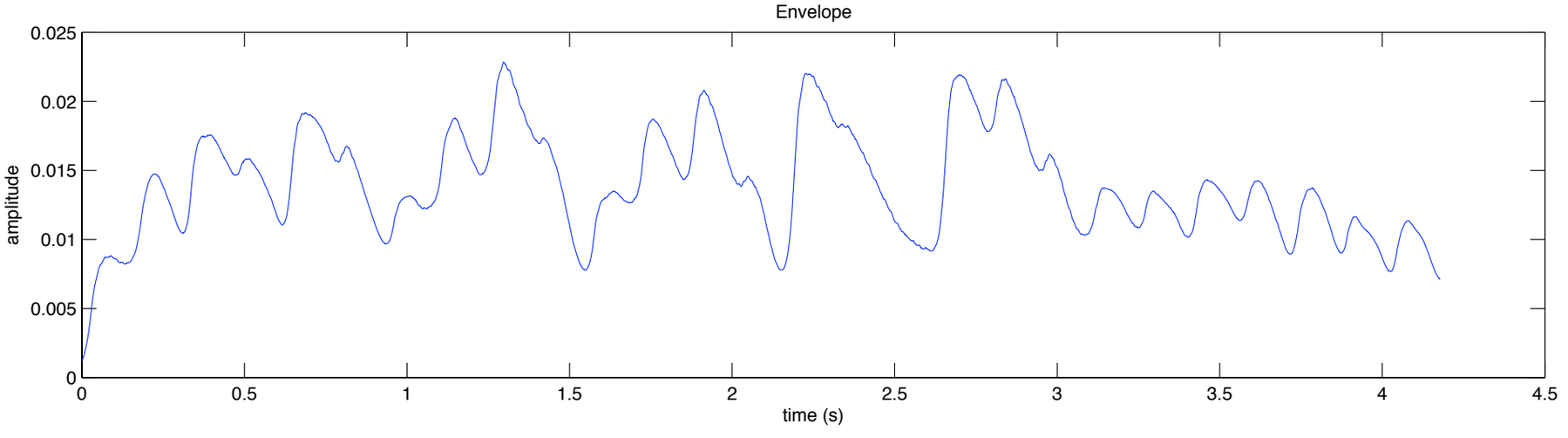


sig.envelope
envelope extraction

- *a:*

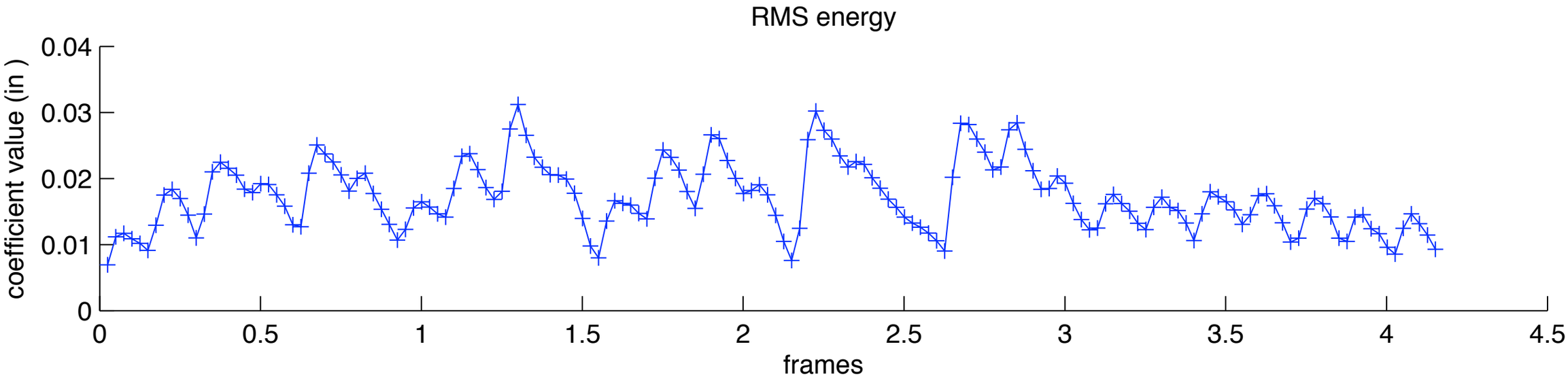


- *e = sig.envelope(a):*

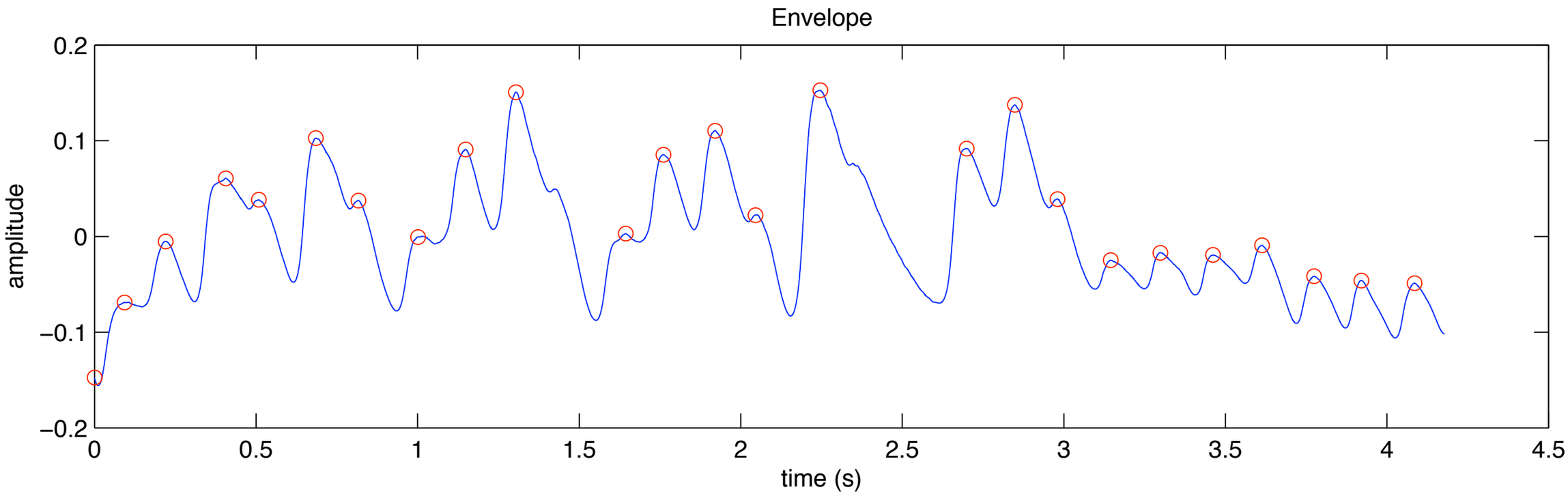


e.play
e.save

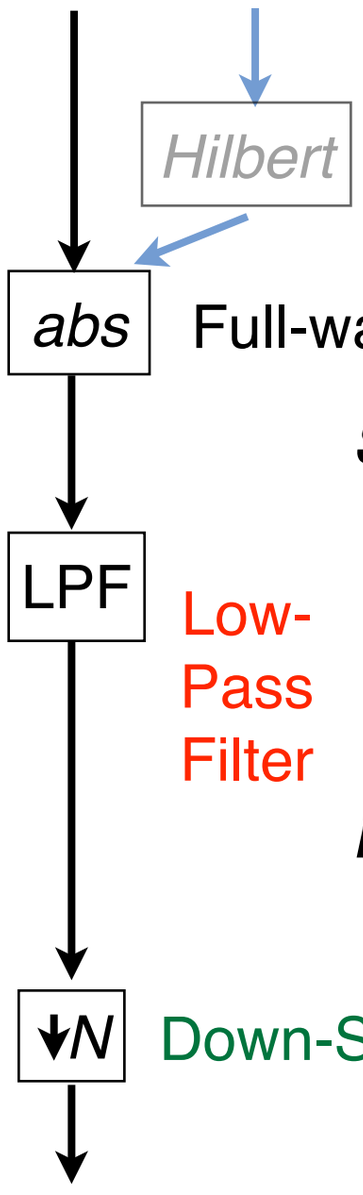
sig.rms



sig.envelope



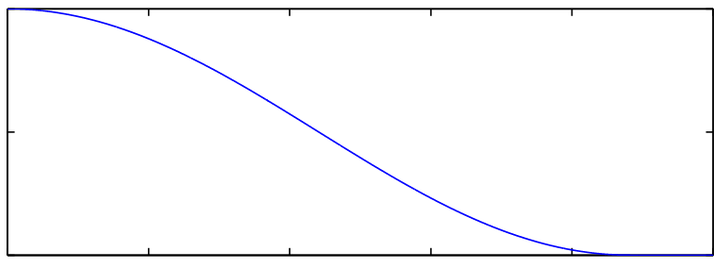
sig.envelope(…, 'Filter') based on low-pass filtering

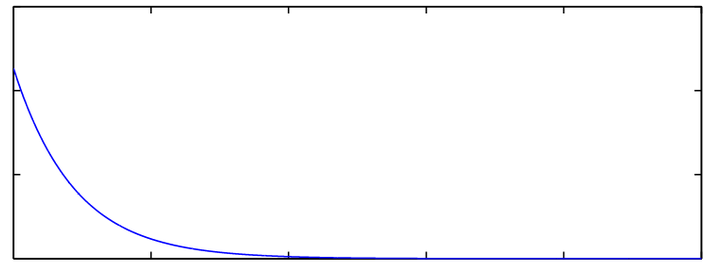


sig.envelope(…, 'Hilbert') (Analytic signal)

Full-wave rectification (Magnitude)

sig.envelope(…, 'Filtertype', 'IIR') *'HalfHann'*





mirenvelope(…, 'Tau', .02): time constant (in s.)

mirenvelope(…, 'PostDecim', N) *N*=16

mirenvelope(…, 'Sampling', f)

sig.envelope(…, ‘Spectro’) based on power spectrogram

- Band decomposition:
  - *sig.envelope(..., ‘Freq’)*: none (default)
  - *aud.envelope(..., ‘Mel’)*: Mel-band
  - *aud.envelope(..., ‘Bark’)*: Bark-band
- *sig.envelope(…, ‘UpSample’, 2)*
- *sig.envelope(…, ‘Complex’)*

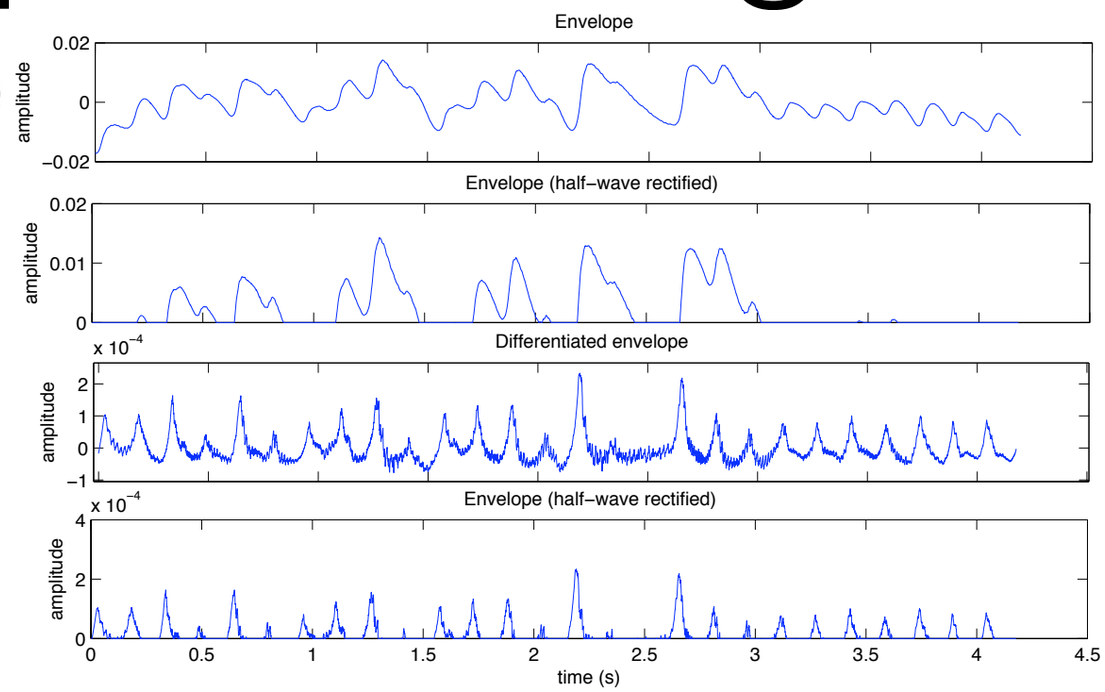
sig.envelope post-processing

- *sig.envelope(…, '**Center**')*

  '***HalfWaveCenter***')

  '***Diff***')

  '***HalfWaveDiff***')



- *sig.envelope(…, '**Power**')*
- *sig.envelope(…, '**Normal**')*
- *sig.envelope(…, '**Smooth**',o)* moving average, order o = 30 sp.
- *sig.envelope(…, '**Gauss**',o)* gaussian, std deviation o = 30 sp.

aud*.envelope*
auditory modeling

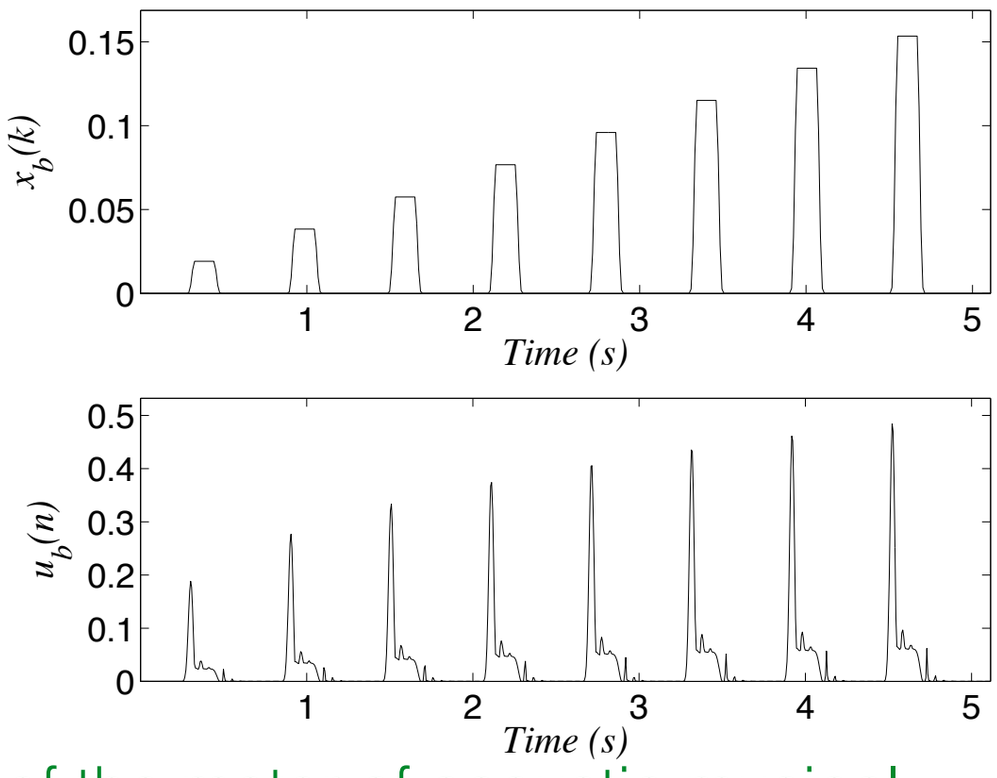
- *aud.envelope(…, 'Mu',* mu*),*
  mu-law compression, mu = 100

$$y_b(k) = \frac{\ln(1 + \mu x_b(k))}{\ln(1 + \mu)}$$

- *aud.envelope(..., 'Lambda',* l*)*

$$u_b(n) = (1 - \lambda)z_b(n) + \lambda \frac{f_r}{f_{\mathrm{LP}}} z_b'(n$$

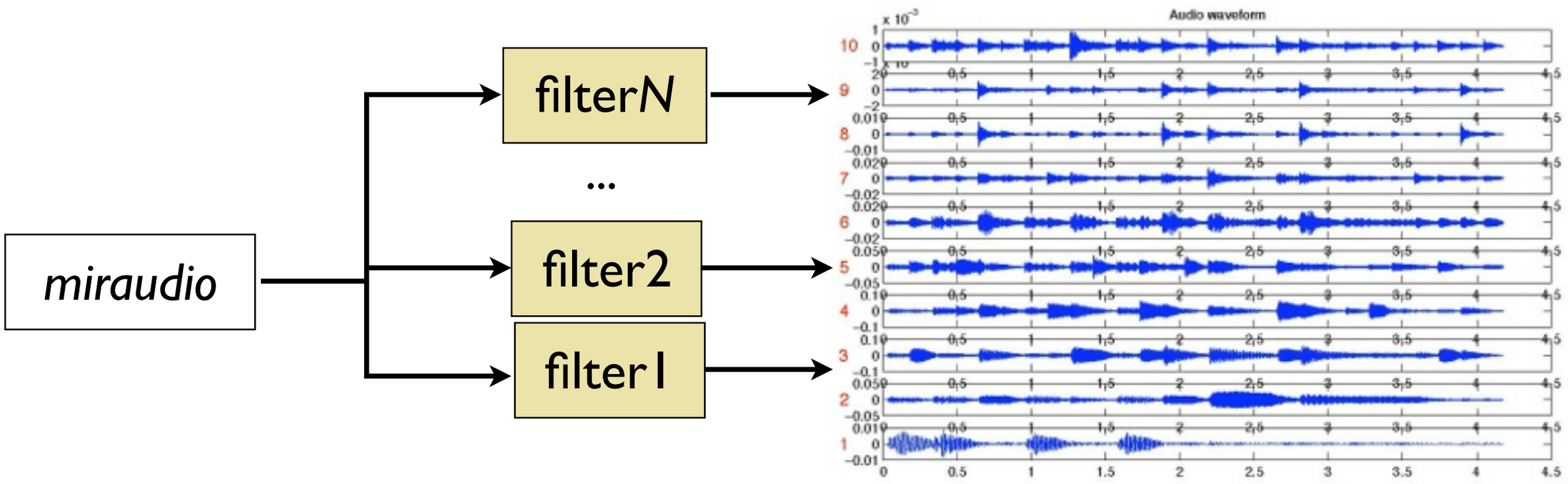
- *aud.envelope(..., 'Klapuri06'):*
  - *e = aud.envelope(..., 'Spectro', 'UpSample', 'Log', 'HalfwaveDiff', 'Lambda', .8);*
  - *sig.sum(e, 'Adjacent', 10)*



Klapuri, A., A. Eronen and J. Astola. (2006). "Analysis of the meter of acoustic musical signals", IEEE Transactions on Audio, Speech and Langage Processing, 14-1, 342– 355.

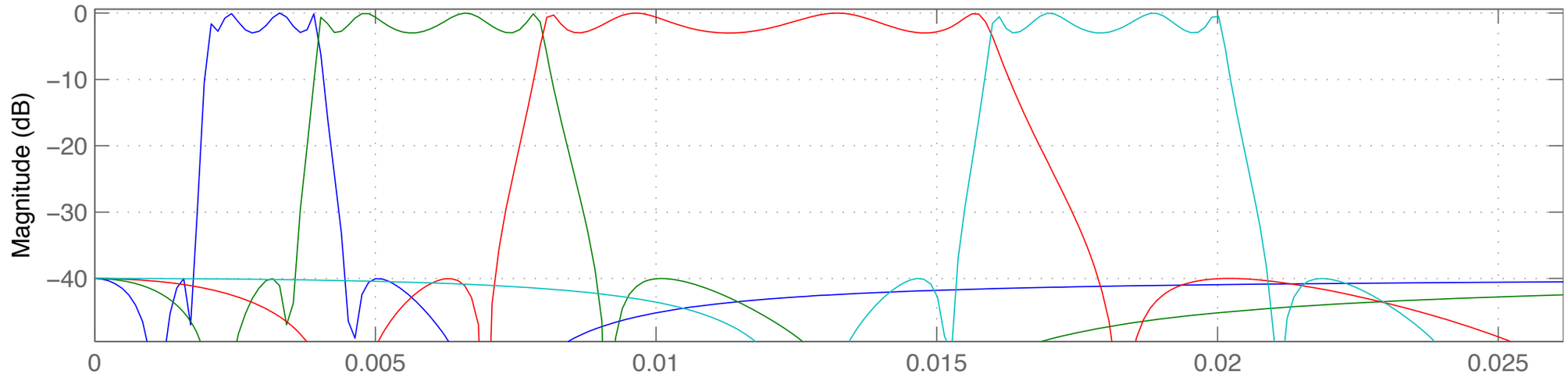
sig.filterbank
filterbank decomposition

- f = sig.filterbank(…, ‘CutOff’, [500, 1000])
- f.play
- f.save

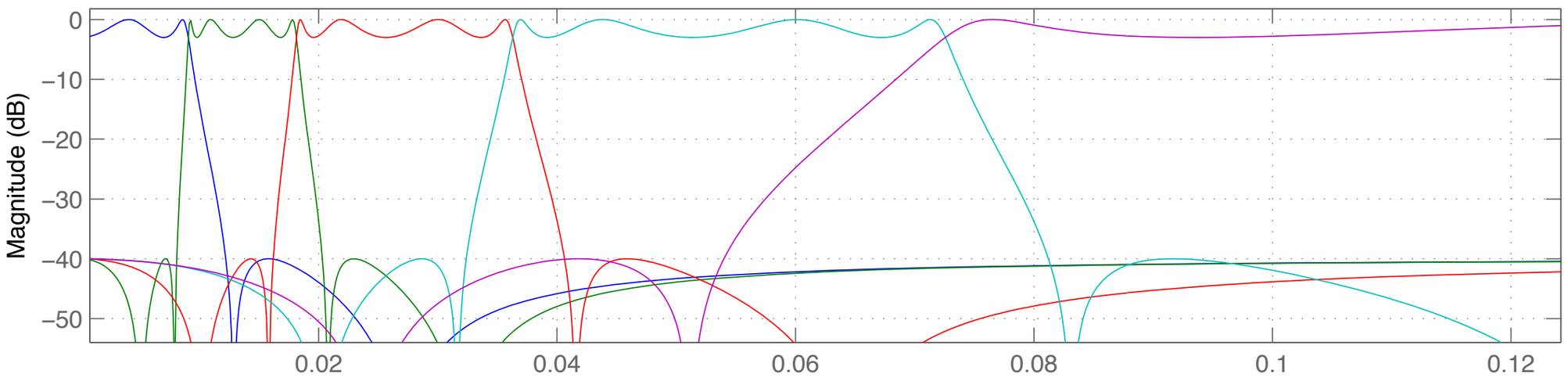


sig.filterbank
filterbank decomposition

sig.filterbank(…, ‘CutOff’, [44, 88, 176, 352, 443])

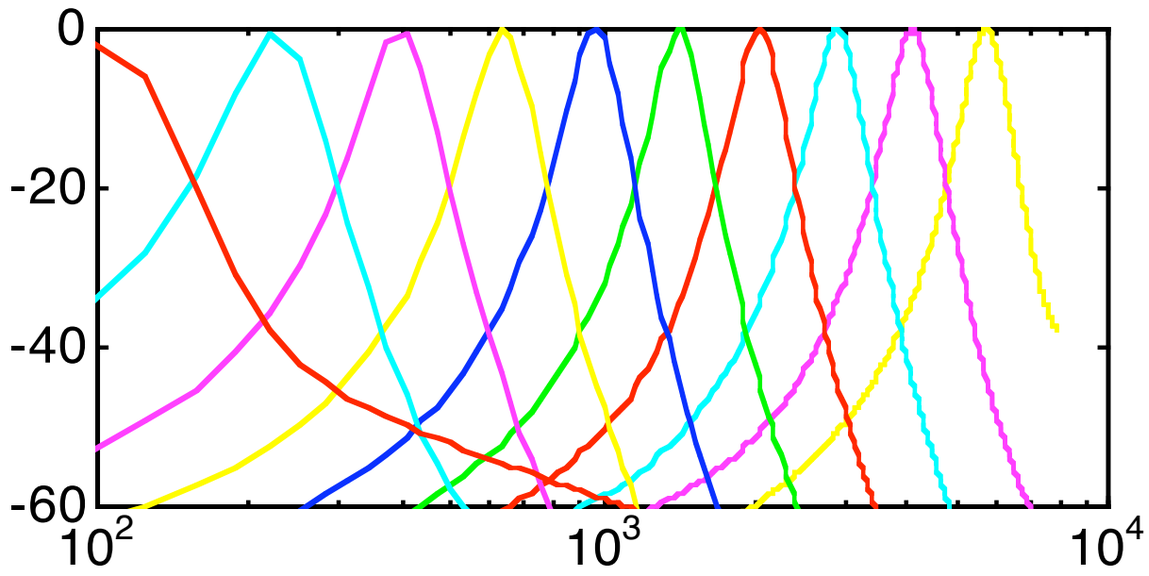


sig.filterbank(…, ‘CutOff’, [-Inf 200 400 800 1600 Inf])



***aud**.filterbank*
auditory modeling

- *aud.filterbank(…)*
- Equivalent Rectangular Bandwidth (ERB) Gammatone filterbank



Filter frequency responses

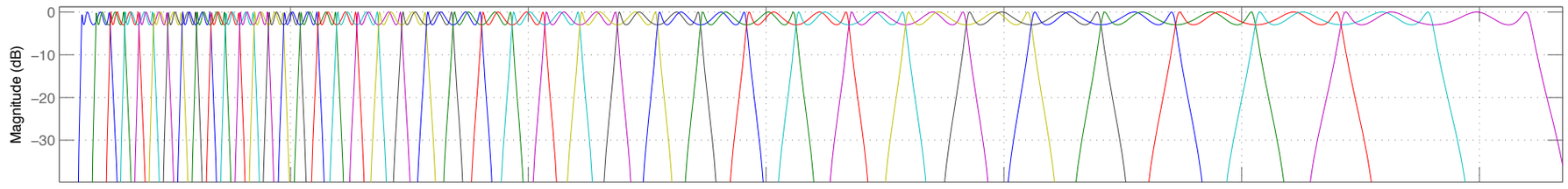
- *aud.filterbank(…, '**NbChannels**', 10)*
- *aud.filterbank(…, '**Channel**', 1:10)*

based on *Auditory toolbox*

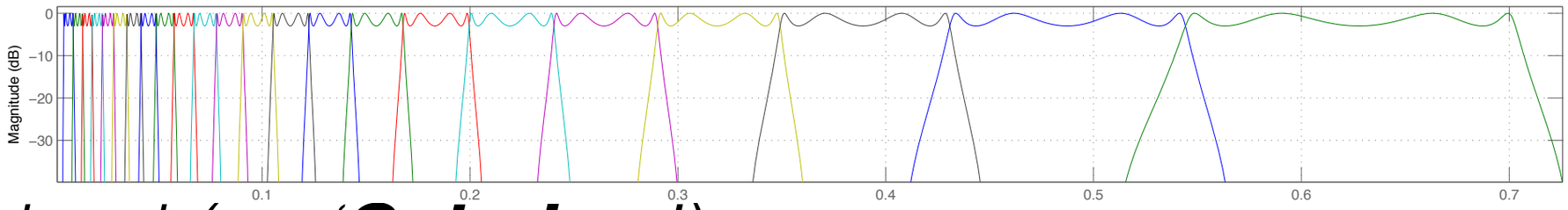
R. D. Patterson et al. "Complex sounds and auditory images," in Auditory Physiology and Perception, Y. Cazals et al, Oxford, 1992, pp. 429-446

aud*.filterbank*
auditory modeling

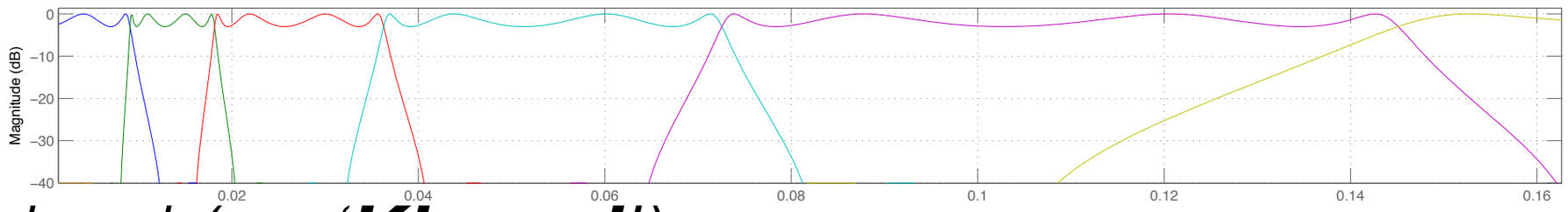
- *aud.filterbank(…, '**Mel**')*



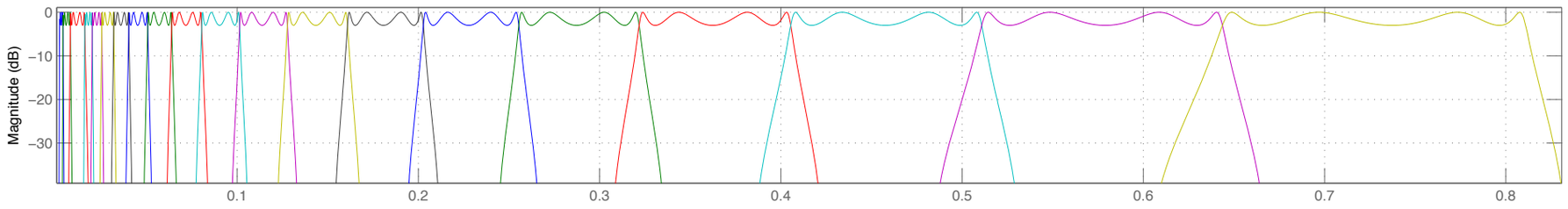
- *aud.filterbank(…, '**Bark**')*



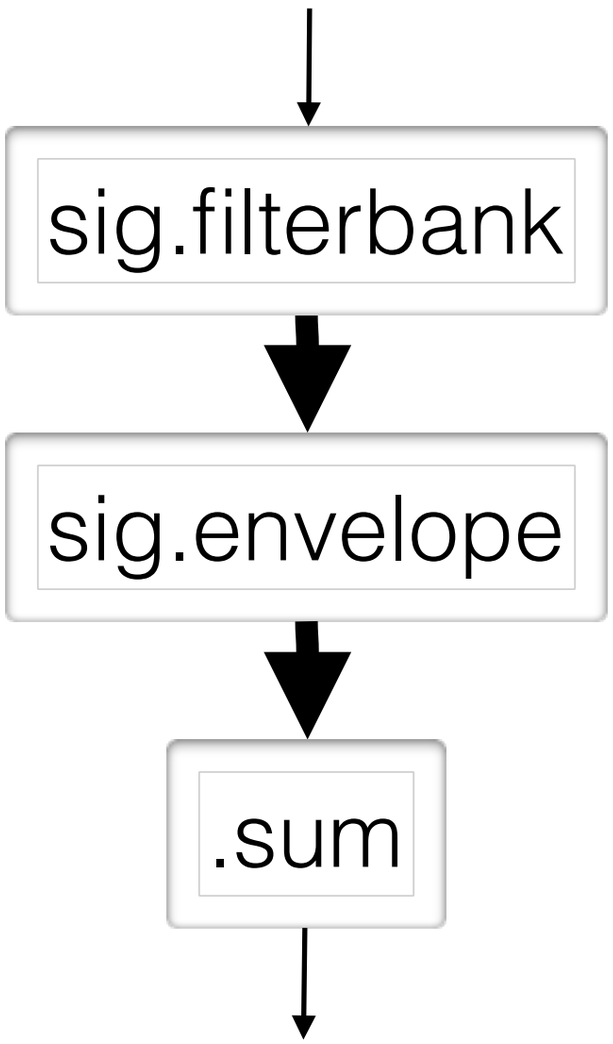
- *aud.filterbank(…, '**Scheirer**')*



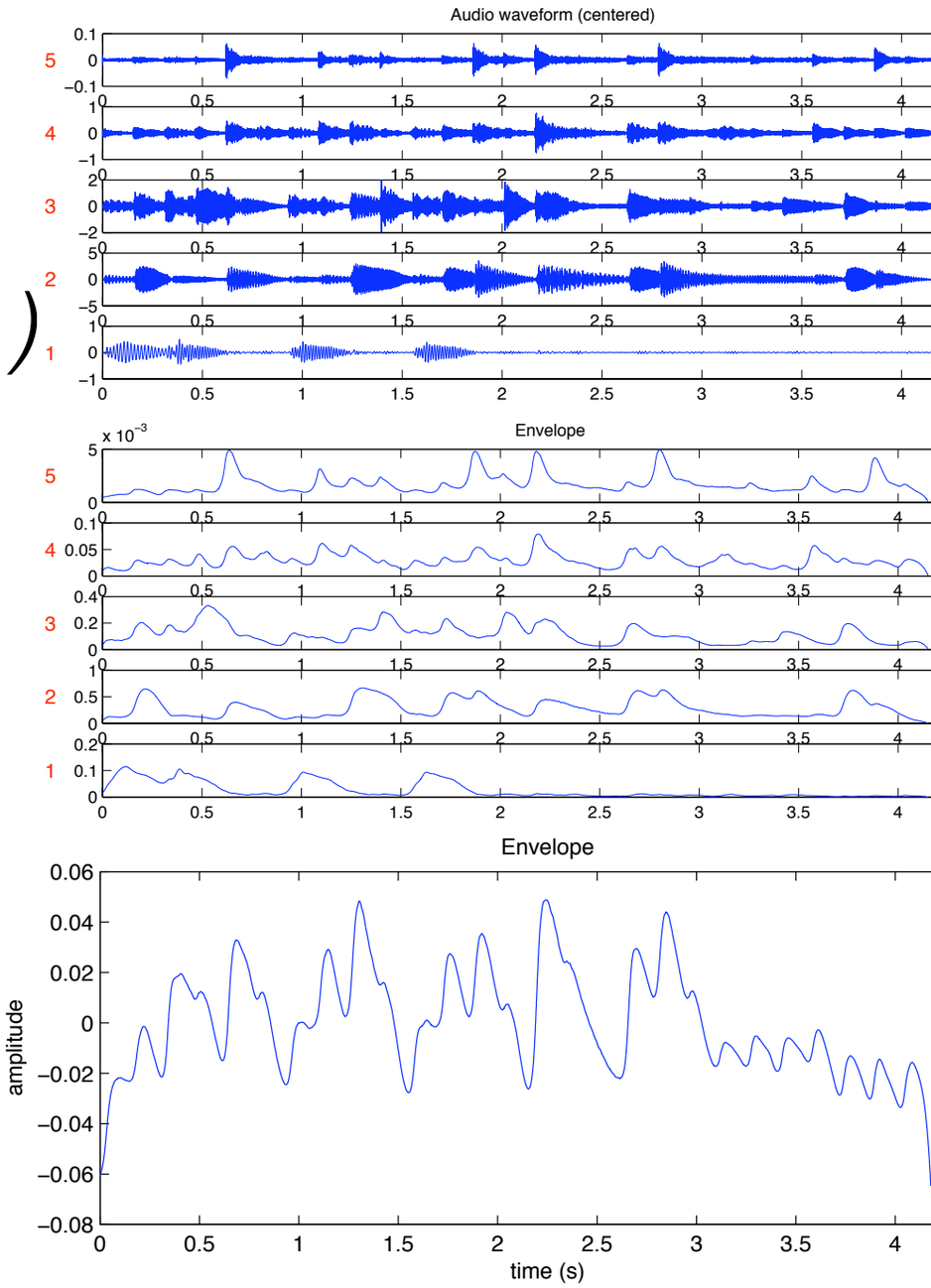
- *aud.filterbank(…, '**Klapuri**')*



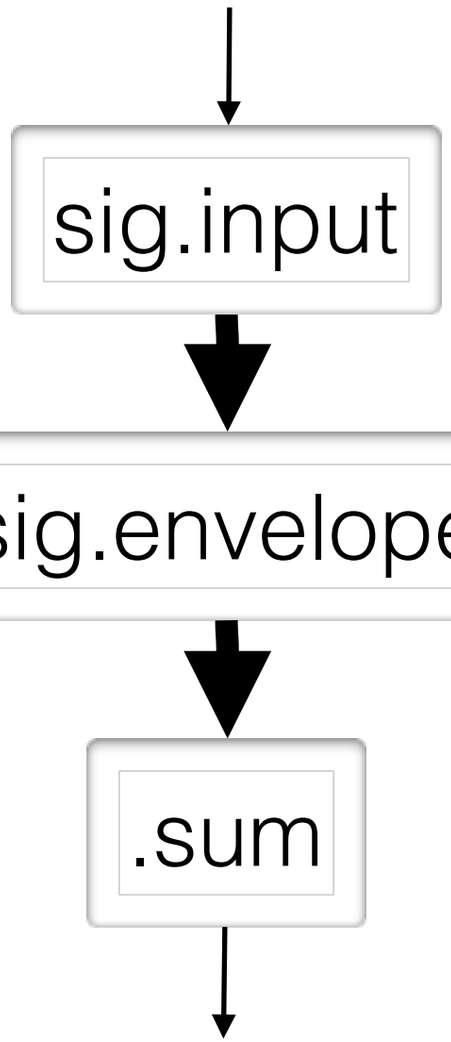
.sum
across-channel summa*tion*



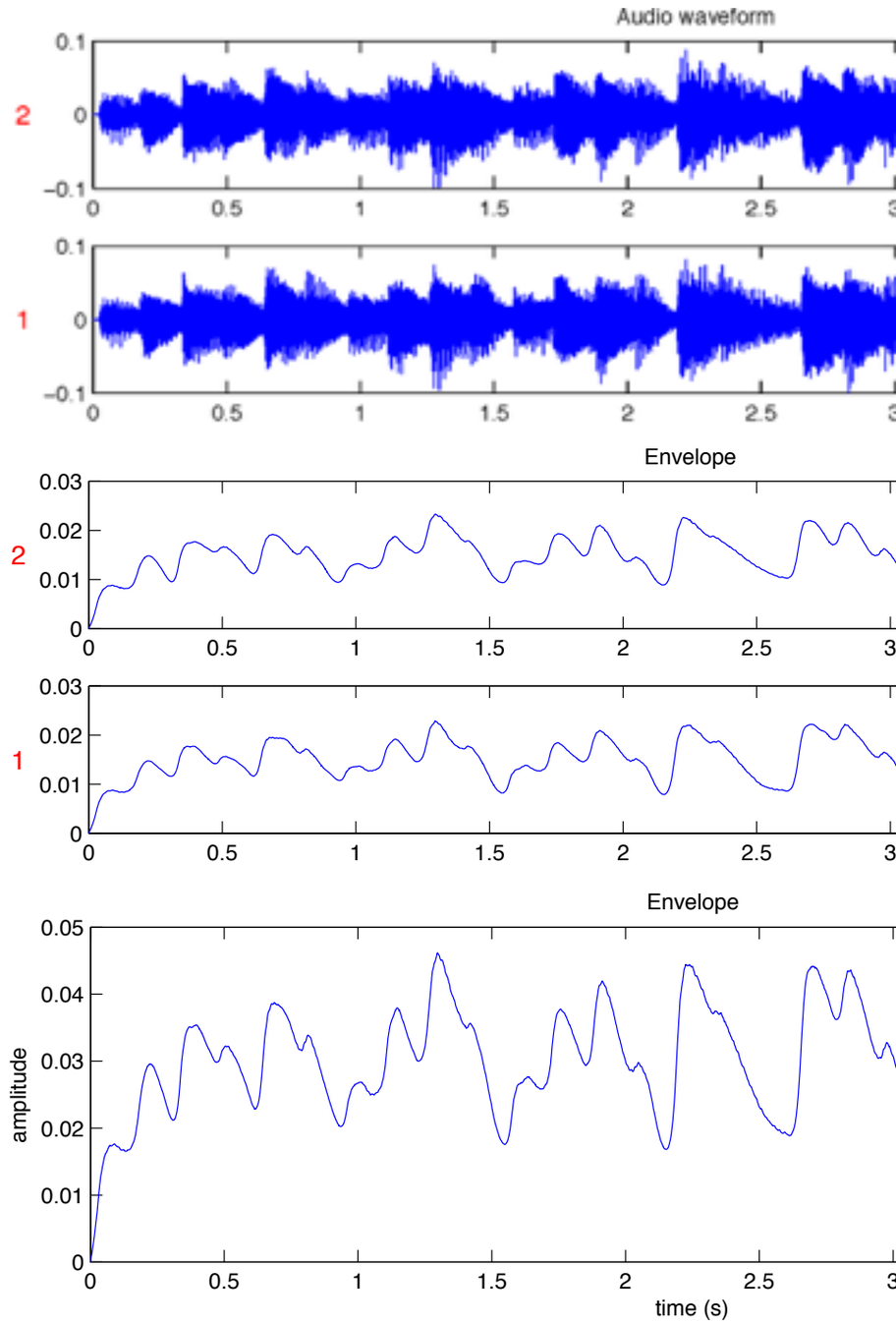
- *f = sig.filterbank(…)*
- *e = sig.envelope(f)*
- *e.sum*



.sum
stereo summa*tion*



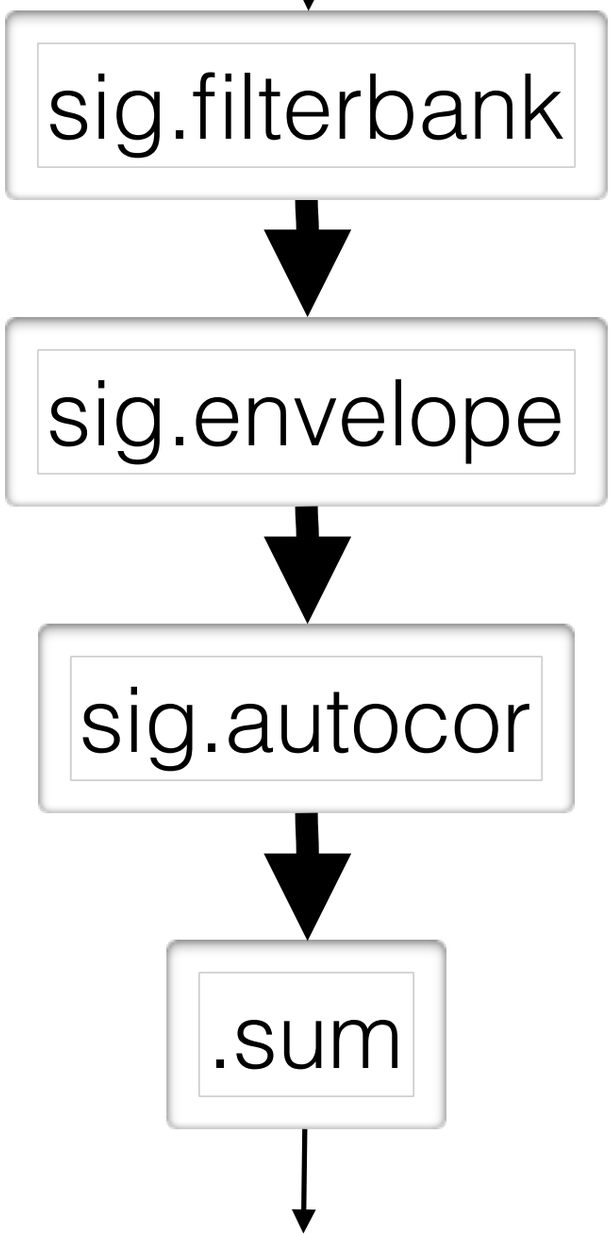
- *a = sig.input(…, ‘Mix’, ‘No’)*
- *e = sig.envelope(a)*
- *e.sum(‘**channel**’)*



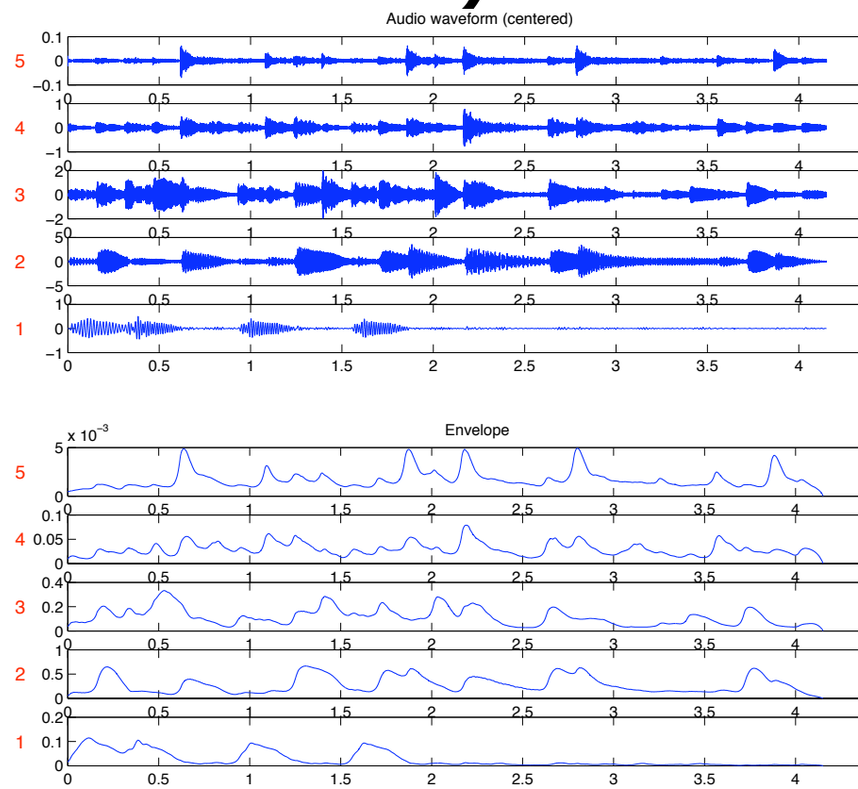
(currently called *sig.sum*)

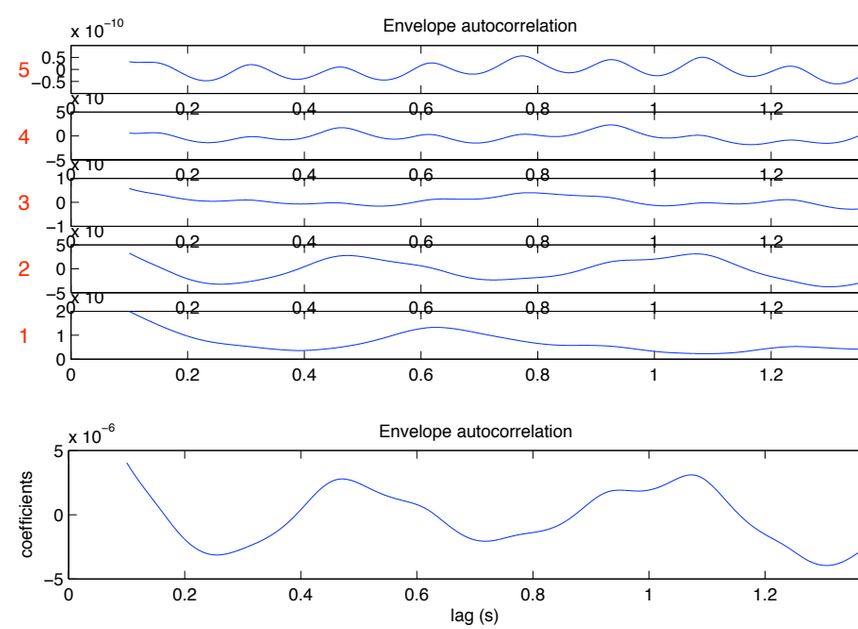
.sum

across-channel summa*ry*

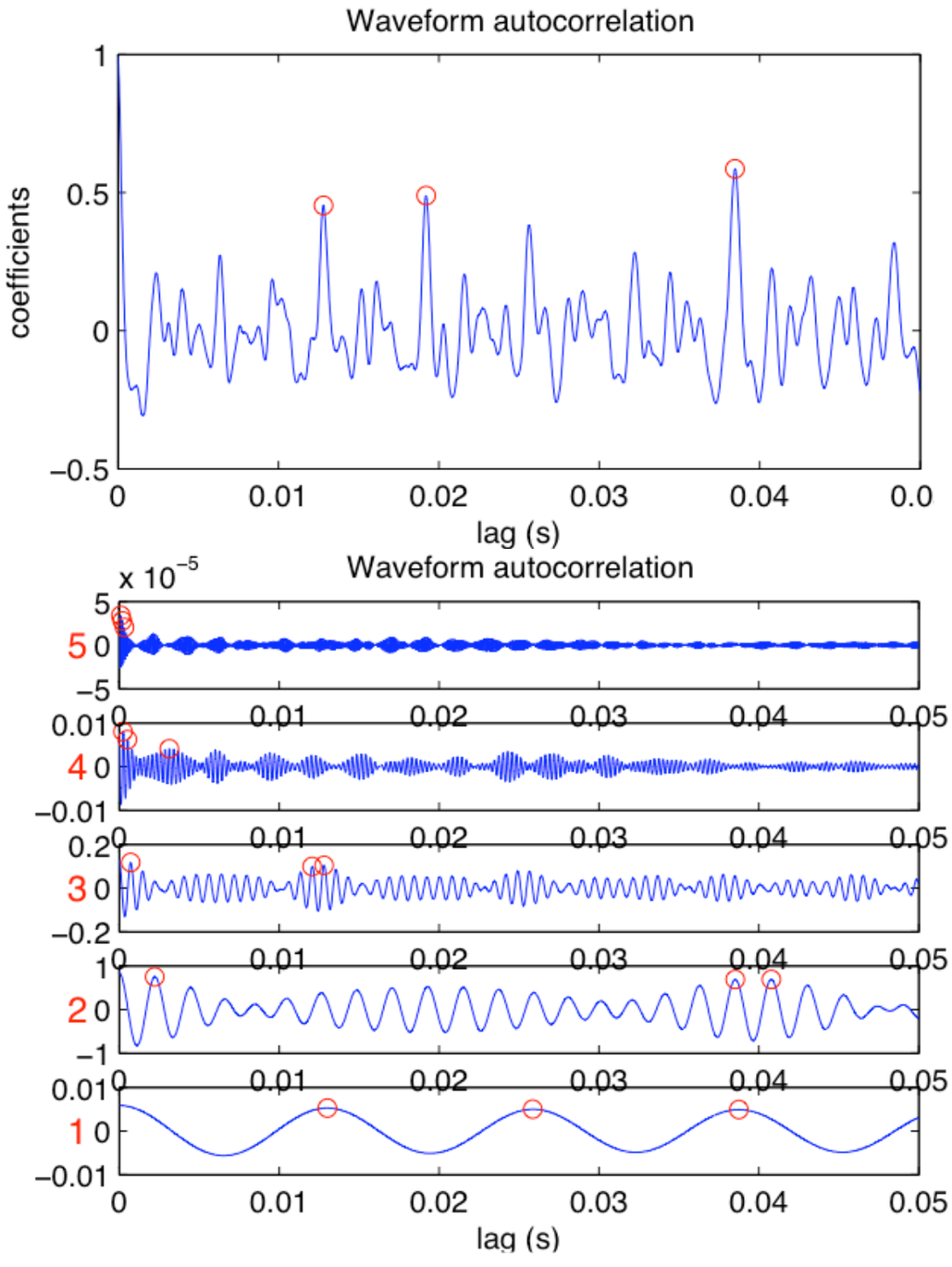


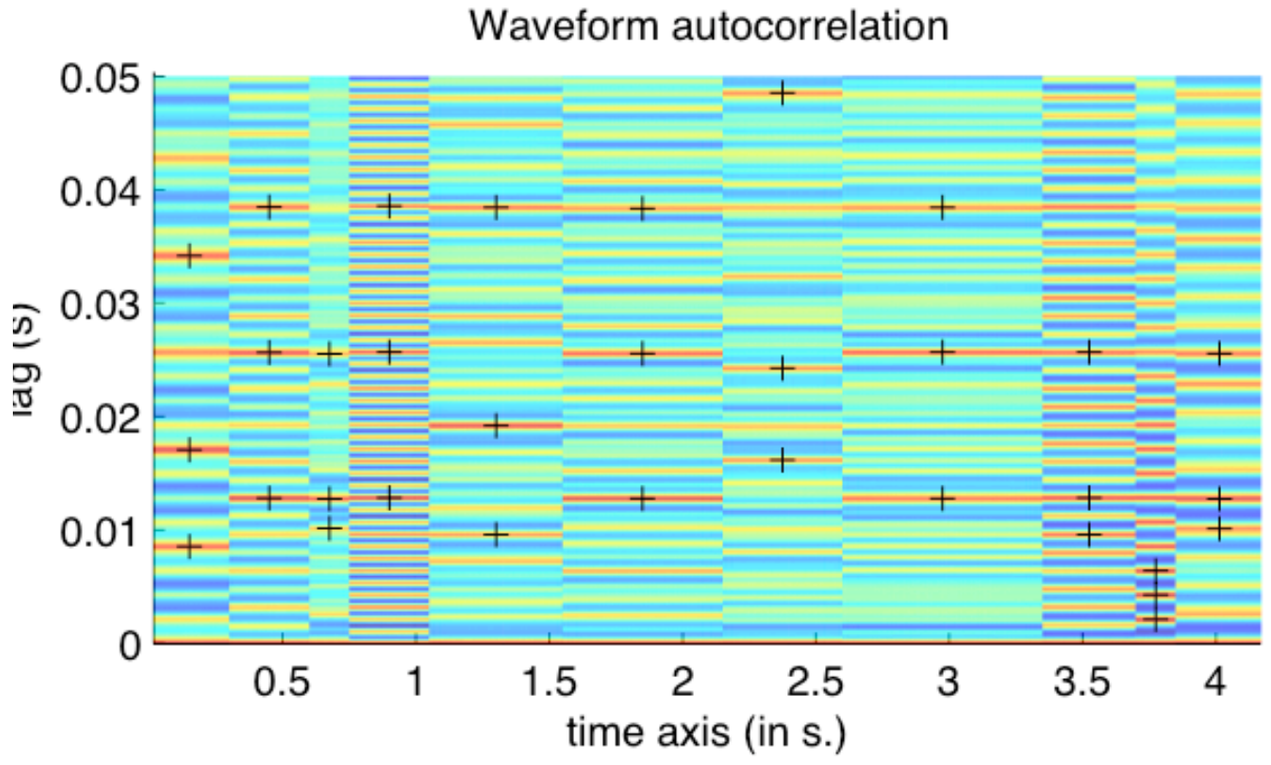
- *f = sig.filterbank(…)*
- *e = sig.envelope(f)*
- *a = sig.autocor(e)*
- *a.sum*





sig.peaks
peak picking

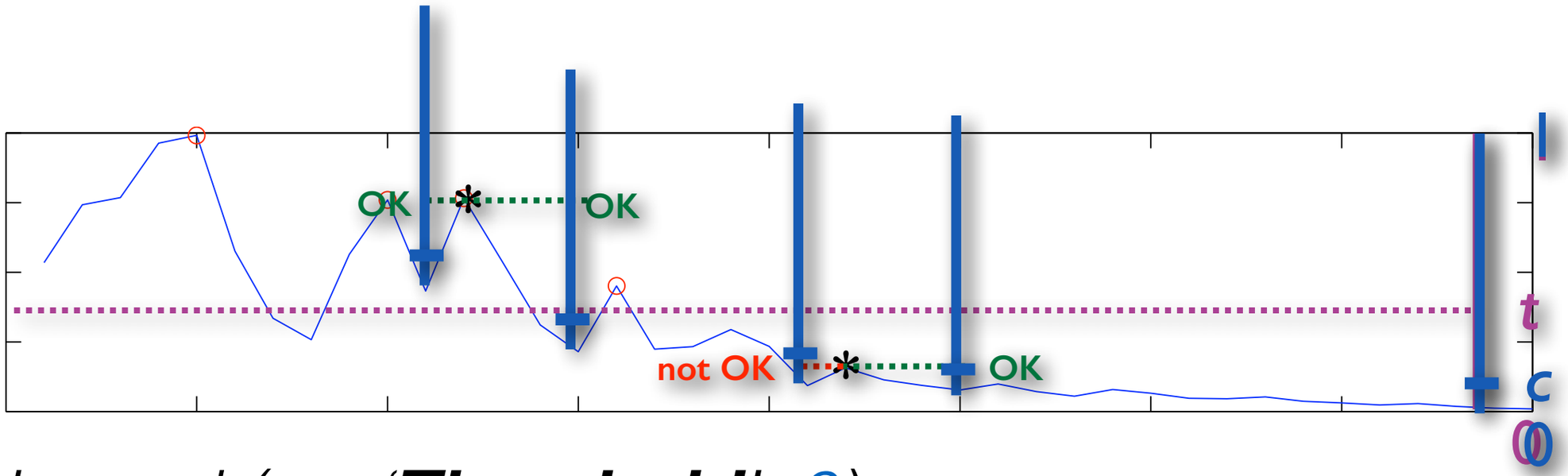




sig.peaks
peak picking

- *sig.peak(…, '**Total**', Inf)* Number of peaks
- Border effects:
  - *sig.peak(…, '**NoBegin**')* First sample excluded
  - *sig.peak(…, '**NoEnd**')* Last sample excluded
- *sig.peak(…, '**Order**', o)* Ordering of peaks
  - o = '***Amplitude***' From highest to lowest
  - o = '***Abscissa***' Along the abscissa axis
- *sig.peak(…, 'Valleys')* Local minima

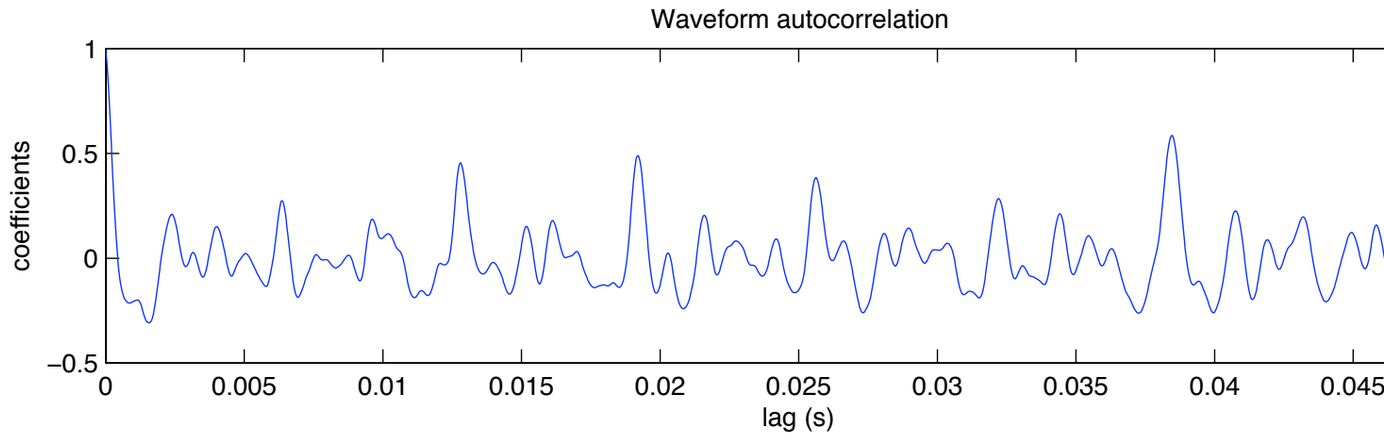
sig.peaks
peak picking



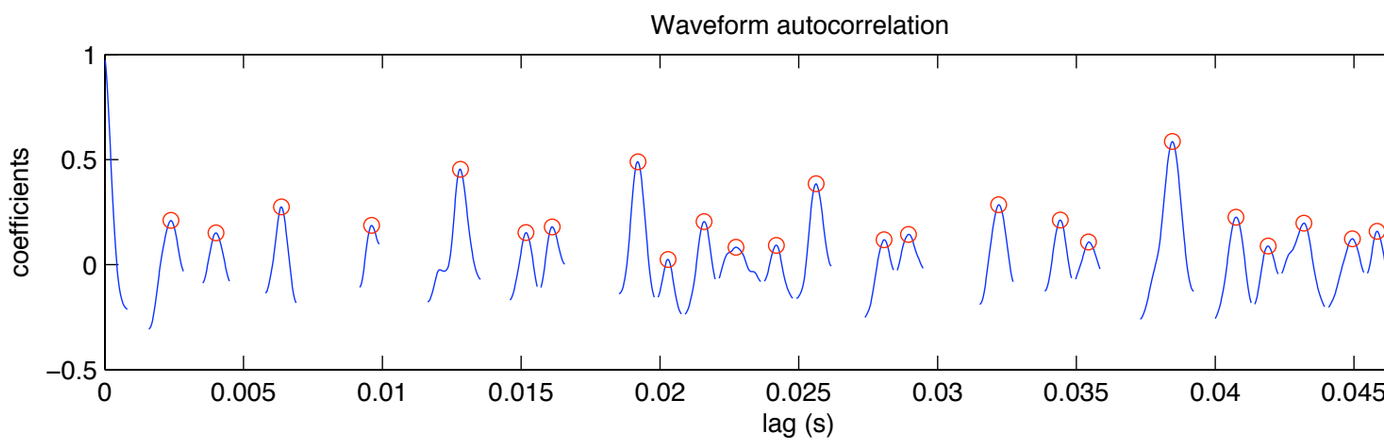
- *sig.peak(…, '**Threshold**', 0)*
- *sig.peak(…, '**Contrast**', .1)*
- *sig.peak(…, '**SelectFirst**', .05)*
- *mus.peak(…, '**Reso**', '**SemiTone**')*

sig.peaks
peak picking

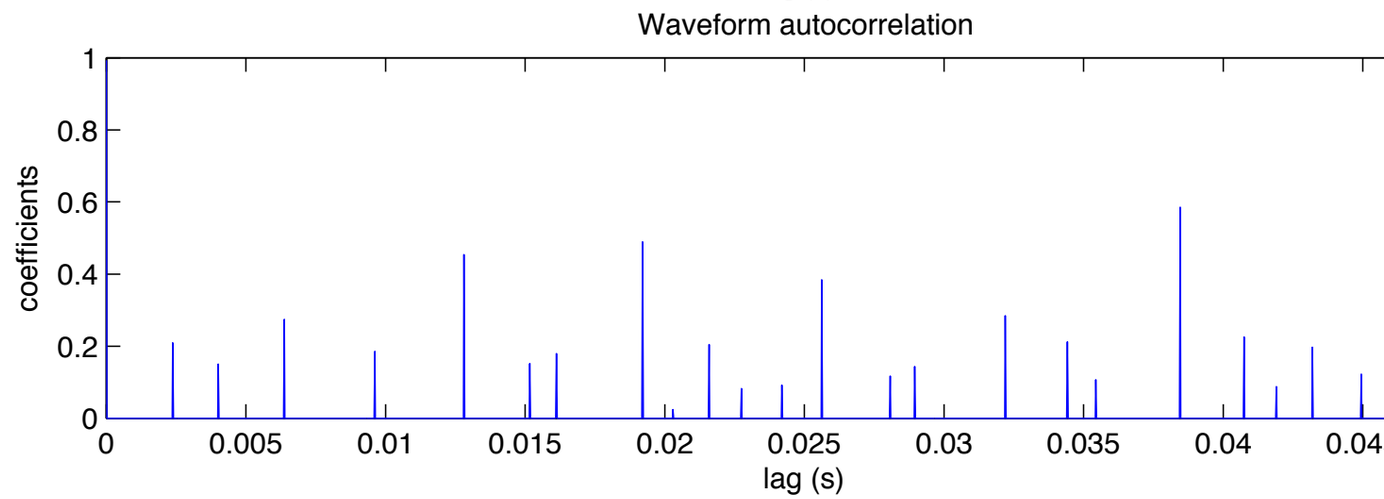
- *sig.peak(…)*



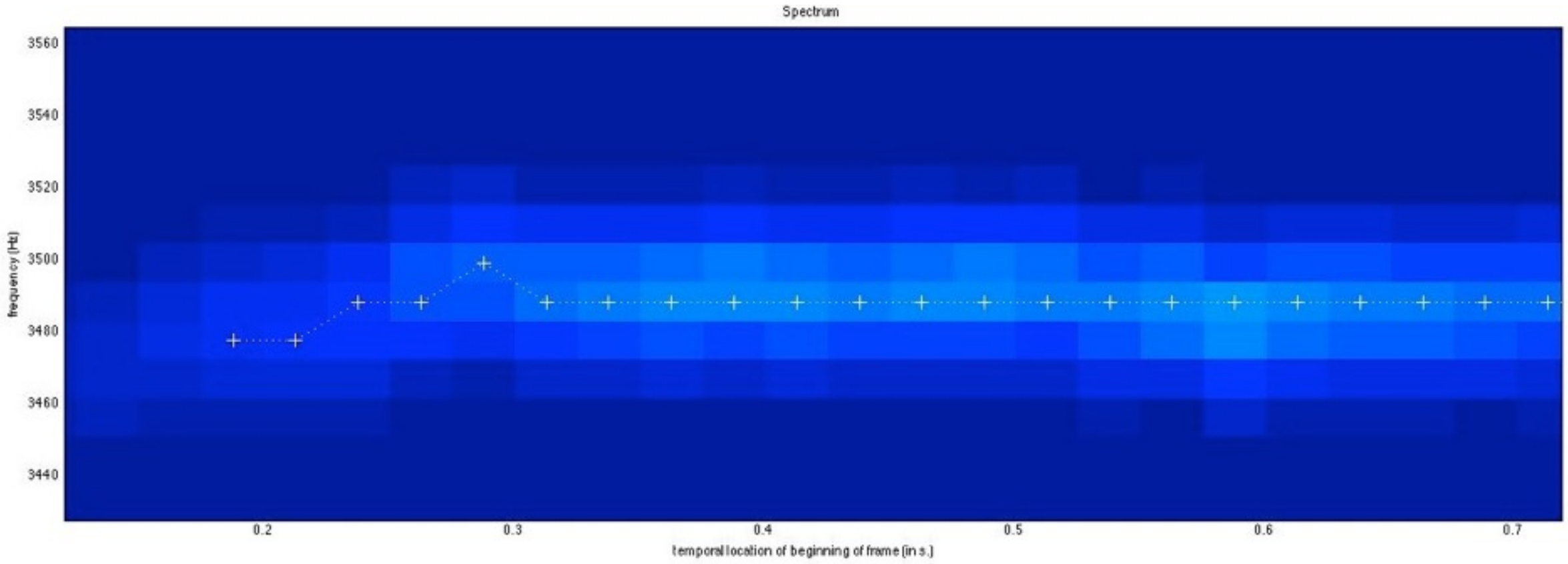
- *sig.peak(…, ‘**Extract**’)*



- *sig.peak(…, ‘**Only**’)*



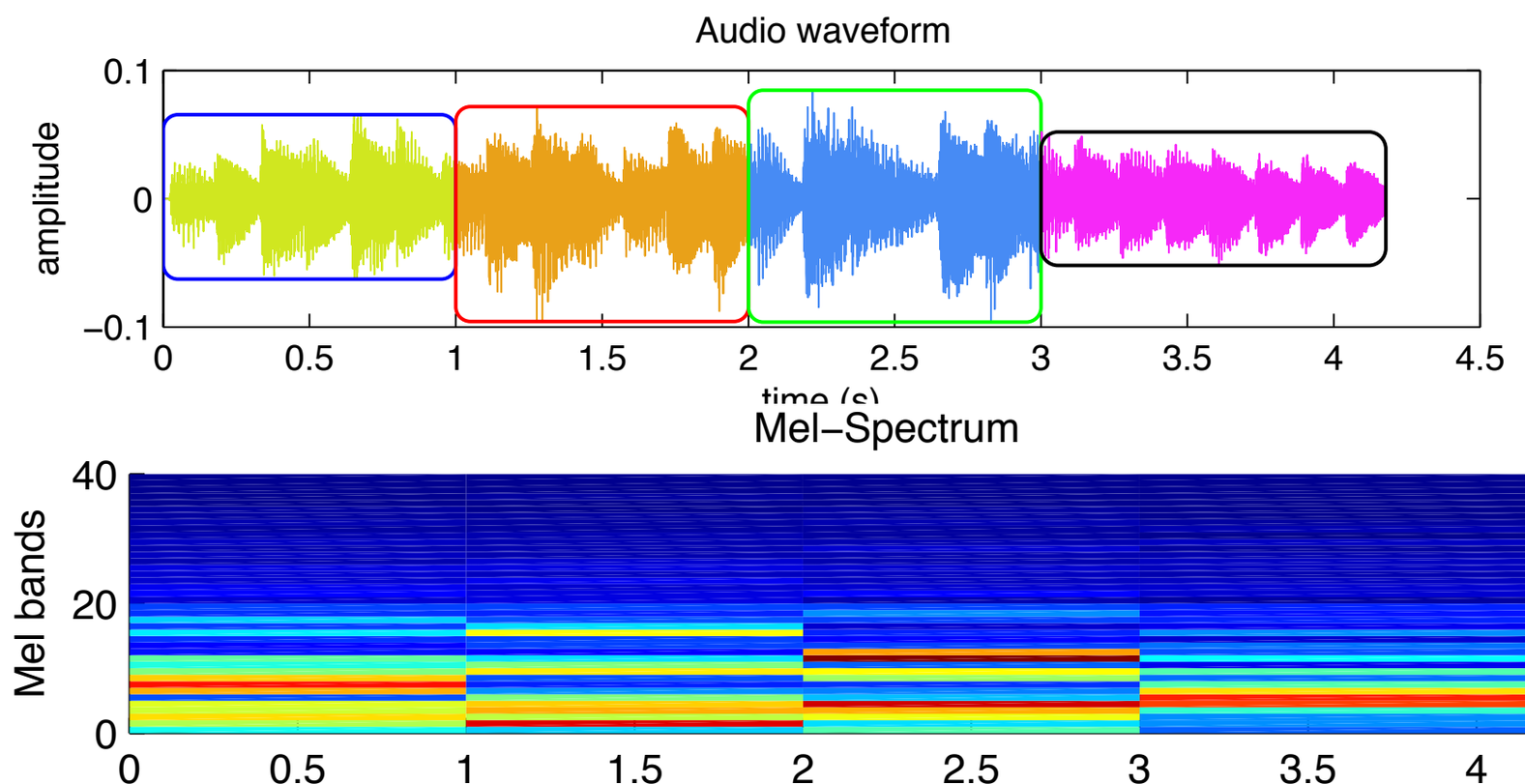
sig.peaks(…, 'Track')
peak tracking



McAulay, R.; Quatieri, T. (1996). "Speech analysis/Synthesis based on a sinusoidal representation", IEEE Transactions on Acoustics, Speech and Signal Processing, 34:4, 744–754.

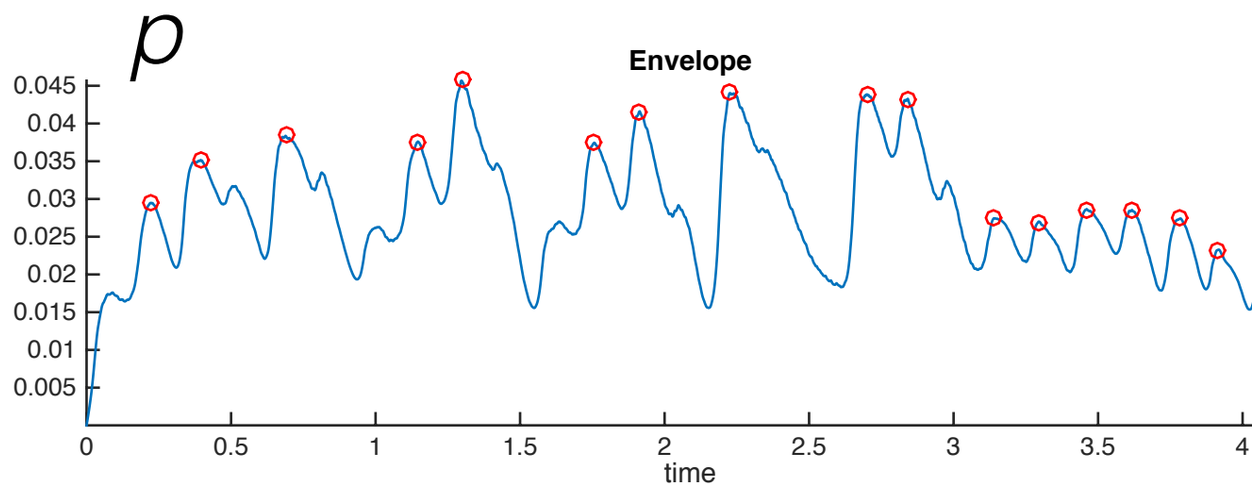
sig.segment segmentation

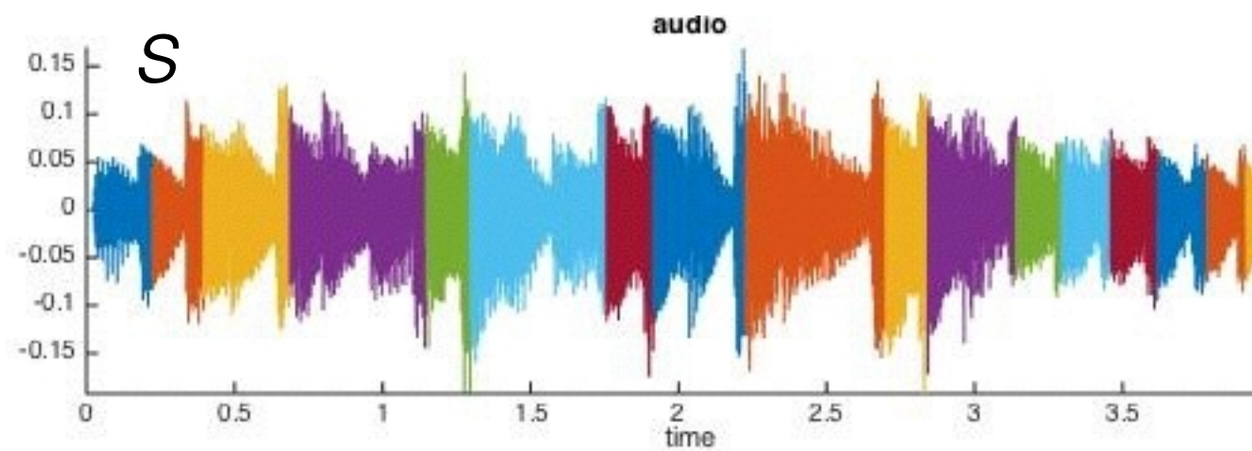
- *s = sig.segment('myfile', [1 2 3])*
- *s.play(1:2)*
- *s.save*
- *sig.spectrum(s)*



sig.segment
segmentation

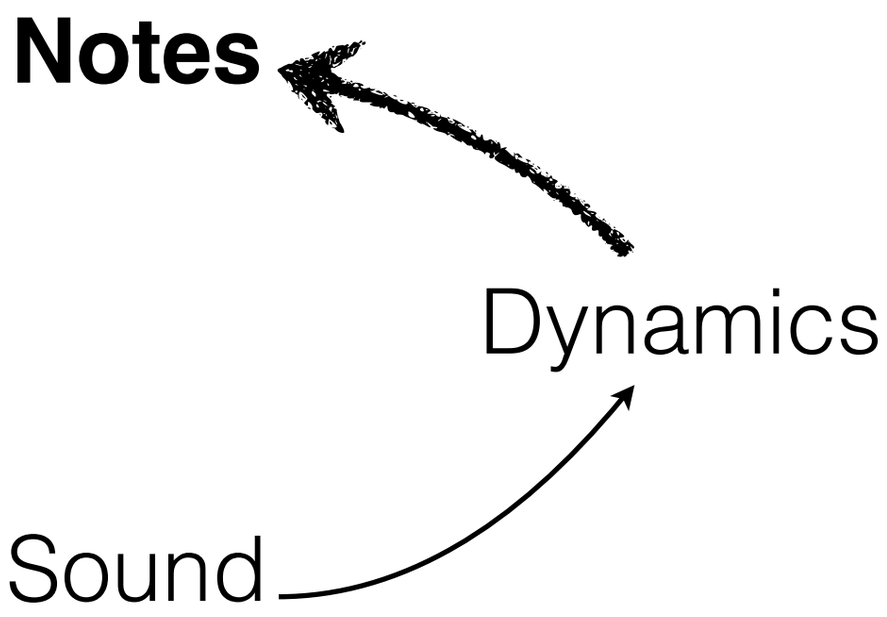
- *e = sig.envelope(‘myfile’)*
- *p = sig.peaks(e)*
- *s = sig.segment(‘myfile’, p)*





Symbolic level

Audio level

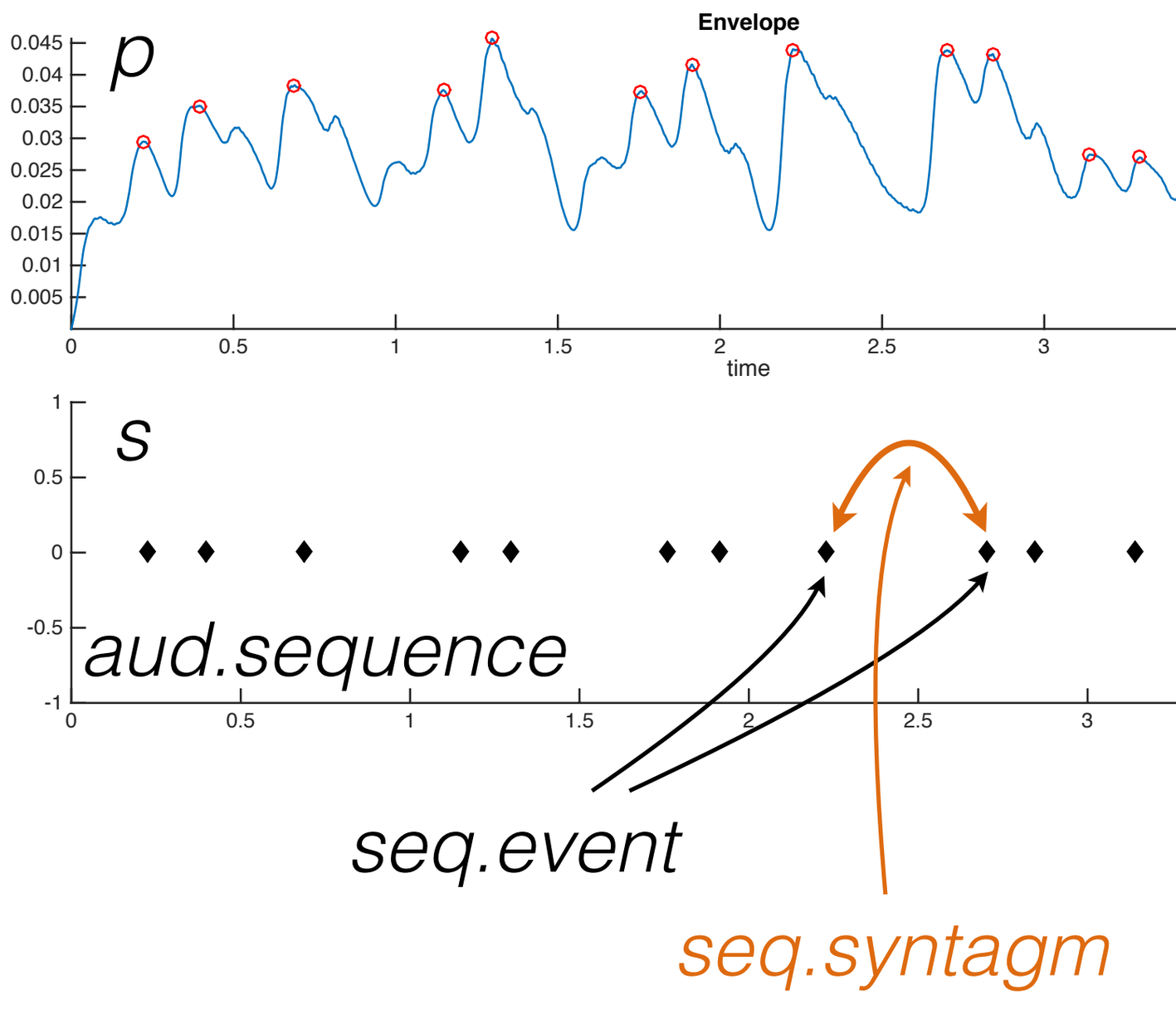


aud.score
onset detection

- *e = sig.envelope('myfile')*
- *p = sig.peaks(e, 'Contrast', .1)*
- *s = aud.score(p)*

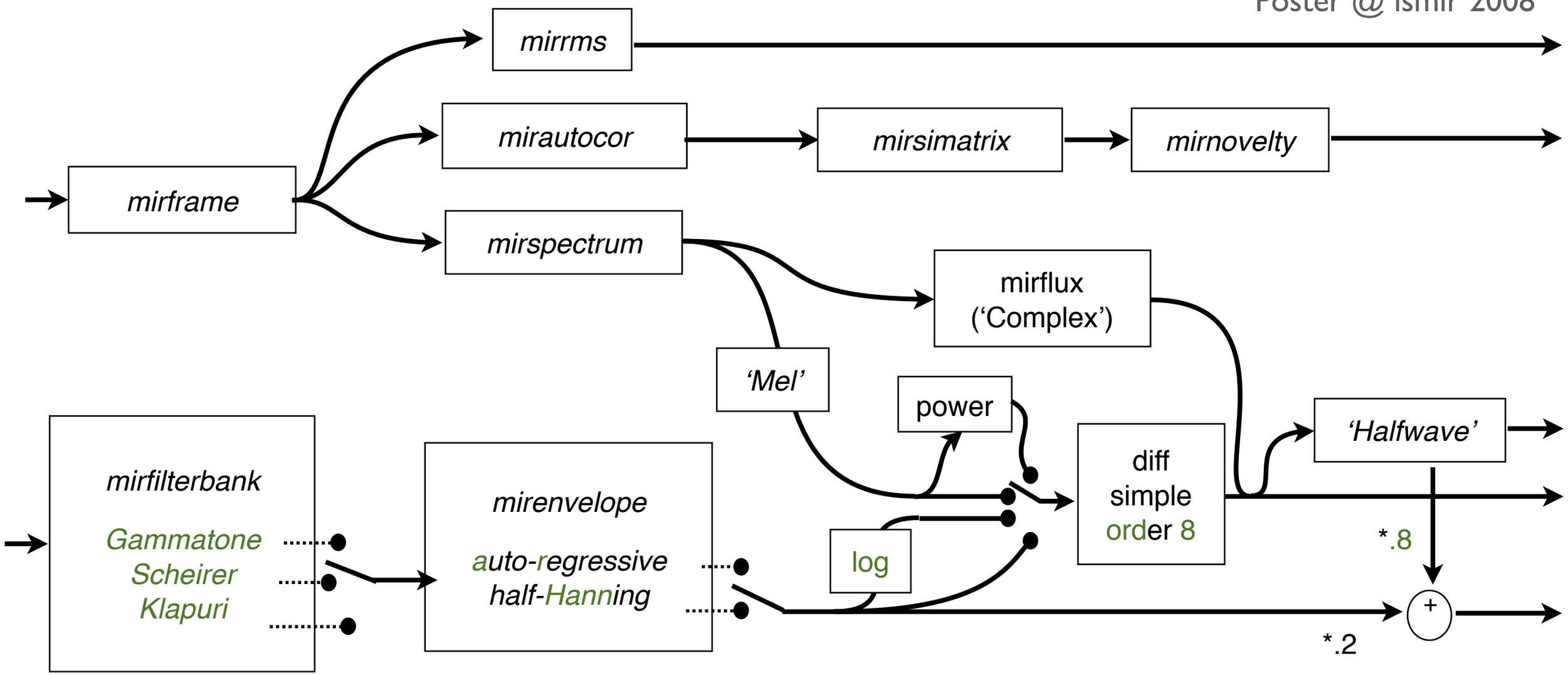
In short:

- *[s p] = aud.score('myfile', **Contrast**', .1)*



mironsets
onset detection

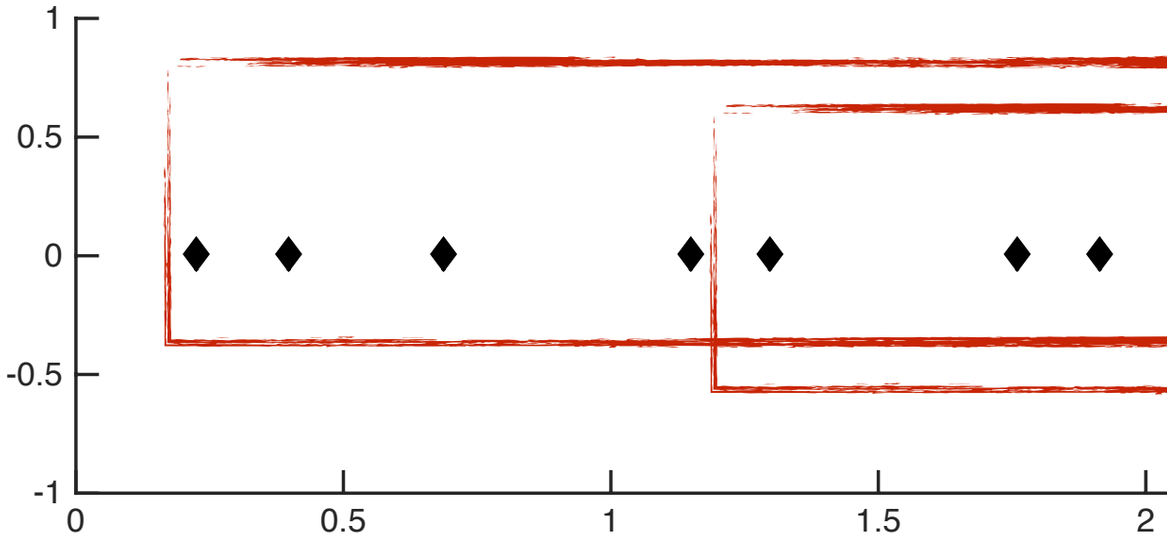
Poster @ ismir 2008

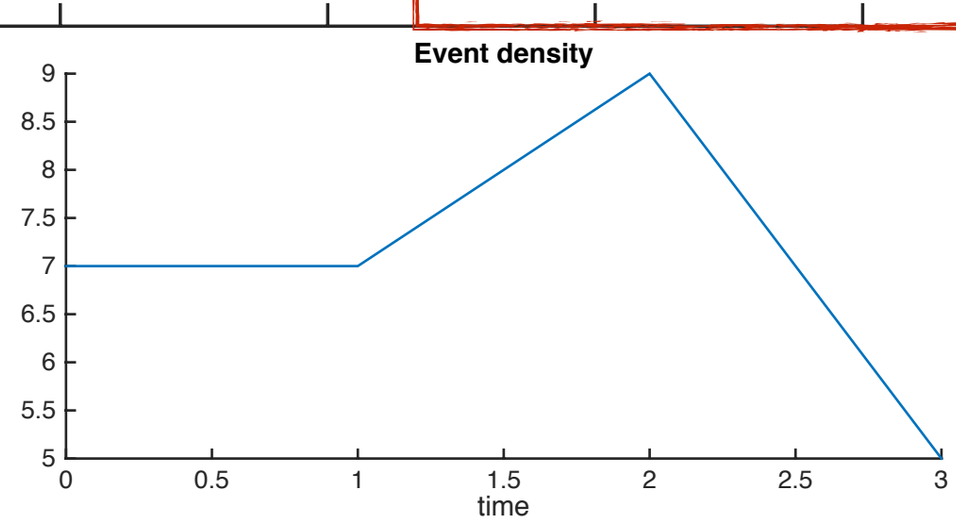


*aud.score(…, '**Scheirer**')*

*aud.score(…, '**Klapuri**')*

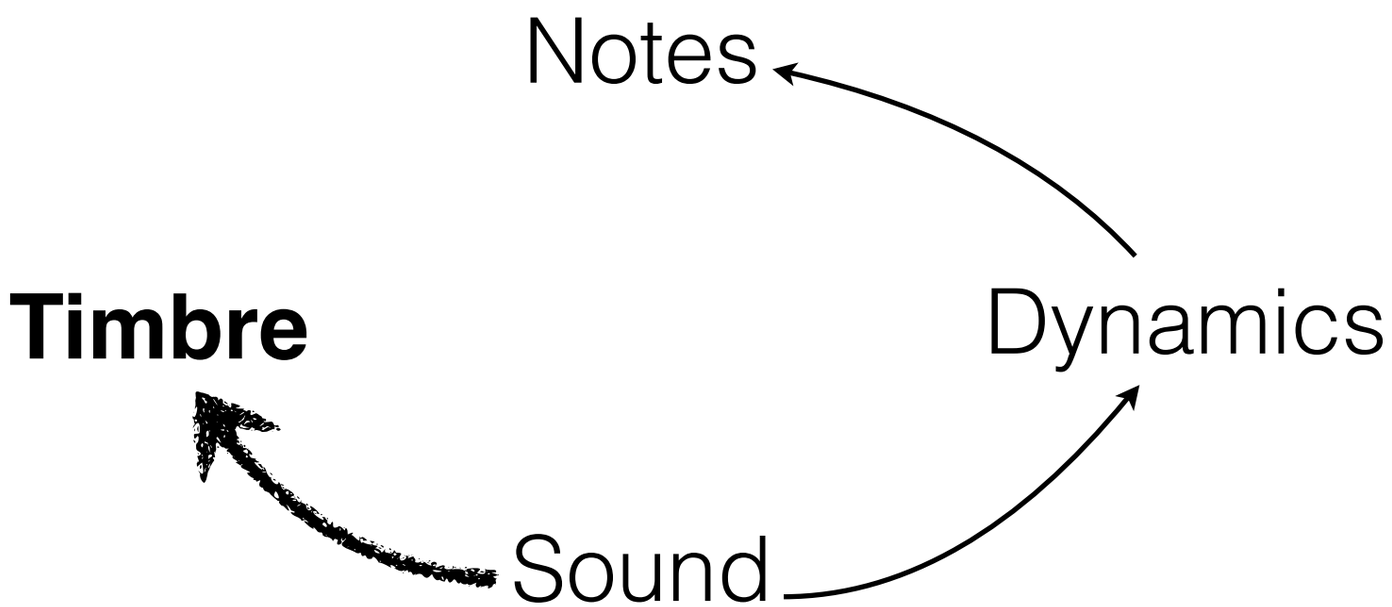
aud.eventdensity
temporal density of events



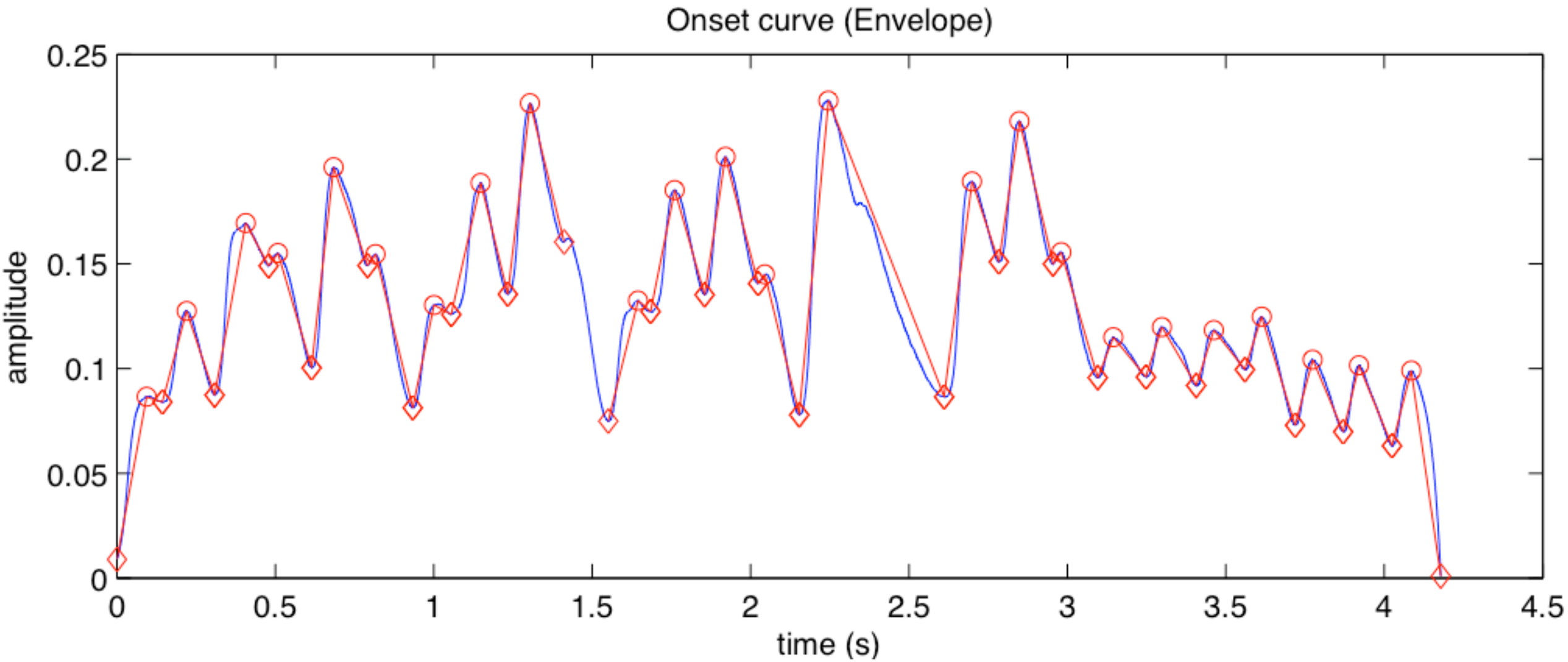


- a = aud.score('audio.wav')
- aud.eventdensity(a)
- aud.eventdensity('audio.wav', 'Frame')
- aud.eventdensity('score.mid')

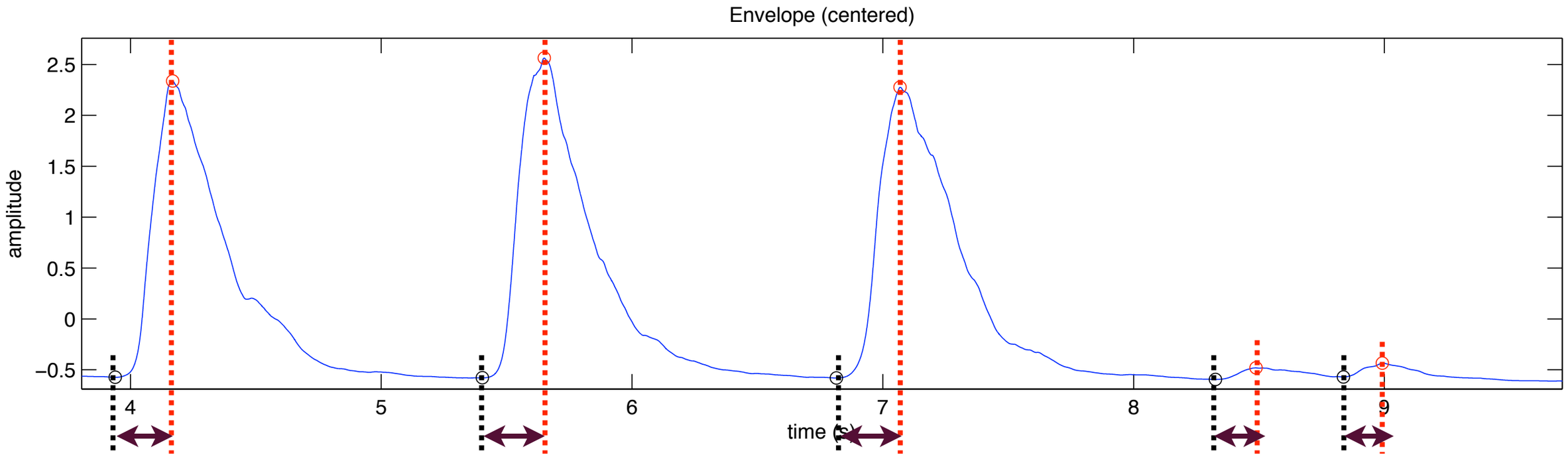
Audio level



aud.score(…, ‘Attack’, ‘Release’)



aud.attacktime
duration of note attacks

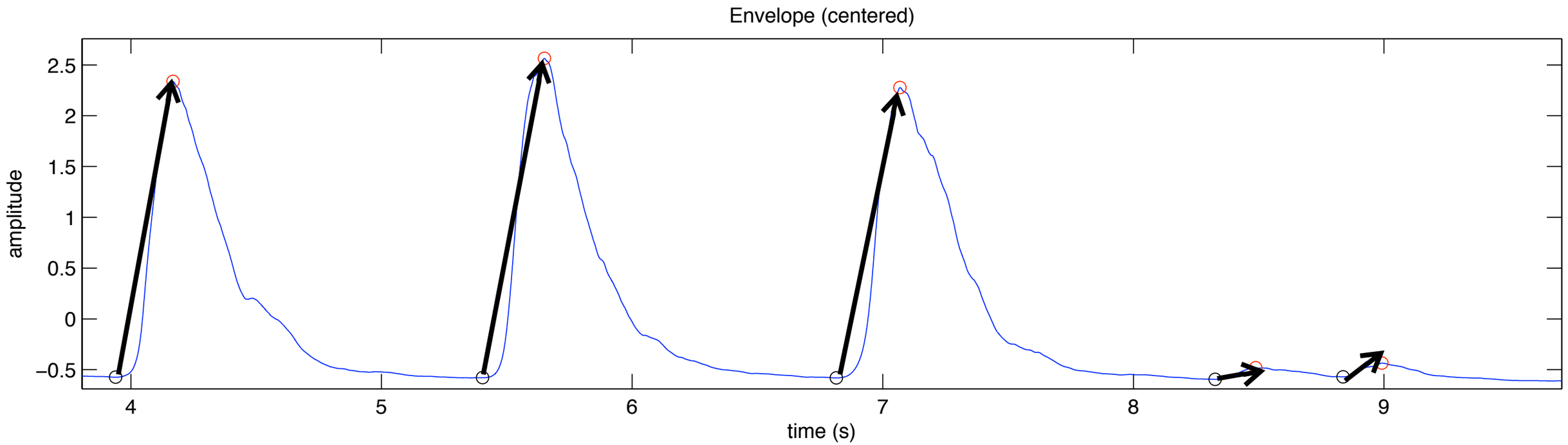


- *aud.attacktime(…, '**Lin**')*: duration in seconds

- *aud.attacktime(…, '**Log**')*: duration in log scale

Krimphoff, J., McAdams, S. & Winsberg, S. (1994), Caractérisation du timbre des sons complexes. II : Analyses acoustiques et quantification psychophysique. Journal de Physique, 4(C5), 625-628.

aud.attackslope
average slope of note attacks

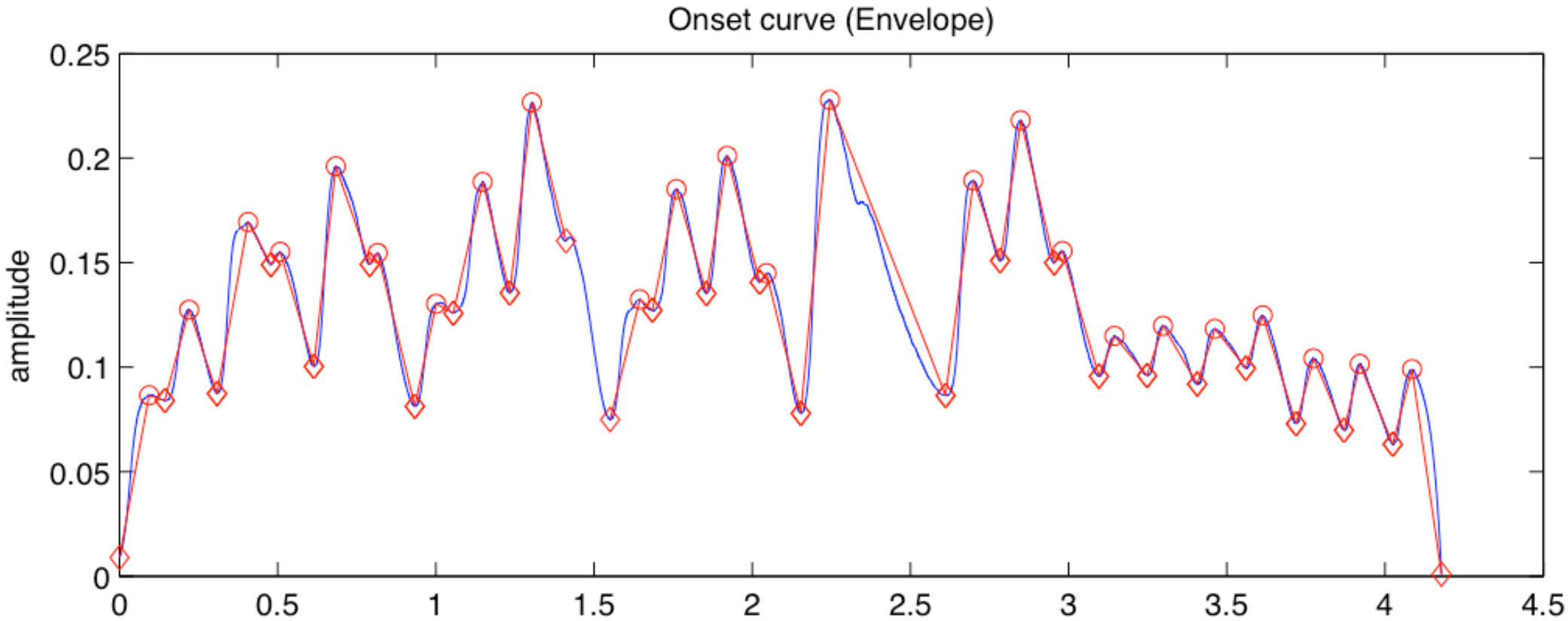


- *mirattackslope(..., '**Diff**')*: average slope

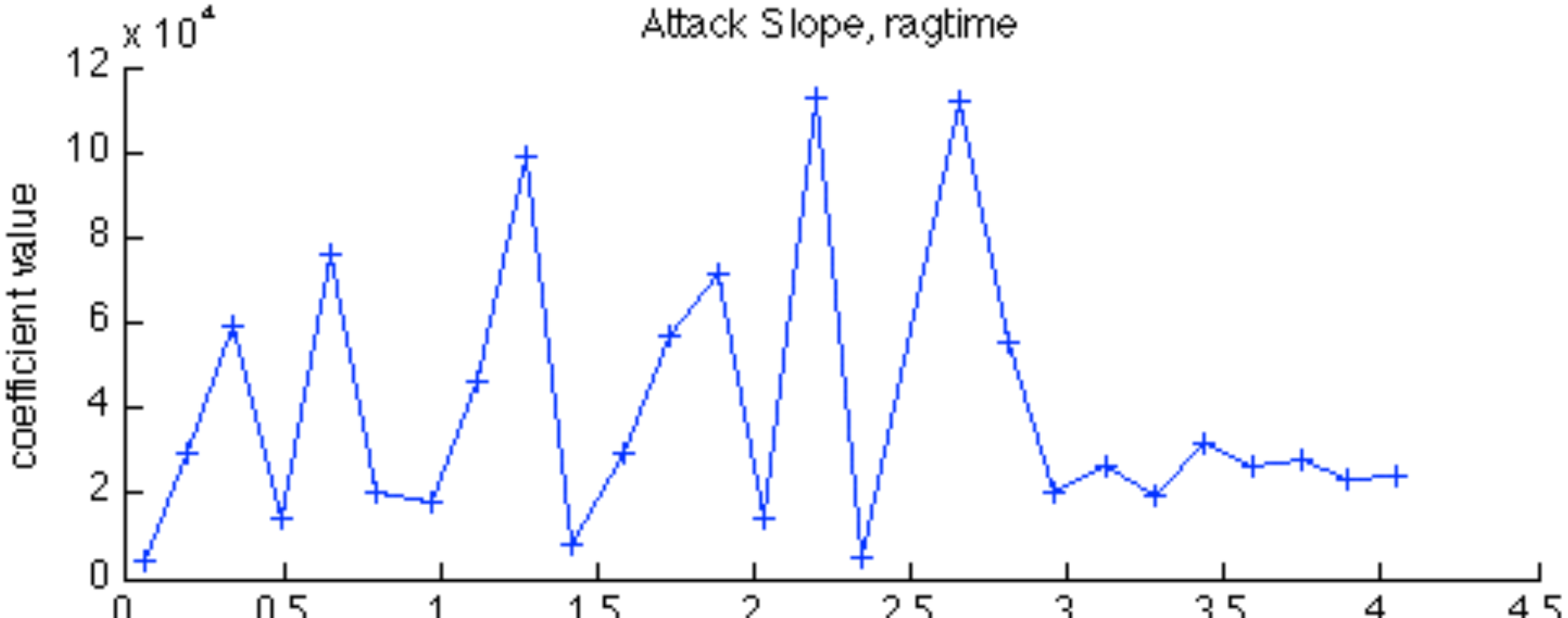
- *mirattackslope(..., '**Gauss**')*: gaussian average, highlighting the middle of the attack phase

Peeters. G. (2004). A large set of audio features for sound description (similarity and classification) in the CUIDADO project. version 1.0

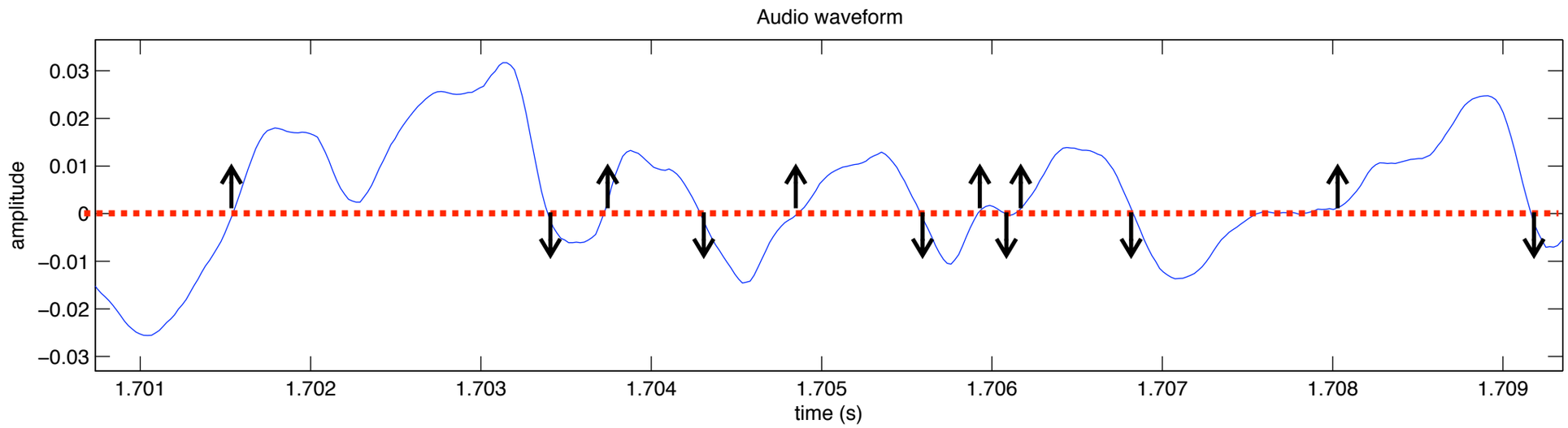
- *o = aud.onsets('audiofile', 'Attack', 'Release')*



- *aud.attackslope(o)*

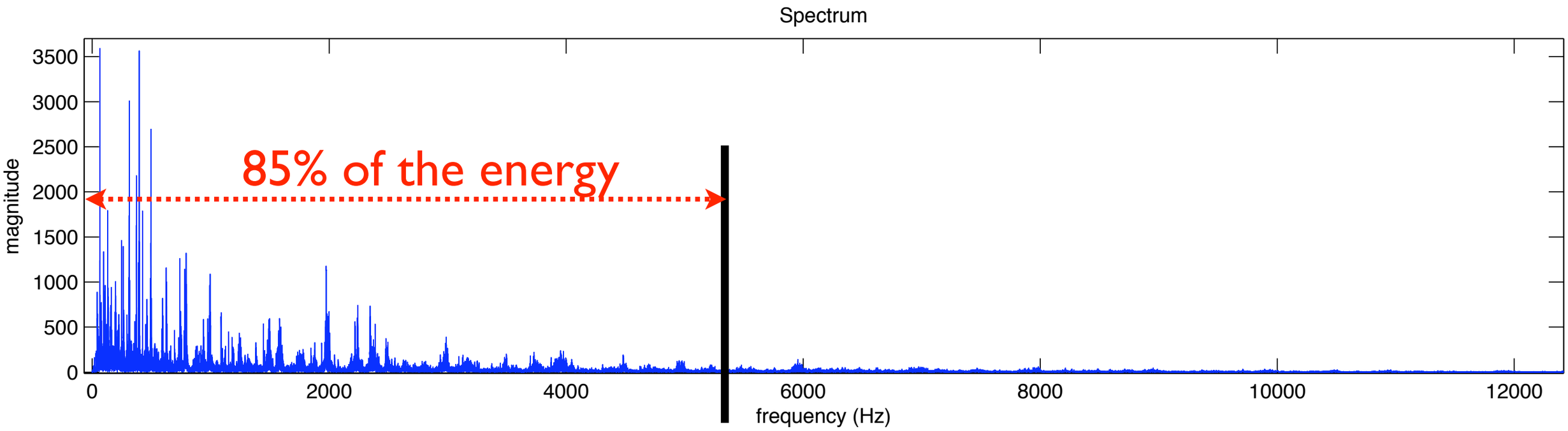


sig.zerocross
waveform sign-change rate



- Indicator of noisiness
- sig.zerocross(…, ‘**Per**’, ‘**Second**’): rate per second
- sig.zerocross(..., ‘Per’, ‘**Sample**’): rate per sample
- sig.zerocross(..., ‘**Dir**’, ‘**One**’): only ↑ or ↓
- sig.zerocross(..., ‘Dir’, ‘**Both**’): both ↑ and ↓

sig.rolloff
high-frequency energy (I)

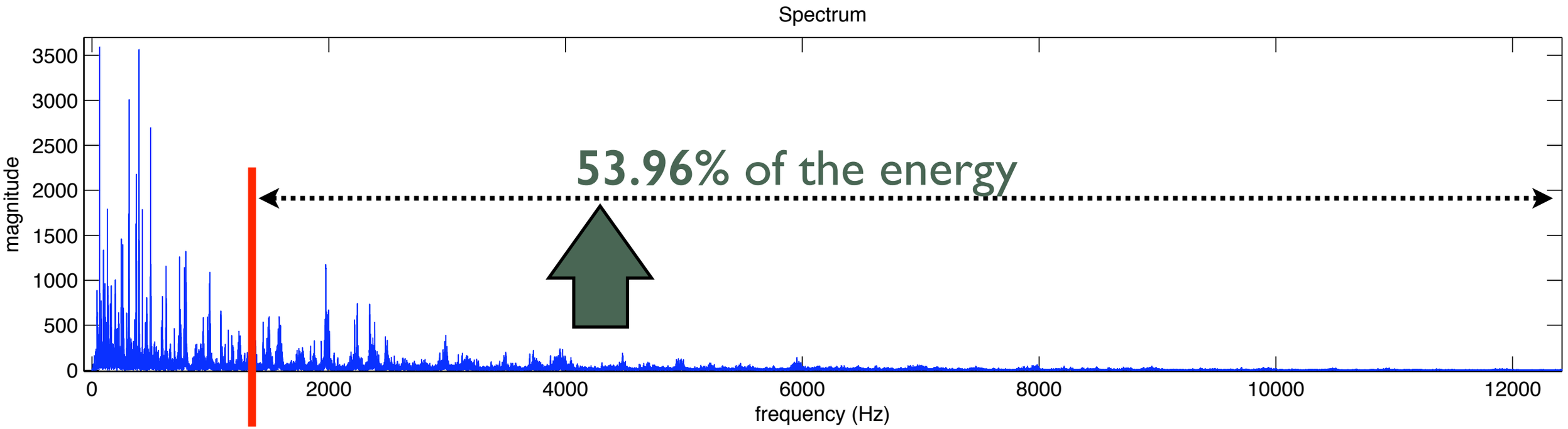


*sig.rolloff(…, '**Threshold**', .85)*

th=**.85** in Tzanetakis, Cook. Musical genre classification of audio signals. IEEE Tr. Speech and Audio Processing, 10(5),293-302, 2002.

th=**.95** in Pohle, Pampalk, Widmer. Evaluation of Frequently Used Audio Features for Classification of Music Into Perceptual Categories, ?

aud.brightness
high-frequency energy (II)



- *aud.brightness(…, '**CutOff**', 1500)* (in Hz)

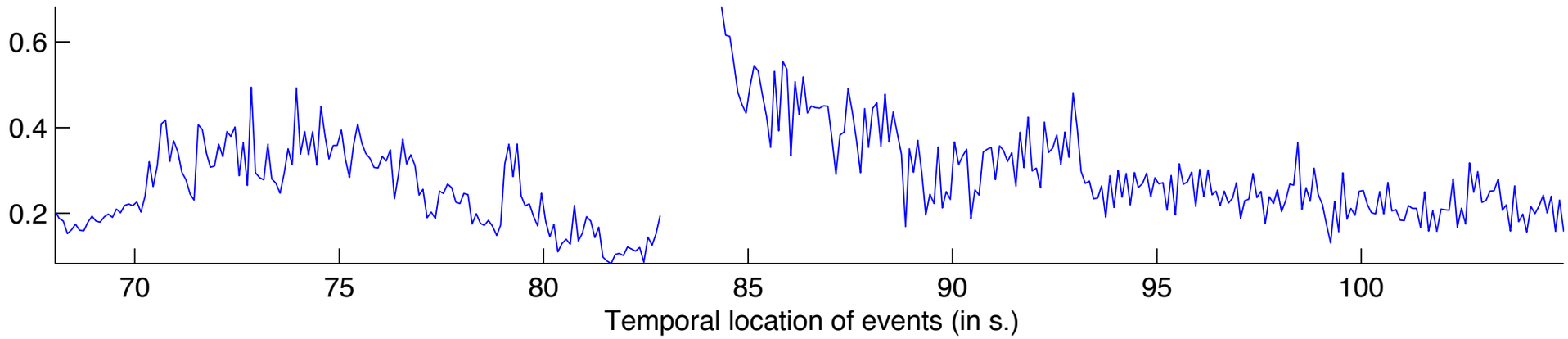
- *aud.brightness(..., '**Unit**', u)* u = *'/1'* or *'%'*

3000 Hz in Juslin 2001, p. 1802.
1500 Hz and **1000 Hz** in Laukka, Juslin and Bresin 2005.

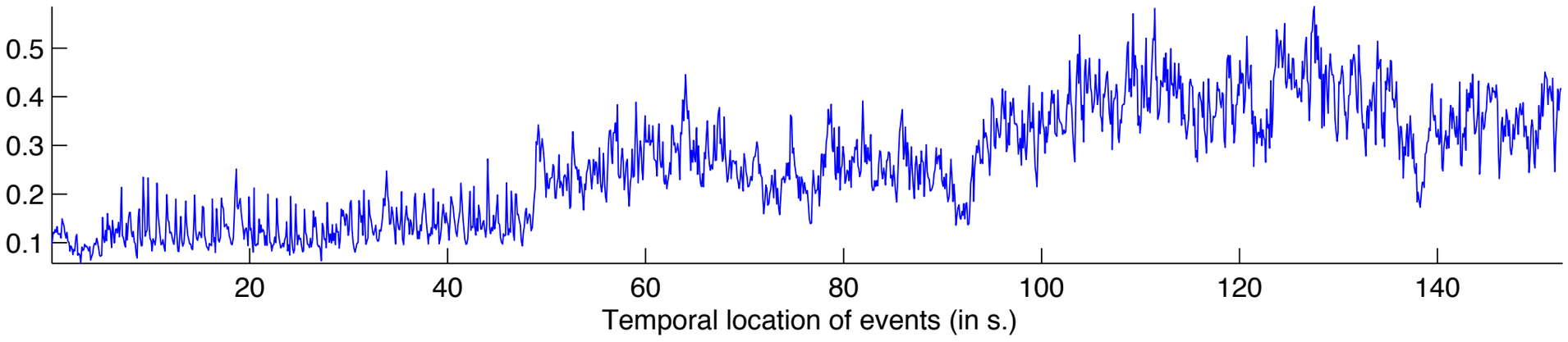
aud.brightness high-frequency energy (II)

- *aud.brightness(…, '**Frame**')*

frame length = .05 s
frame hop = 50%

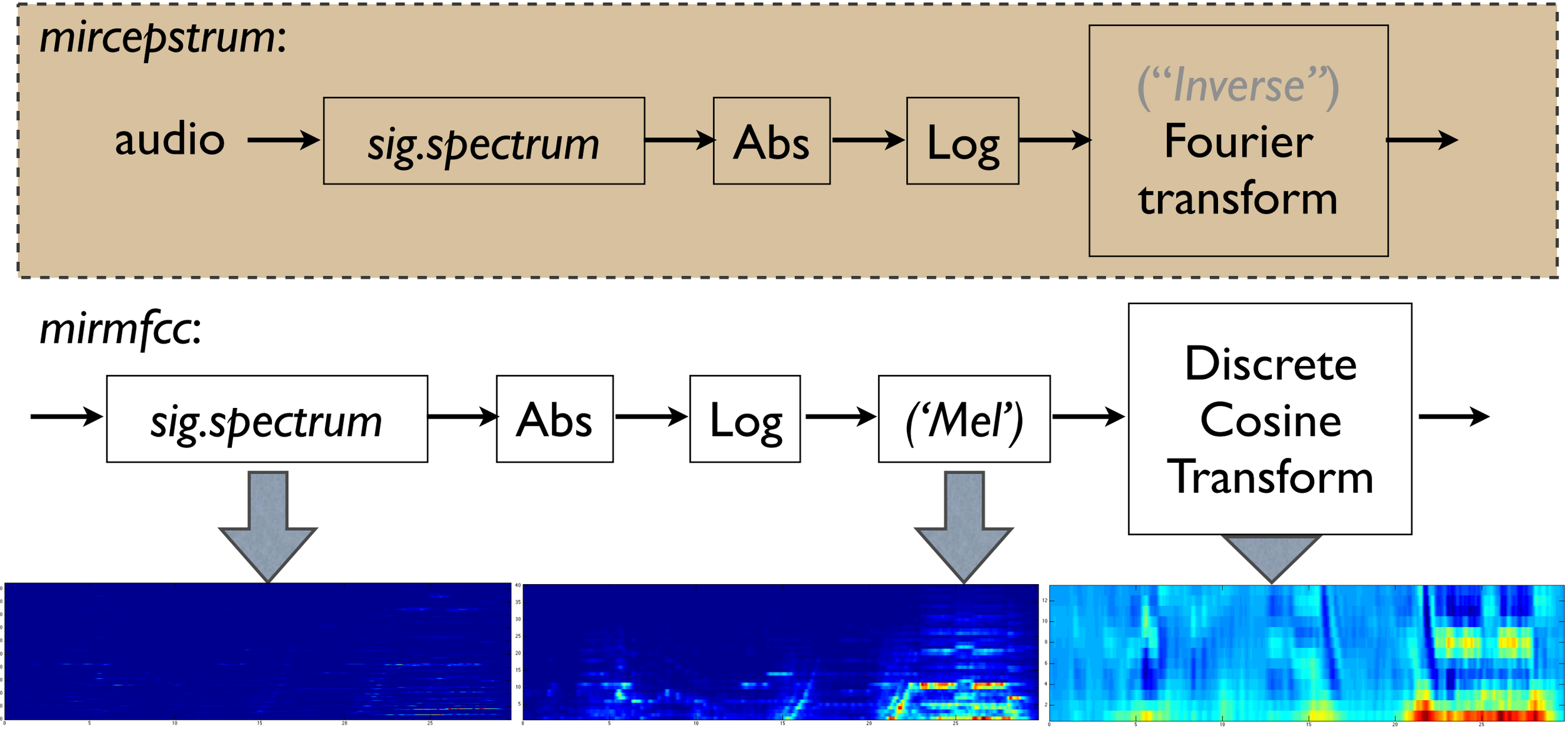


Beethoven, 9th Symphony, *Scherzo*



Beethoven, 7th Symphony, *Allegretto*

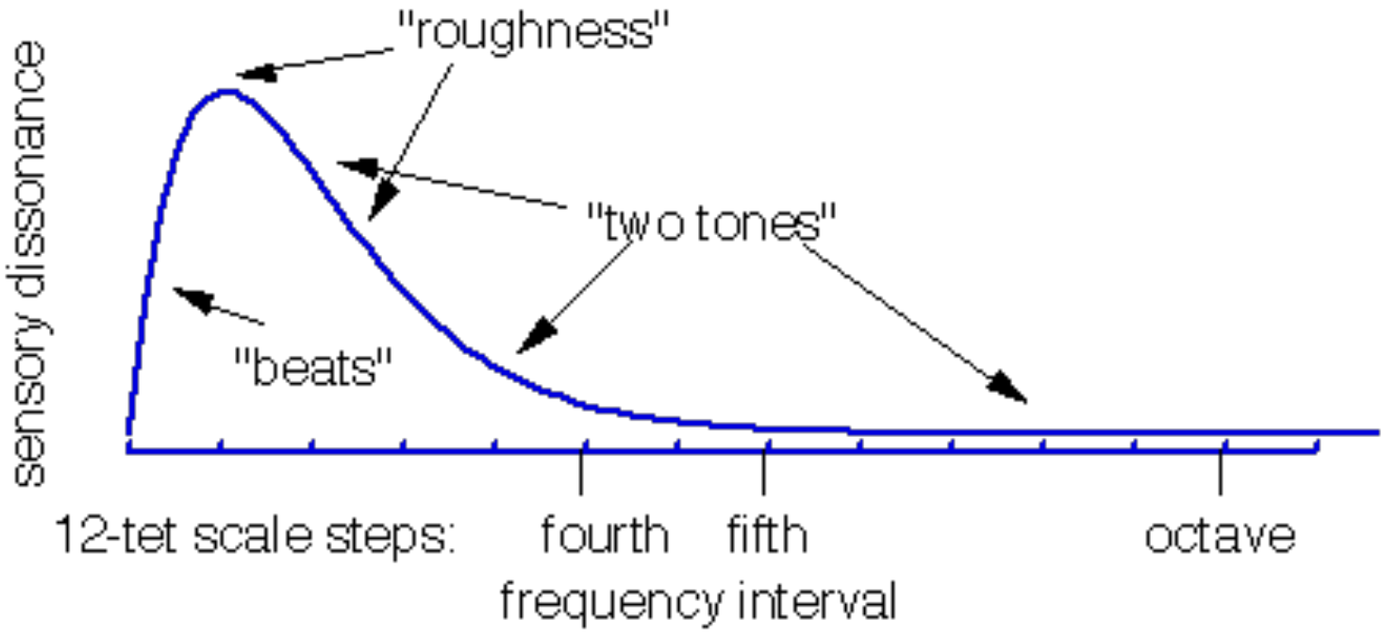
aud.mfcc
mel-frequency cepstral coefficients



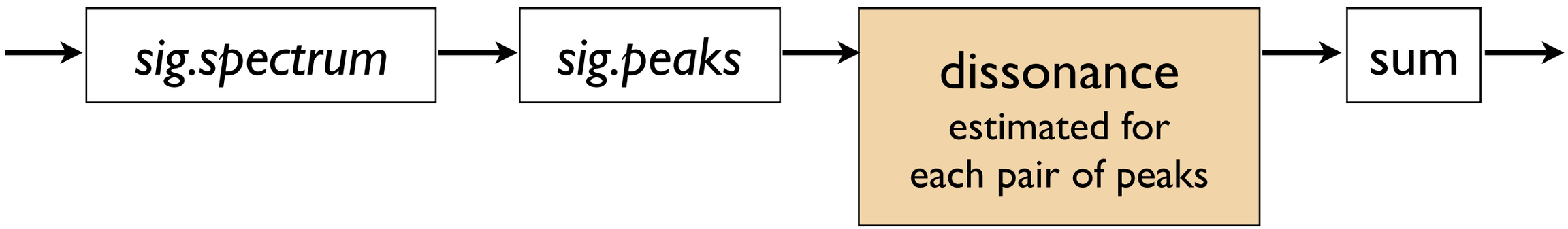
- Description of spectral shape

aud.roughness sensory dissonance

- *aud.roughness(…, '**Sethares**')*

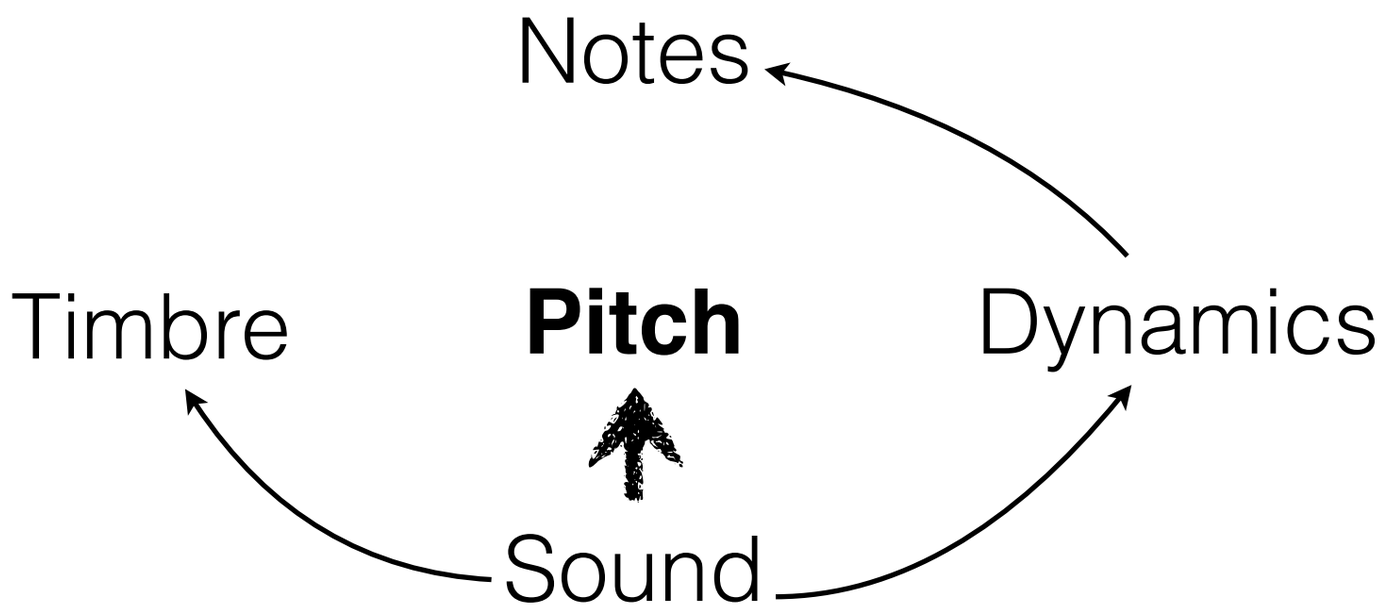


Dissonance produced by two sinusoids depending on their frequency ratio

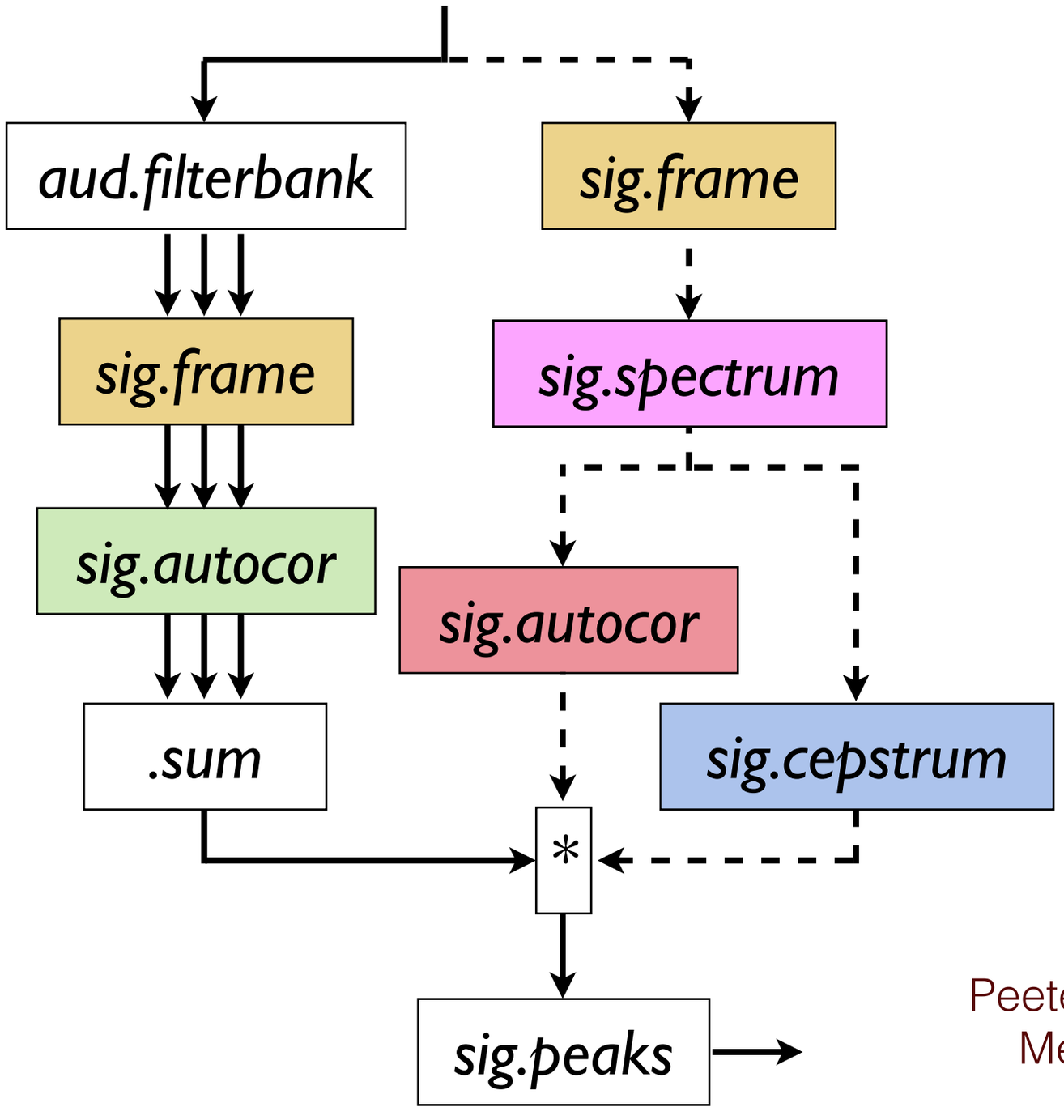


Plomp & Levelt "Tonal Consonance and Critical Bandwidth" Journal of the Acoustical Society of America, 1965.
Sethares, W. A. (1998). Tuning, Timbre, Spectrum, Scale, Springer-Verlag.

Audio level



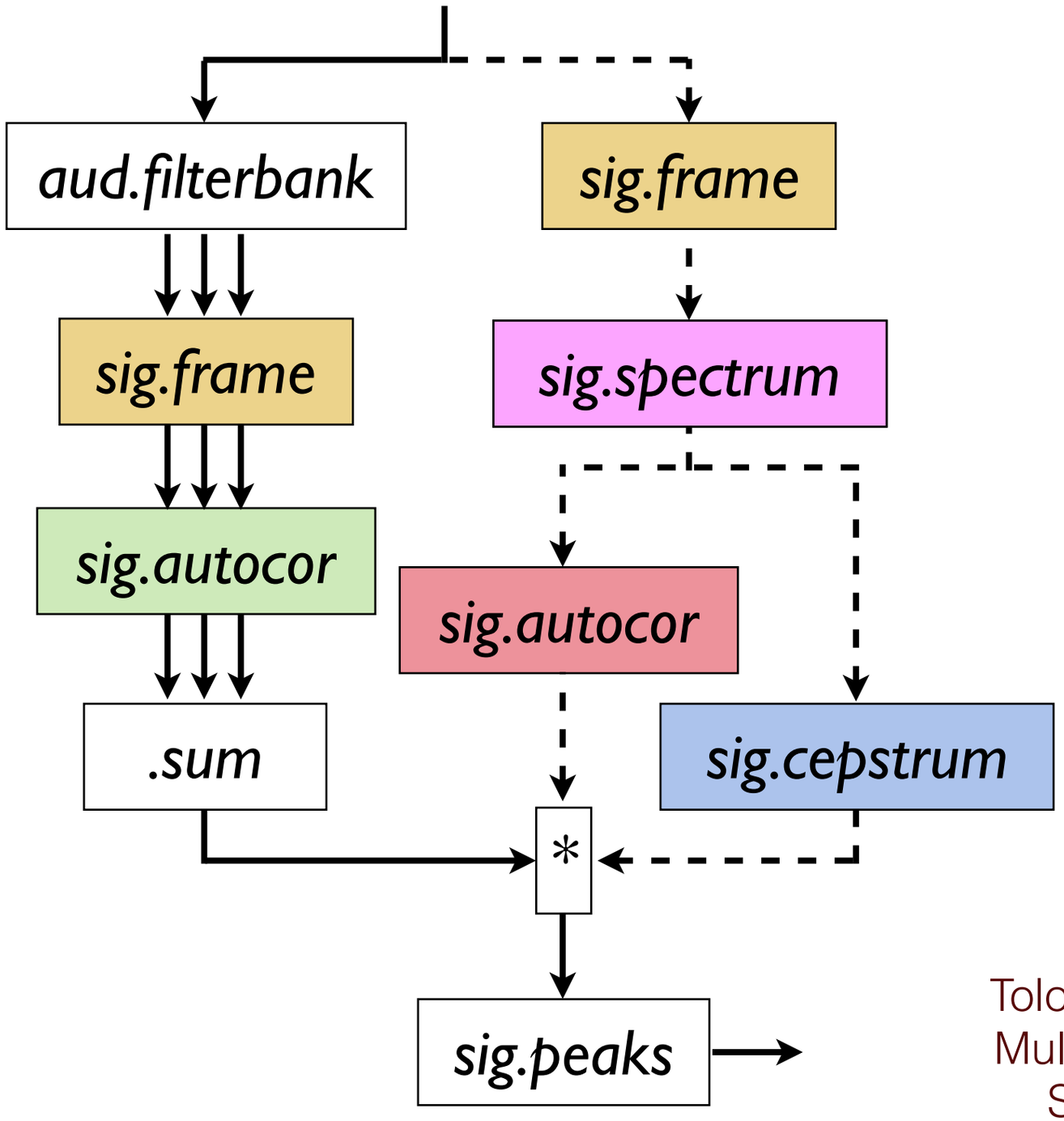
aud.pitch
f0 estimation



- *p = aud.pitch(…, '**Autocor**')*
- *aud.pitch(…, '**AutocorSpectrum**')*
- *aud.pitch(…, '**Cepstrum**')*
- *aud.pitch(…, '**Frame**',…)*

Peeters. Music Pitch Representation by Periodicity Measures Based on Combined Temporal and Spectral Representations. ICASSP 2006.

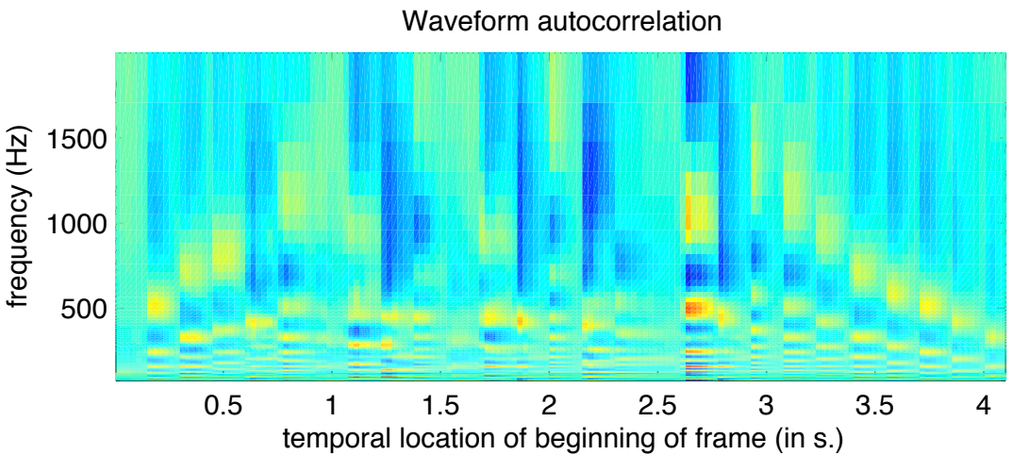
aud.pitch
f0 estimation



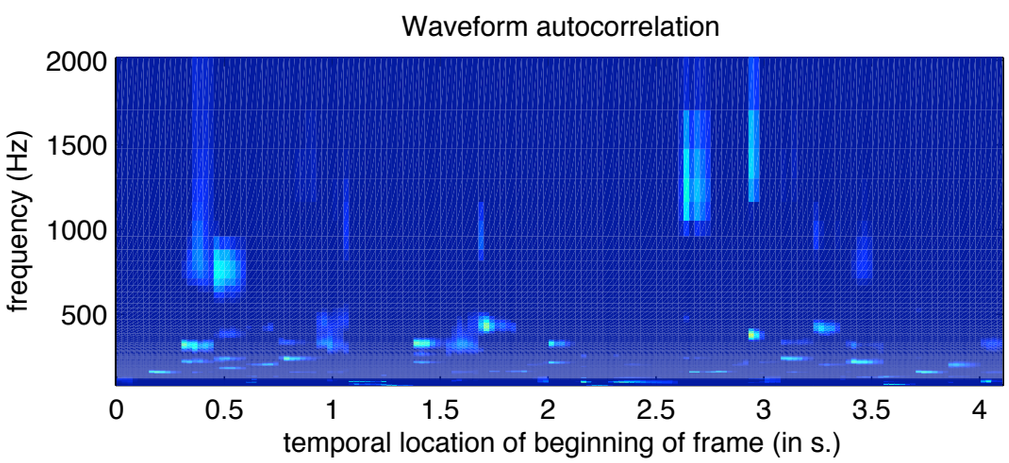
- *aud.pitch(…, '**Tolonen**')*
- *aud.pitch(…, '**2Channels**', '**Enhanced**', 2:10, '**Generalized**', .67)*

Tolonen, Karjalainen. A Computationally Efficient Multipitch Analysis Model. IEEE Transactions on Speech and Audio Processing, 8(6), 2000.

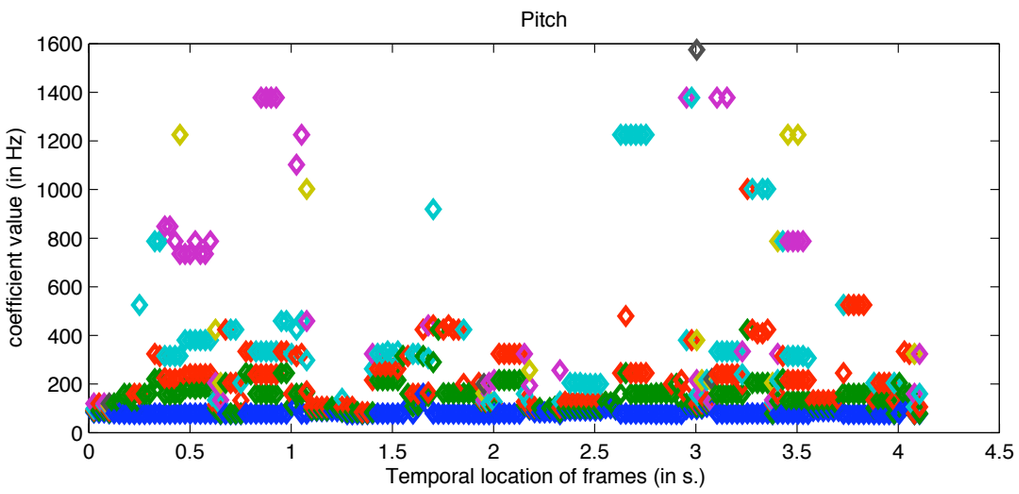
aud.pitch
f0 estimation



- *ac = sig.autocor('ragtime', 'Frame')*



- *ac = sig.autocor(ac, 'Enhanced', 2:10)*



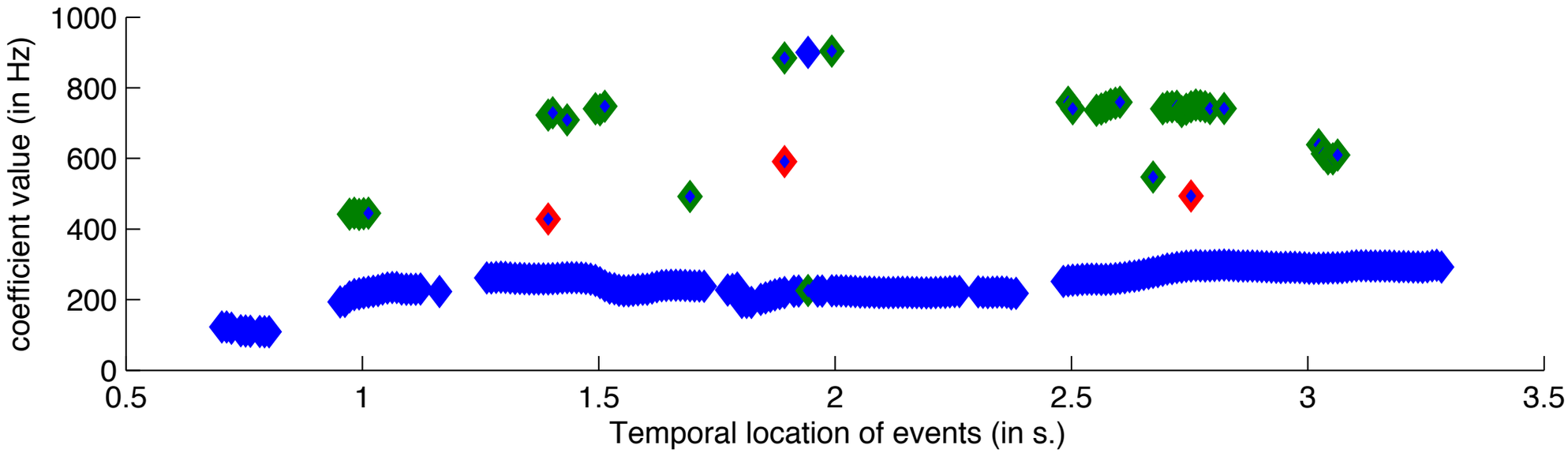
- *aud.pitch(ac)*

Tolonen, Karjalainen. A Computationally Efficient Multipitch Analysis Model. IEEE Transactions on Speech and Audio Processing, 8(6), 2000.

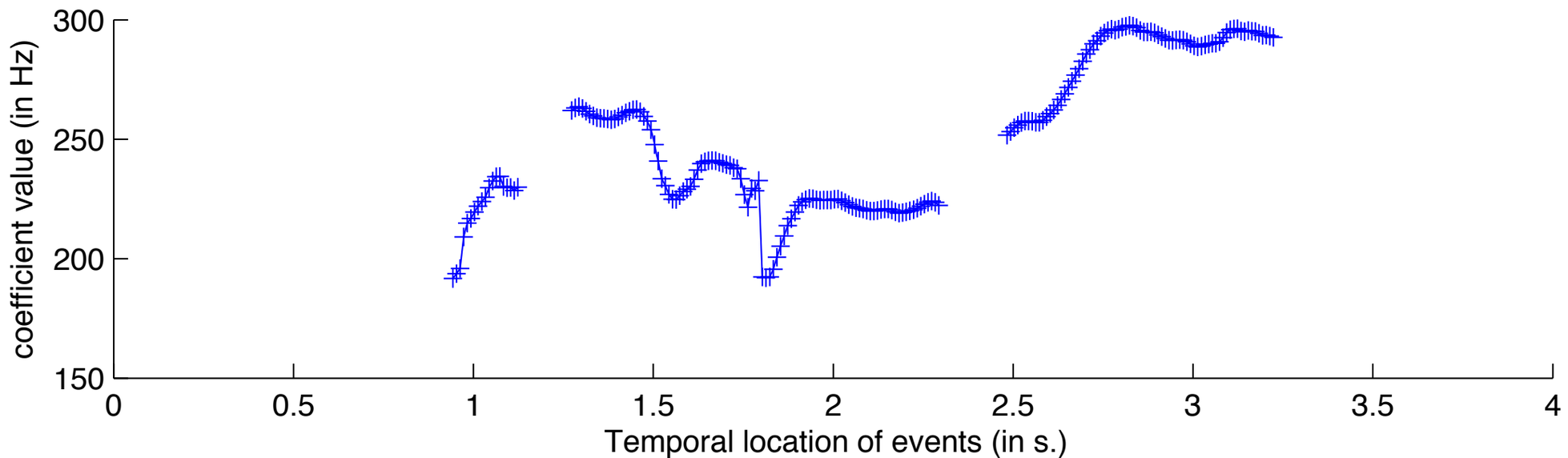
aud.pitch
f0 estimation

p.play
p.save

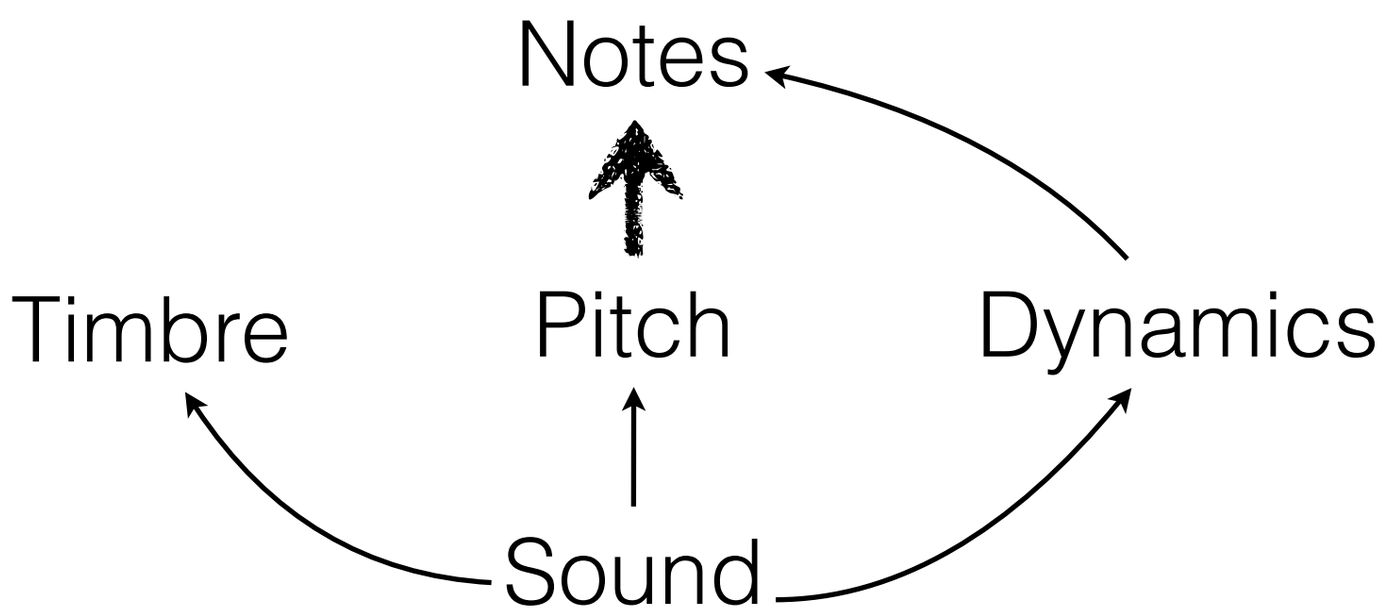
- aud.pitch(…, ‘Frame’)



- aud.pitch(…, ‘Frame’, ‘Total’, 1, ‘Max’, 400)

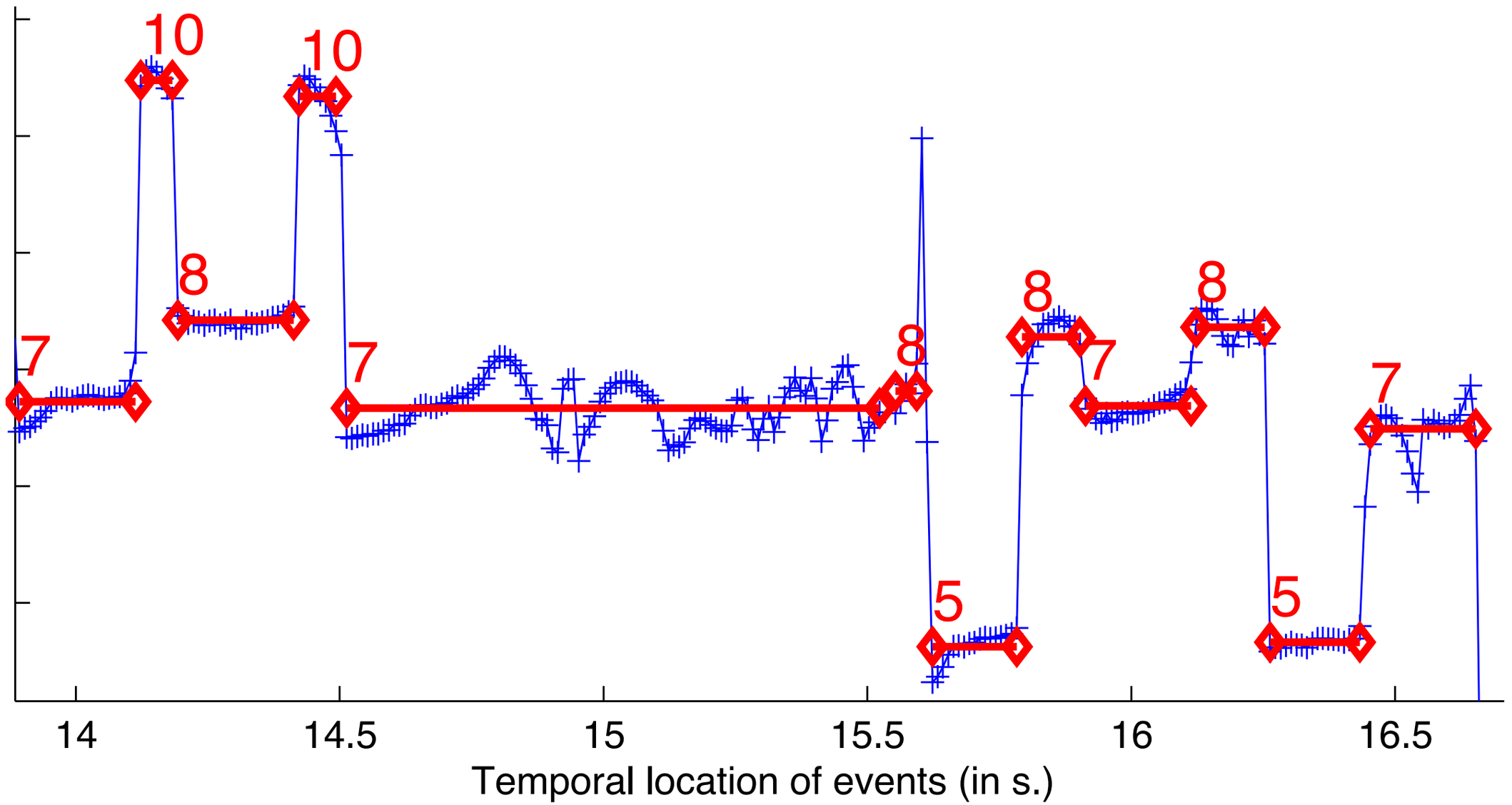


Symbolic level



Audio level

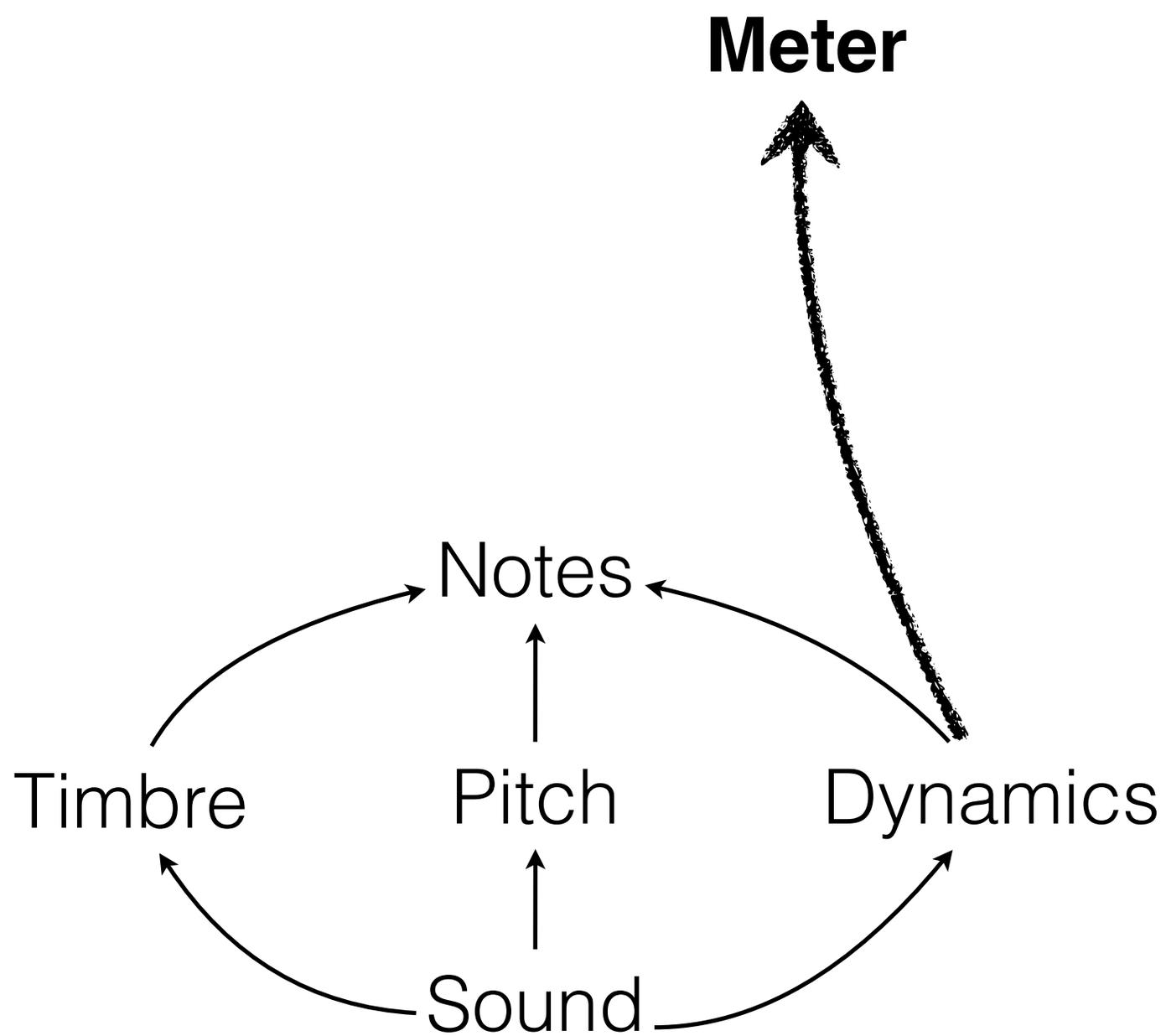
mus.pitch
pitch segmentation and discretisation



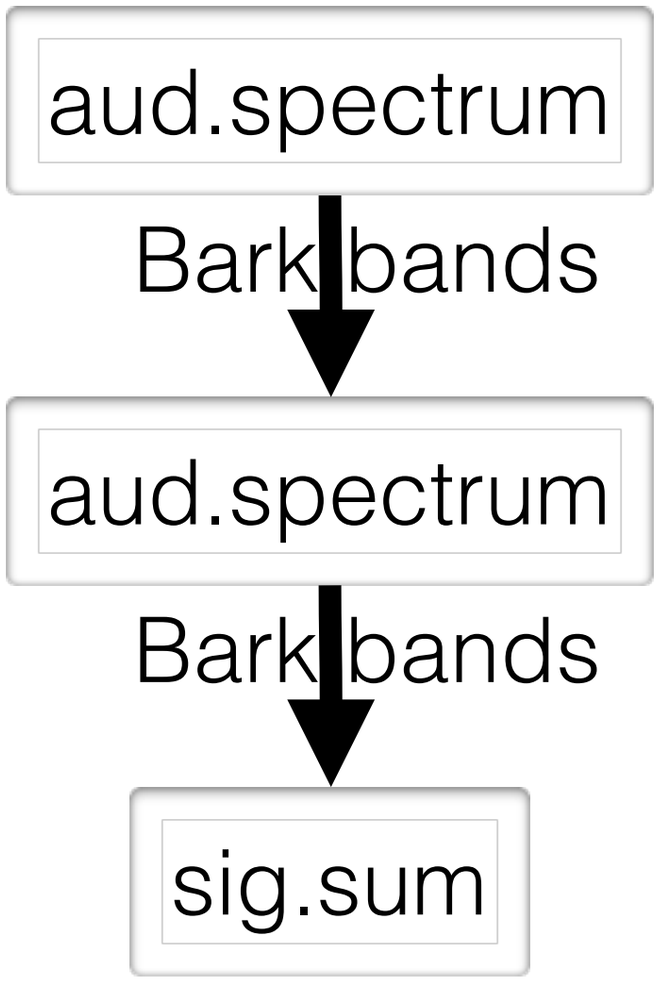
Structural levels

Symbolic level

Audio level

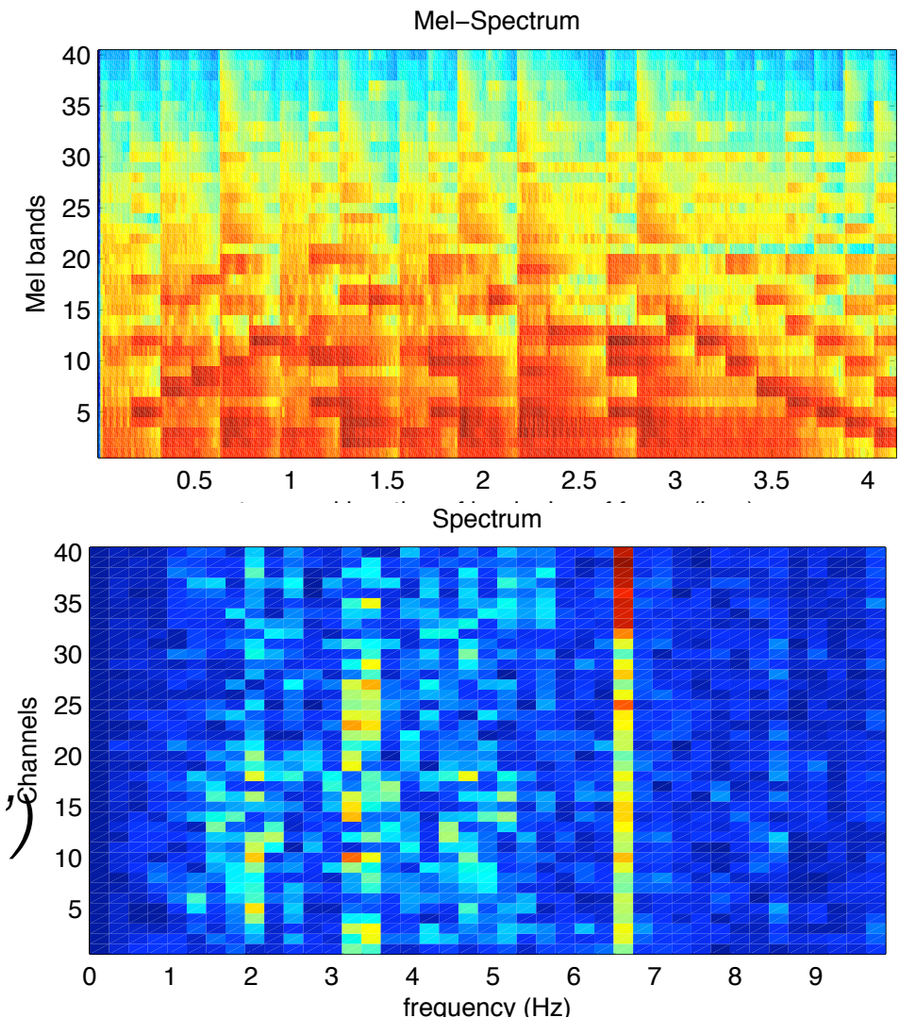


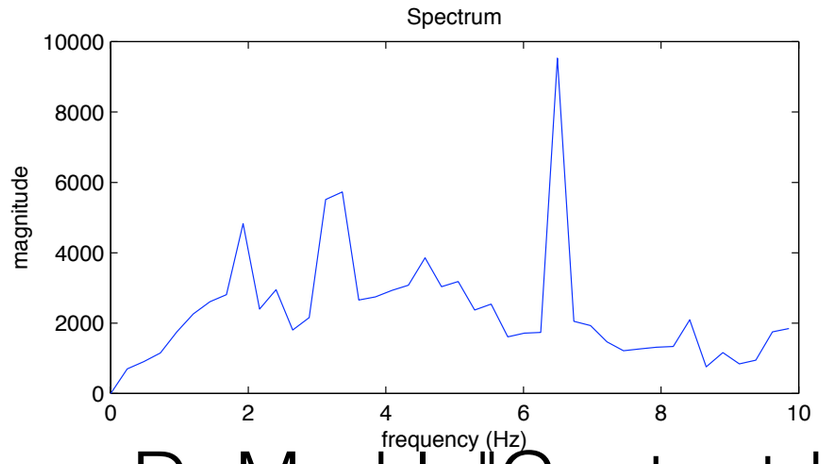
aud.fluctuation
rhythmic periodicity along auditory channels



('Frame',.023,.5, 'Terhardt', 'Bark', 'Mask', 'dB')

*('**AlongBands**', 'Max',10, 'Window', 'No', '**Resonance**', '**Fluctuation**')*



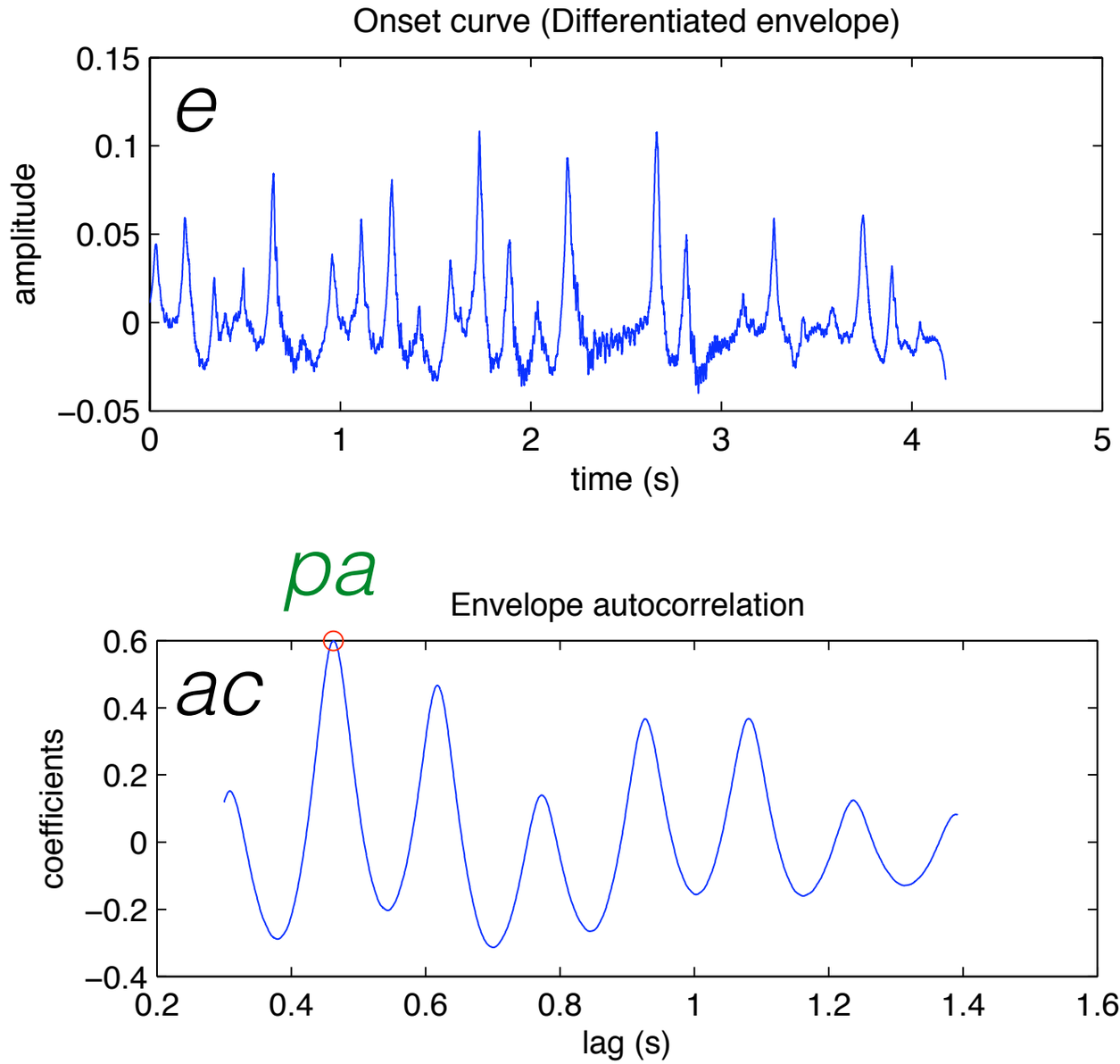


E. Pampalk, A. Rauber, D. Merkl, "Content-based Organization and Visualization of Music Archives", ACM Multimedia 2002, pp. 570-579.

mus.tempo
tempo estimation

- *e = sig.envelope('mysong', 'Diff')*
- *ac = sig.autocor(do)*
- *pa = sig.peaks(ac, 'Total', 1)*
- *mus.tempo(pa)*
- ***t = mus.tempo('mysong')***
- *t = t.eval*

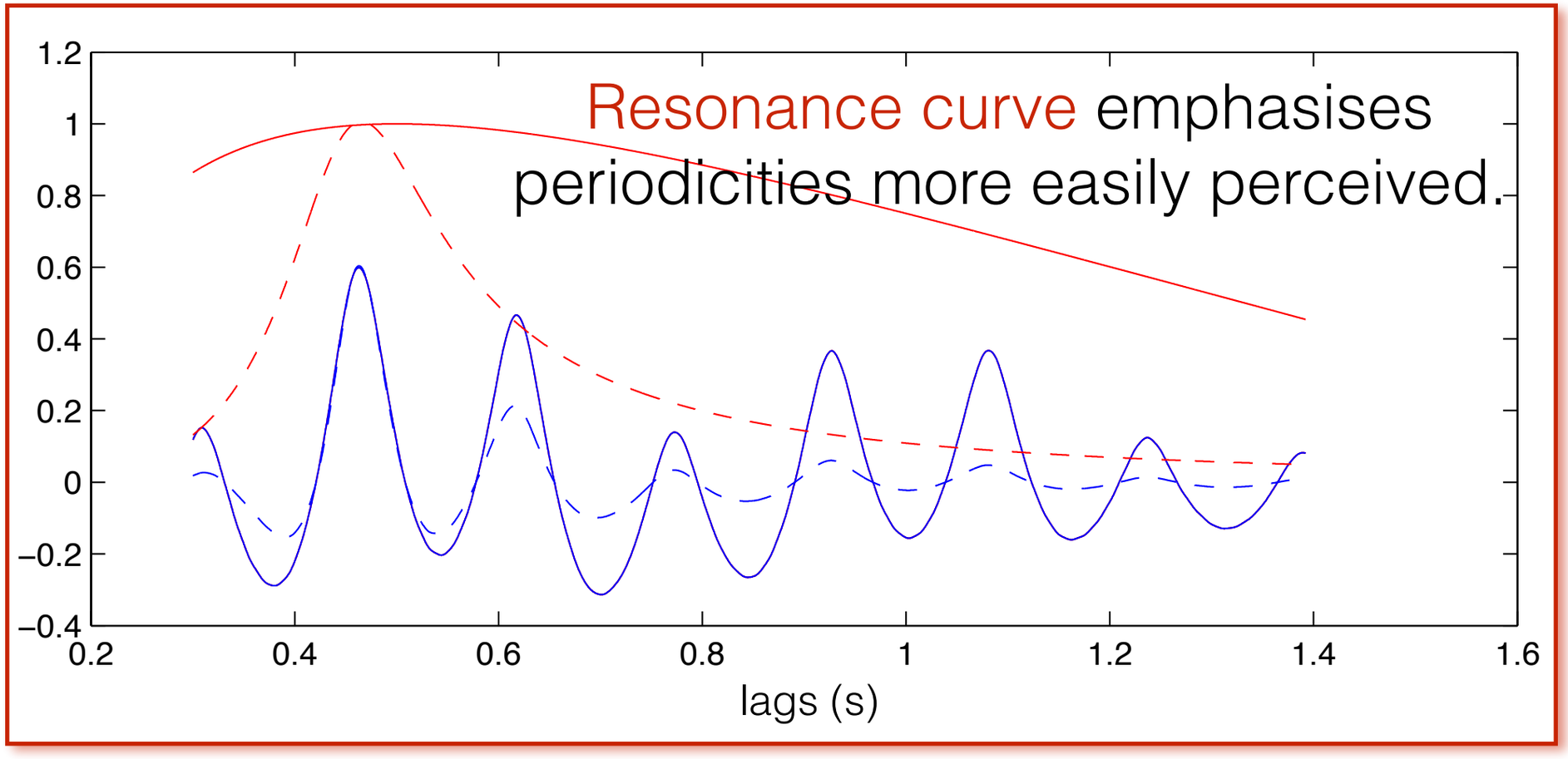
t = {sig.signal, sig.Autocor}



tempo: 129.6333 bpm

mus.tempo
tempo estimation

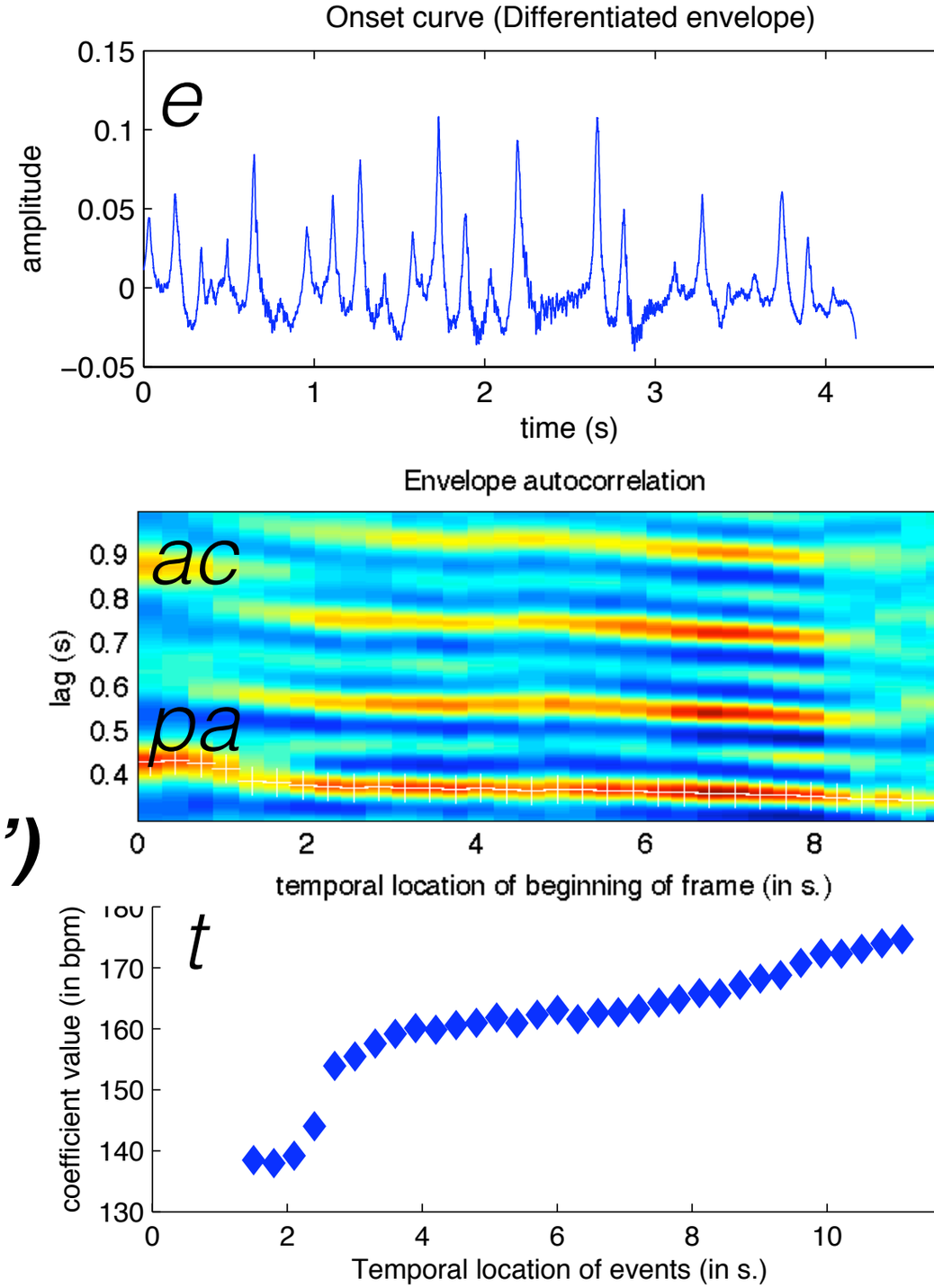
- *e = sig.envelope('mysong', 'Diff')*
- *ac = **aud**.autocor(do, '**Resonance**')*



mus.tempo
tempo estimation

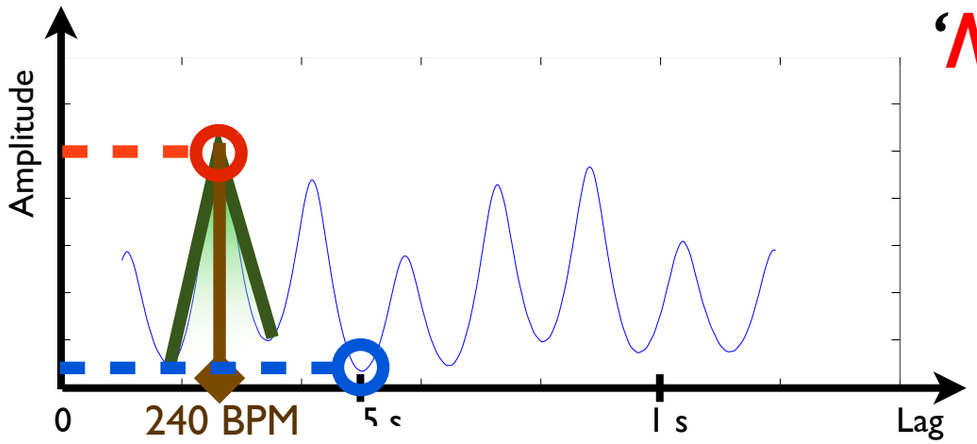
- *e = sig.envelope('mysong', 'Diff')*
- *ac = aud.autocor(do, '**Frame**', 'Resonance')*
- *pa = sig.peaks(ac, 'Total', 1)*
- *mus.tempo(pa)*
- ***t = mus.tempo('mysong', 'Frame')***
- *t = t.eval*

t = {sig.signal, sig.Autocor}



mus.pulseclarity
rhythmic clarity, beat strength

mus.pulseclarity(…,'Enhanced', 'No')



'MaxAutocor' ***'MinAutocor'***

'KurtosisAutocor'

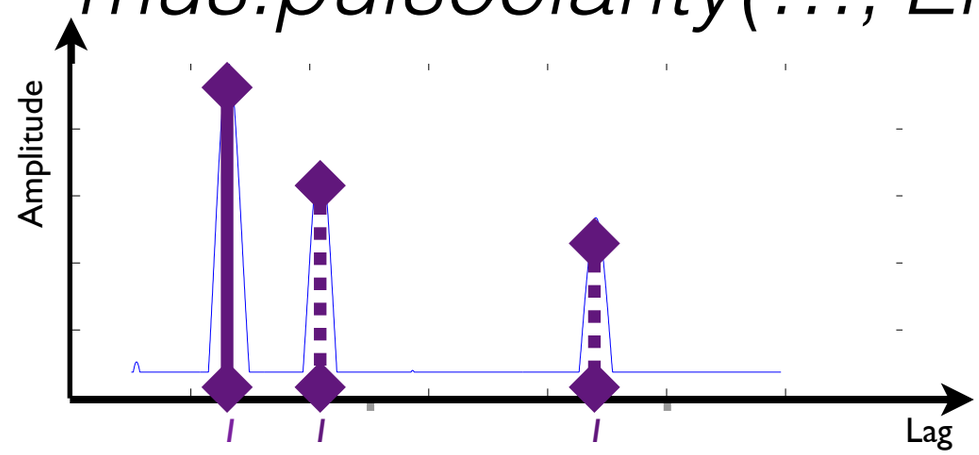
'TempoAutocor'

'EntropyAutocor'

'InterfAutocor

0

mus.pulseclarity(…,'Enhanced', 'Yes')

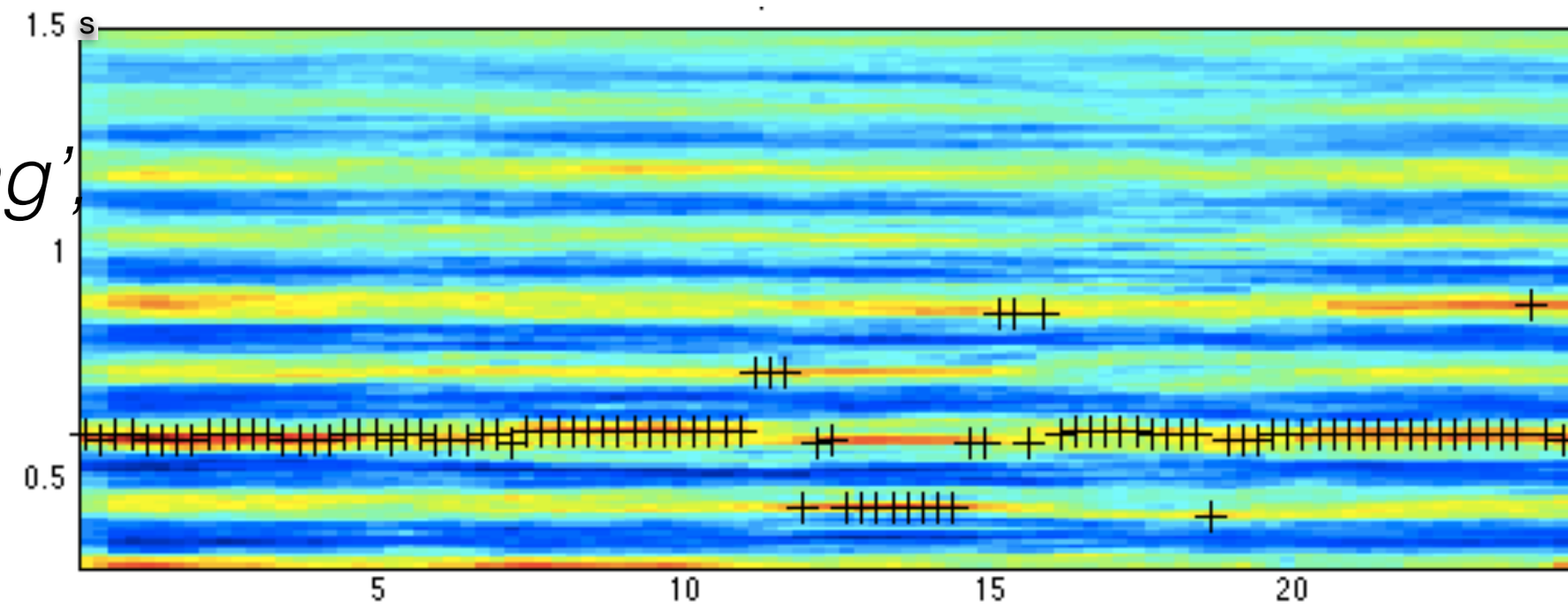


'EntropyAutocor'

'InterfAutocor'

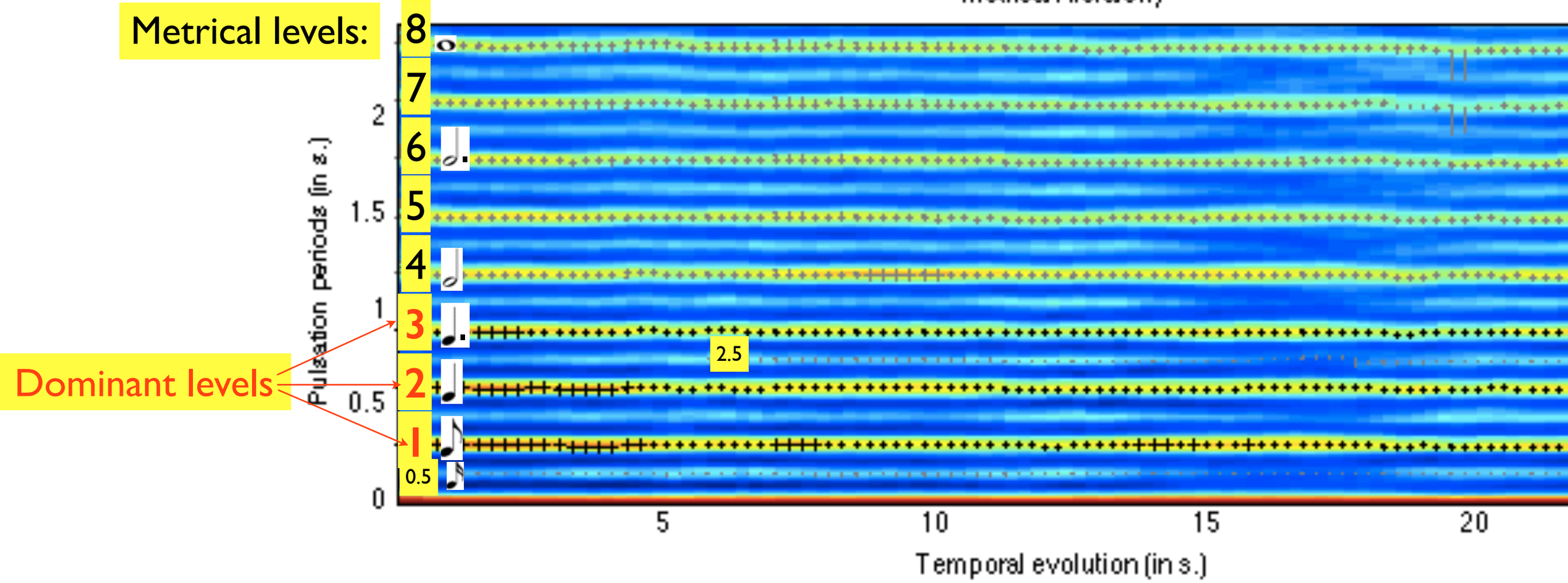
Lartillot et al., ISMIR 2008

*mus.tempo('mysong', '**Frame**')*



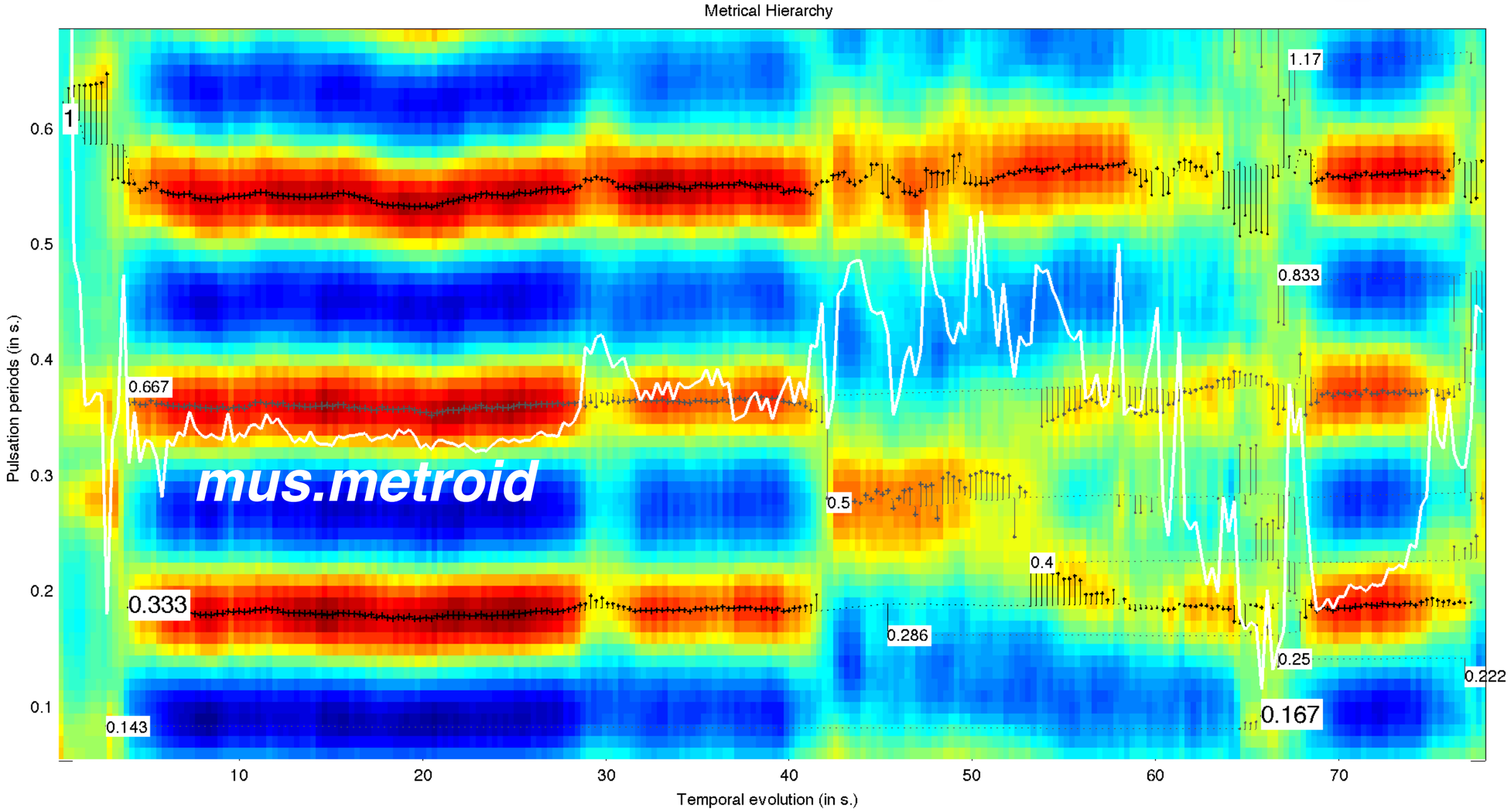
Pulsation does not always focus on one single metrical level.

mus.metre tracks all metrical levels in parallel.



mus.metre

metrical hierarchy tracking

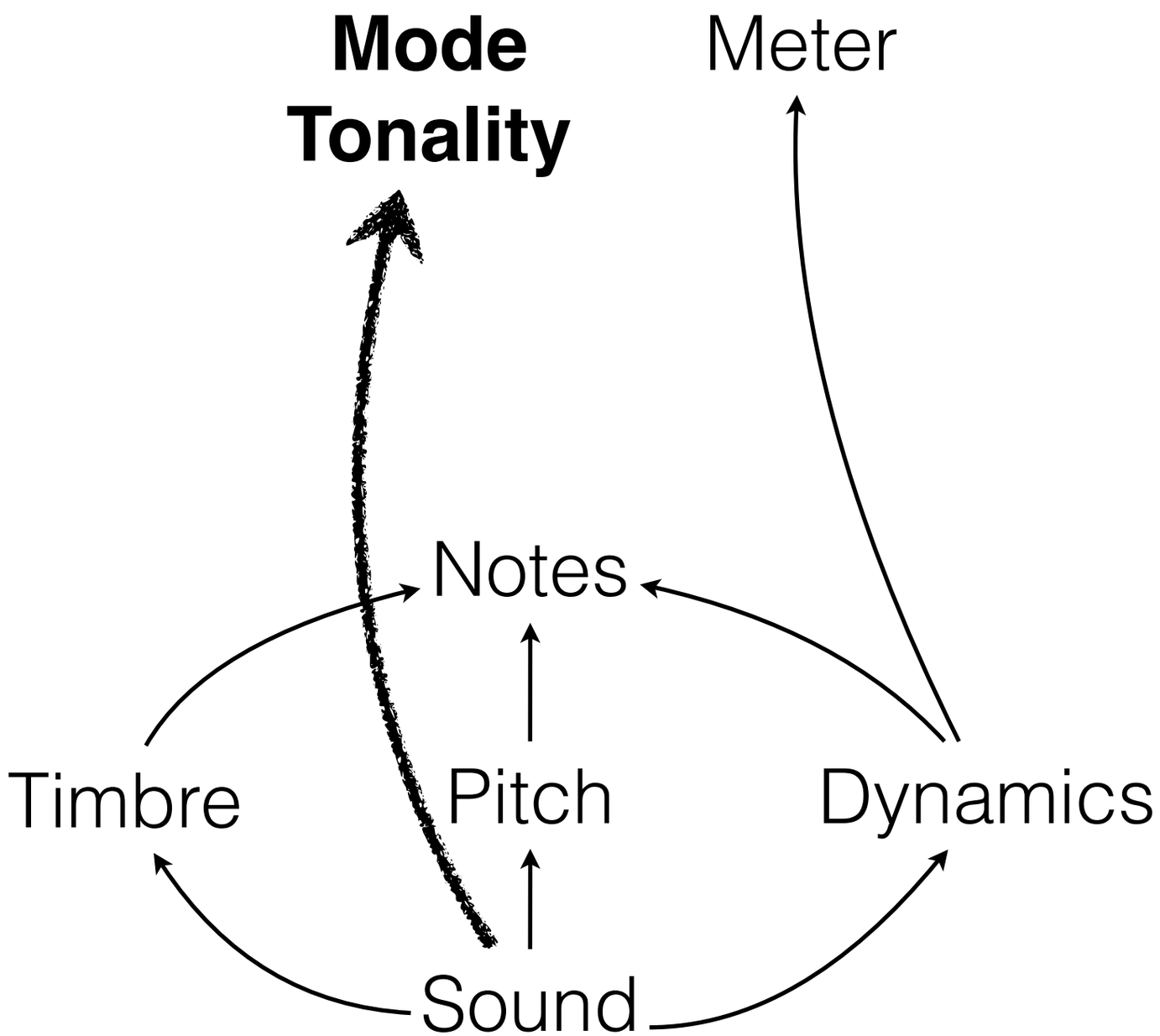


Beethoven, 9th Symphony, *Scherzo*

Structural levels

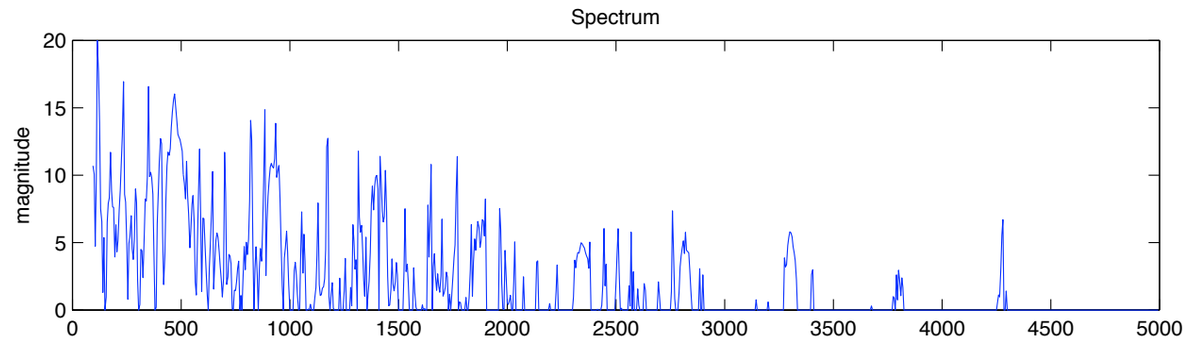
Symbolic level

Audio level

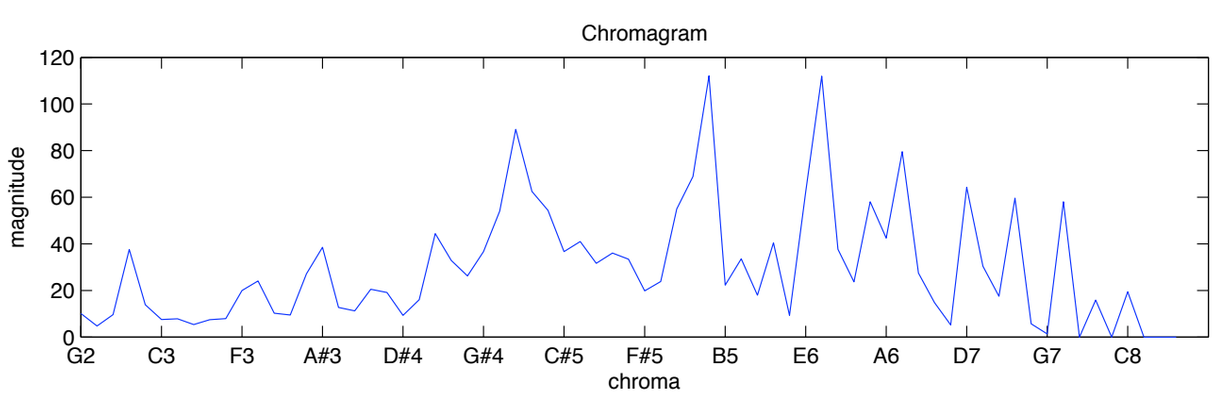


mus.chromagram
energy distribution along pitches

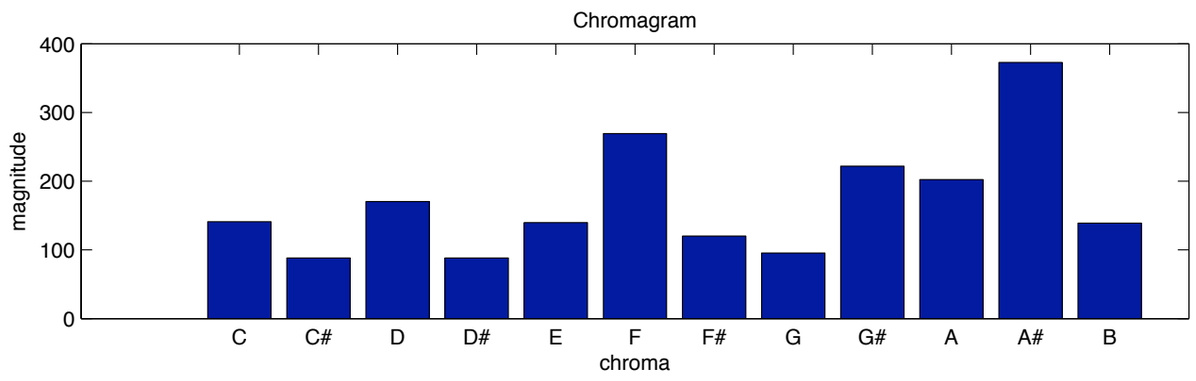
- *s = sig.spectrum(a, ‘dB’, 20, 'Min', 100, 'Max', 6400)*



- *c = mus.chromagram(s, ‘**Wrap**’, ‘no’)*

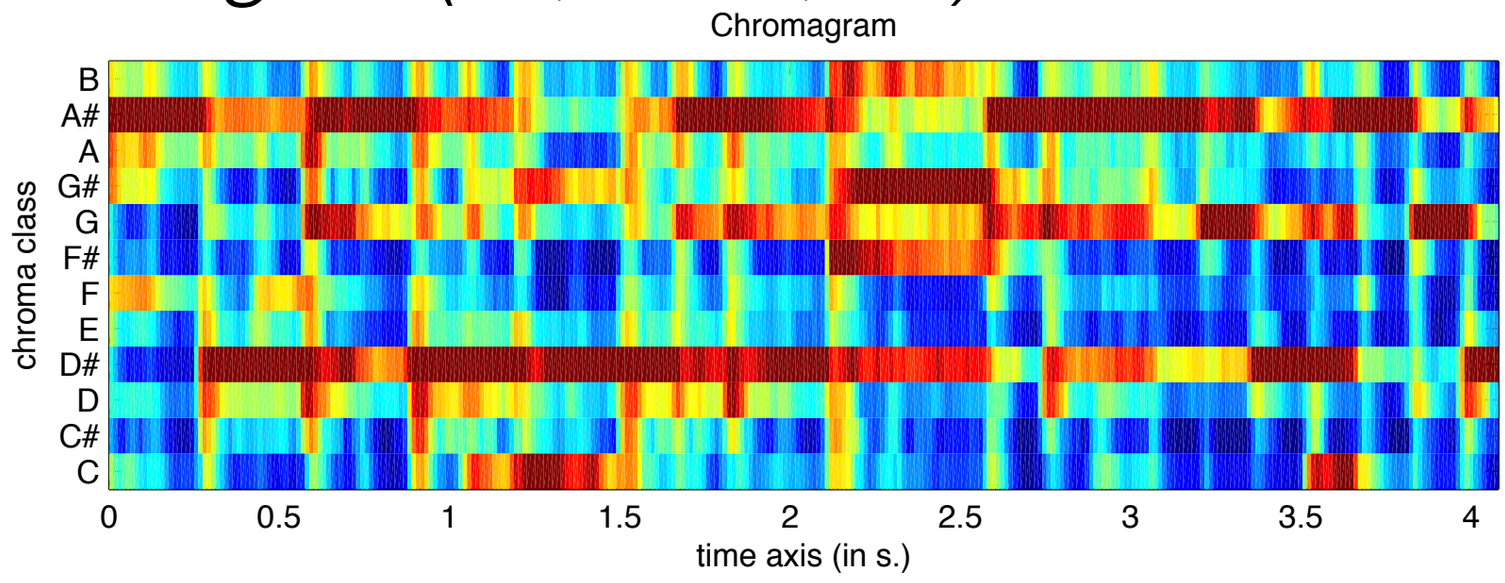


- *c = mus.chromagram(c, ‘**Wrap**’, ‘yes’)*

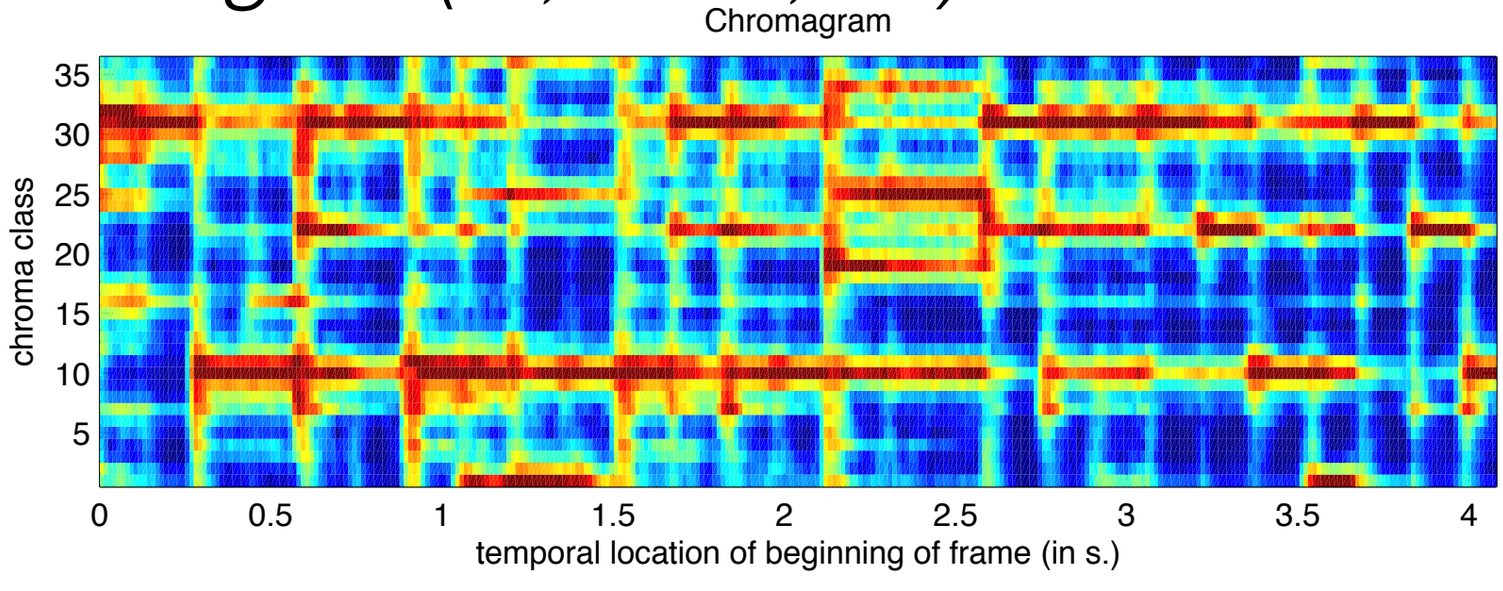


mus.chromagram chroma resolution

- *mus.chromagram(…, 'Res', 12)*



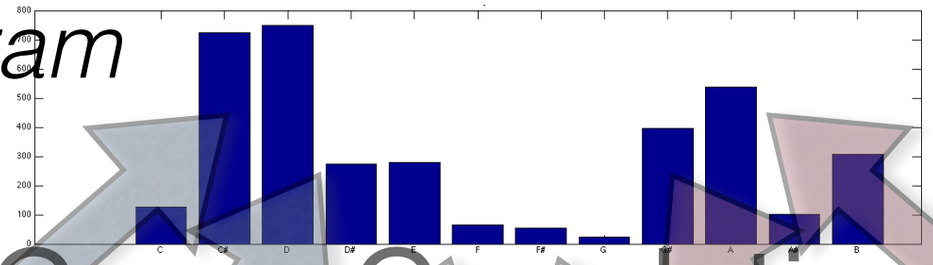
- *mus.chromagram(..., 'Res', 36)*



mus.keystrength

probability of key candidates

mus.chromagram

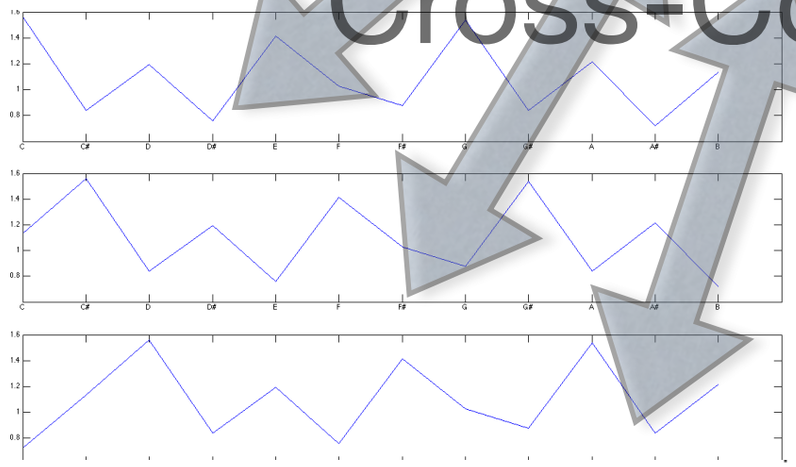


Cross-Correlations

C major

C# major

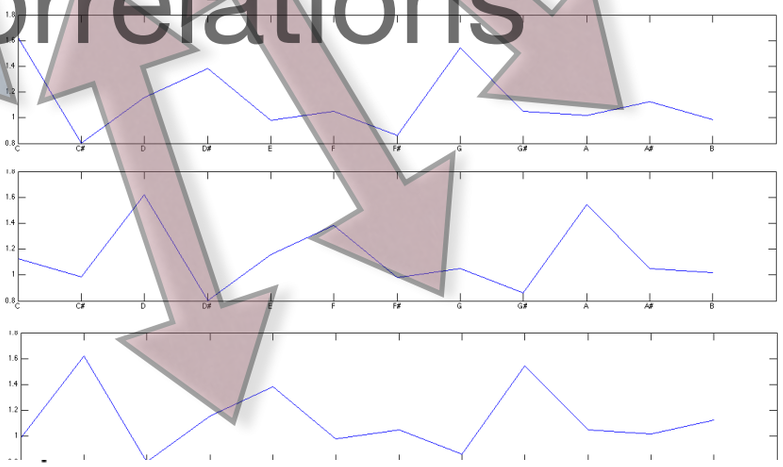
D major

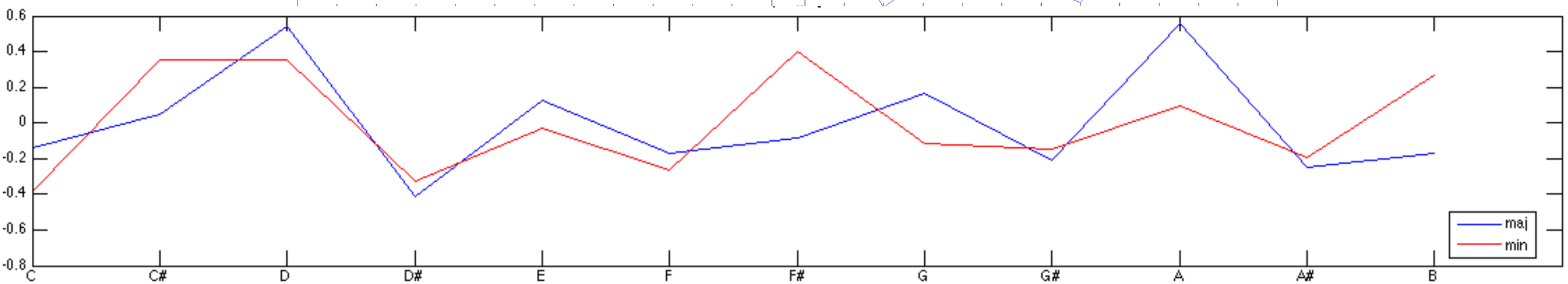


C minor

C# minor

D minor

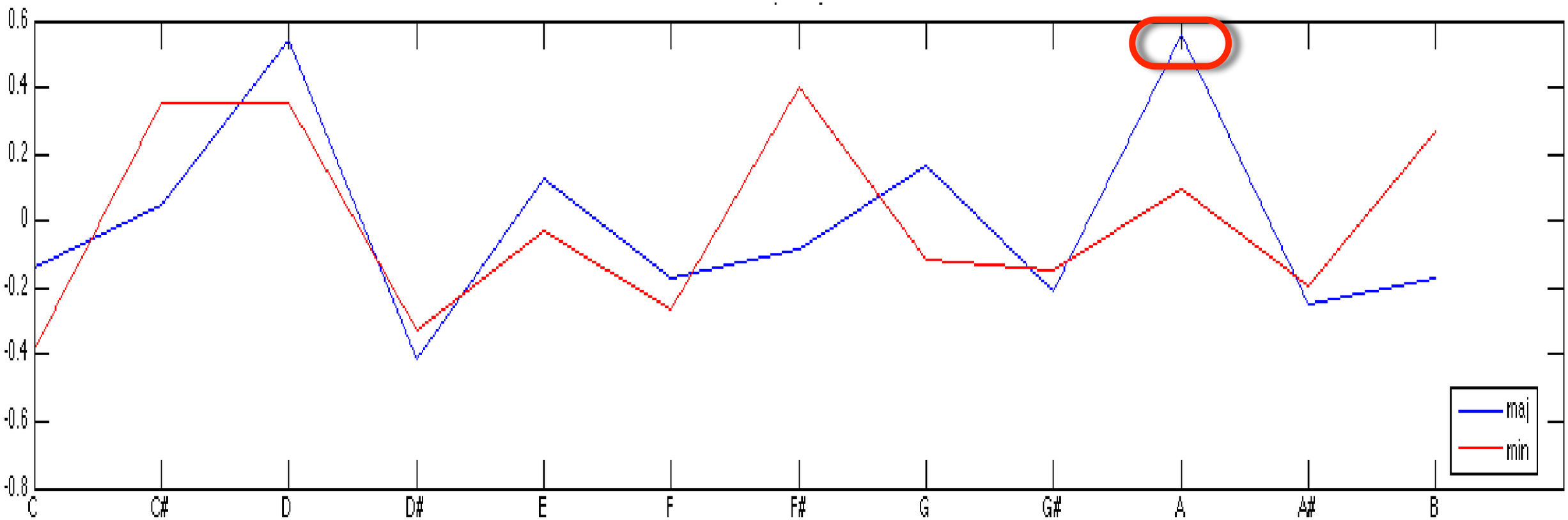




Krumhansl, Cognitive foundations of musical pitch. Oxford UP, 1990.

Gomez, “Tonal description of polyphonic audio for music content processing,” INFORMS Journal on Computing, 18-3, pp. 294–304, 2006.

mus.key
key estimation



sig.peaks(mus.keystrength(…))

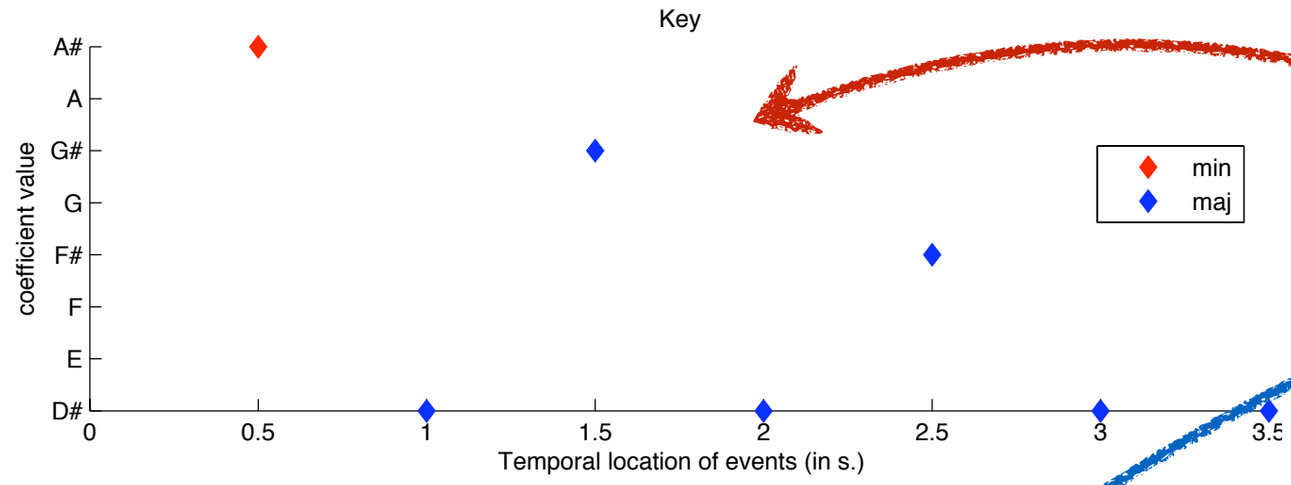
- *mus.key(…, '**Total**', 1)*

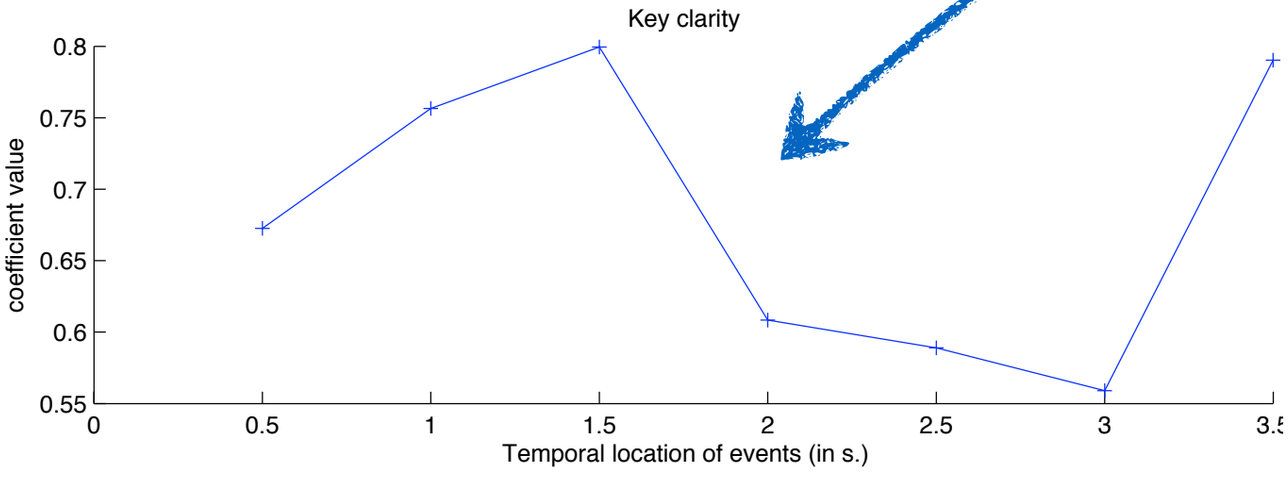
Krumhansl, Cognitive foundations of musical pitch. Oxford UP, 1990.
Gomez, "Tonal description of polyphonic audio for music content processing," INFORMS Journal on Computing, 18-3, pp. 294–304, 2006.

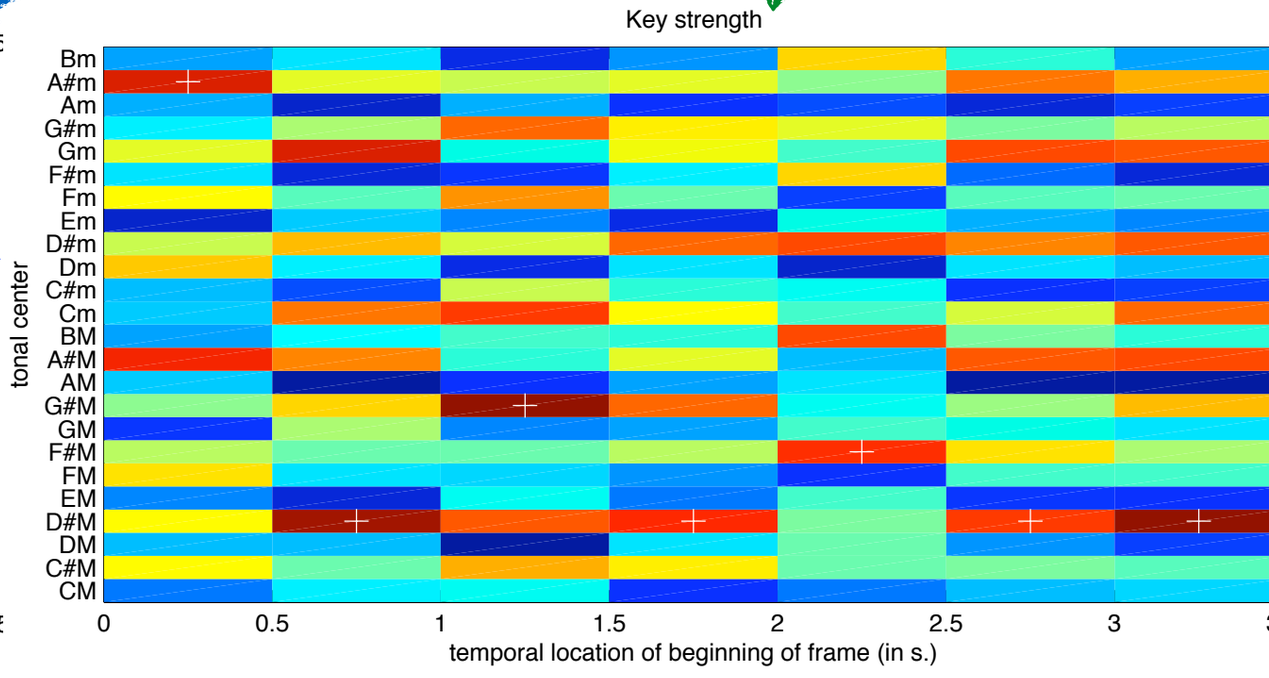
mus.key
key estimation

- ***k = mus.key('mysong', 'Frame')***
- *k = k.eval*

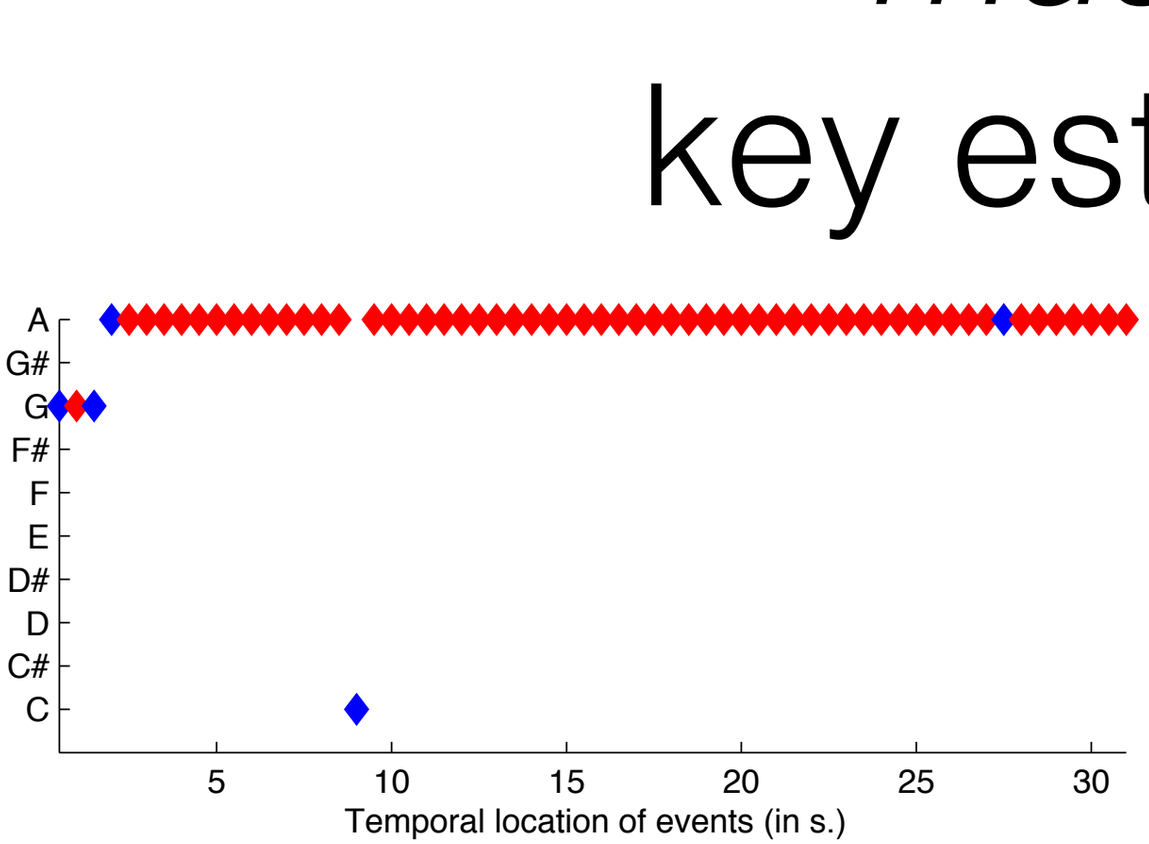
k= {sig.signal, sig.signal, mus.Keystrength}



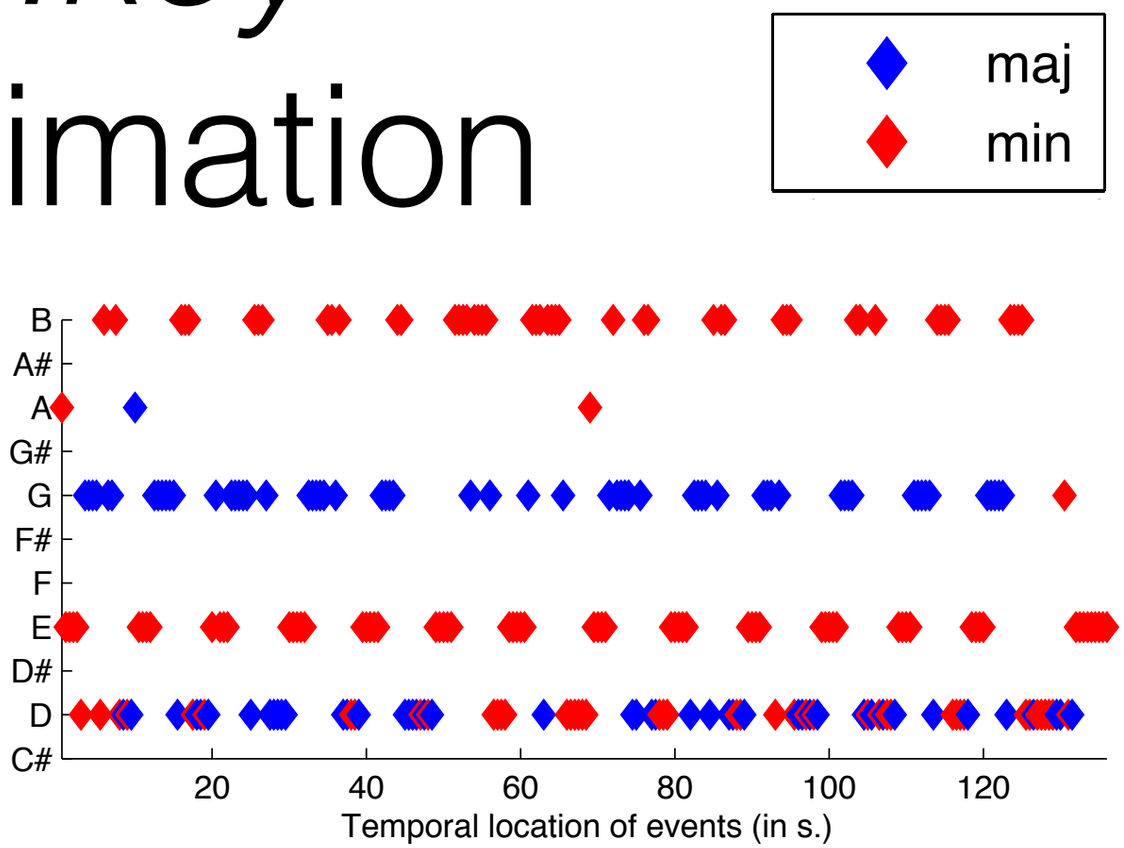




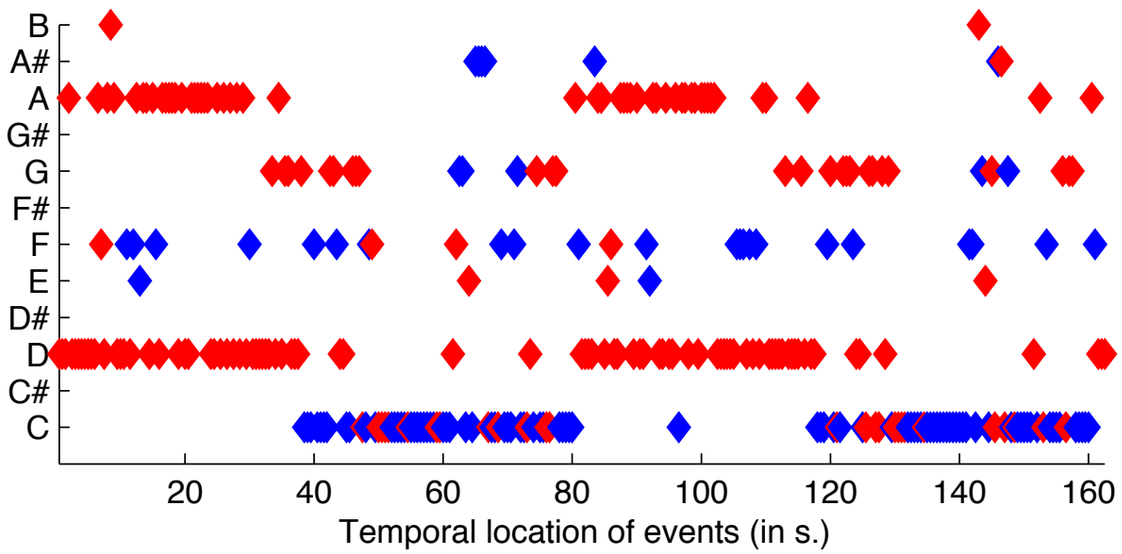
mus.key
key estimation



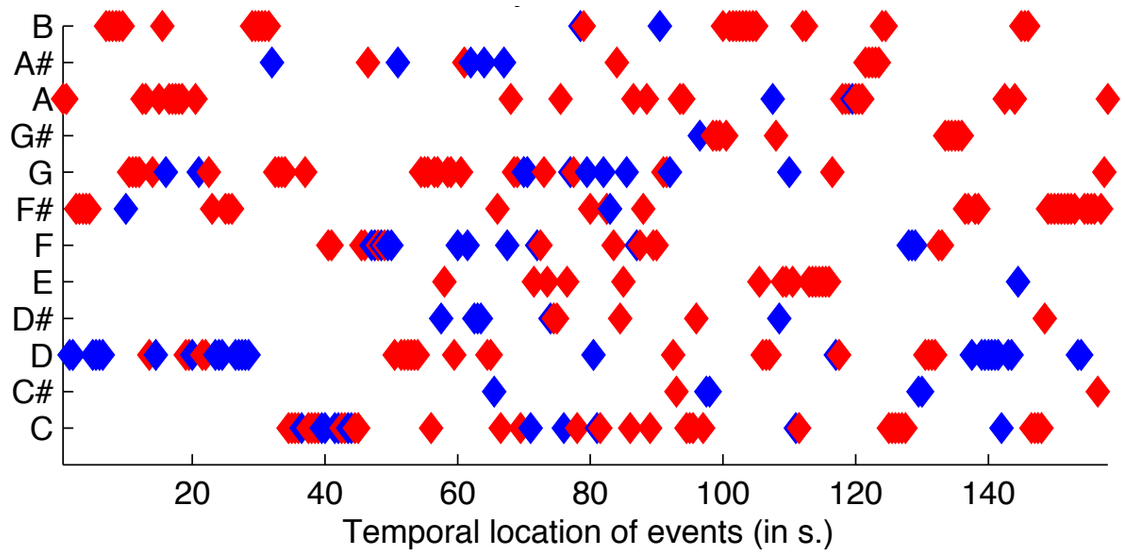
Monteverdi, *Hor che'l ciel e la terra*, 1st part



Tiersen, *Comptine d'un autre été : L'après-midi*

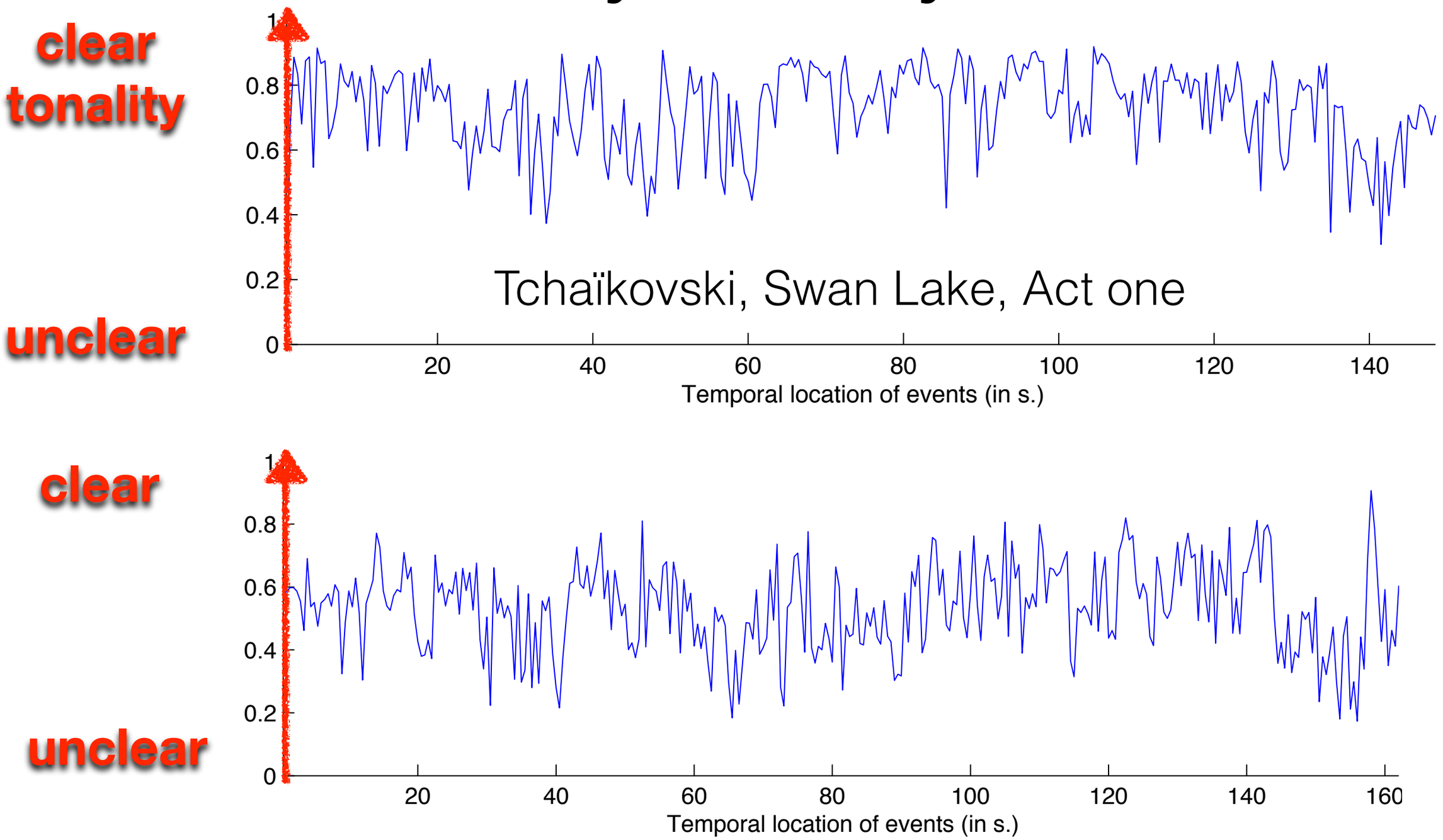


Beethoven, 9th Symphony, *Scherzo*

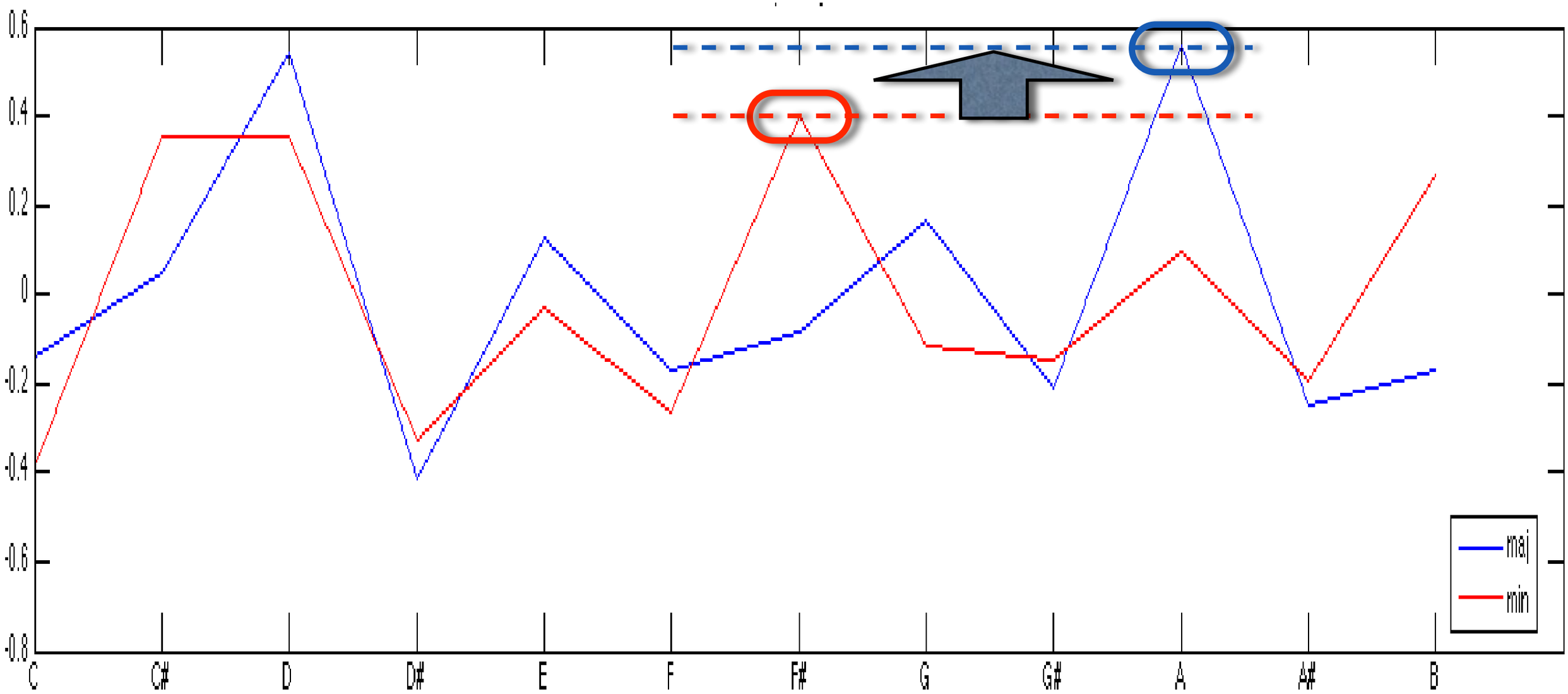


Schönberg, *Verklärte Nacht*, *Sehr Ruhig*

*[k **c**] = mus.key*
key clarity

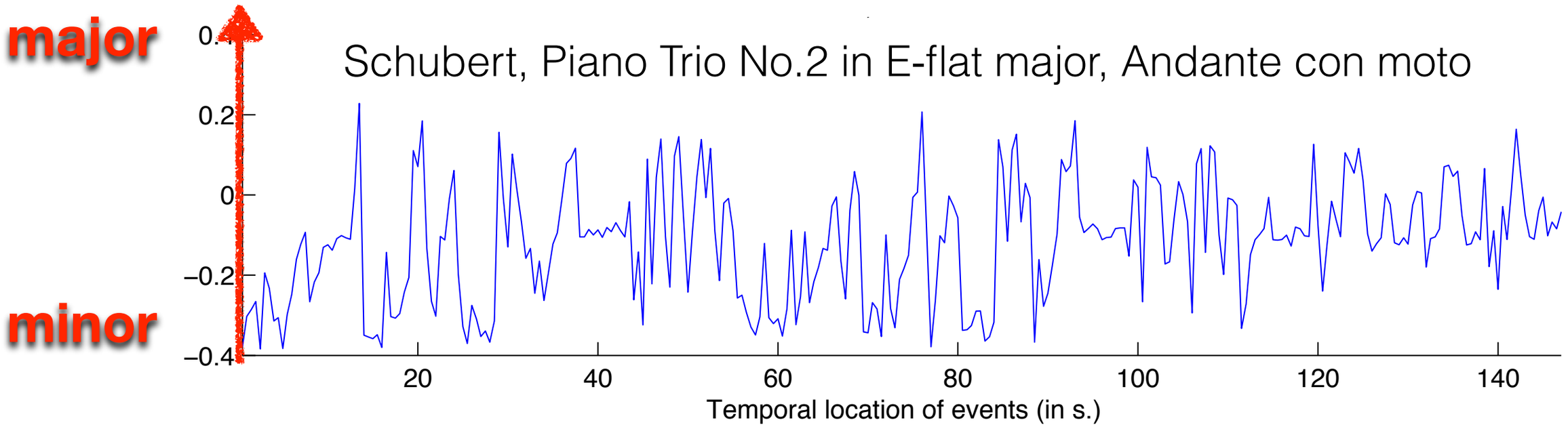


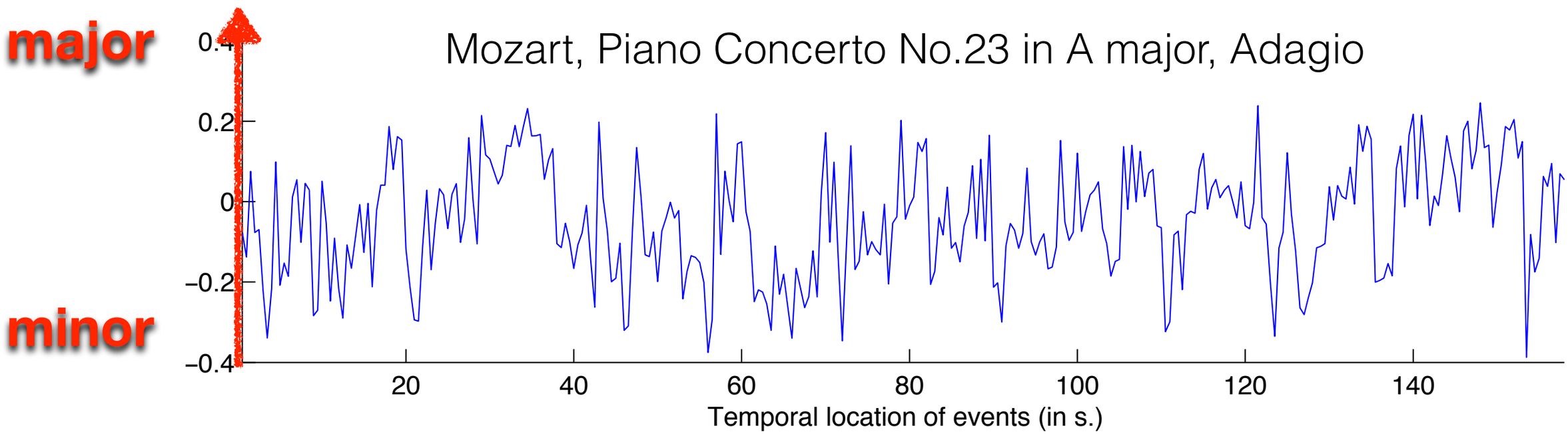
mus.mode
mode estimation



mus.mode

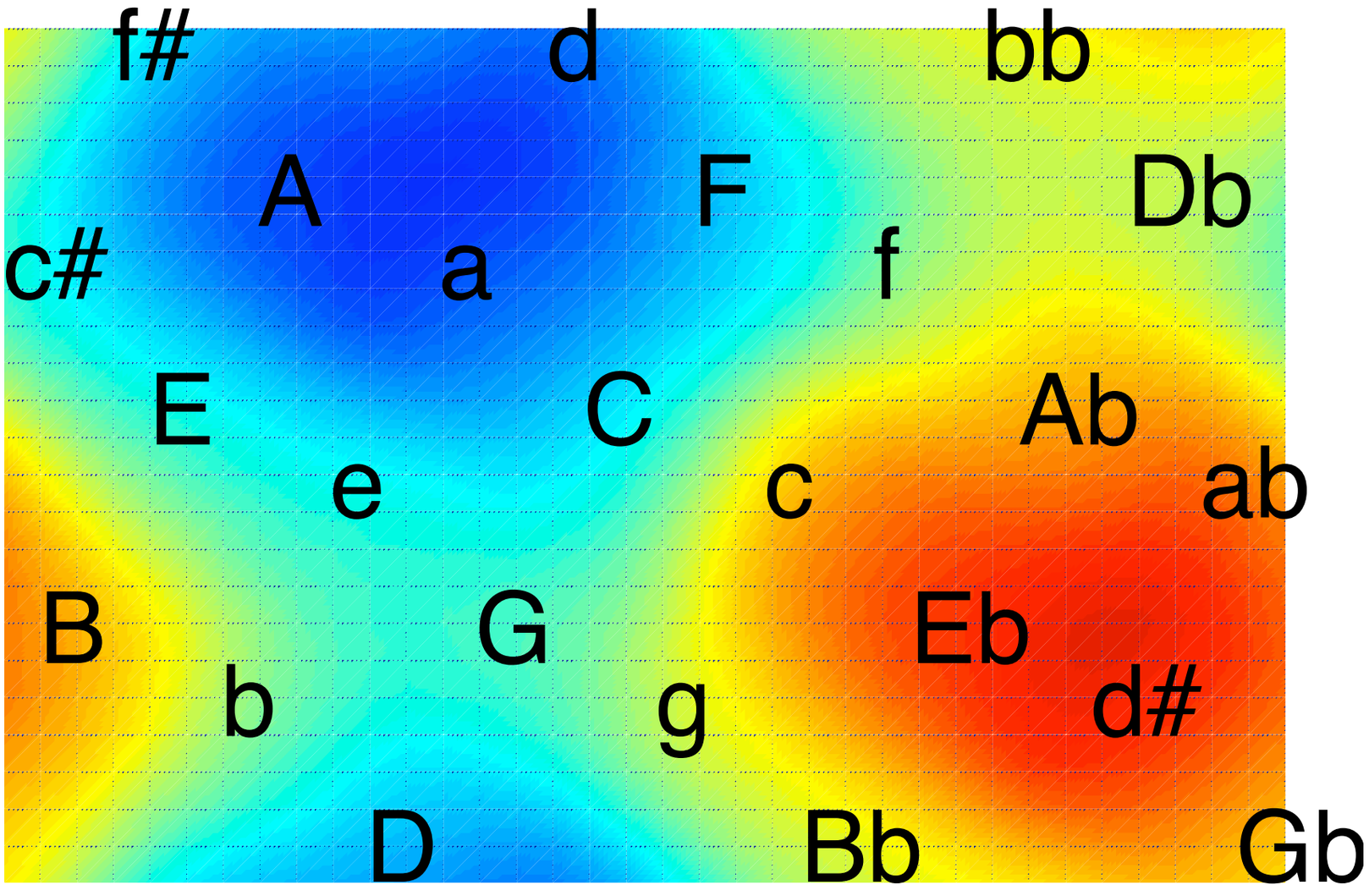
mode estimation





mus.keysom
self-organizing map

Self–organizing map projection of chromagram

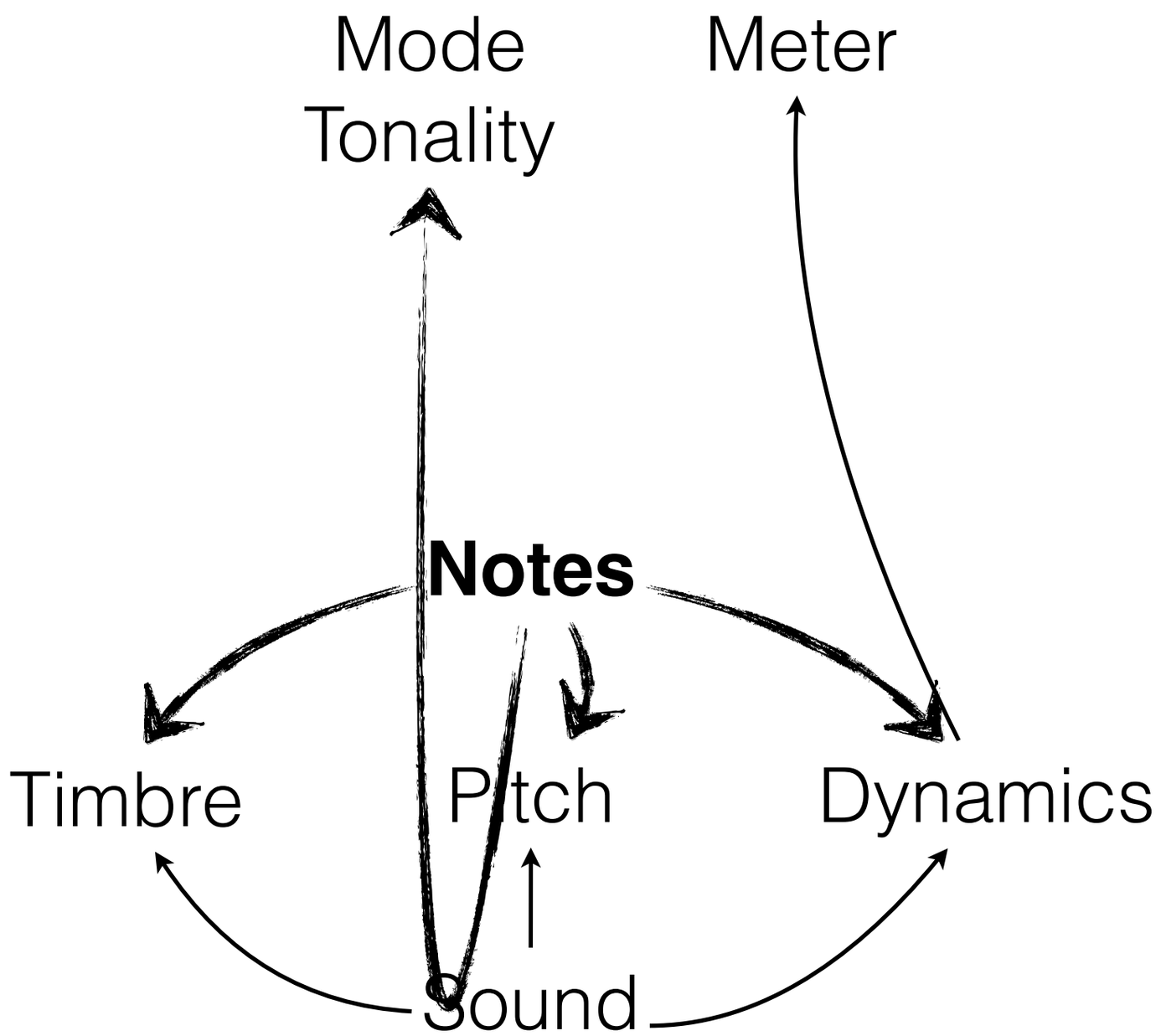


Toiviainen & Krumhansl, “Measuring and modeling real-time responses to music: The dynamics of tonality induction”, Perception 32-6, pp. 741–766, 2003.

Structural levels

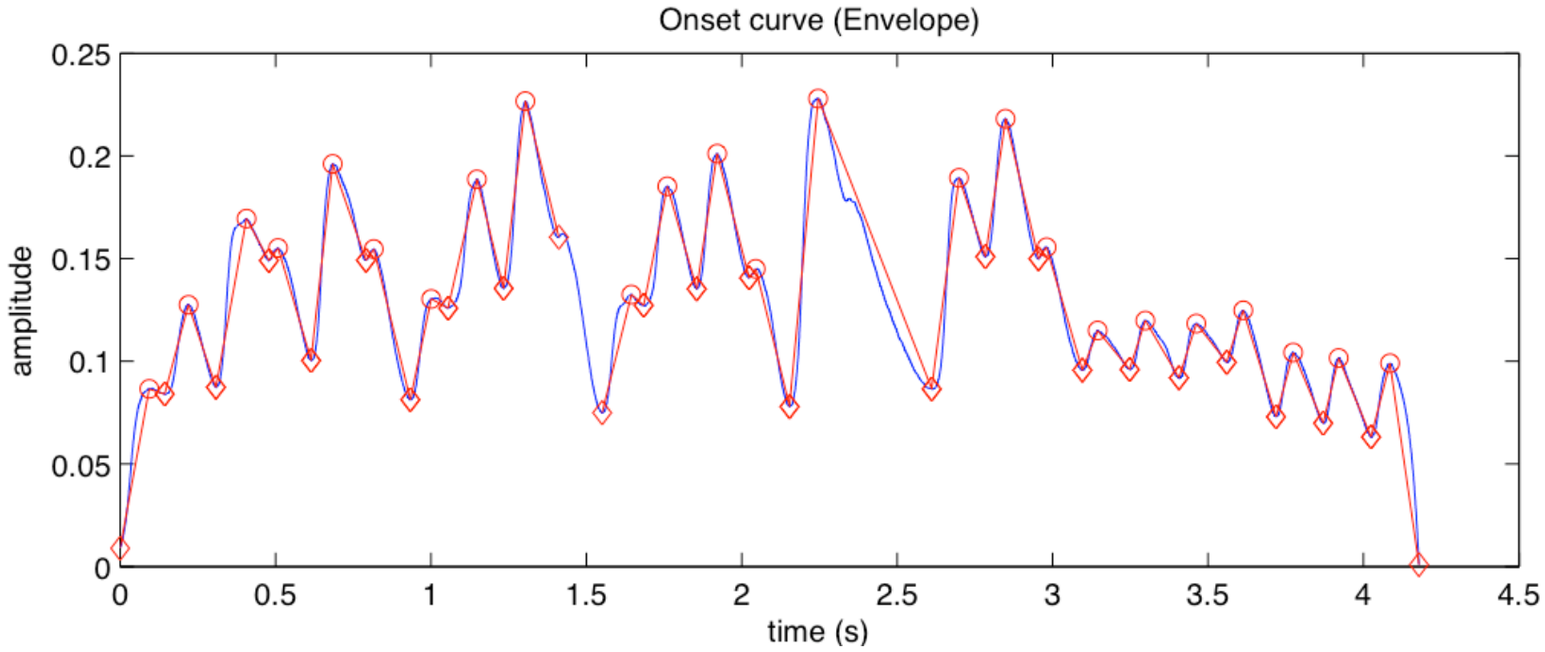
Symbolic level

Audio level

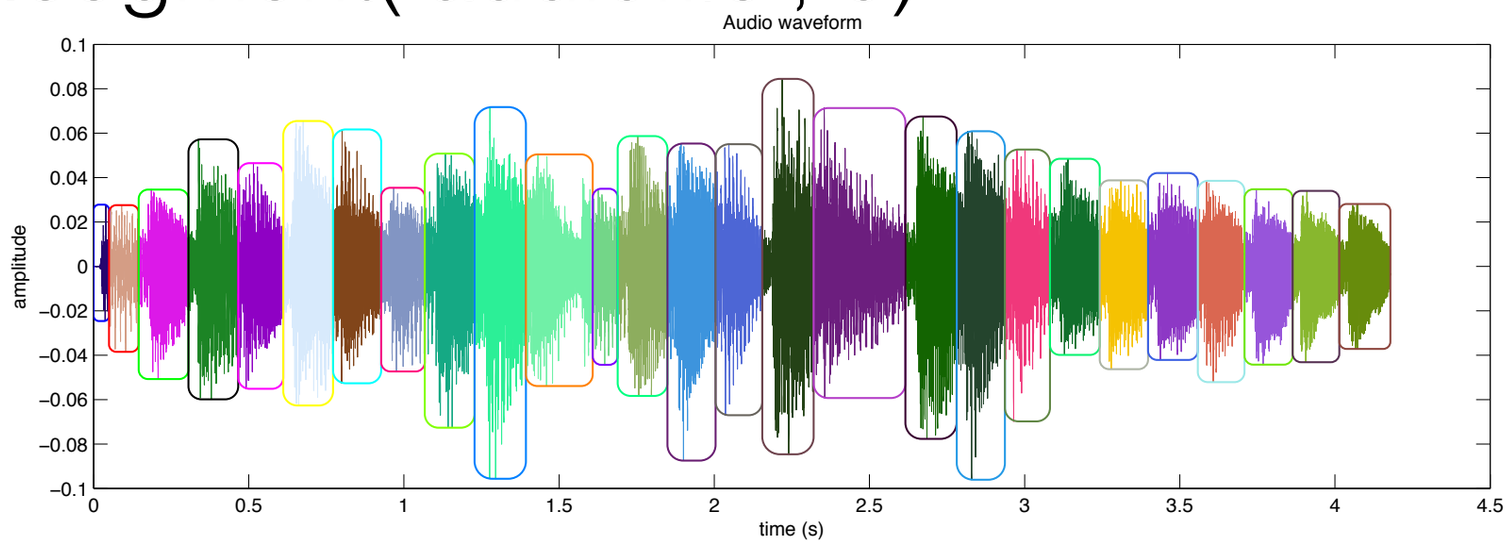


onset-based segmentation

o = aud.onsets('audiofile', 'Attack', 'Release')

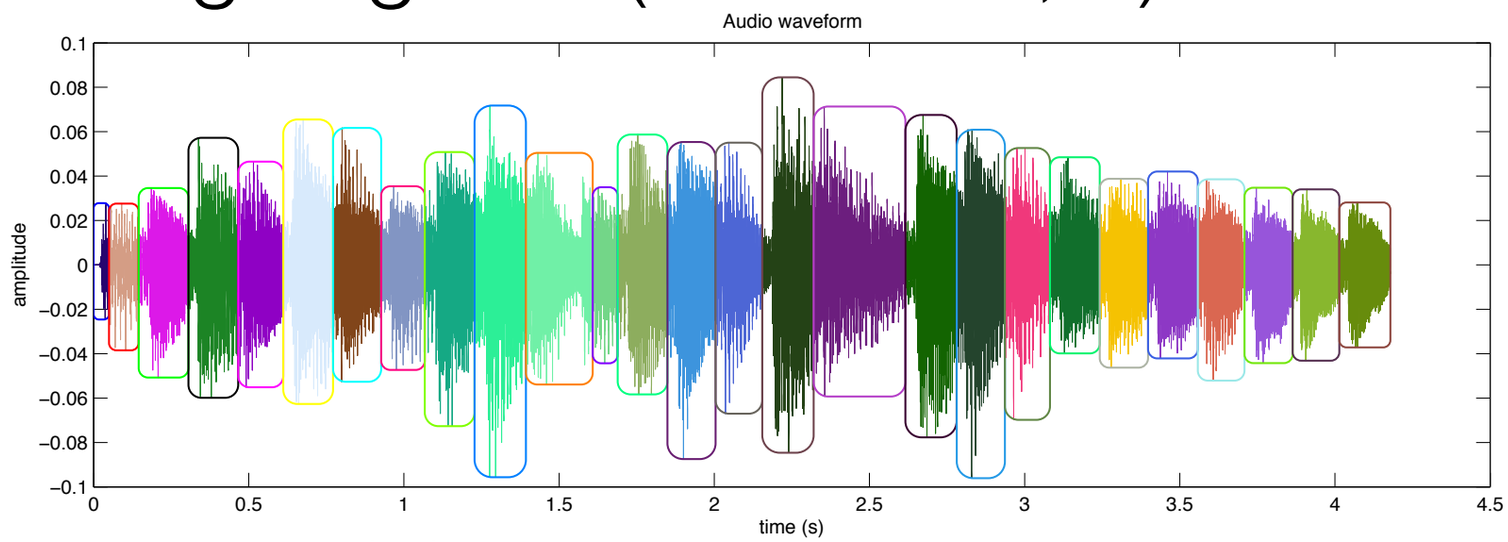


sig.segment('audiofile', o)

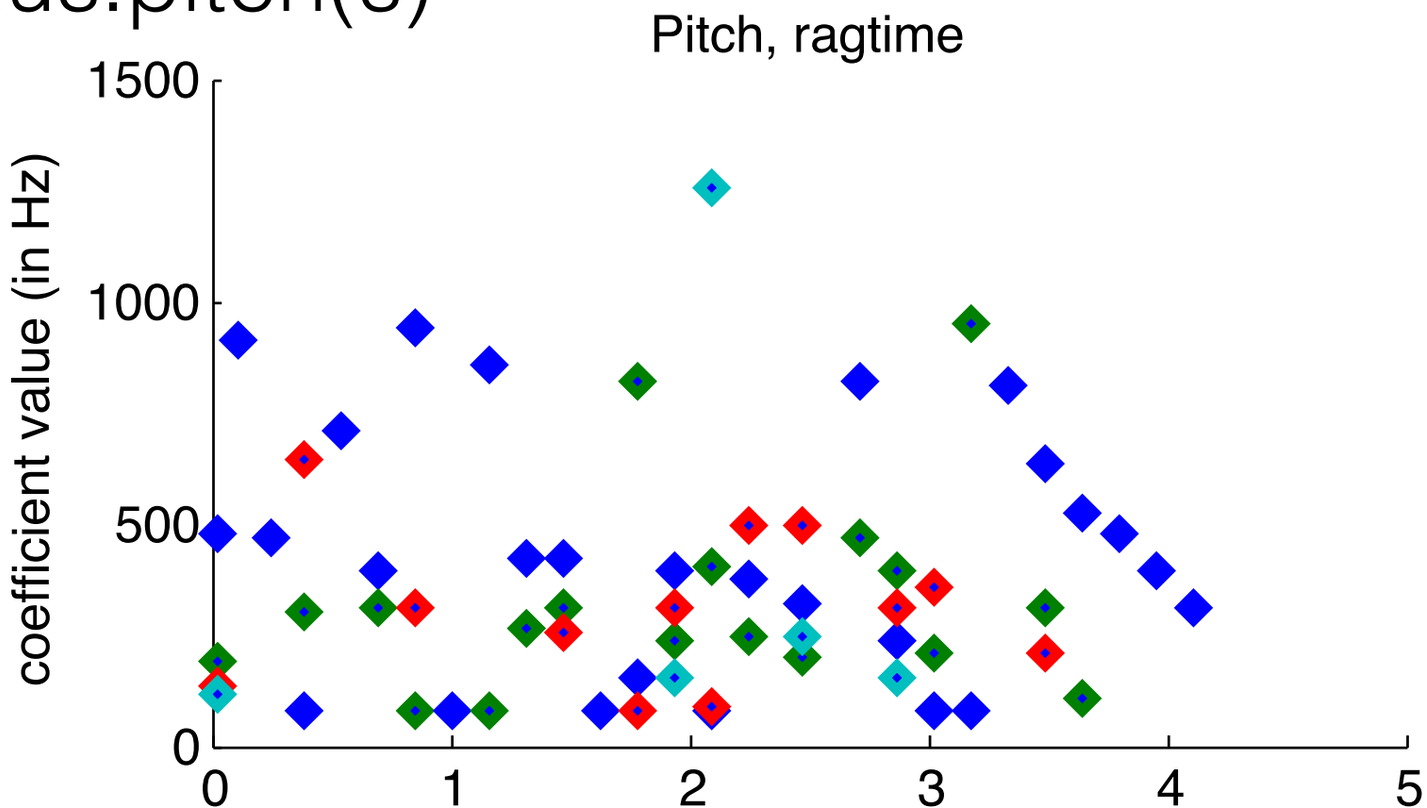


onset-based segmentation

s = sig.segment('audiofile', o)

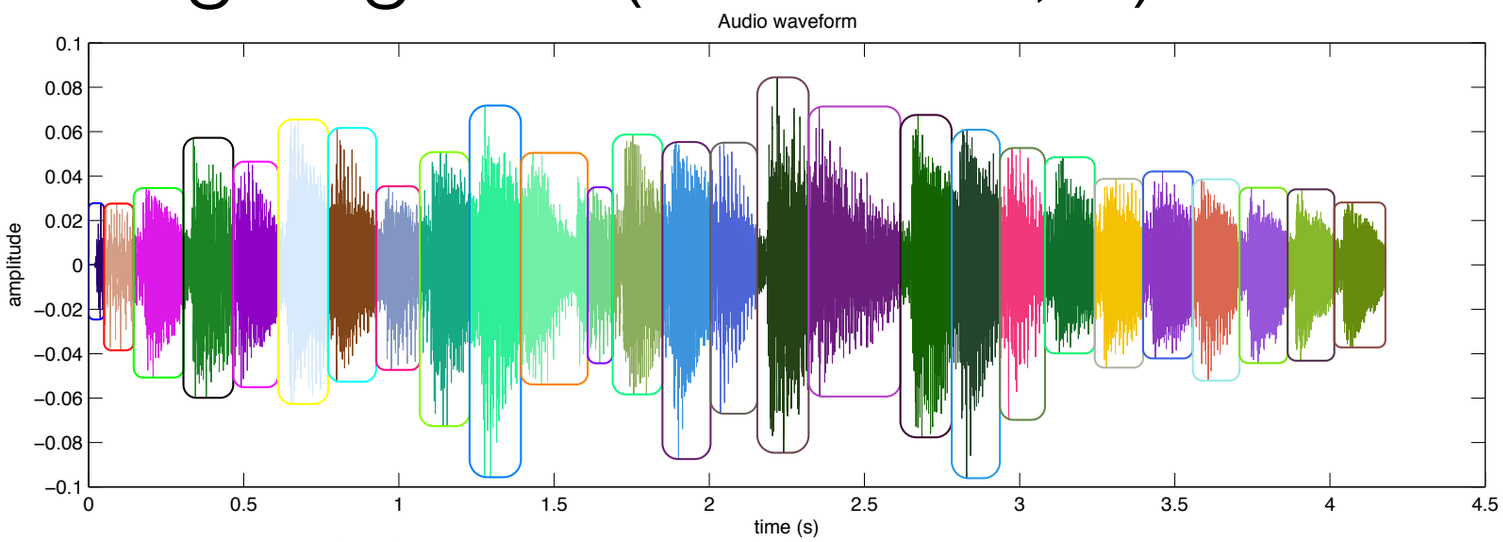


mus.pitch(s)

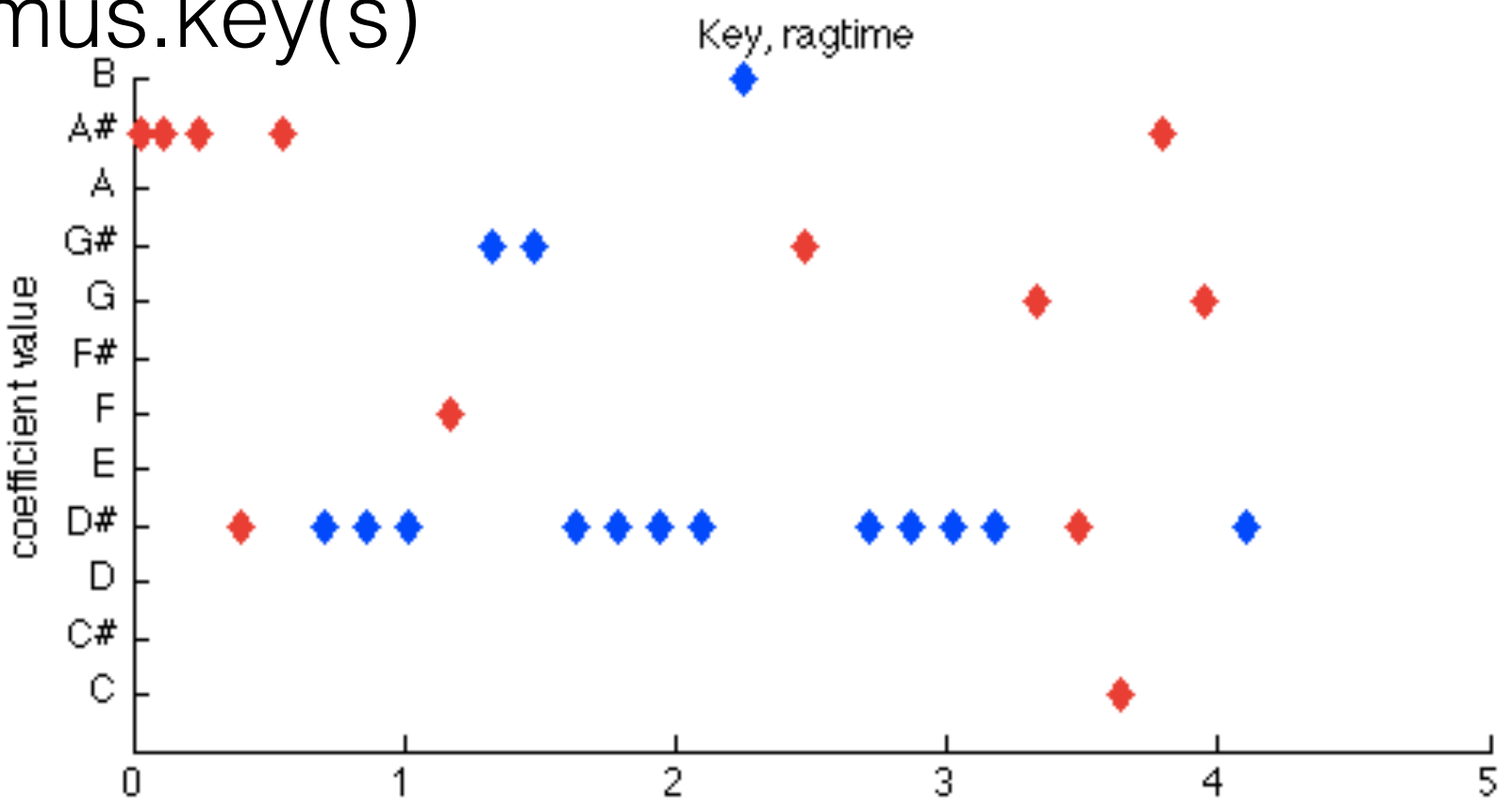


onset-based segmentation

s = sig.segment('audiofile', o)



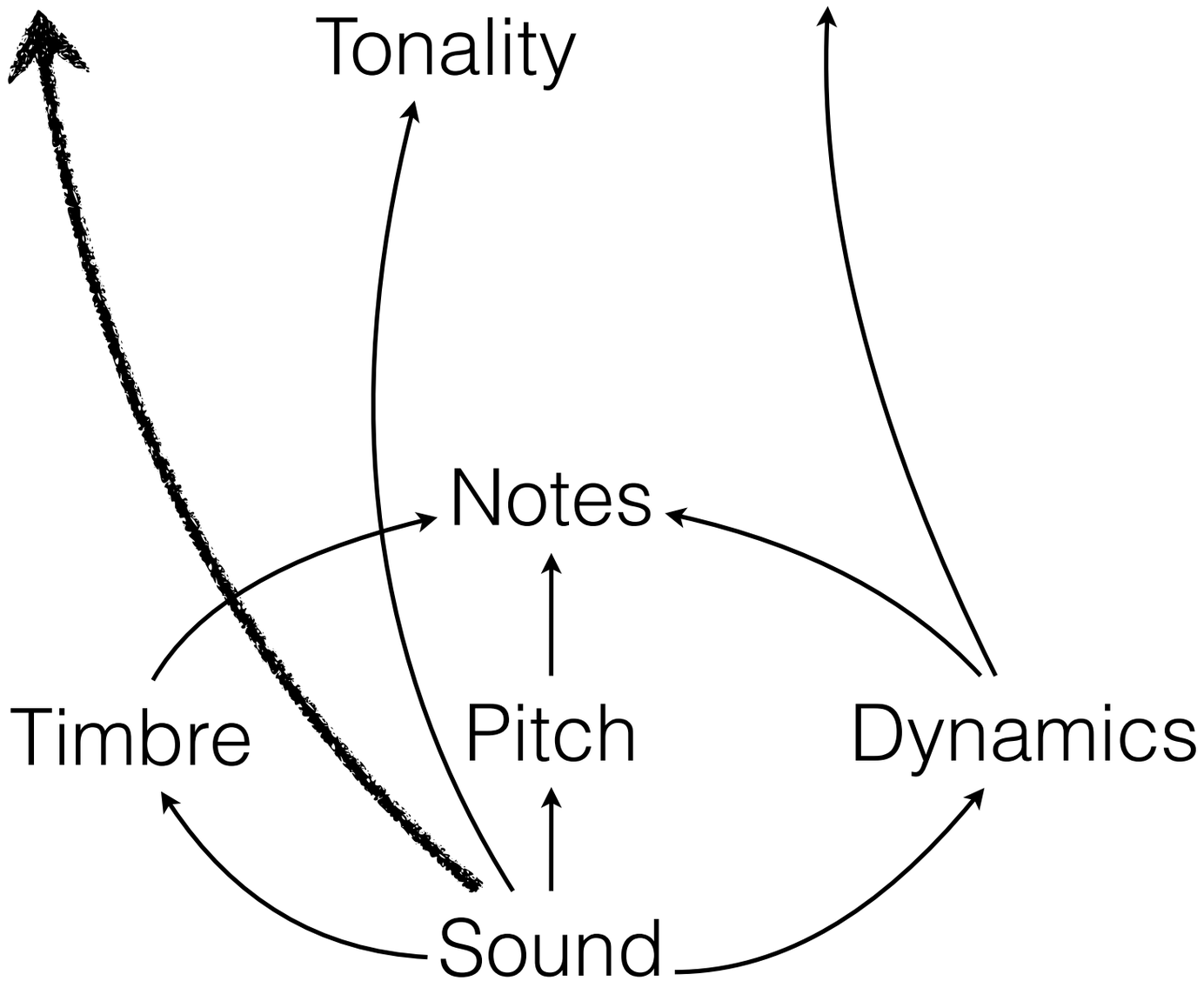
mus.key(s)



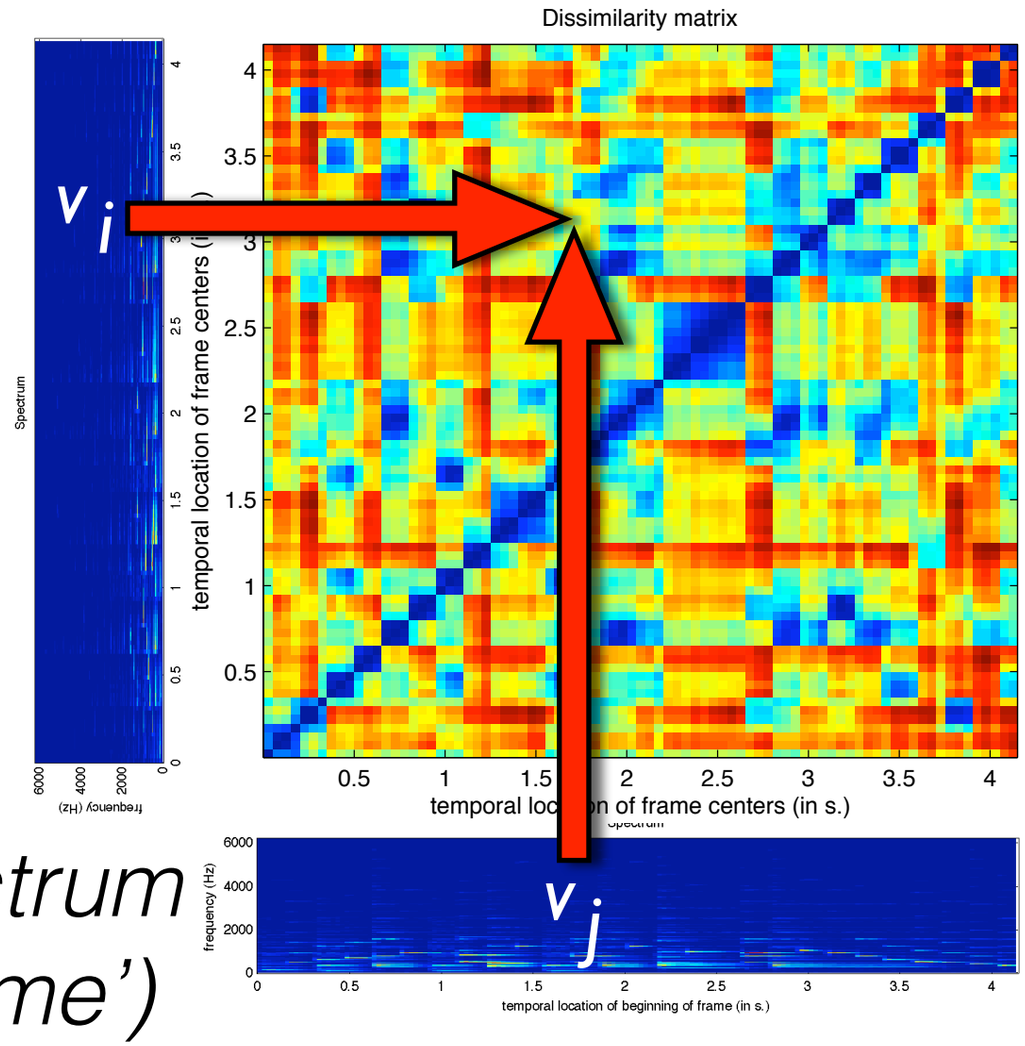
Structural levels

Symbolic level

Audio level



sig.simatrix
*dis*similarity matrix



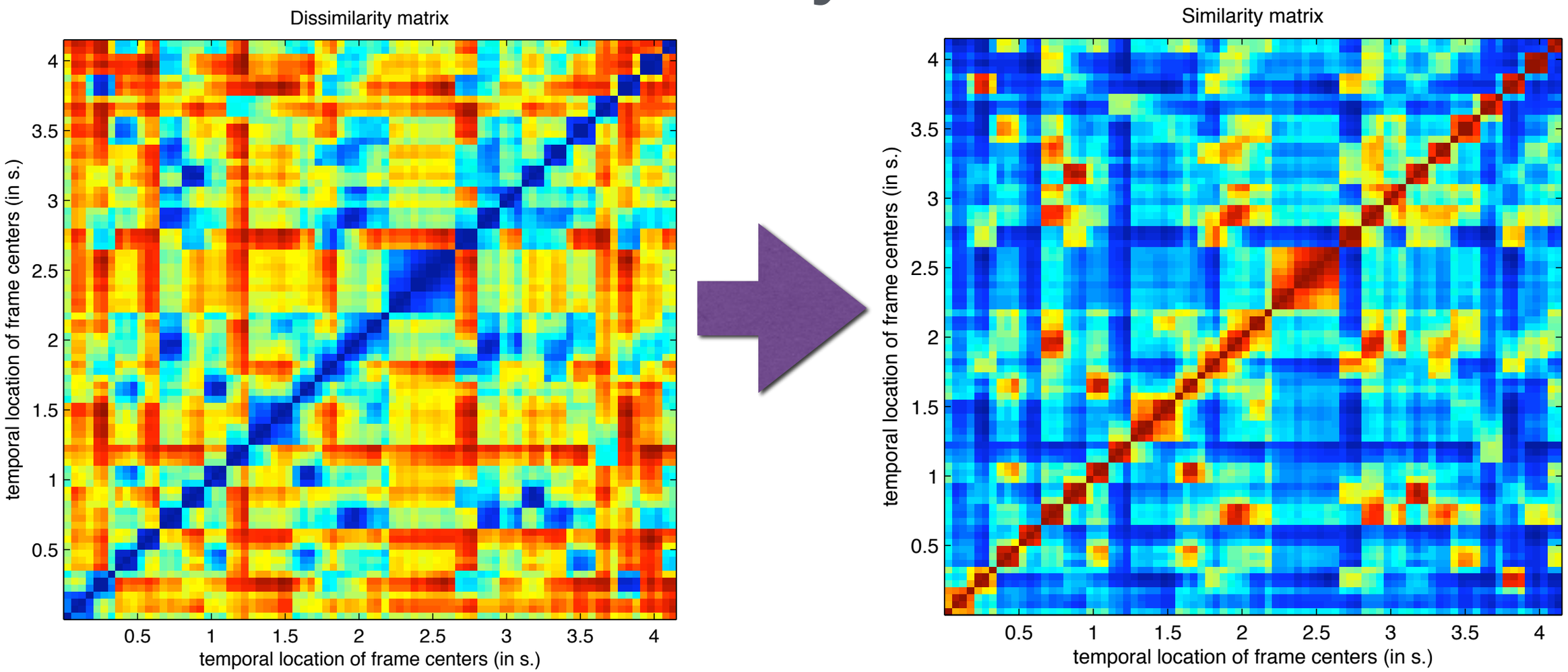
sig.spectrum (…,'Frame')

- *sig.simatrix(a, '**Dissimilarity**')*
- *sig.simatrix(…, '**Distance**', 'cosine')*

$$d_{cos}(v_i, v_j) = \frac{< v_i, v_j >}{|v_i||v_j|}$$

Foote, Cooper. "Media Segmentation using Self-Similarity Decomposition", SPIE Storage and Retrieval for Multimedia Databases, 5021, 167-75.

sig.simatrix
similarity matrix



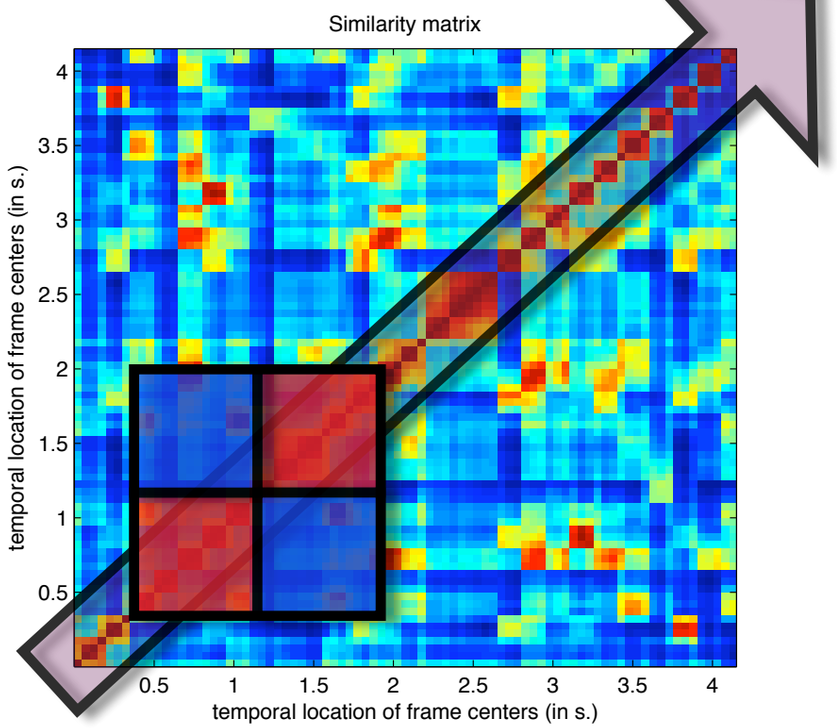
- *sig.simatrix(a, '**Similarity**', 'exponential')*

$$d_{exp}(v_i, v_j) = \exp\left(-d_{cos}(v_i, v_j)\right)$$

Foote, Cooper. "Media Segmentation using Self-Similarity Decomposition", SPIE Storage and Retrieval for Multimedia Databases, 5021, 167-75.

aud.novelty
novelty curve

sig.simatrix(a)



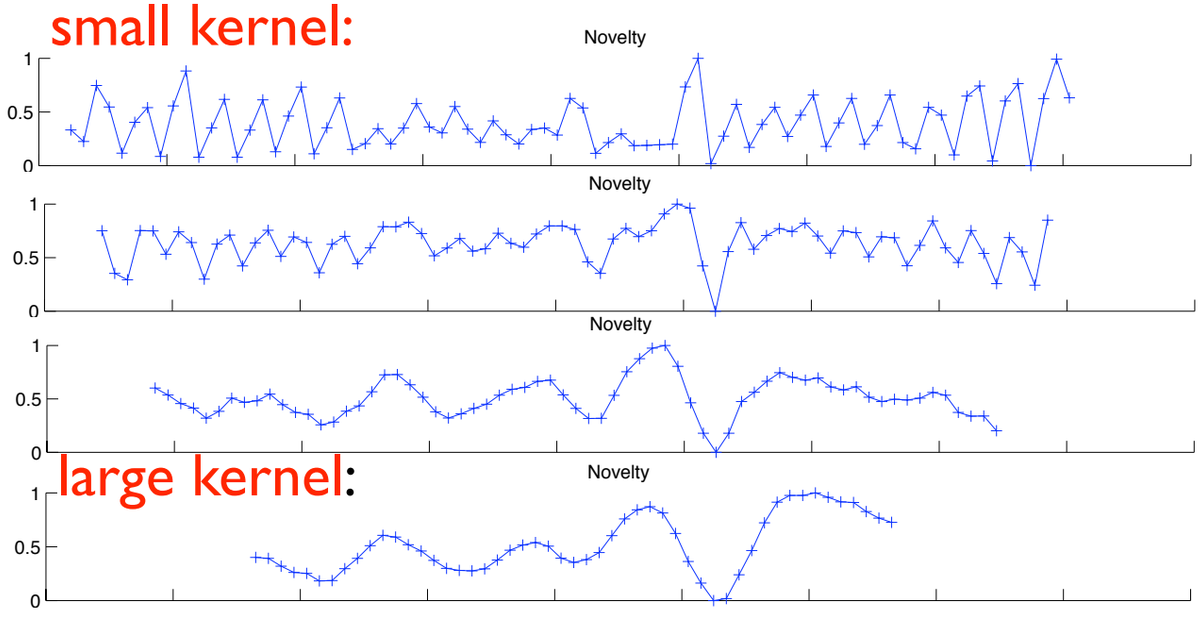
Convolution with Gaussian checkerboard kernel

*aud.novelty(a, '**KernelSize**', s)*

s = 128 samples

small kernel:

large kernel:

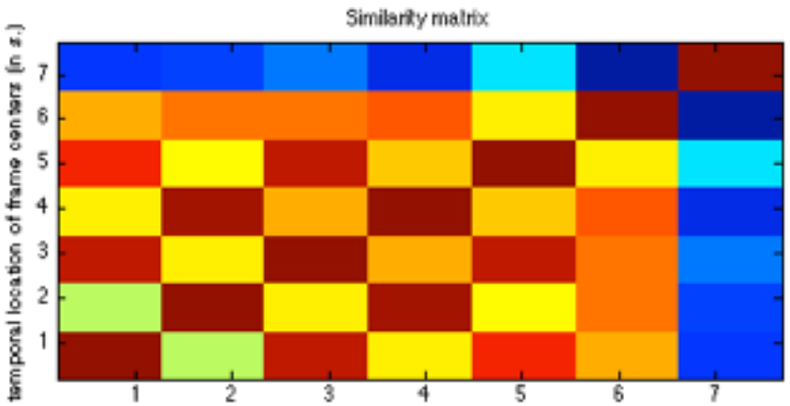


Foote, Cooper. "Media Segmentation using Self-Similarity Decomposition", SPIE Storage and Retrieval for Multimedia Databases, 5021, 167-75.

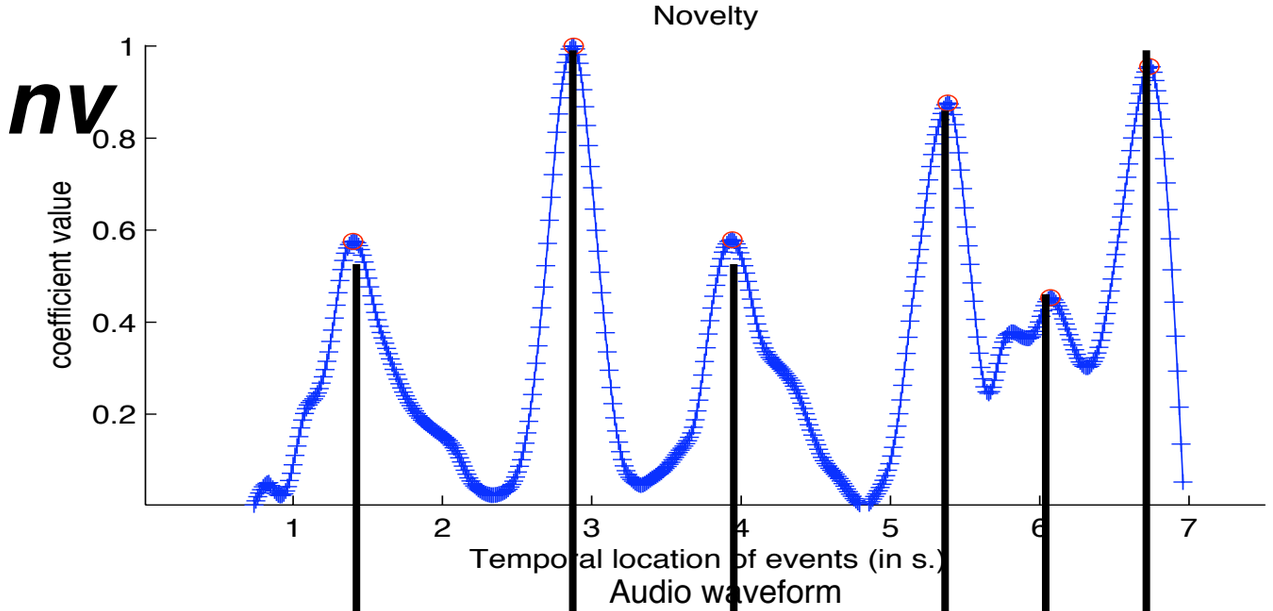
aud.segment
novelty-based segmentation

- *nv = aud.novelty(sm)*
- *sg = sig.segment('mysong', nv)*
- *sg = sig.segment('mysong')*
- *sg.play*
- *s = aud.mfcc(sg)*
- *sm = sig.simatrix(s)*

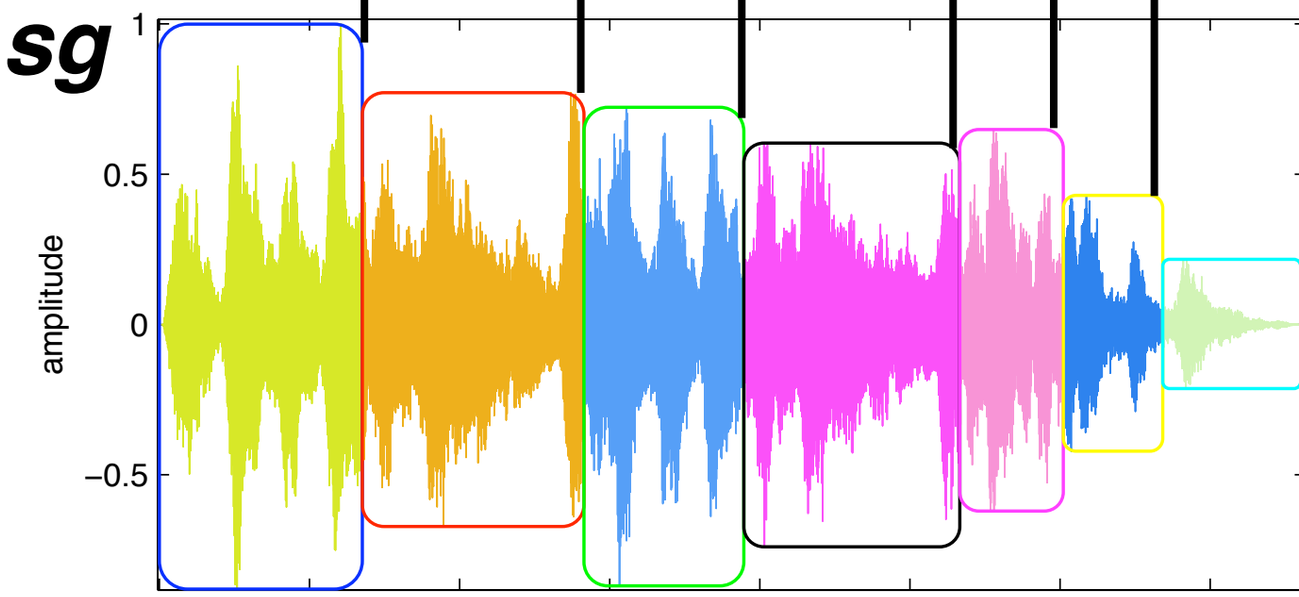
sm



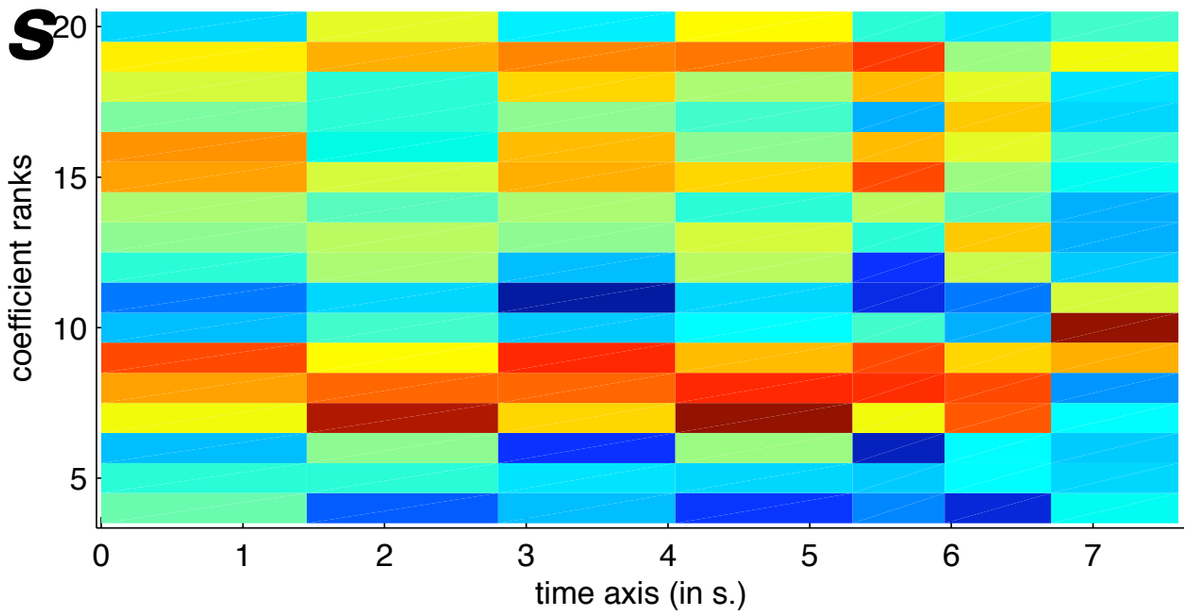
nv



sg

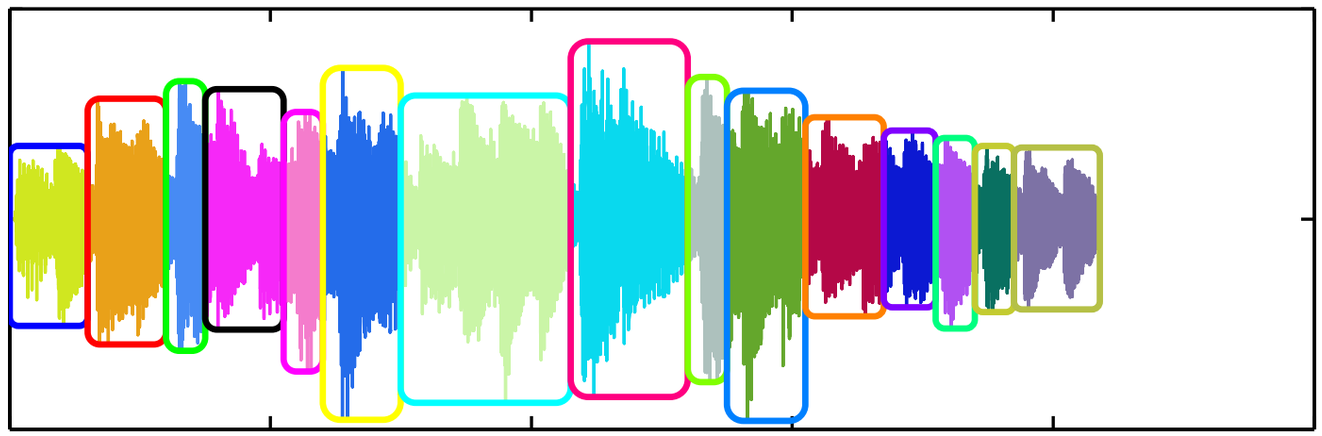


s

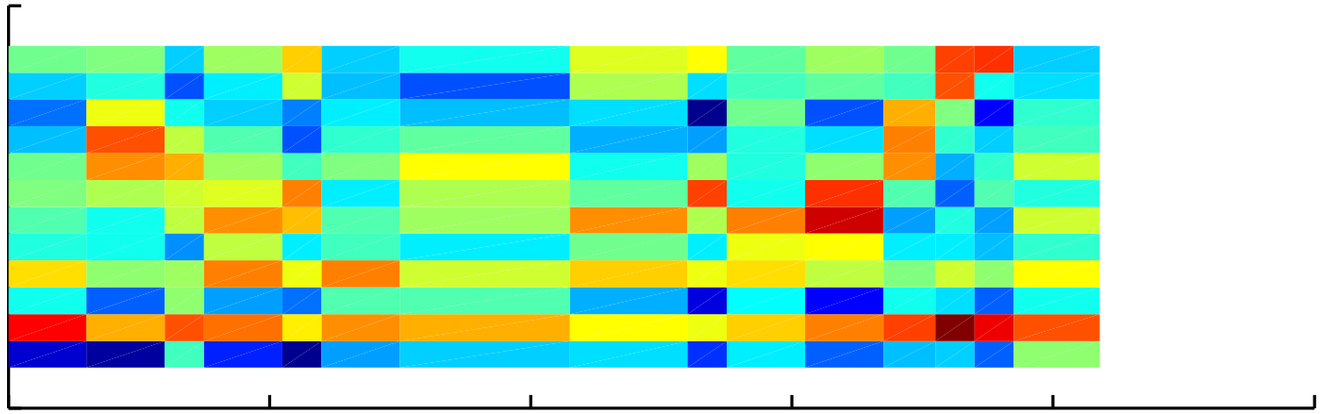


sig.cluster
clustering of audio segments

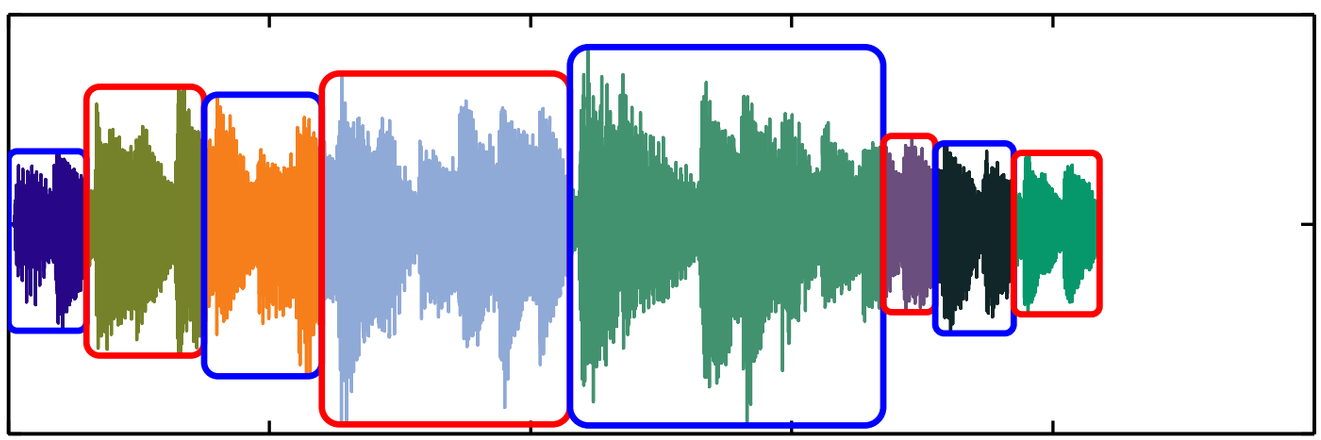
- *sg = aud.segment(a)*



- *cc = aud.mfcc(sg)*

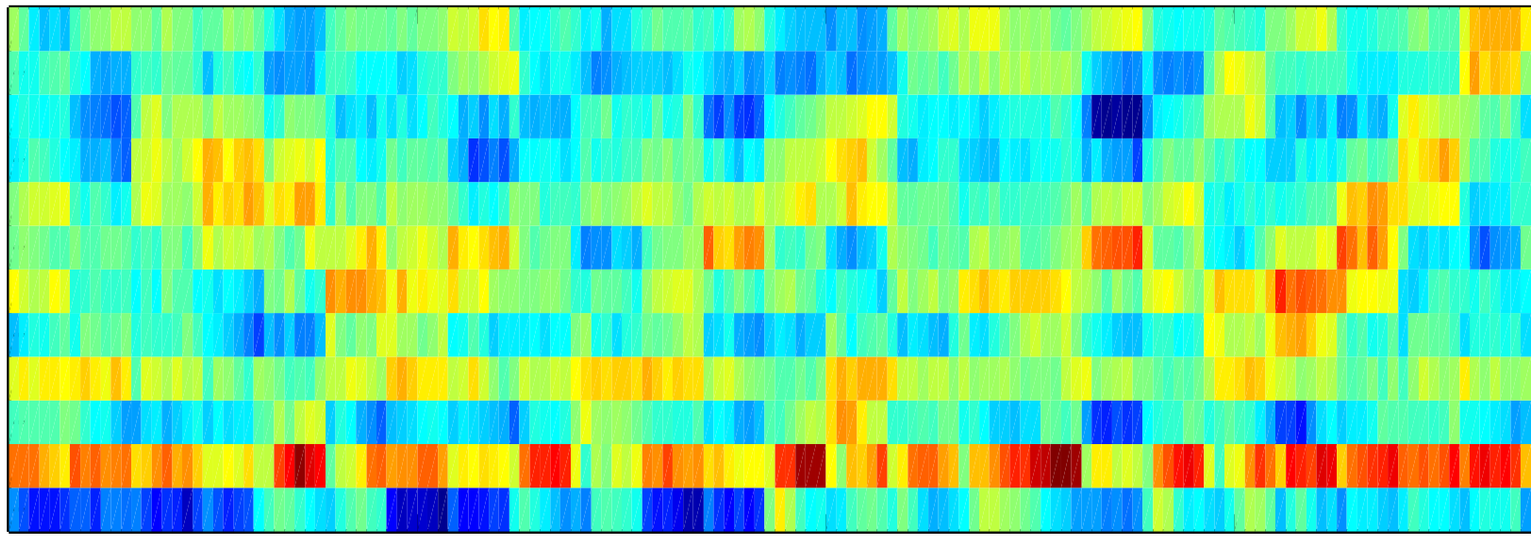


- *sig.cluster(sg, cc)*

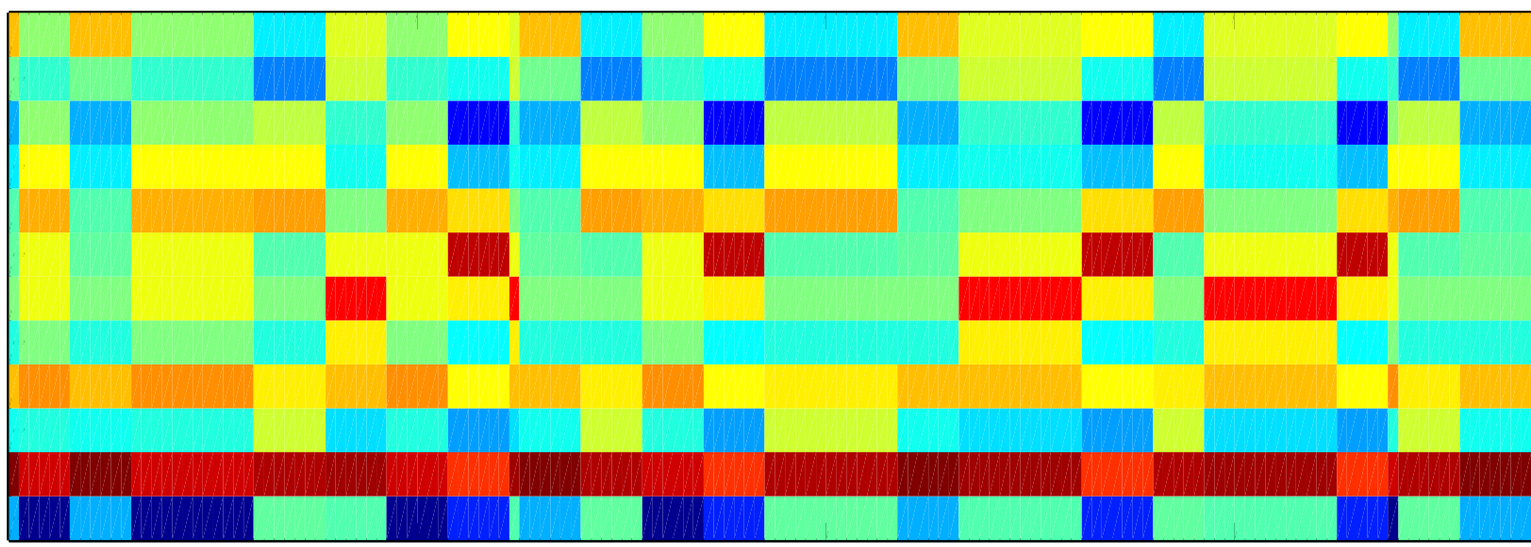


sig.cluster
clustering of frame-decomposed feature

- *cc = aud.mfcc(…, 'Frame')*



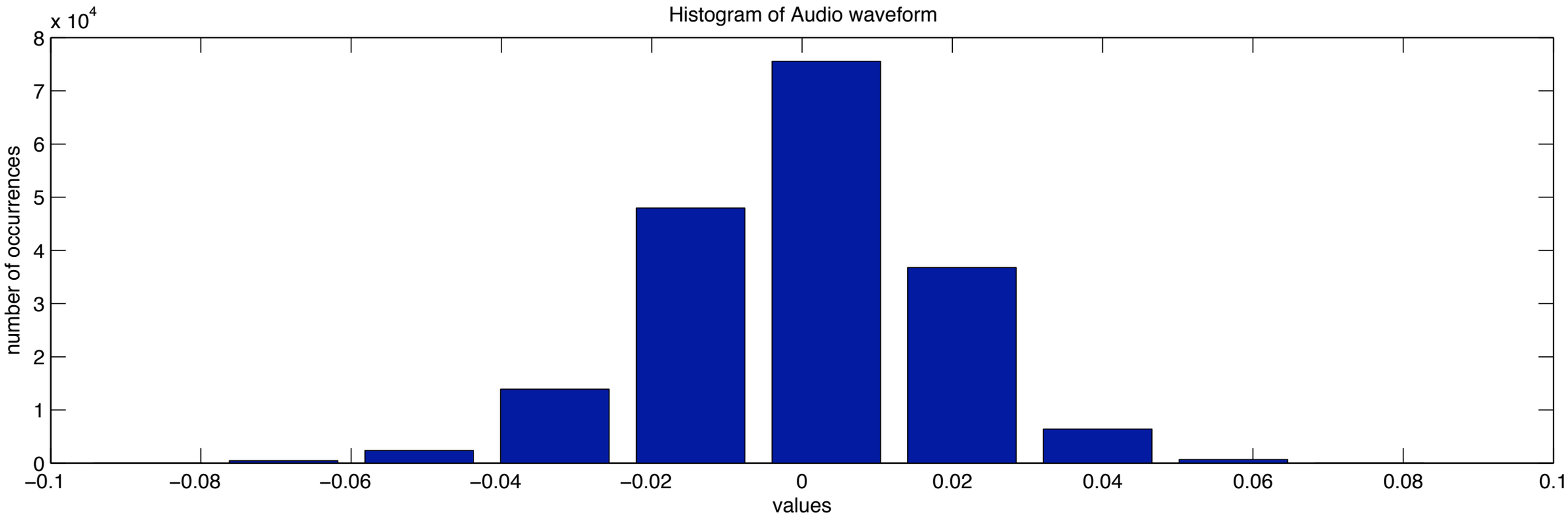
- *sig.cluster(cc, 4)*



sig.stat
basic statistics

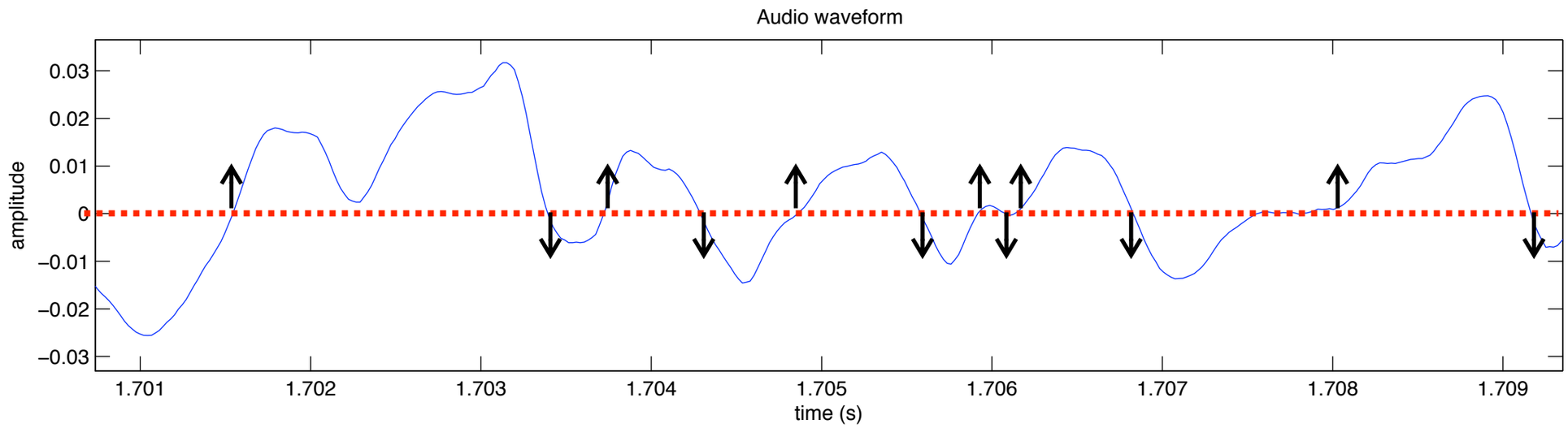
- mean
- standard deviation
- temporal slope
- main periodicity:
  - frequency
  - amplitude
  - periodicity entropy

sig.hist
histogram



*sig.hist(…, '**Number**',10)*

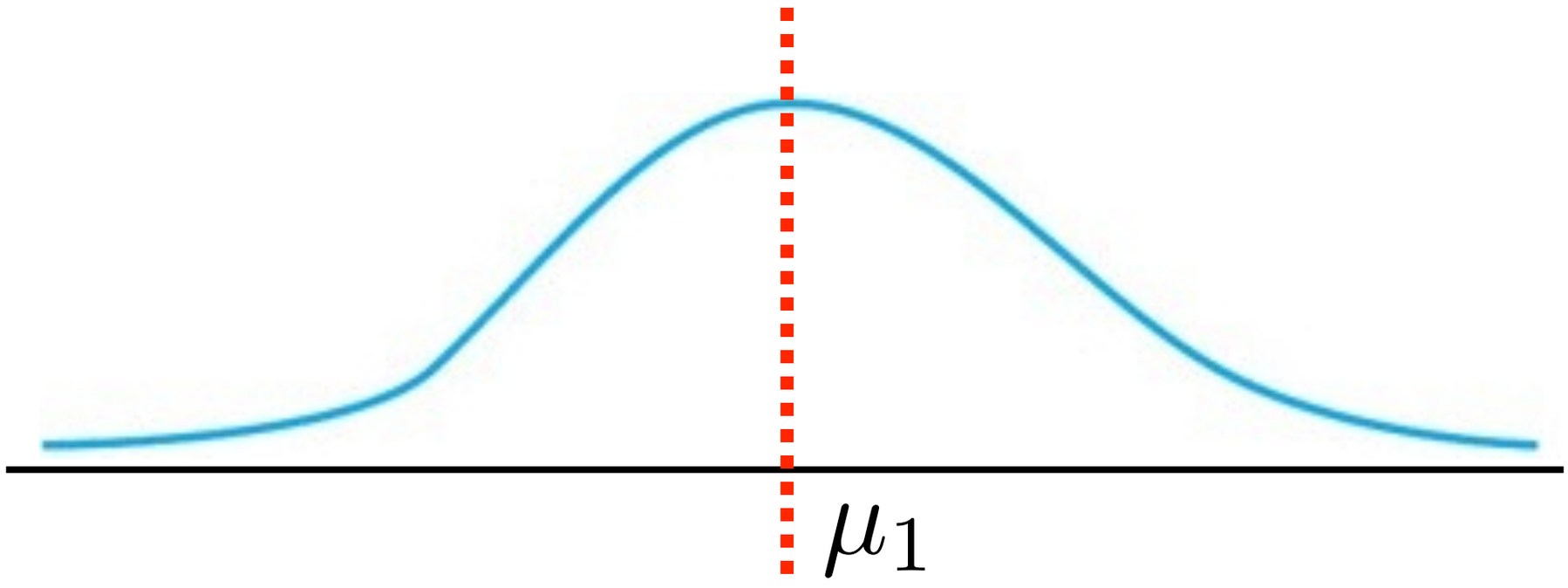
sig.zerocross
waveform sign-change rate



- on any curve
- sig.zerocross(…, ‘**Per**’, ‘**Second**’): rate per second
- sig.zerocross(..., ‘Per’, ‘**Sample**’): rate per sample
- sig.zerocross(..., ‘**Dir**’, ‘**One**’): only ↑ or ↓
- sig.zerocross(..., ‘Dir’, ‘**Both**’): both ↑ and ↓

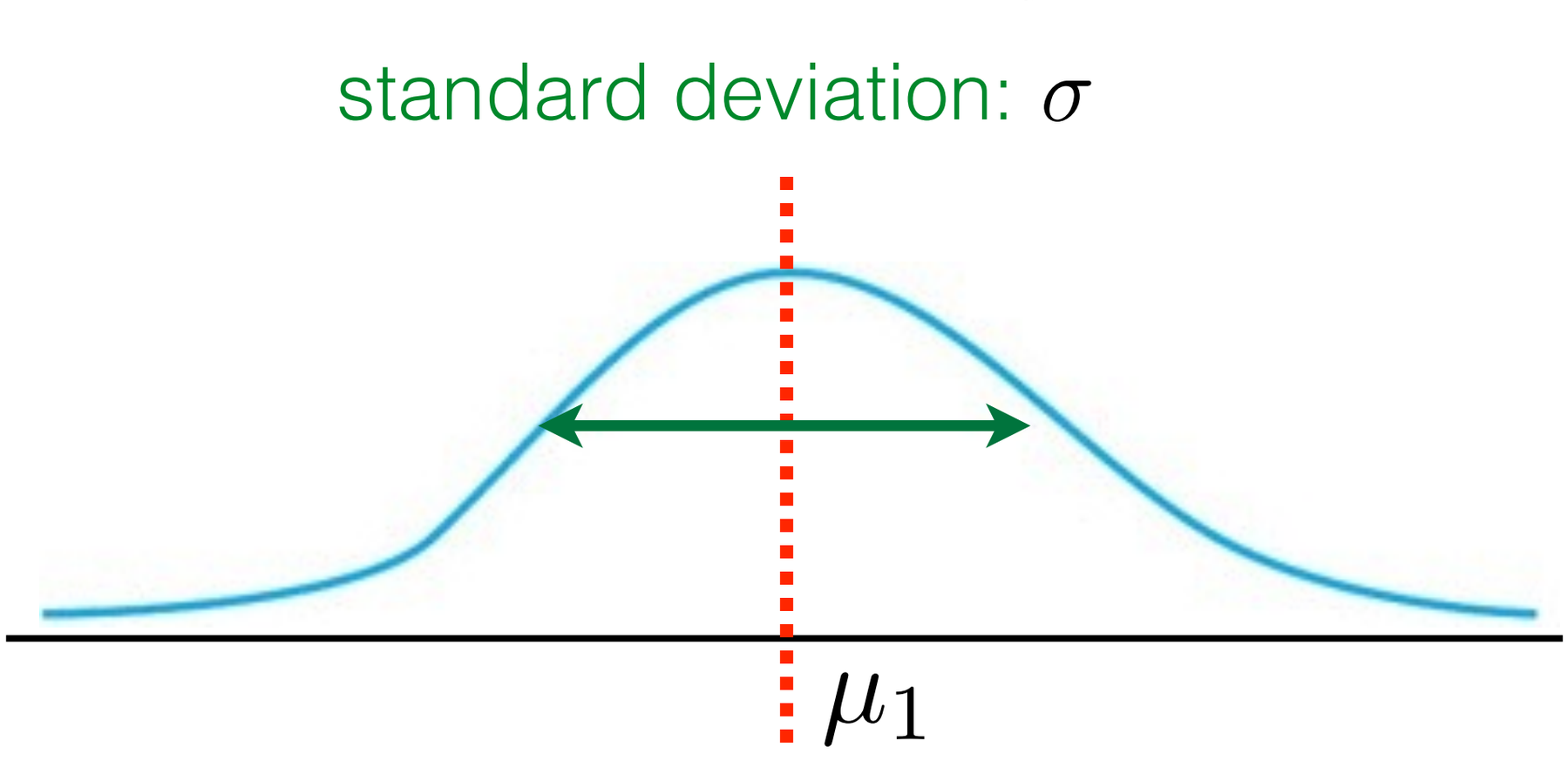
sig.centroid
geometric center

first moment: $\mu_1 = \int x f(x) dx$



sig.spread
variance, dispersion

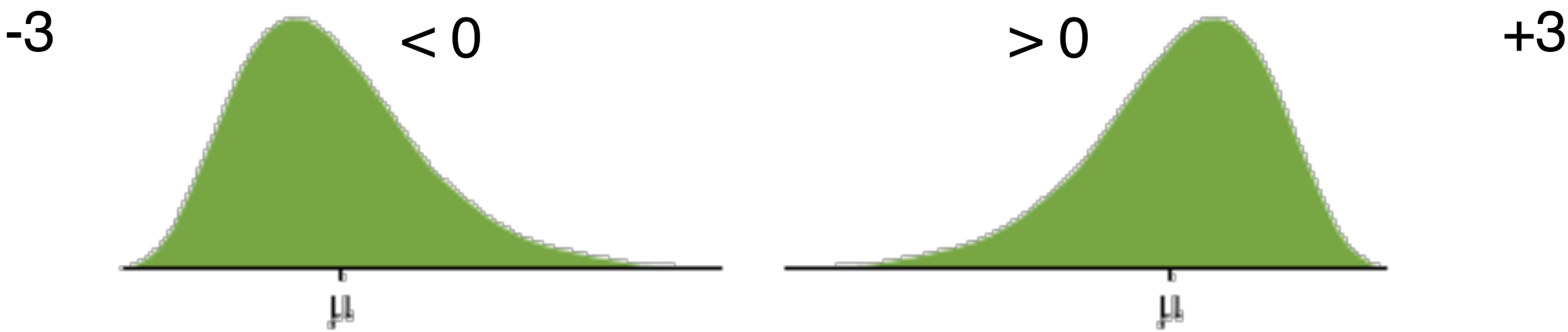
second moment: $\sigma^2 = \mu_2 = \int (x - \mu_1)^2 f(x) dx$



sig.skewness
non-symmetry

third moment: $\mu_3 = \int (x - \mu_1)^3 f(x) dx$

third standardized moment: $\frac{\mu_3}{\sigma^3}$

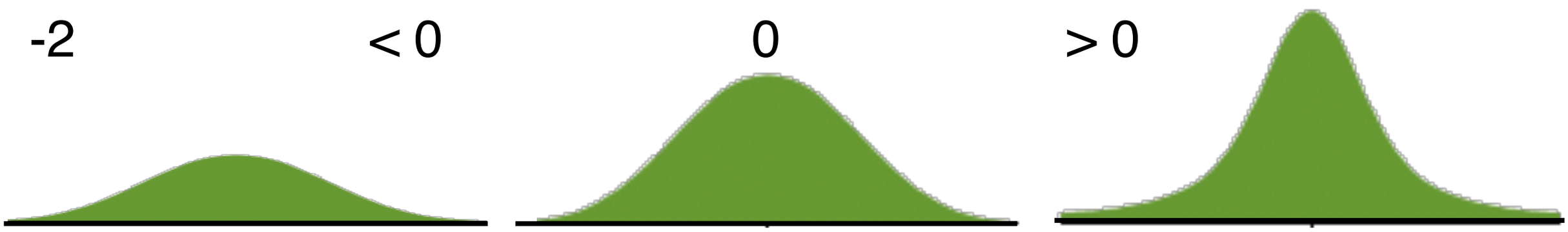


sig.kurtosis
pickiness

fourth moment: $\mu_4 = \int (x - \mu_1)^4 f(x) dx$

fourth standardized moment: $\frac{\mu_4}{\sigma^4}$

excess kurtosis: $\frac{\mu_4}{\sigma^4} - 3$



sig.flatness
smooth vs. spiky

$$\frac{\text{geometric mean}}{\text{arithmetic mean}} \quad \frac{\sqrt[N]{\prod_{n=0}^{N-1} x(n)}}{\left(\frac{\sum_{n=0}^{N-1} x(n)}{N}\right)}$$

sig.entropy
relative Shannon entropy

- Data considered as probability distribution:
  - p≥0: half-wave rectification
  - ∑p=1: normalization
- Shannon entropy: $H(p) = -\sum(p \ log(p))$
- Relative entropy, independent on the sequence length:

$$H(p) = -\sum(p \ log(p)) / log(length(p))$$

- Entropy gives an indication of the curve:
  - High entropy ≈ uncertainty ≈ flat curve
  - Low entropy ≈ certainty ≈ peak(s)

Shannon, C. E. 1948. “A Mathematical Theory of Communication.” Bell Systems Technical Journal 27:379–423.

sig.export
exportation of statistical data to files

- *m = aud.mfcc(…*

- *sig.export(filename, m, …)* adding one or several data from *MiningSuite* operators.

- *sig.export('result.txt', ...)* saved in a text file.

- *sig.export('result.arff', ...)* exported to WEKA for data-mining.

- *sig.export('Workspace', ...)* saved in a *Matlab* variable.

aud.play
feature-based playlist

- *zc = sig.zerocross('Folder');*

- *aud.play('Folder', '**Increasing**', zc)*

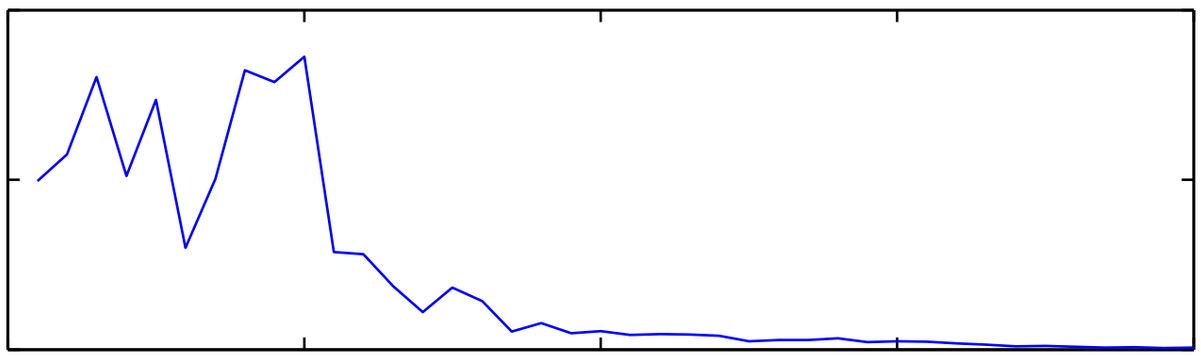
    - Plays the folder of audio files in increasing order of zero-crossing rate.

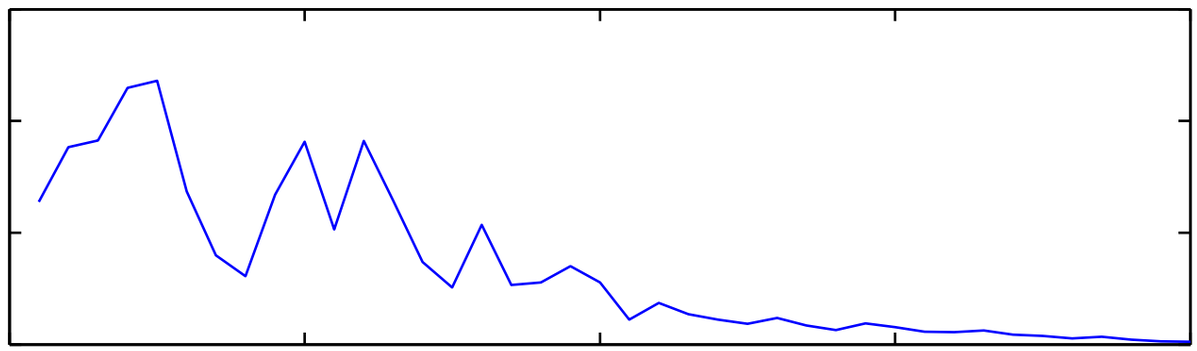
- *aud.play('Folder', 'Increasing', zc, '**Every**', 5)*

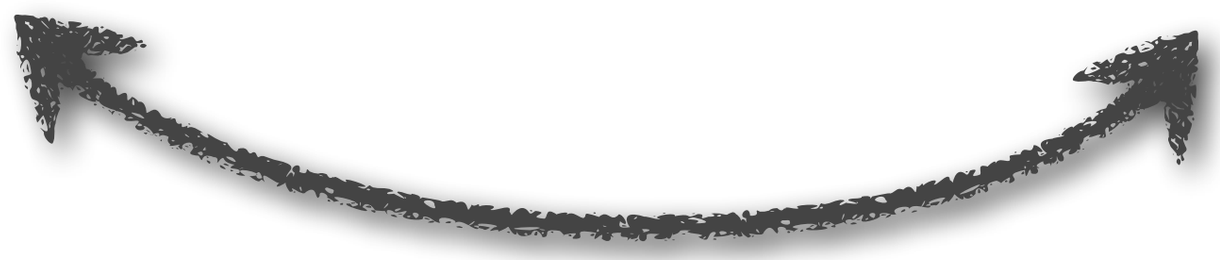
    - Plays one out of five audio files.

sig.dist
distance between features

- *s1 = aud.spectrum('a','Mel')*
- *s2 = aud.spectrum('b','Mel')*







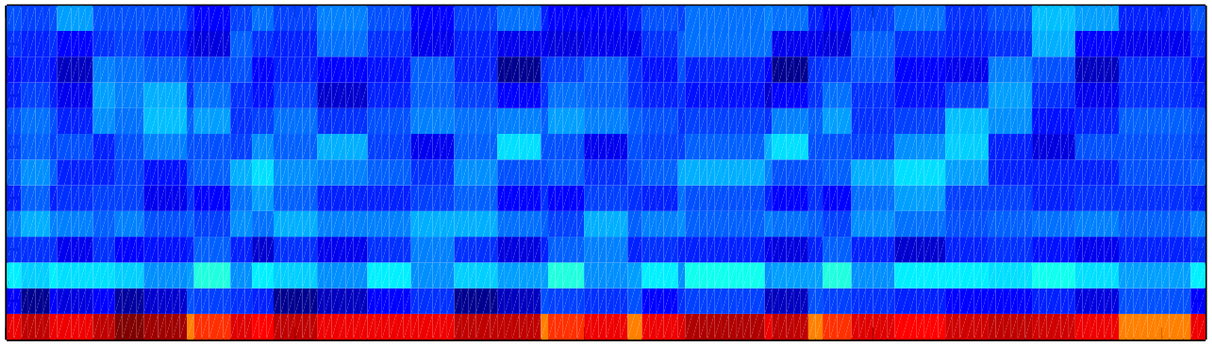
- *sig.dist(s1, s2, 'Cosine')*

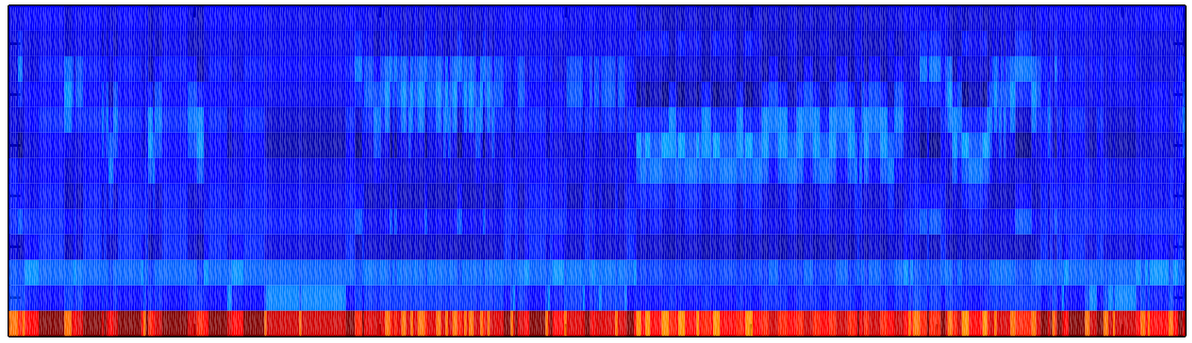
```
The Mel-Spectrum Distance between files a and b is 0.1218
```

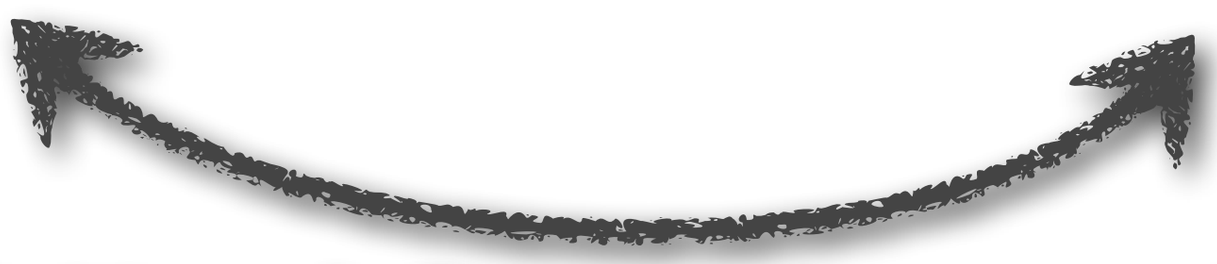
sig.dist
distance between clusters

- *c1 = aud.mfcc('a','Frame')*
- *c1 = sig.cluster(c1, 16)*

- *c2 = aud.mfcc('b','Frame')*
- *c2 = sig.cluster(c2, 16)*







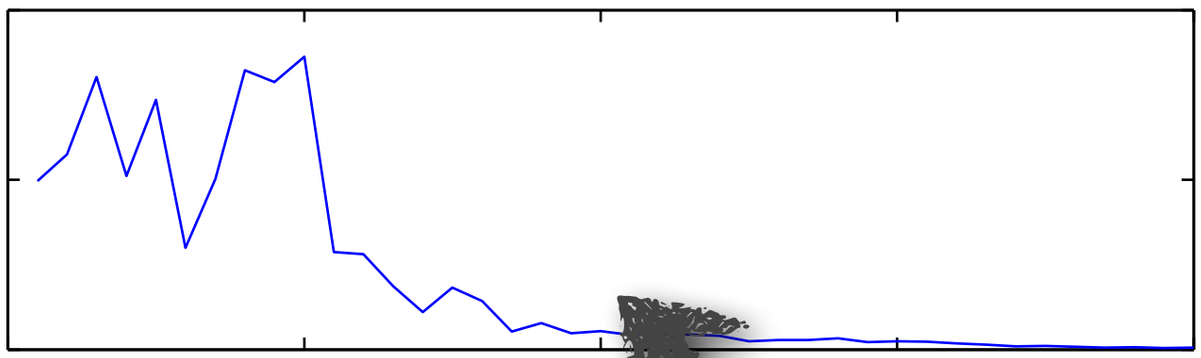
Earth Mover's Distance between clusters

- *sig.dist(c1, c2)*

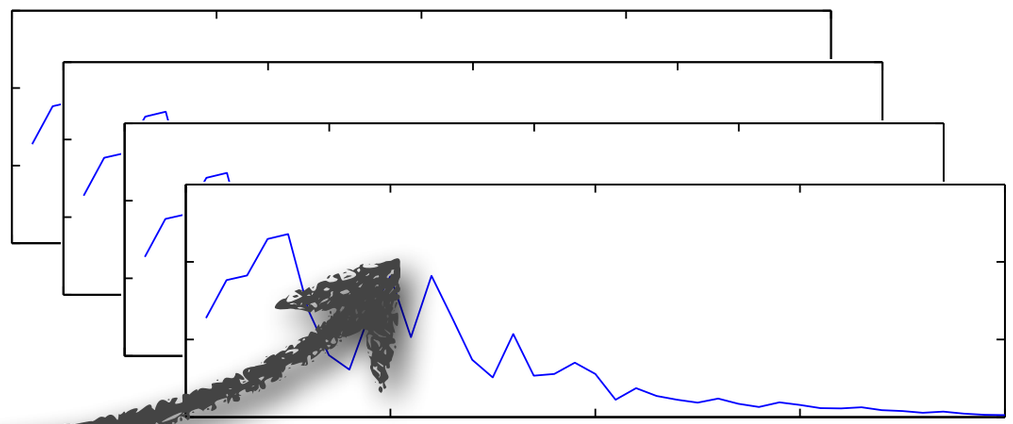
```
The MFCC Distance between files a and b is 19.3907
```

sig.dist
distance between features

- *s1 = aud.spectrum('a', 'Mel')*



- *s2 = aud.spectrum('**Folder**', 'Mel')*



- *sig.dist(s1, s2)*

```
The Mel-Spectrum Distance between files a and b1 is 0.2386
The Mel-Spectrum Distance between files a and b2 is 0.45729
The Mel-Spectrum Distance between files a and b3 is 0.6338
The Mel-Spectrum Distance between files a and b4 is 0.20082
```

.getdata
returns data in Matlab format

s *= sig.spectrum('file');* ⟶

Encapsulated data
numerical data,
related sampling rates,
related file name,
etc.

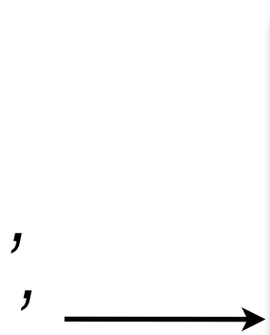
s

s.getdata

vector

.getdata
returns data in Matlab format

***s** = sig.spectrum('file', 'Frame');*



s

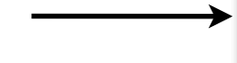
Encapsulated data
numerical data,
related sampling rates,
related file name,
etc.

s.getdata

matrix

.getdata
returns data in Matlab format

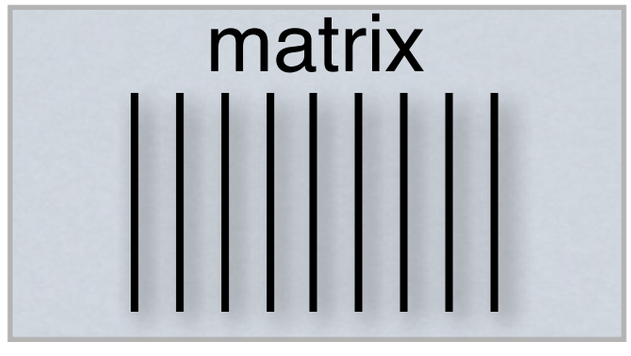
***f** = sig.filterbank('file', 'Frame');*



f

Encapsulated data
numerical data,
related sampling rates,
related file name,
etc.

f.getdata



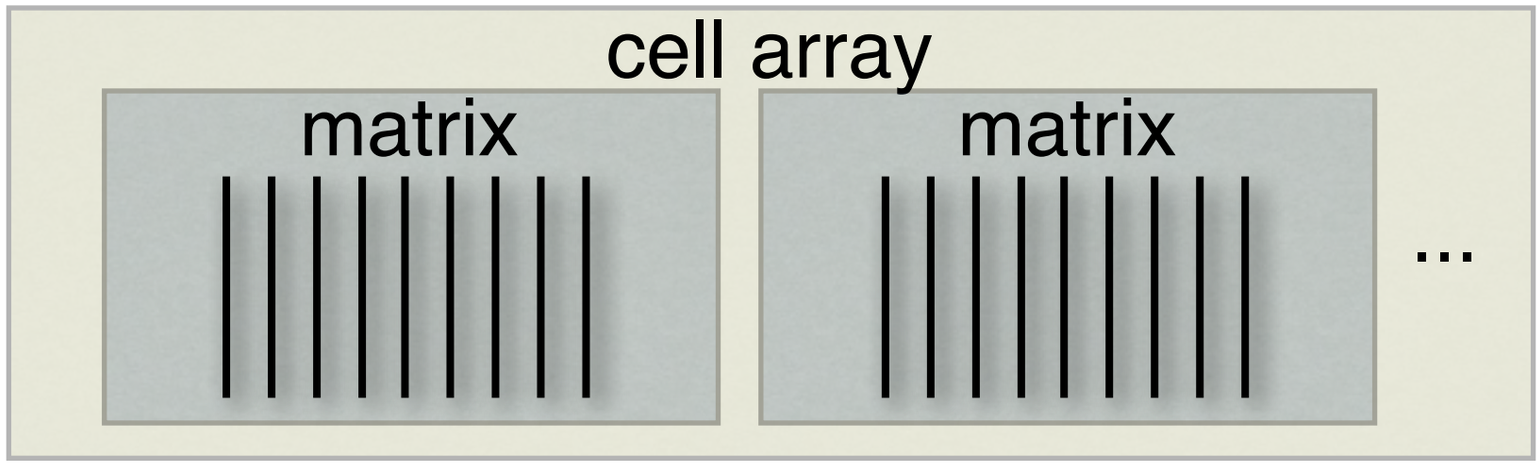
.getdata
returns data in Matlab format

sg = sig.segment('file')
***f** = sig.filterbank(sg, 'Frame');* ⟶

Encapsulated data
numerical data,
related sampling rates,
related file name,
etc.

f

f.getdata



.getpeakpos, .getpeakval returns data in Matlab format

p *= sig.peaks…*

Encapsulated data
numerical data,
related sampling rates,
related file name,
etc.

p

p.getpeakpos

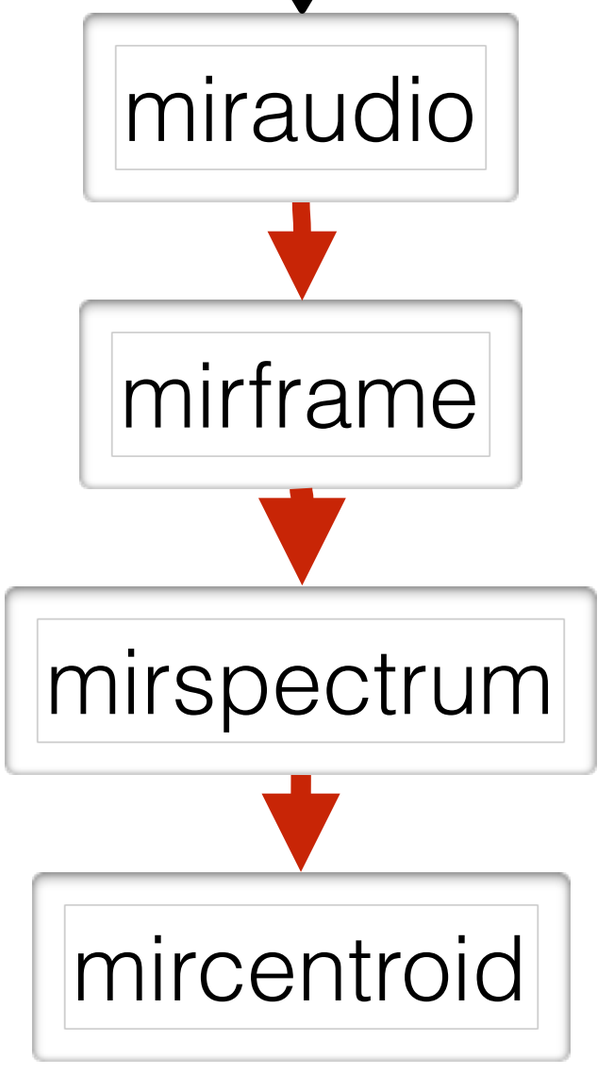
p.getpeakval

vector

vector

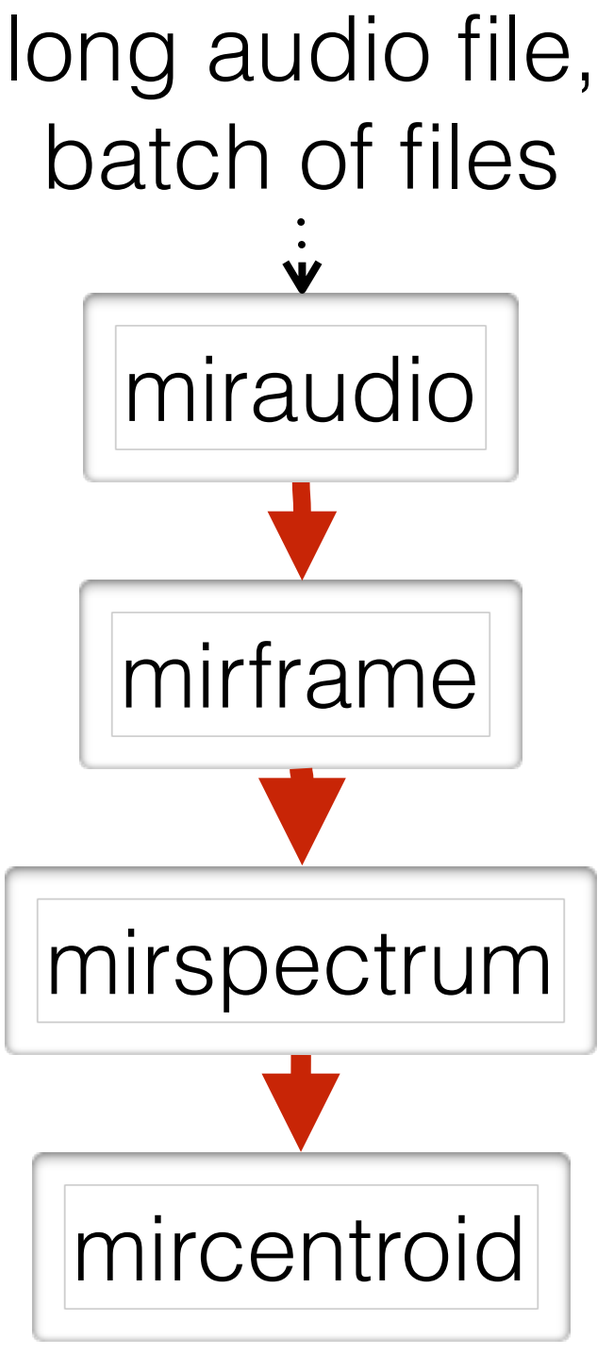
Limitations of data flow in *MIRtoolbox*

long audio file,
batch of files



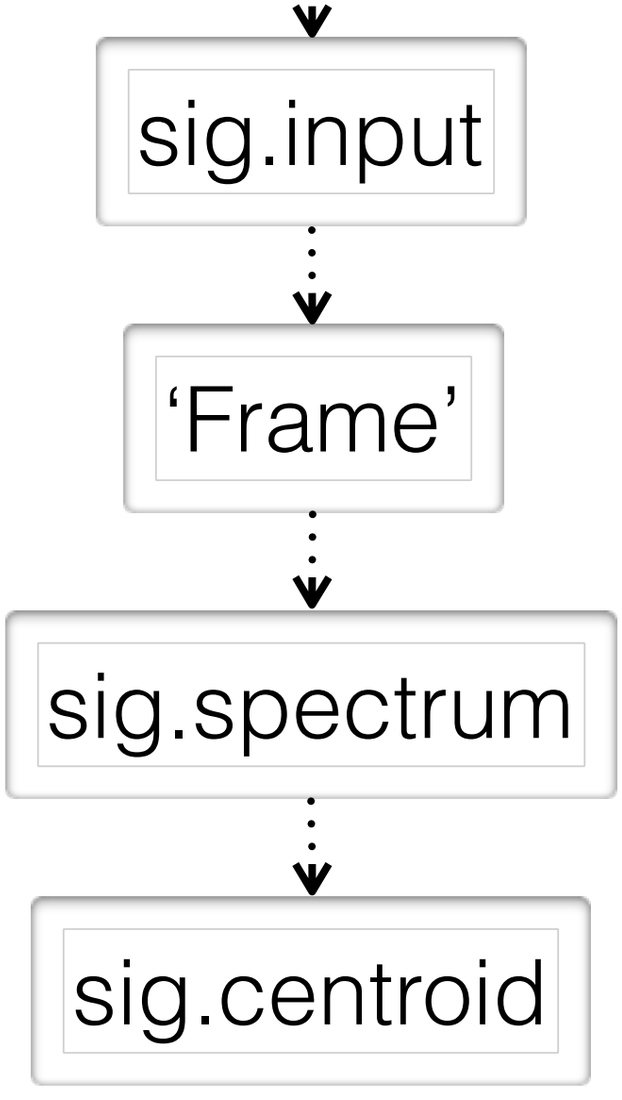
- a = miraudio('bigfile')
- f = mirframe(a)
- s = mirspectrum(f)
- mircentroid(s)
- mircentroid('bigfile', 'Frame')

Data flow graph design & evaluation



- a = miraudio('**Design**', …)
- s = mirspectrum(f, 'Frame', …)
- c = mircentroid(s)
- **mireval**(c, 'bigfile')

Data flow graph in MiningSuite



- a = sig.input('bigfile', …);
- s = sig.spectrum(f, 'Frame', …);
- c = sig.centroid(s)

; → No operation is performed.
(The data flow graph is constructed without actual computation.)

sig.design
data flow graph design

- ***a*** *= sig.input('bigfile', ...);*
- ***s*** *= sig.spectrum(a);*
- ***c*** *= sig.centroid(s)*
- ***c***
- *d =* ***sig.ans***
- *d = c.**eval***
- *d = c.**getdata***

sig.design objects, storing only the data flow graph

Design now evaluated in order to display the results.

But results was not stored in **c**, so displaying again **c** triggers another evaluation of the design.

The last evaluation is stored in ***sig.ans***.

Evaluate and store in a variable.

sig.design.eval
data flow graph evaluation

- *a = sig.input('bigfile', …);*
- *s = sig.spectrum(a);*
- *c = sig.centroid(s)*
- *c.**eval***

  Evaluate the data flow graph for the particular audio file (or 'Folder') assigned during the graph design

- *c.**eval**('anotherfile')*

  Apply the same data flow graph to another audio file (or 'Folder')

sig.design.show
data flow graph display

- ***a*** *= sig.input(…);*
- ***s*** *= sig.spectrum(a);*
- ***c*** *= sig.centroid(s)*
- *c****.show***

```
> sig.input ( 'ragtime' )
    frameconfig: 0
            mix: 'Pre'
       sampling: 0
         center: 0
       sampling: 0
        extract: []
           trim: 0
      trimwhere: 'BothEnds'
   trimthreshold: 0.0600
       halfwave: 0
```

```
> sig.spectrum ( ... )
            win: 'hamming'
            min: 0
            max: Inf
             mr: 0
            res: NaN
         length: NaN
             zp: 0
             wr: 0
         octave: 0
         constq: 0
     alongbands: 0
             ni: 0
      collapsed: 0
          rapid: 0
          phase: 1
             nl: 0
           norm: 0
          mprod: []
           msum: []
            log: 0
             db: 0
            pow: 0
      collapsed: 0
           aver: 0
          gauss: 0
     timesmooth: 0
```

```
> sig.centroid ( ... )
```

sig.signal.design
design stored in the results

- *a = sig.input(…);*
- *s = sig.spectrum(a);*
- *c = sig.centroid(s);*
- *d = c.eval*
- *d**.design***
- *d.design.show*

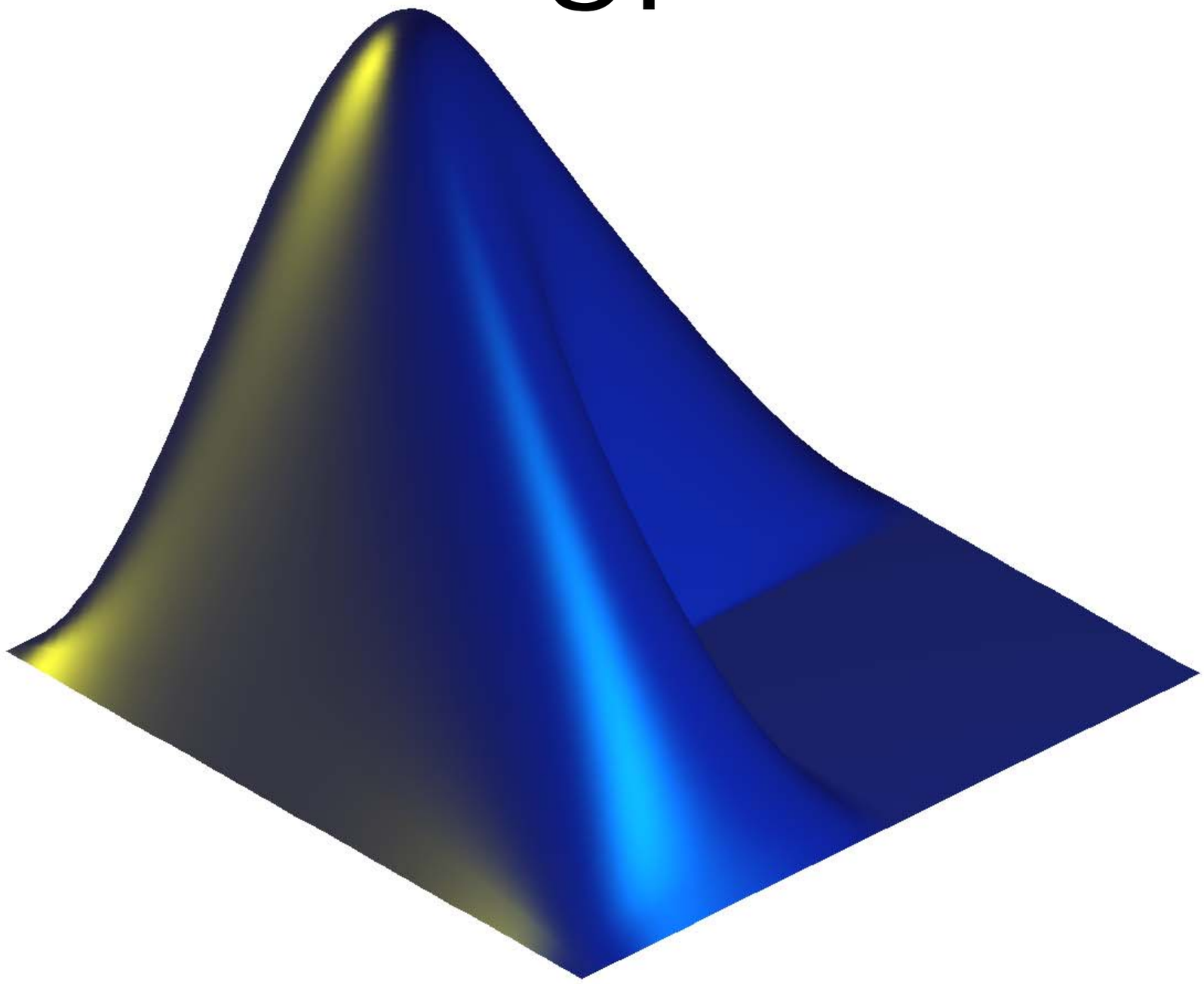
- *save result.mat d*

1 year later:

- *load result.mat*
- *d* ⟶ the results
- *d**.design***
- *d.design.show*


Signal domain
• SIGMINR
• sig.input, sig.spectrum, ...
• AUDMINR
• aud.spectrum, ...
• aud.mfcc, aud.brightness, ...
• Sets of operators related to signal processing operations, audio and musical features
MiningSuite

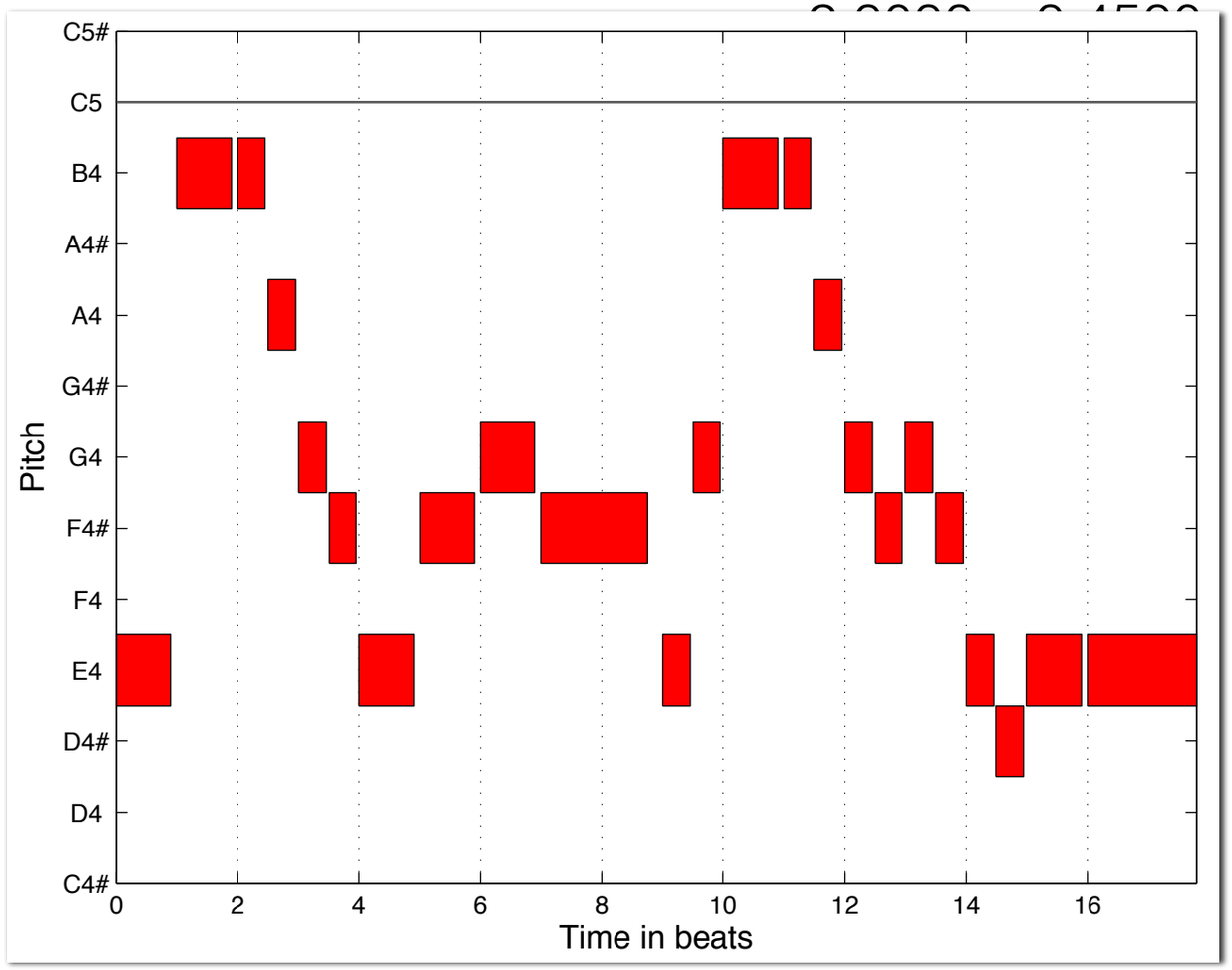
3.



Symbolic approaches

MIDI Toolbox

- nmat = readmidi('laksin.mid')
- pianoroll(nmat)



MIDI data

nmat =

0	0.9000	0	64.0000	82.0000	0	0.5510
1.0000	0.9000	0	71.0000	89.0000	0.6122	0.5510
		0	71.0000	82.0000	1.2245	0.2755
		0	69.0000	70.0000	1.5306	0.2755
		0	67.0000	72.0000	1.8367	0.2772
		0	66.0000	72.0000	2.1429	0.2772
		0	64.0000	70.0000	2.4490	0.5510
		0	66.0000	79.0000	3.0612	0.5510
		0	67.0000	85.0000	3.6735	0.5510
		0	66.0000	72.0000	4.2857	1.0714
		0	64.0000	74.0000	5.5102	0.2772
		0	67.0000	81.0000	5.8163	0.2772
		0	71.0000	83.0000	6.1224	0.5510
		0	71.0000	78.0000	6.7347	0.2772
		0	69.0000	73.0000	7.0408	0.2772
		0	67.0000	71.0000	7.3469	0.2772
		0	66.0000	69.0000	7.6531	0.2772

mus.score
score excerpt selection

- *mus.score(…, '**Notes**',* 10:20*)*
- *mus.score(…, '**StartTime**',* 30*, '**EndTime**',* 60*)*
- *mus.score(…, '**Channel**',* 1*)*
- *mus.score(…, '**Trim**')*
  - *mus.score(…, '**TrimStart**', '**TrimEnd**')*

mus.score
score information

⏳ • **metrical grid**: hierarchical construction of pulsations over multiple metrical levels

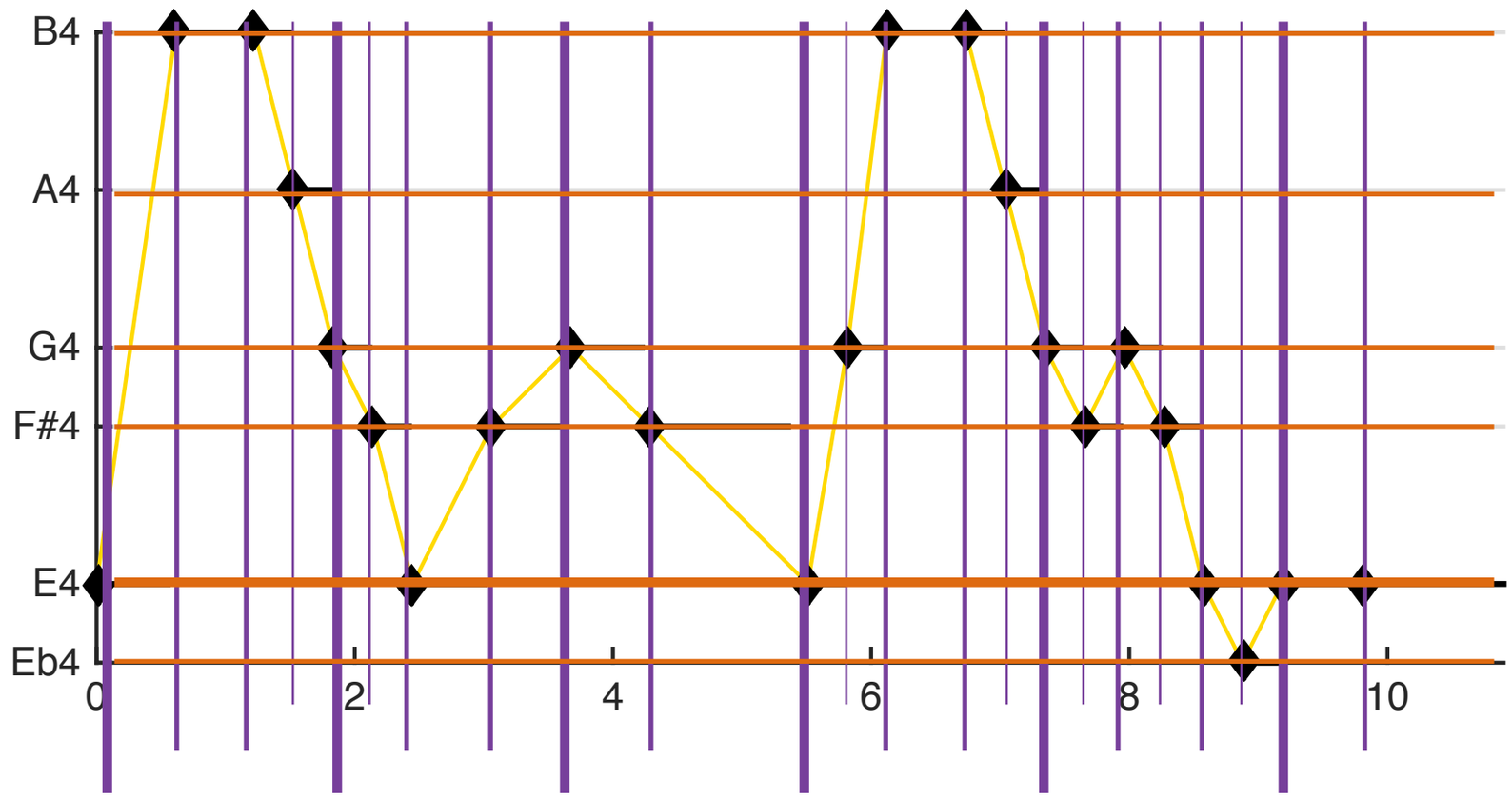
⏳ • **modal and tonal spaces**: mapping pitch values on scale patterns (on delimited temporal regions)

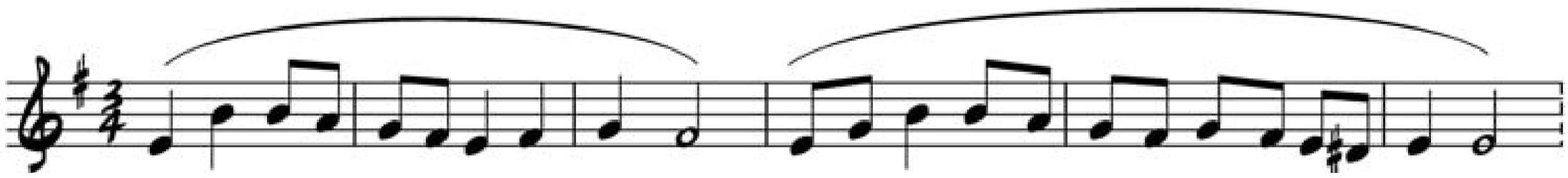
✔ • **syntagmatic chains**: successive notes forming voices, enabling to express relative distance between successive notes (rhythmic values)

mus.score
score information

mus.save
mus.play

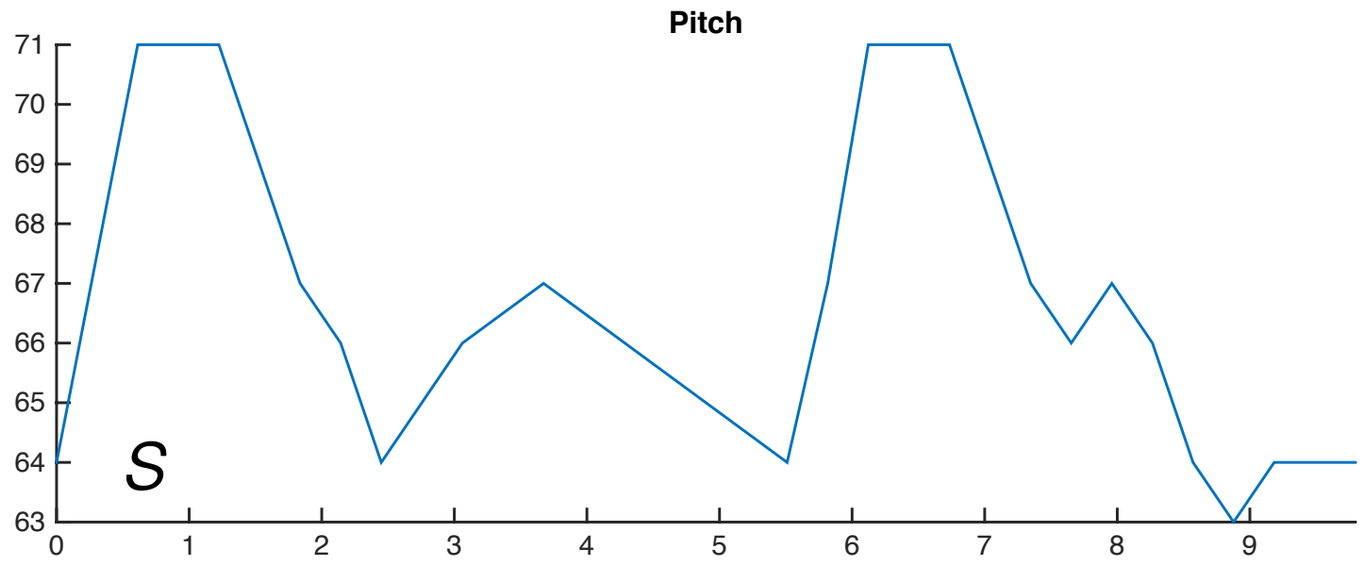
mus.score('laksin.mid')

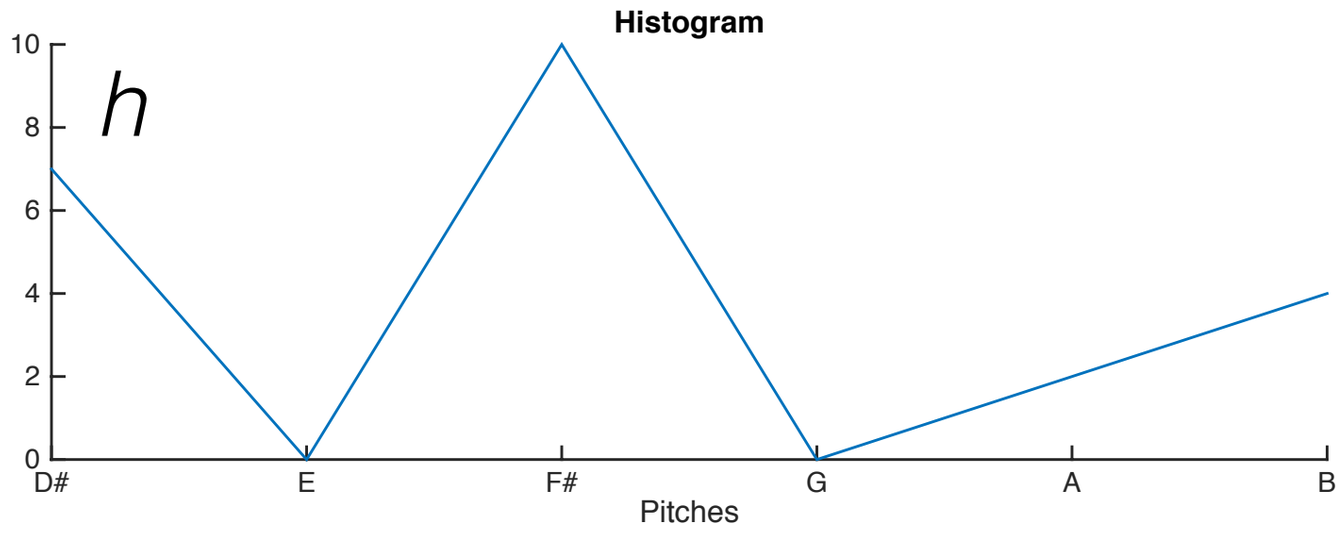




mus.pitch
pitch contour

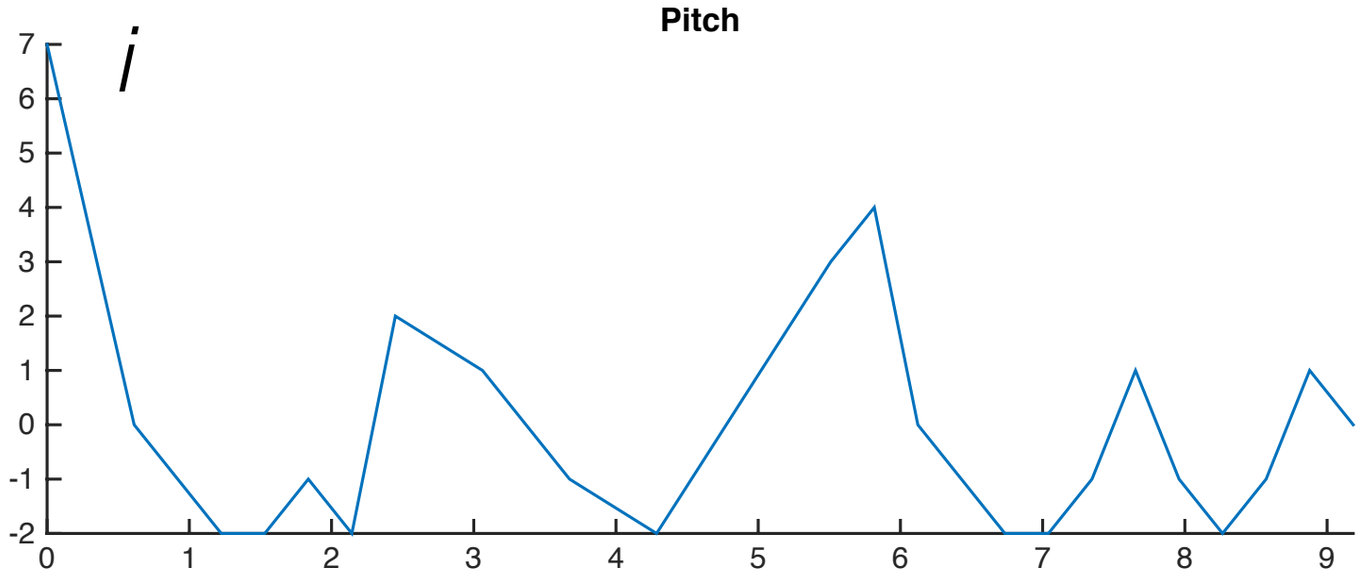
- *m = mus.score('myfile')*
  - *m* is of class *mus.sequence*
- *s =* ***mus.pitch****(m)*
  - *s* is of class *sig.signal*
- *h =* ***mus.hist****(s, '****Class****')*

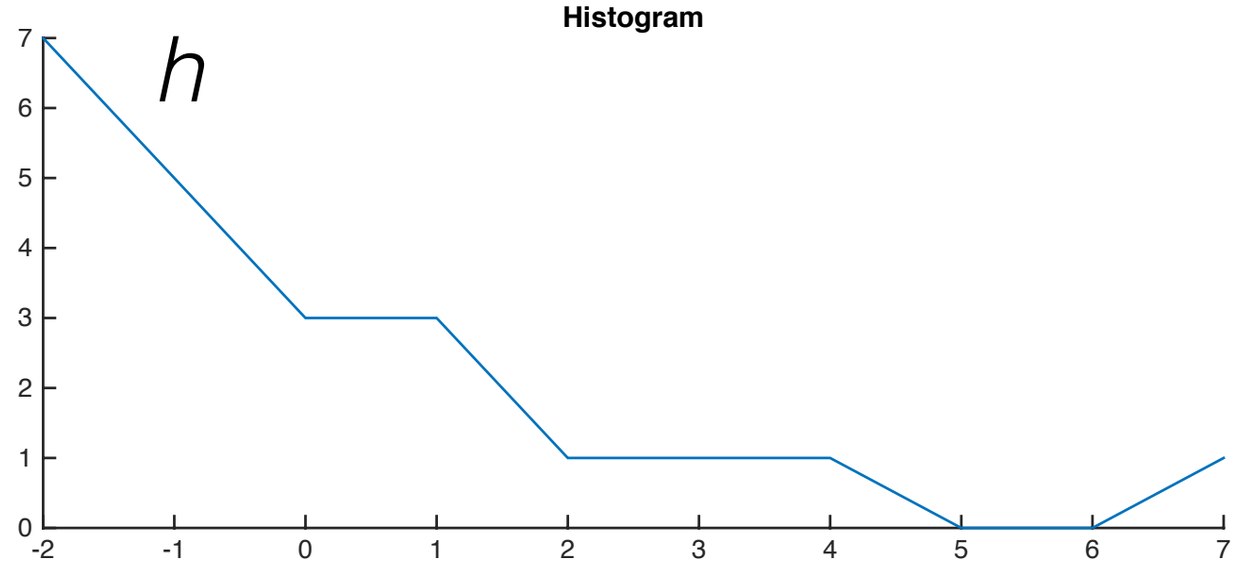




mus.pitch('Inter')
pitch interval contour

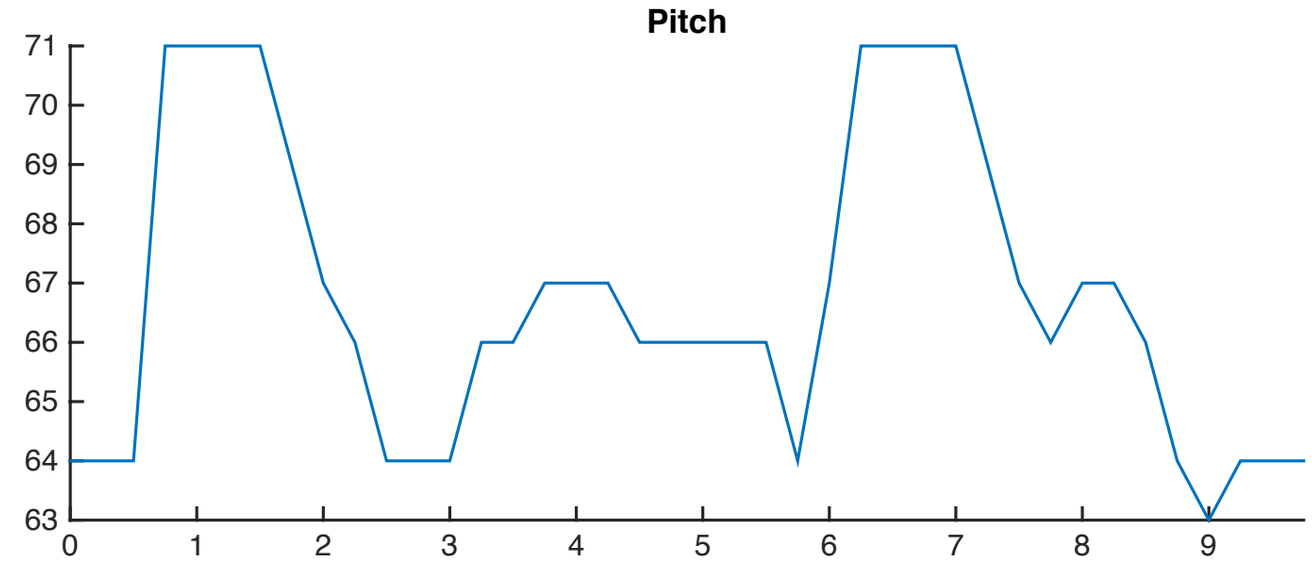
- *m = mus.score('myfile')*
- *i = mus.pitch(m, '**Inter**')*
- *h = mus.histo(i)*
- *mus.histo(i, '**Sign**', 0)*

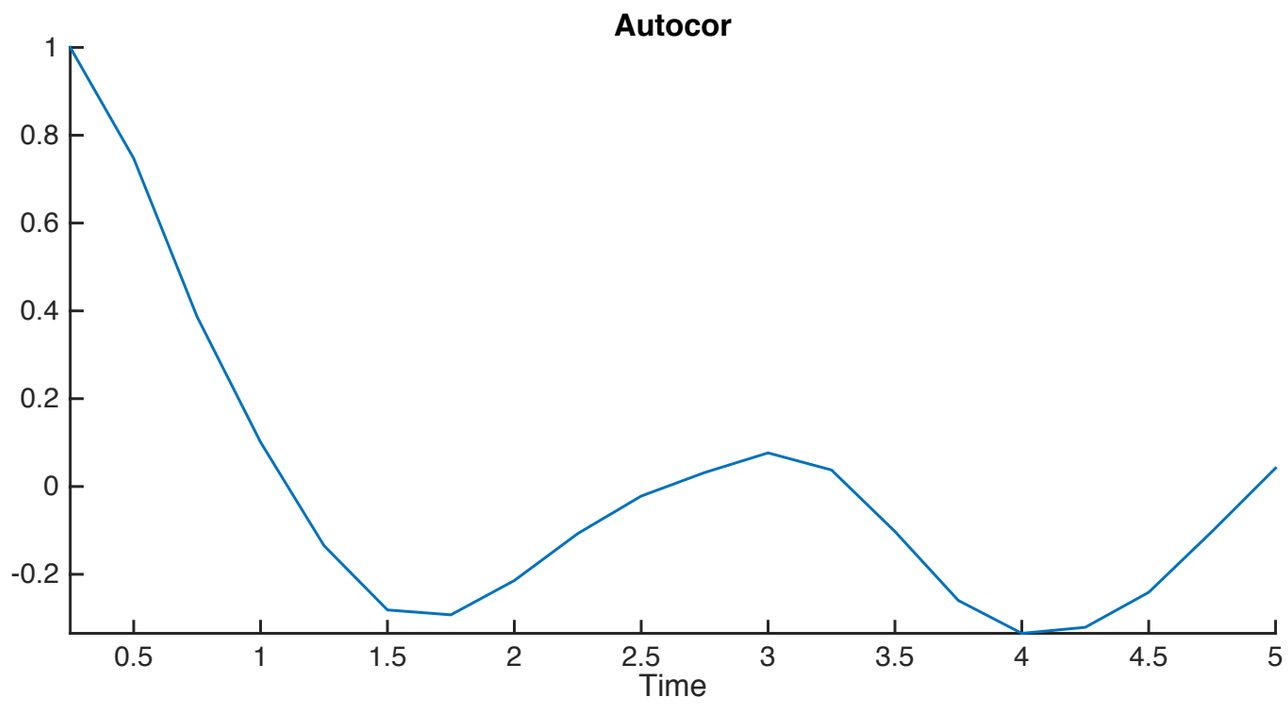




mus.pitch
pitch contour

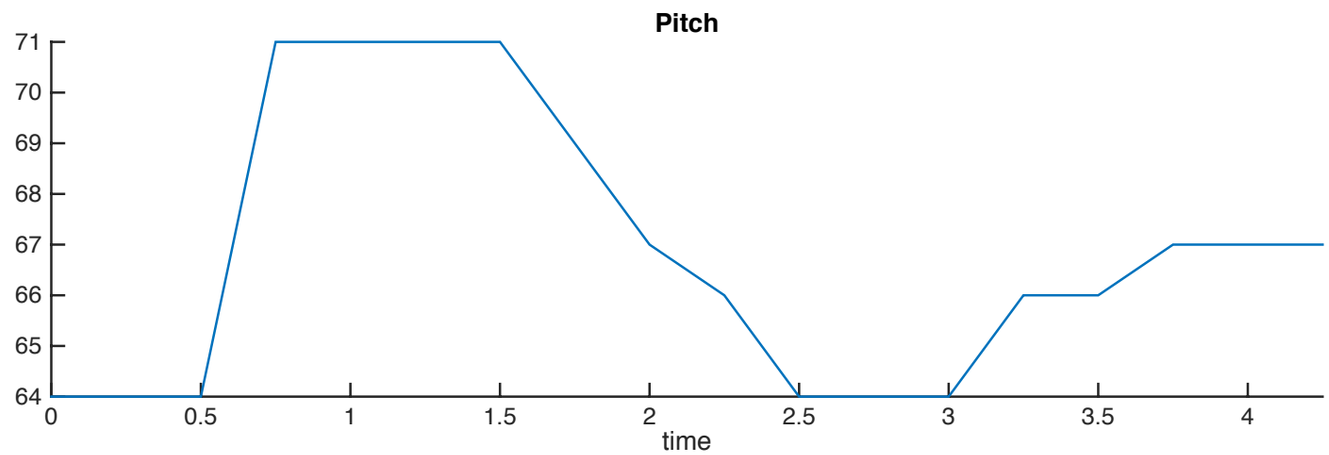
- *m = mus.score('myfile')*
- *c = mus.pitch(m, '**Sampling**', .25)*
- *mus.autocor(c)*

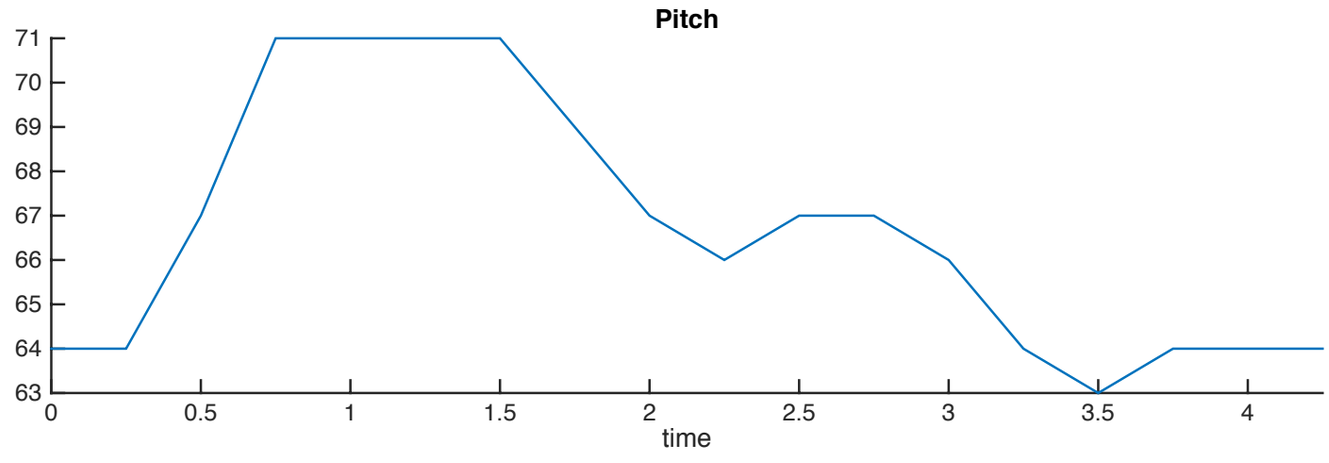




mus.pitch
pitch contour

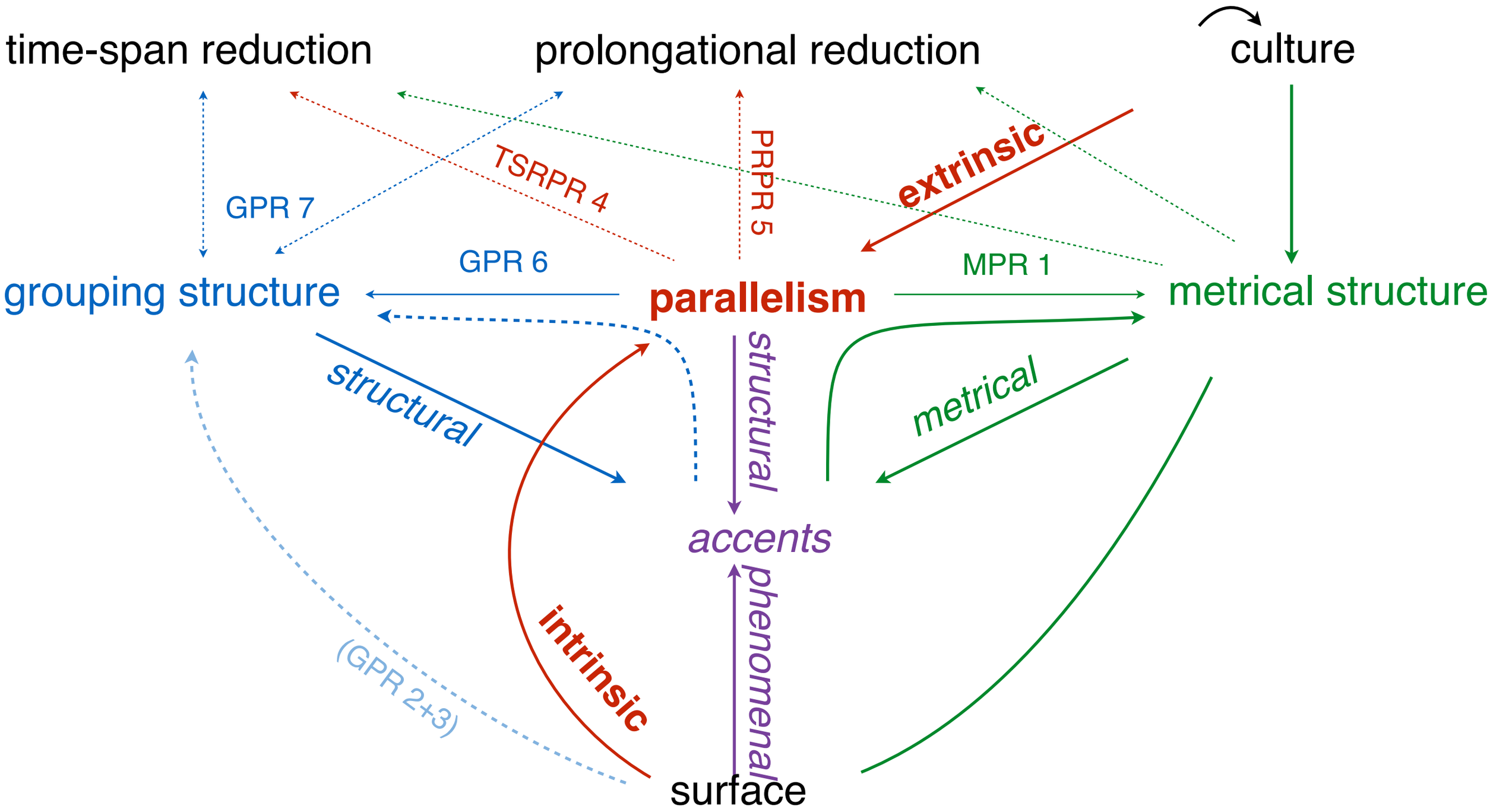
- *m1 = mus.score('myfile', 'EndTime', 5)*
- *m2 = mus.score('myfile', 'StartTime', 5)*
- *p1 = mus.pitch(m1, 'Sampling', .25)*
- *p2 = mus.pitch(m2, 'Sampling', .25)*





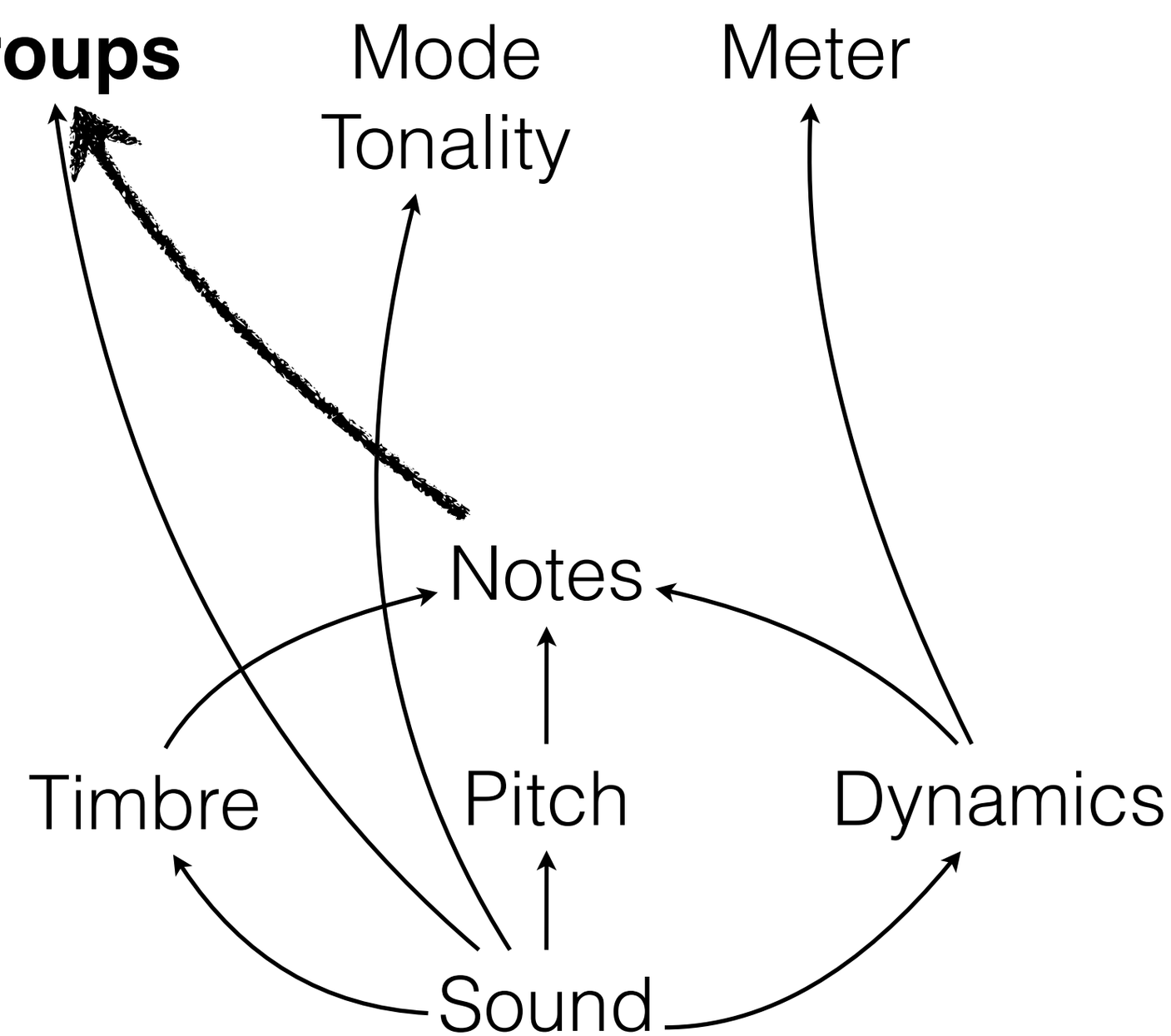
- ***sig.dist***(*p1, p2, 'Cosine'*)

F. Lerdahl, R. Jackendoff, *A generative theory of tonal music*, MIT Press, 1983



O. Lartillot, “Reflexions towards a generative theory of musical parallelism”, *Musicae Scientiae*, DF 5, 2010.

Structural levels



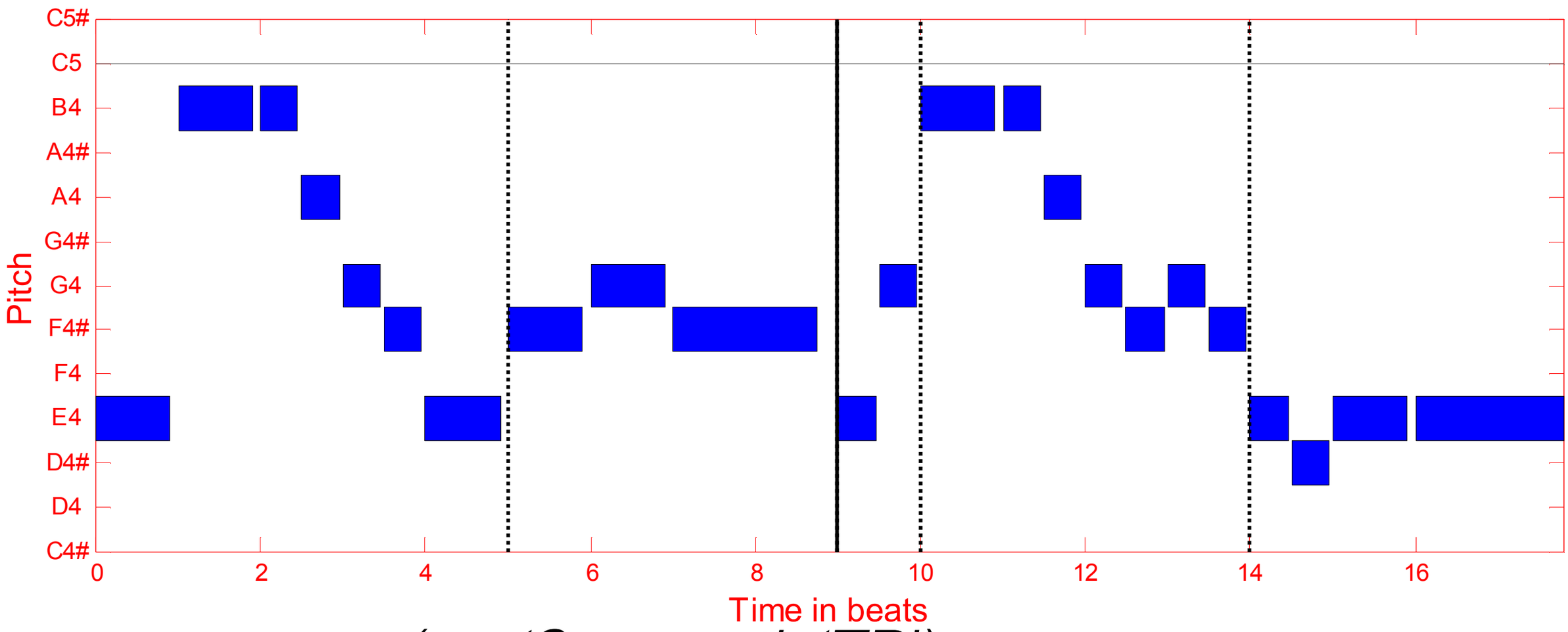
Symbolic level

Audio level

mus.score(…, 'Segment')
local segmentation

- Tenney & Polansky, 1980
- LBDM (Cambouropoulos, 1997)
- Bod, 2002

mus.score(…, 'Segment')
local segmentation

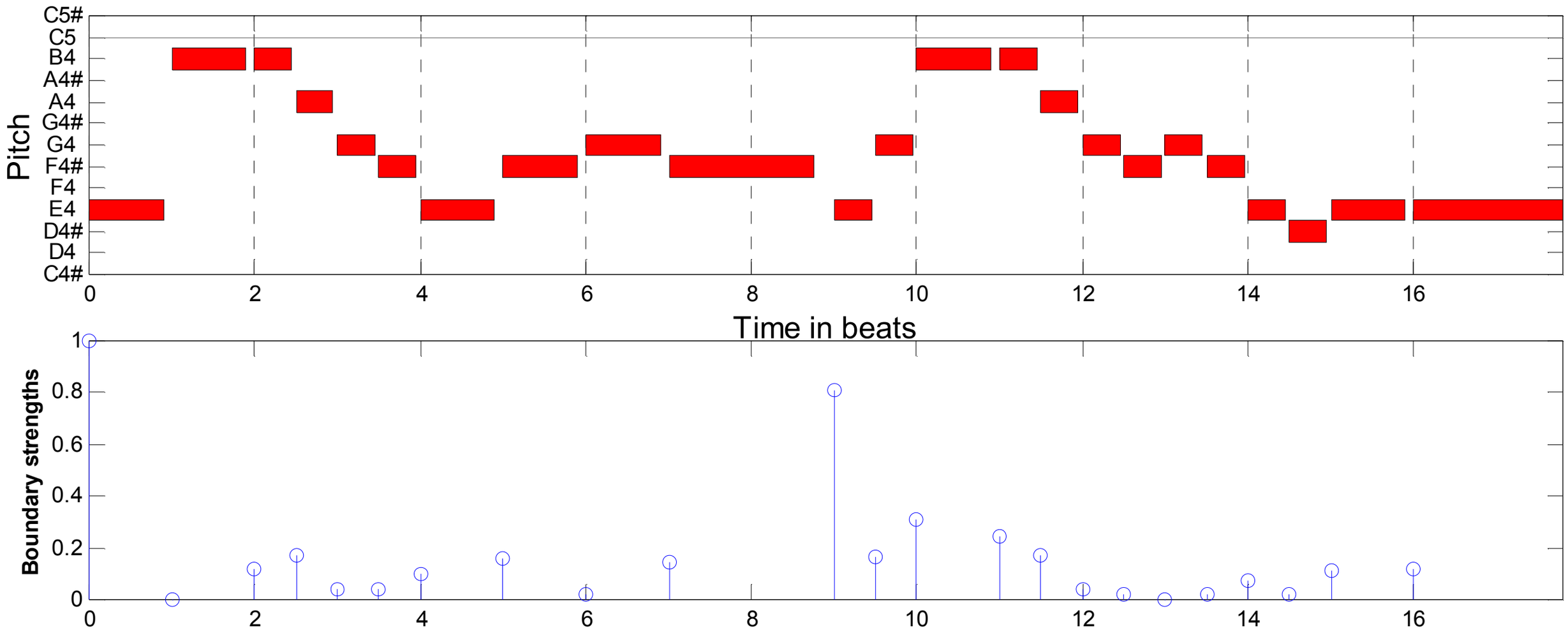


- *mus.score(…, 'Segment', '**TP**')*

(Tenney & Polansky, 1980)

from *MIDI Toolbox*

mus.score(…, 'Segment')
local segmentation

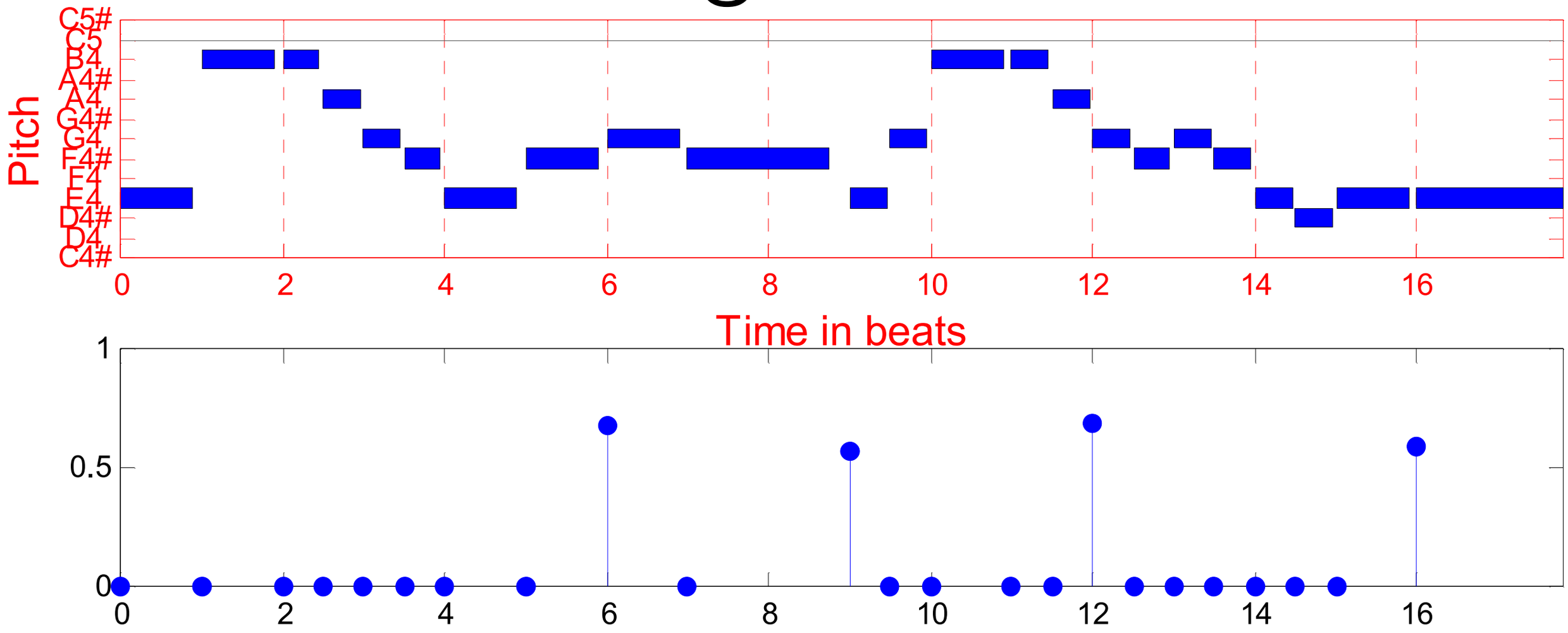


- *mus.score(…, 'Segment', '**LBDM**')*

(Cambouropoulos, 1997)

from *MIDI Toolbox*

mus.score(…, 'Segment')
local segmentation

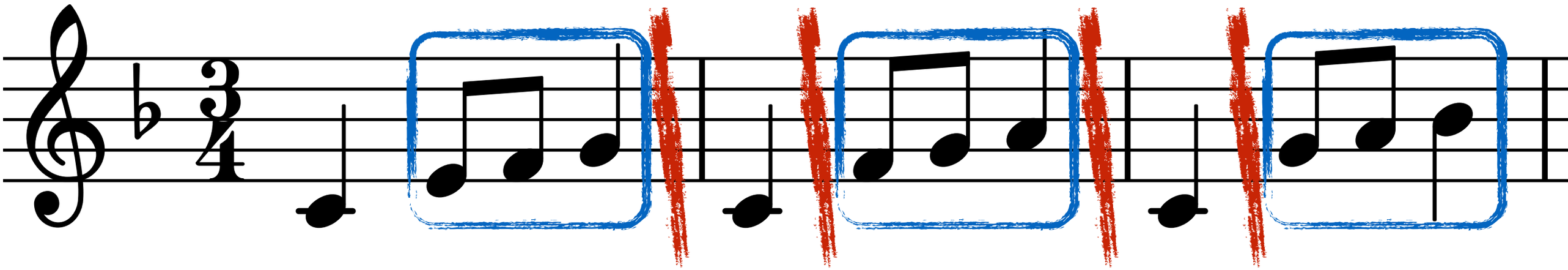


- *mus.score(…, 'Segment', '**Essen**')*

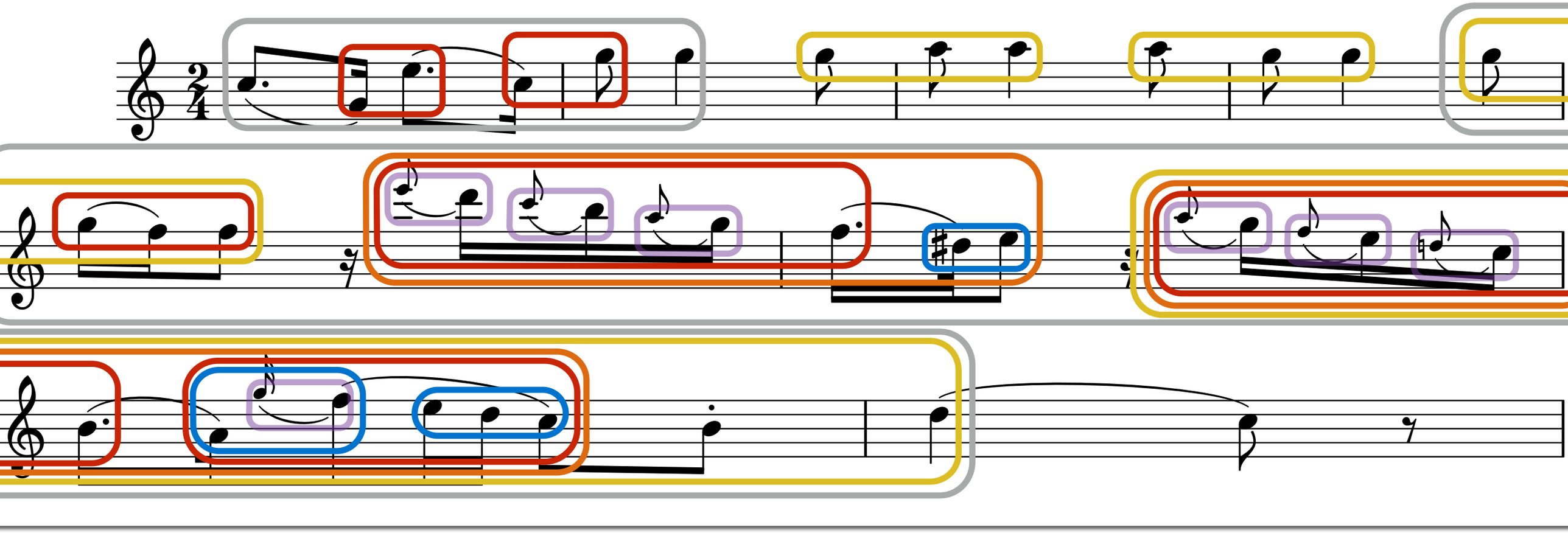
(Bod, 2002)

from *MIDI Toolbox*

mus.score(…, 'Segment') vs.
mus.score(…, 'Group')

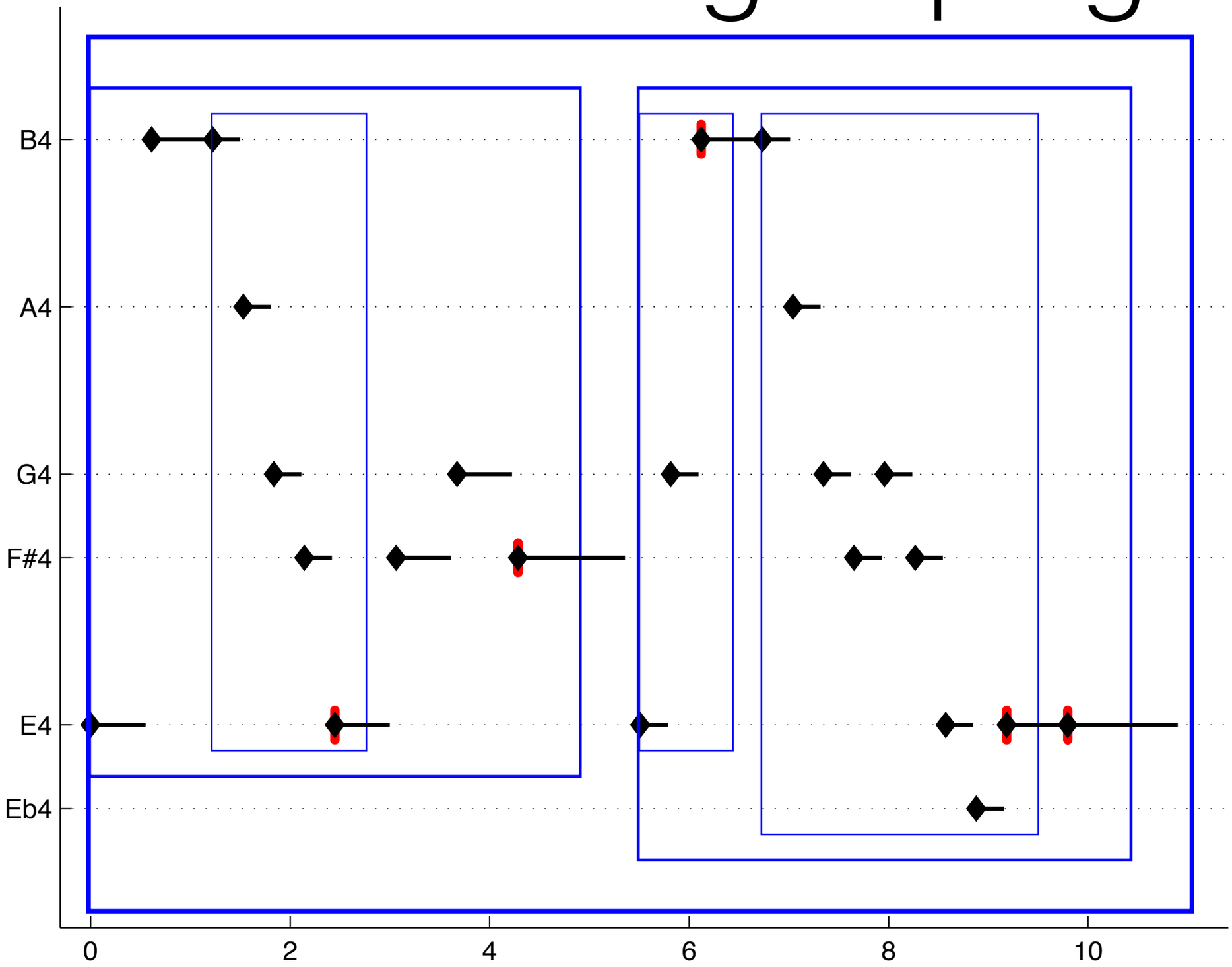


mus.score(…, 'Group')
hierarchical grouping



Mozart, Variation XI on "*Ah, vous dirai-je maman*", K.265/300e

mus.score(…, 'Group')
hierarchical grouping



Structural levels

Groups

Mode
Tonality

Meter

Ornamentation reduction

Symbolic level

Notes

Timbre

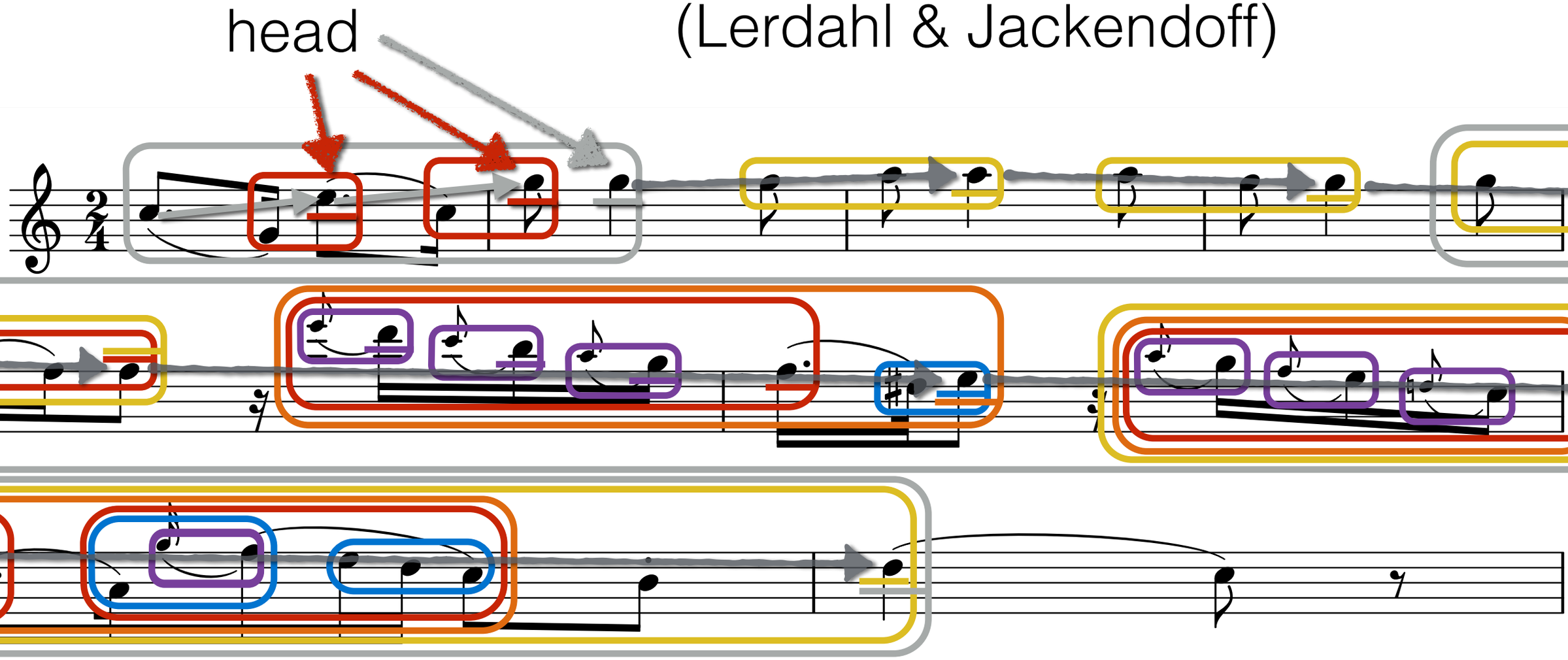
Pitch

Dynamics

Audio level

Sound

mus.score(…, 'Reduce')
ornamentation reduction

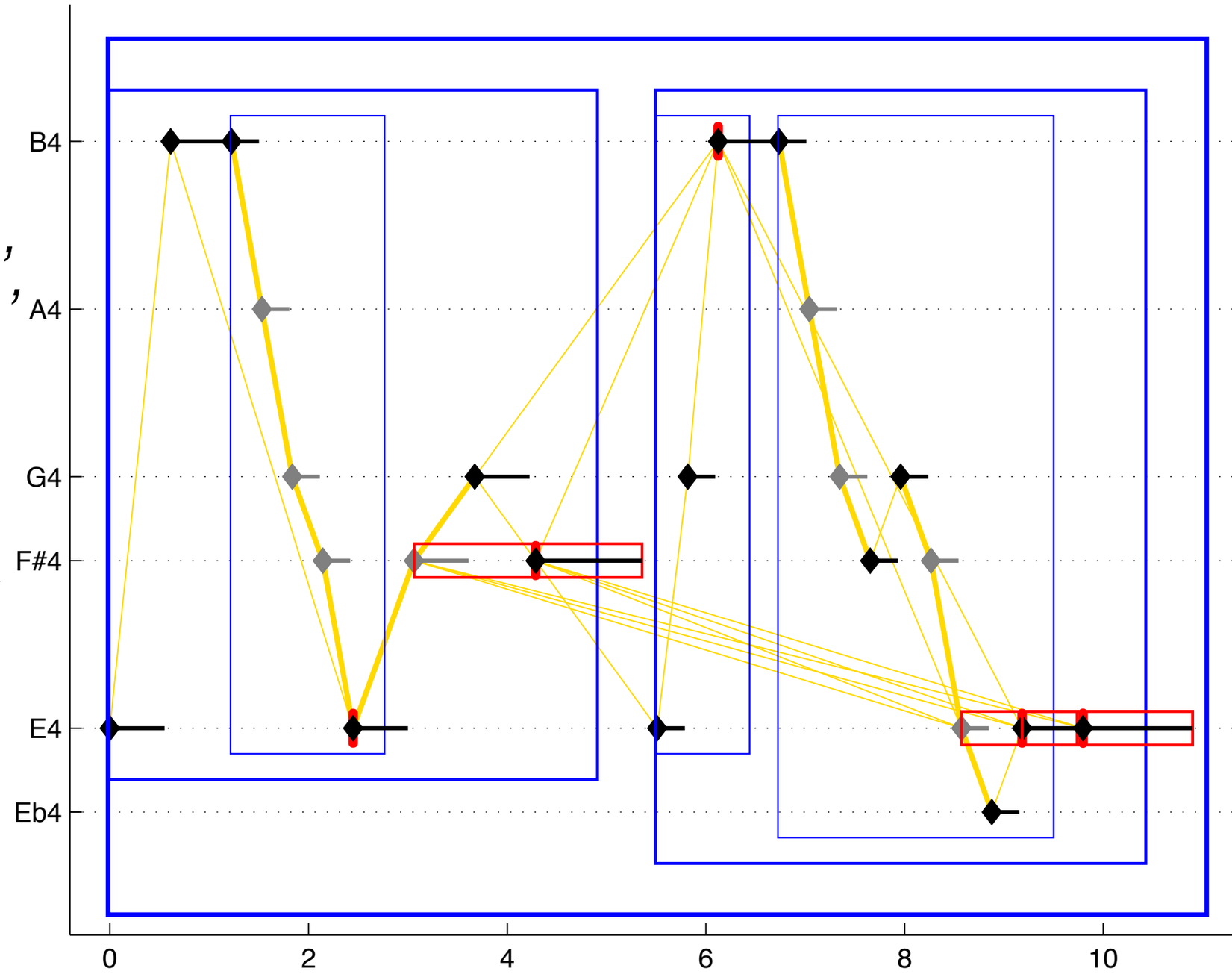


Mozart, Variation XI on "*Ah, vous dirai-je maman*", K.265/300e

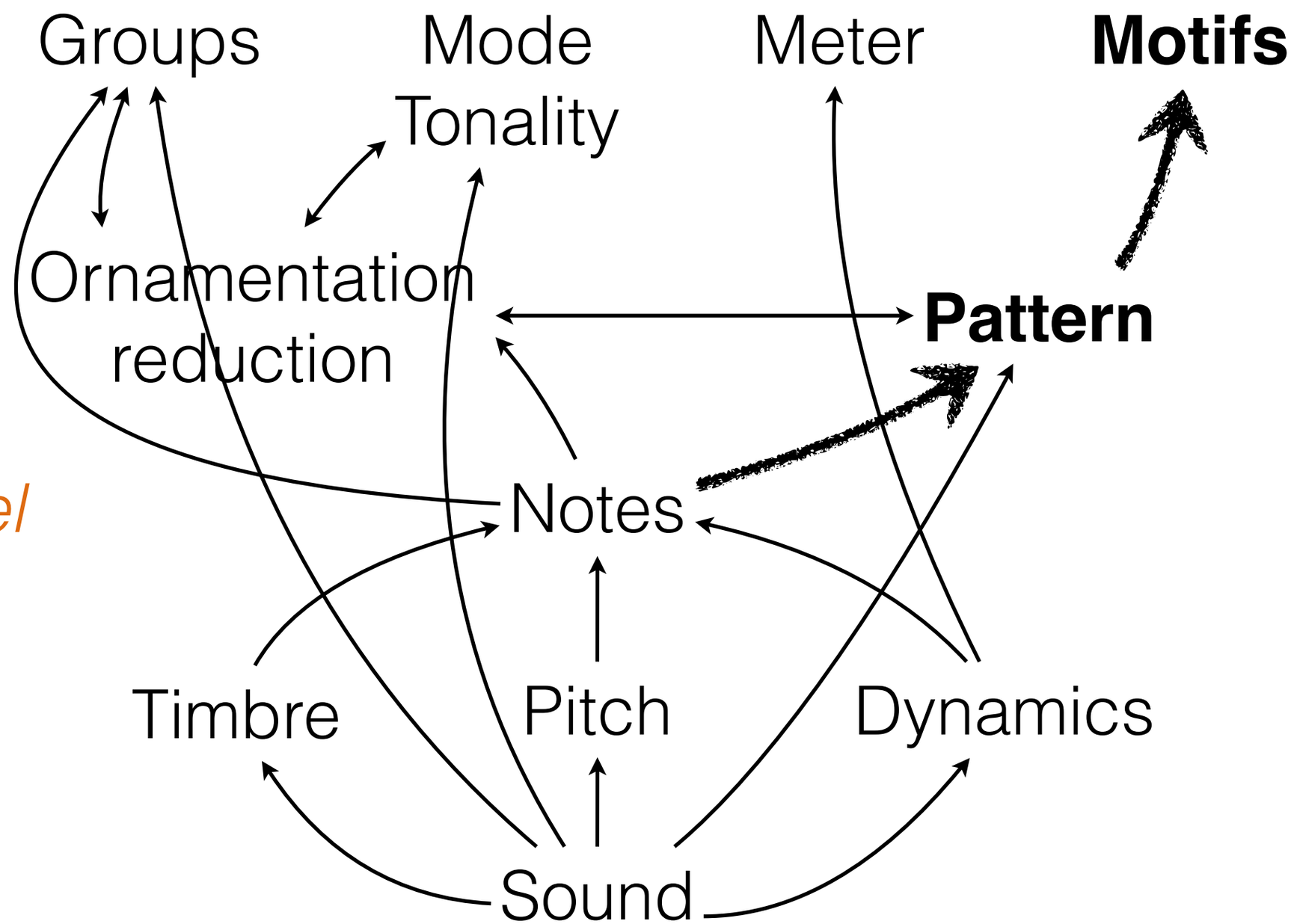
mus.score(…, 'Reduce') ornamentation reduction

mus.minr('laksin.mid', 'Group', 'Reduce')

Construction of a *syntagmatic network*



Structural levels

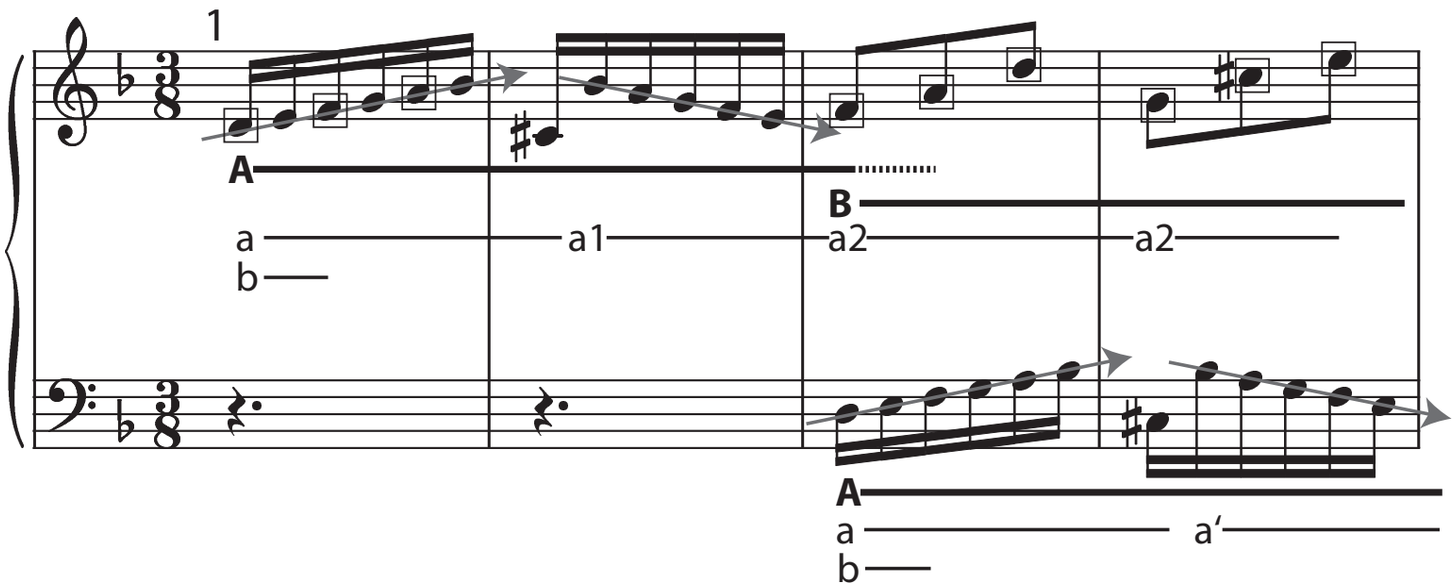


Symbolic level

Audio level

motivic pattern analysis

Bach Invention in D minor



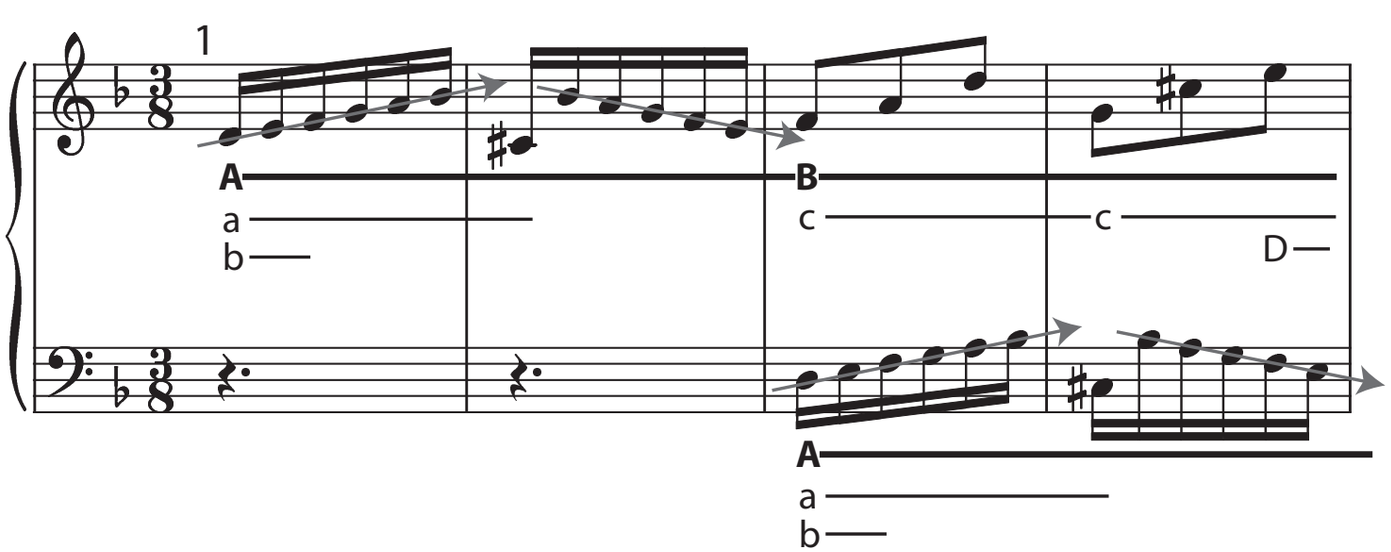
Kresky (1977) analysis

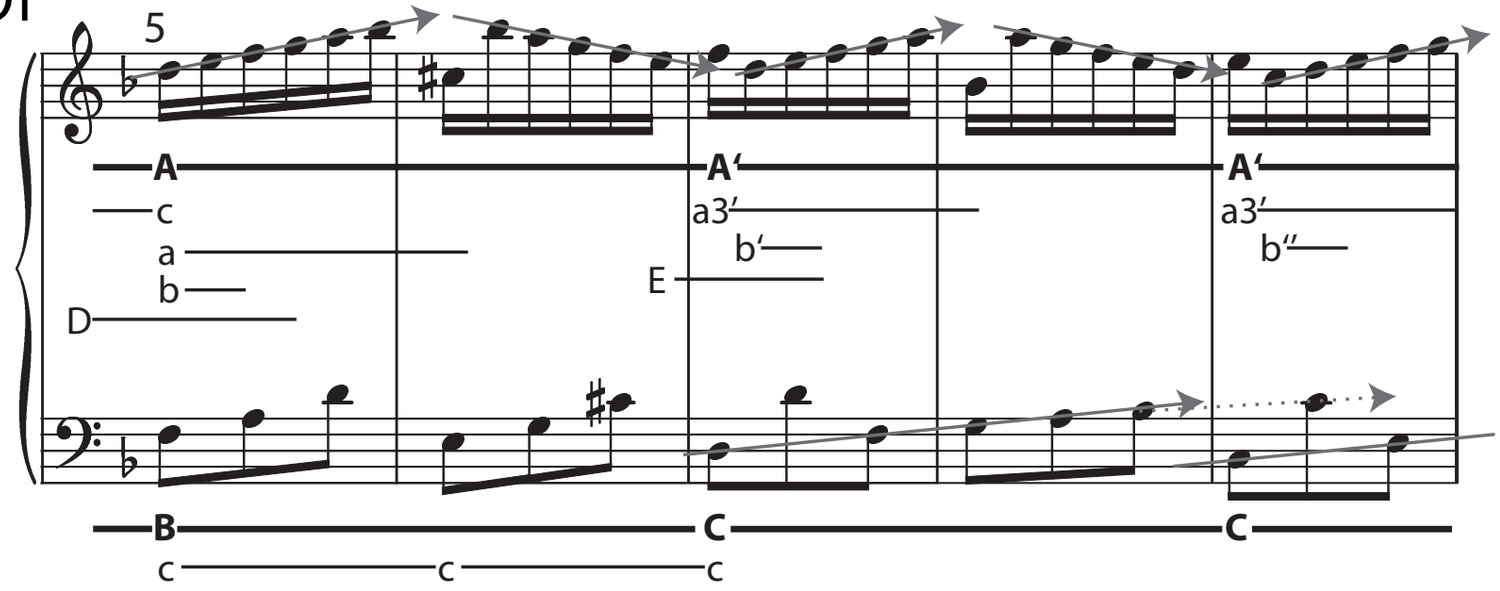
Name	Kresky's interpretation
A	Opening motive
A'	First sequence unit
B	Accompanying figure
a	Motive shape
a1	Reversed motive shape
a2=c	Triadic structure
a3=a3'	Retarded scalar climb
a4=C	Bass line
a5	Seconde sequence unit
a6	*(not considered)*
b	Three-note scale
b'	Identifying a5 with a3
b''	Same, transposed
b'''	Three shape in bass line

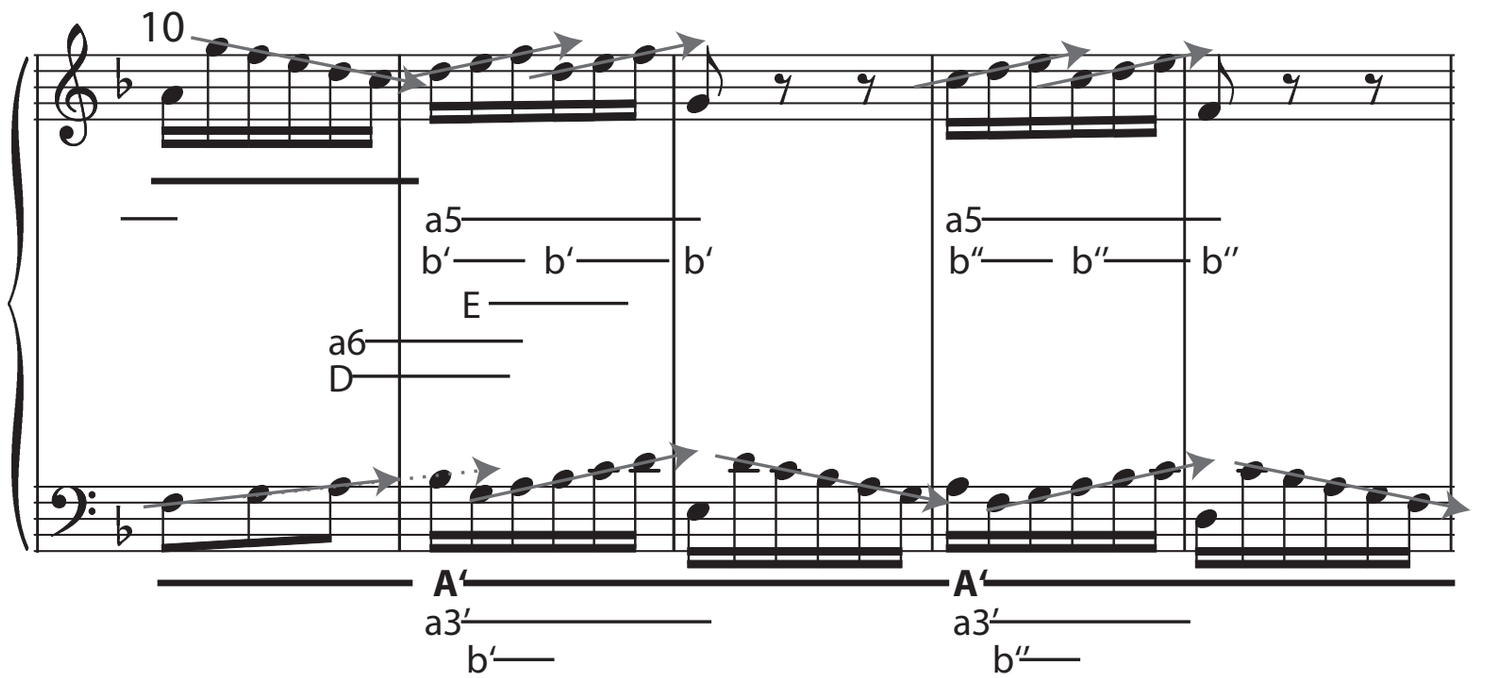
motivic pattern analysis

Bach Invention in D minor

Computer analysis







Lartillot, Toiviainen, "Motivic matching strategies for automated pattern extraction", Musicae Scientiae, DF4A, 281-314, 2007.

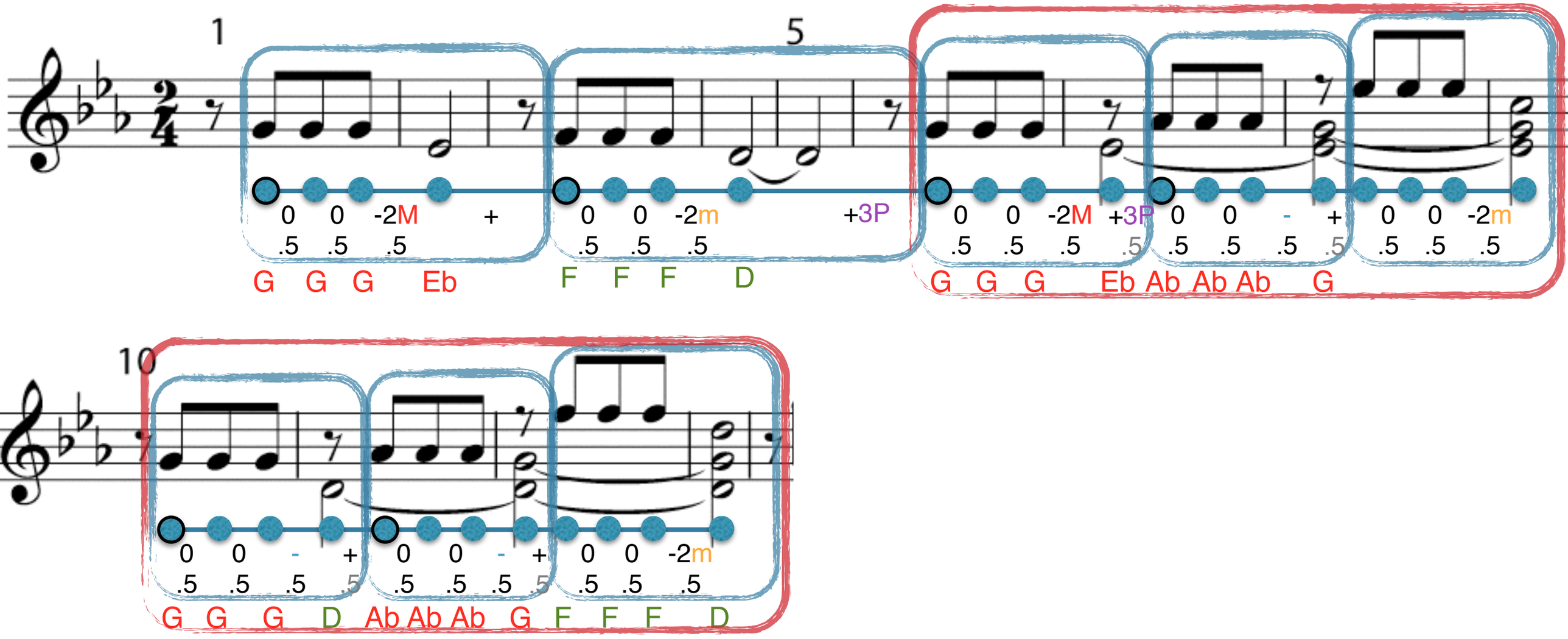
motivic pattern analysis

Bach Invention in D minor

Name	Kresky's interpretation	Computational description	
		Melodic	**Rhythmic**
A	Opening motive	(D,E,F,G,A,Bb,C#,Bb,A,G,F,E,F)	16th notes
A'	First sequence unit	(-2,+1,+1,+1,+1,-6,+6,-1,-1,-1,-1,+1)	16th notes
B	Accompanying figure	(F,A,D+,-,+,+,-)	8th notes
a	Motive shape	(prefix of A)	
a1	Reversed motive shape	(not detected)	
a2=c	Triadic structure	(+,+,-)	8th notes
a3=a3'	Retarded scalar climb	(-2,+1,+1,+1,+1,-6)	16th notes
a4=C	Bass line	(+7,-5,+1,+1,+1,-6)	8th notes
a5	Seconde sequence unit	(+1,+1,-2,+1,+1,-6)	16th notes
a6	*(not considered)*	*(-,+1,+1,+1)*	*16th notes*
b	Three-note scale	(+1,+1)	16th notes
b'	Identifying a5 with a3	(D5,E5,F5)	16th notes
b''	Same, transposed	(C5,D5,E5)	16th notes
b'''	Three shape in bass line	(not detected)	
D	*(not considered)*	*(-1,+1,+1,+1)*	*16th except 1st*
E	*(not considered)*	*(E5,F5,D5,E5,F5)*	*16th start. offbeat*

Lartillot, Toiviainen, "Motivic matching strategies for automated pattern extraction", Musicae Scientiae, DF4A, 281-314, 2007.

motivic pattern analysis

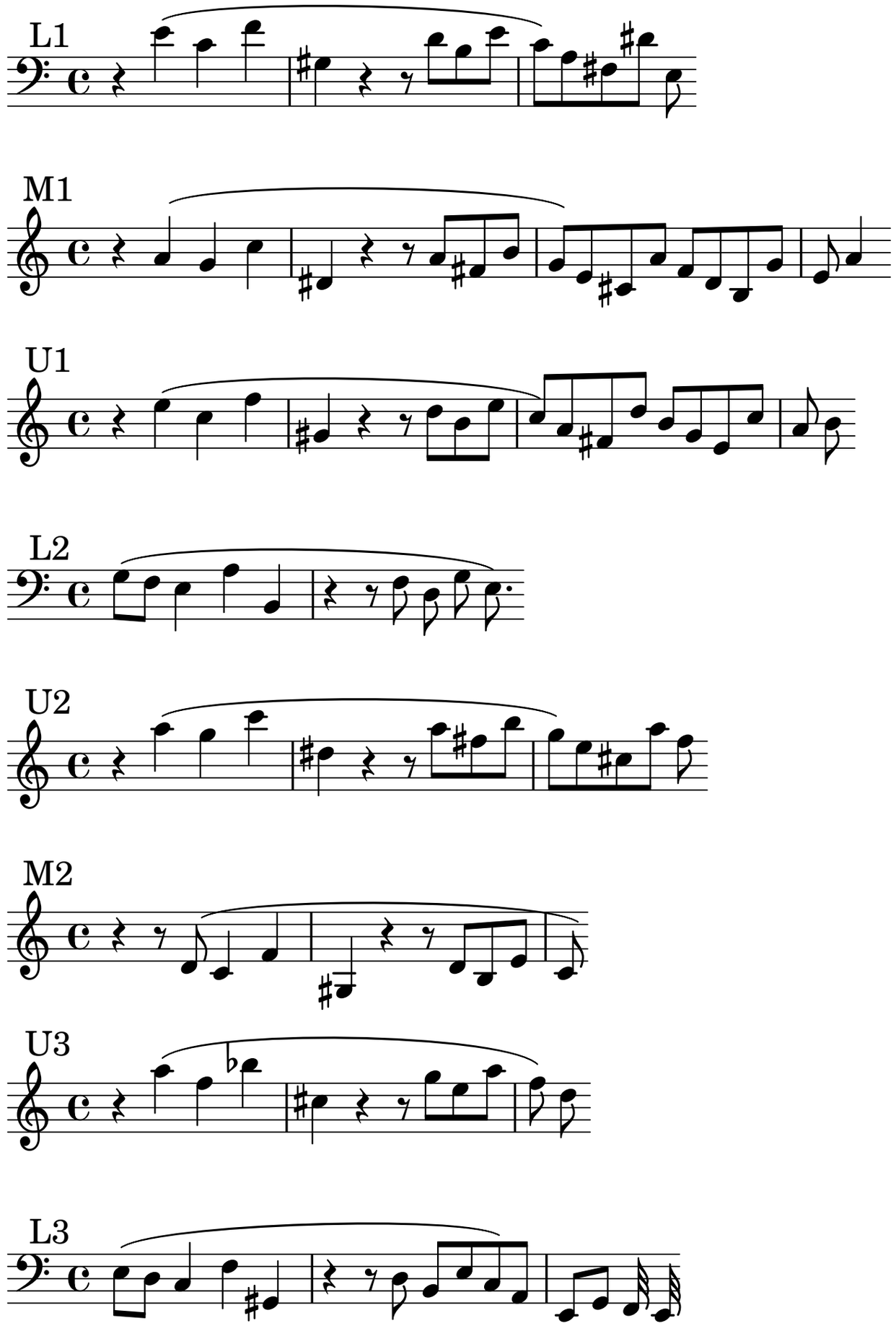


Beethoven, 5th Symphony, *Allegro con brio*

motivic pattern analysis

J.S. Bach, Well-Tempered Clavier, Book II, Fugue XX
Detected subject entries

Lartillot, ISMIR 2014

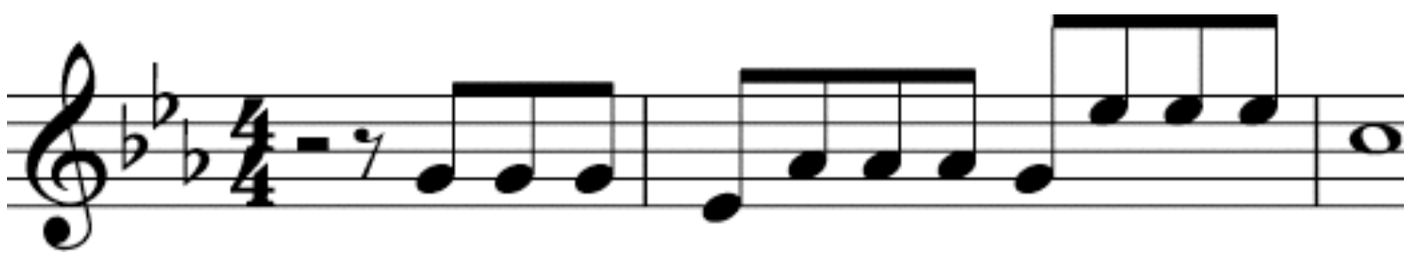


mus.score(…, 'Motif')
motivic pattern analysis

mus.minr('beethoven', 'Motif')

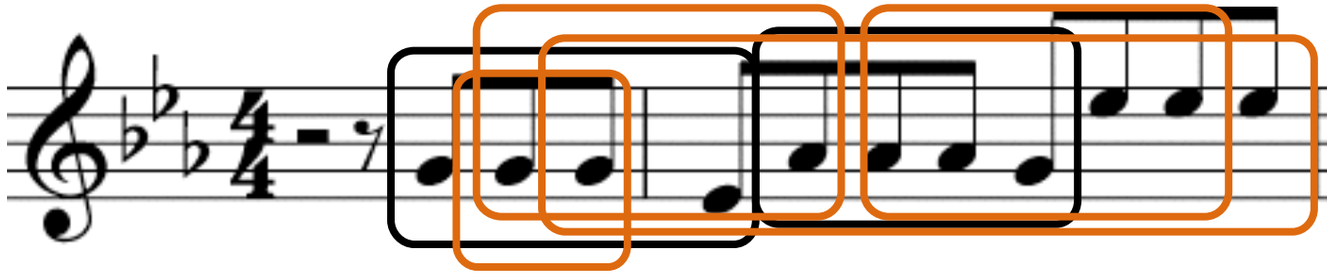
Lartillot, Poster, ISMIR 2014

structure complexity



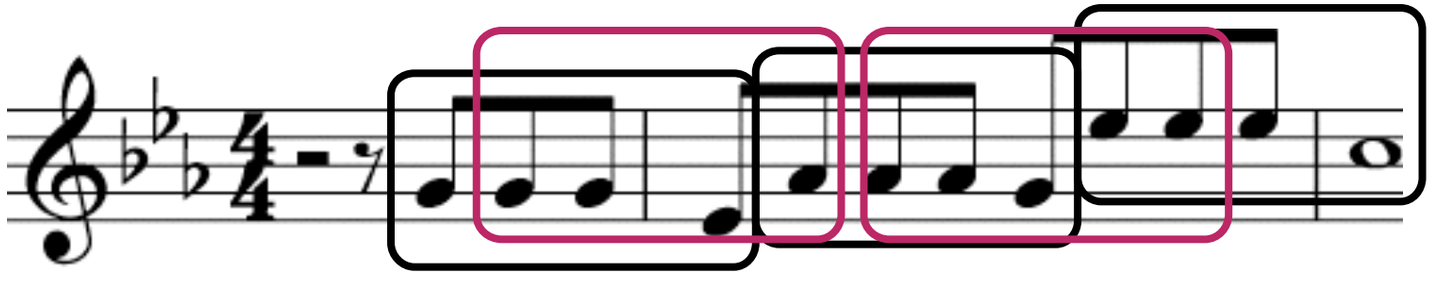
Pattern extraction

- Large set of unrelevant structures during extraction phase
  - cannot be computed extensively



Pattern selection
(longest, frequent, ...)

- Imperfections of the selection phase:
  - expected patterns accidentally deleted
  - insufficiently selective



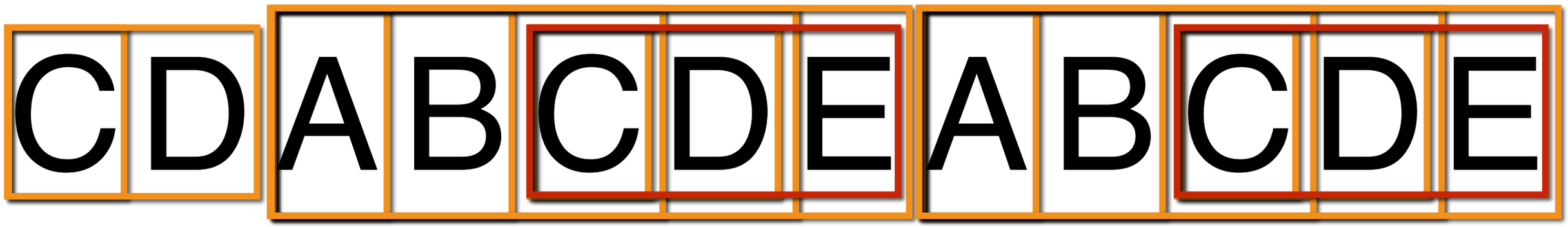
- Improvement of the extraction process

Cambouropoulos (2006), Conklin & Anagnostopoulou (2001), Rolland (1999)

closed patterns

Complete and compact description of pattern repetition

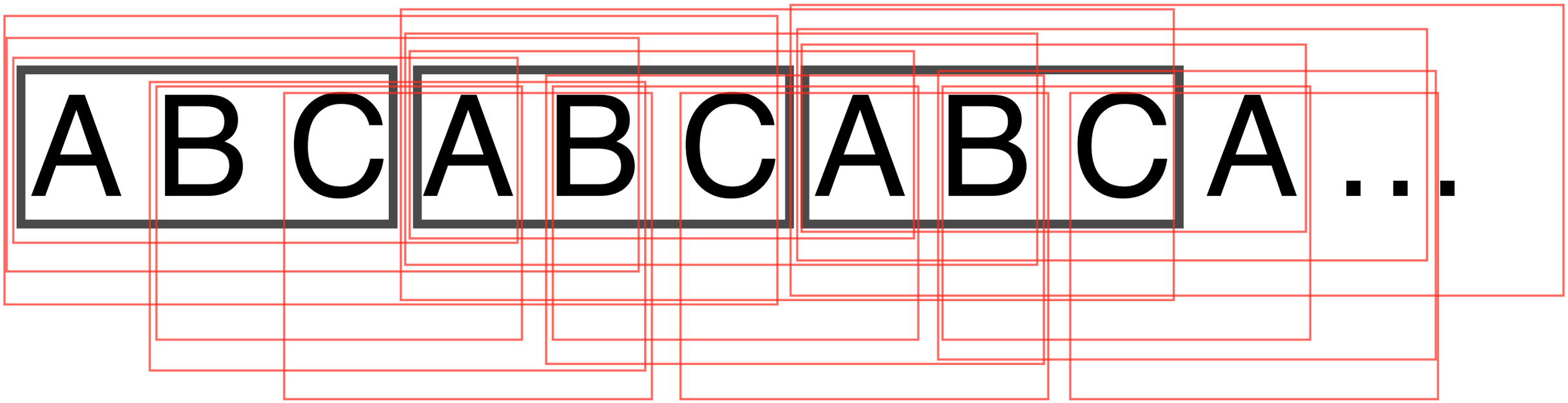
incremental approach



- Progressively analysing music through one single pass

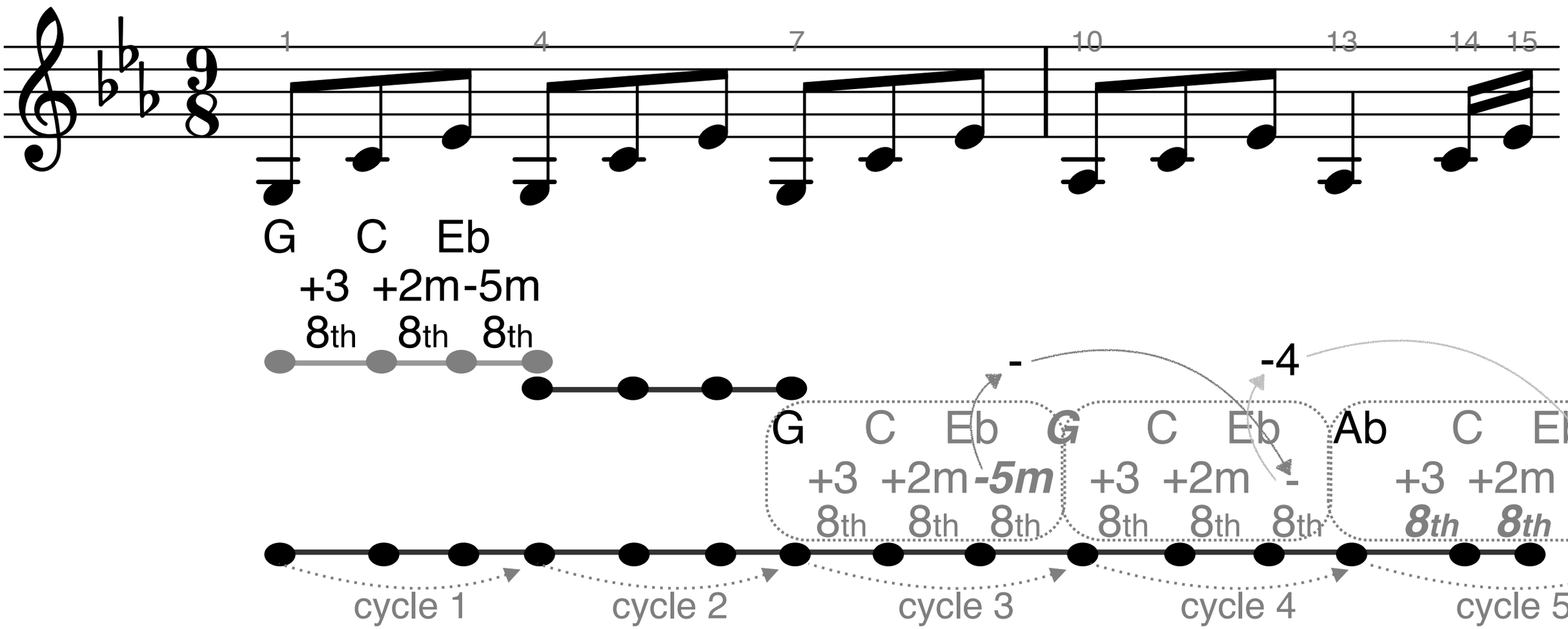
- Controls structural complexity in a way similar to the way listeners perceive music.

pattern cyclicity



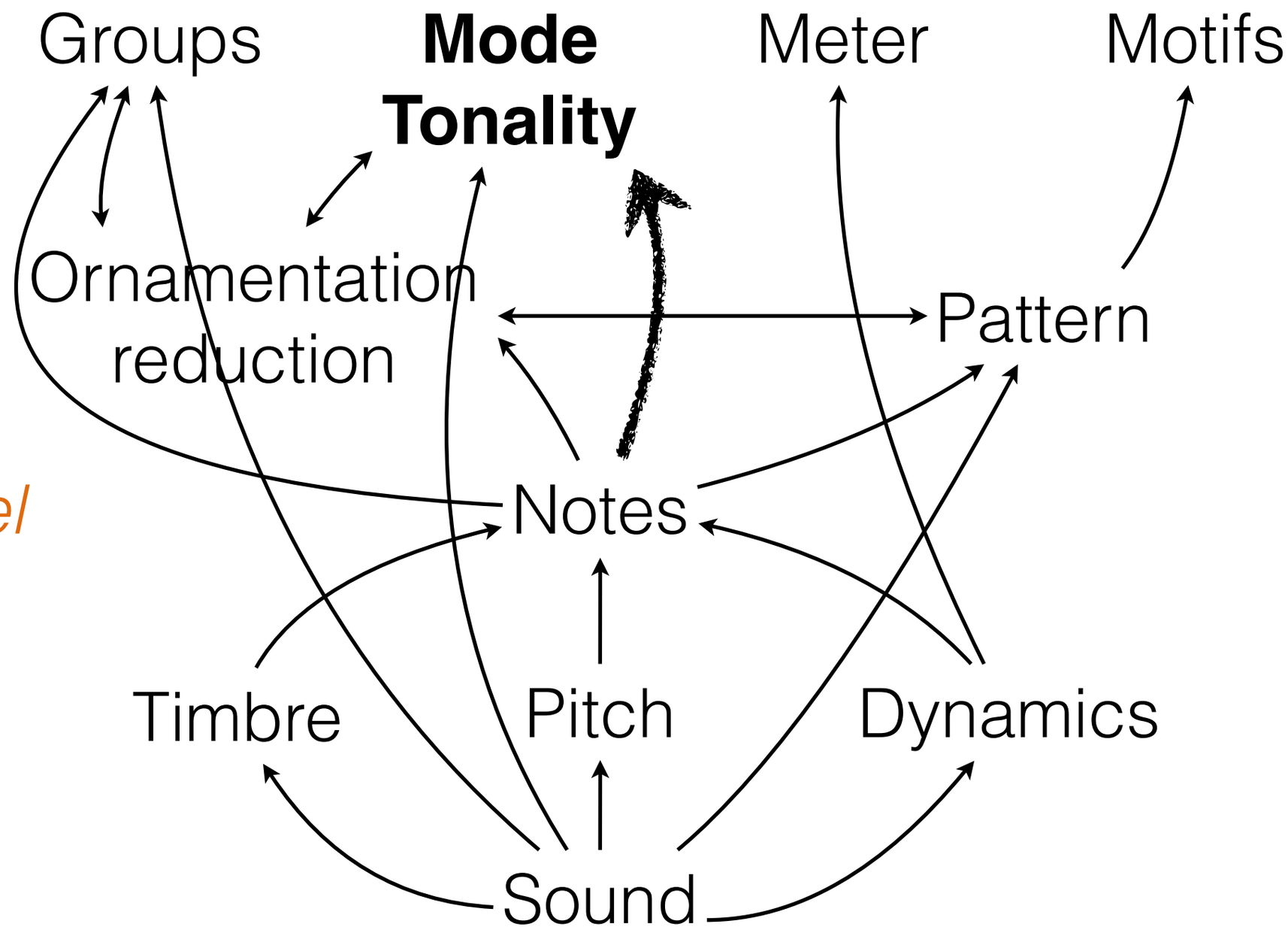
Cambouropoulos, 1998

heterogeneous pattern cycles



Lartillot, ISMIR 2014

Structural levels

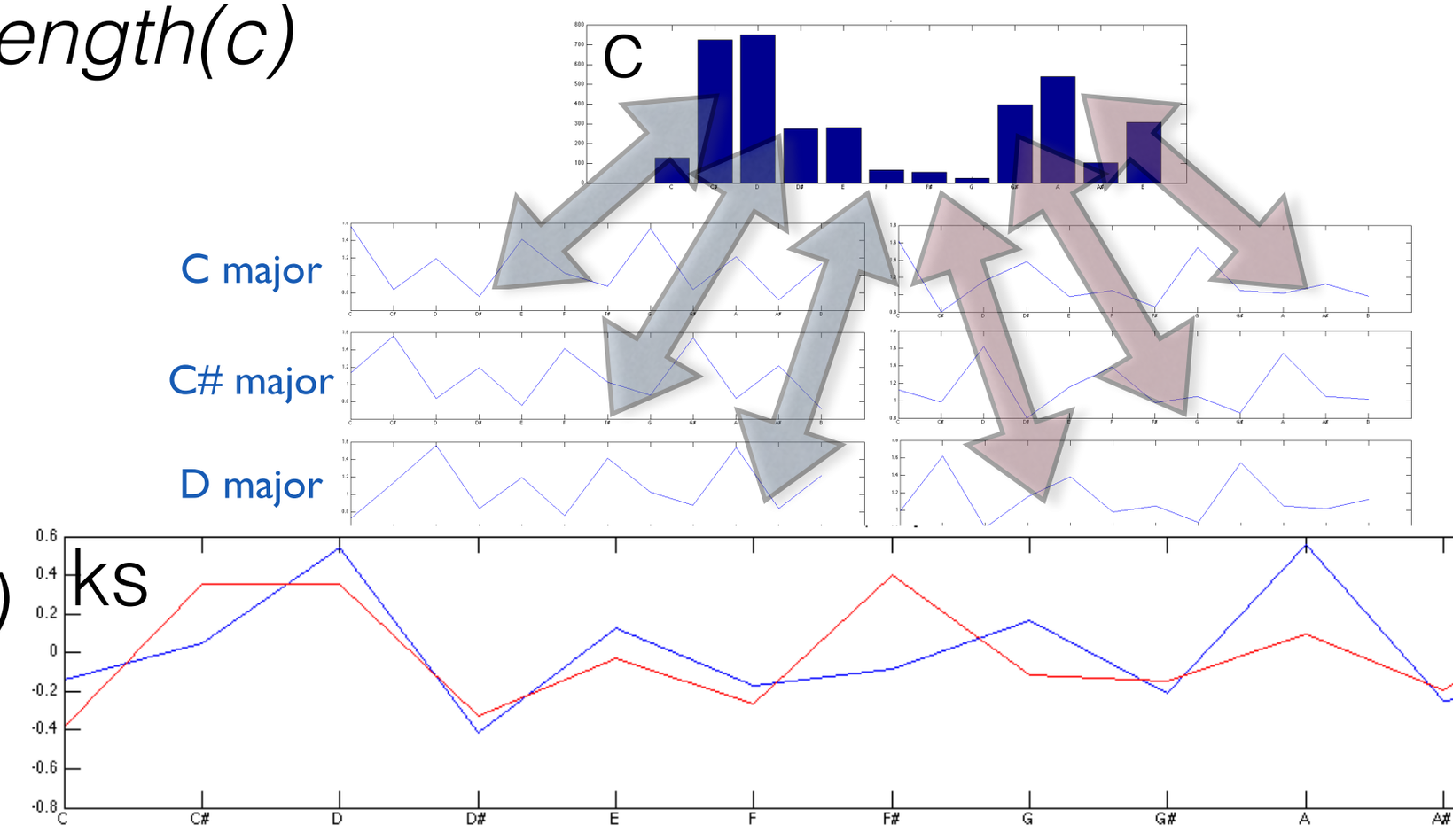


Symbolic level

Audio level

Statistical m/tonal analysis

- *c = mus.chromagram('score.mid')*
- *ks = mus.keystrength(c)*
- *mus.key(ks)*
- *mus.mode(ks)*
- *mus.keysom(ks)*

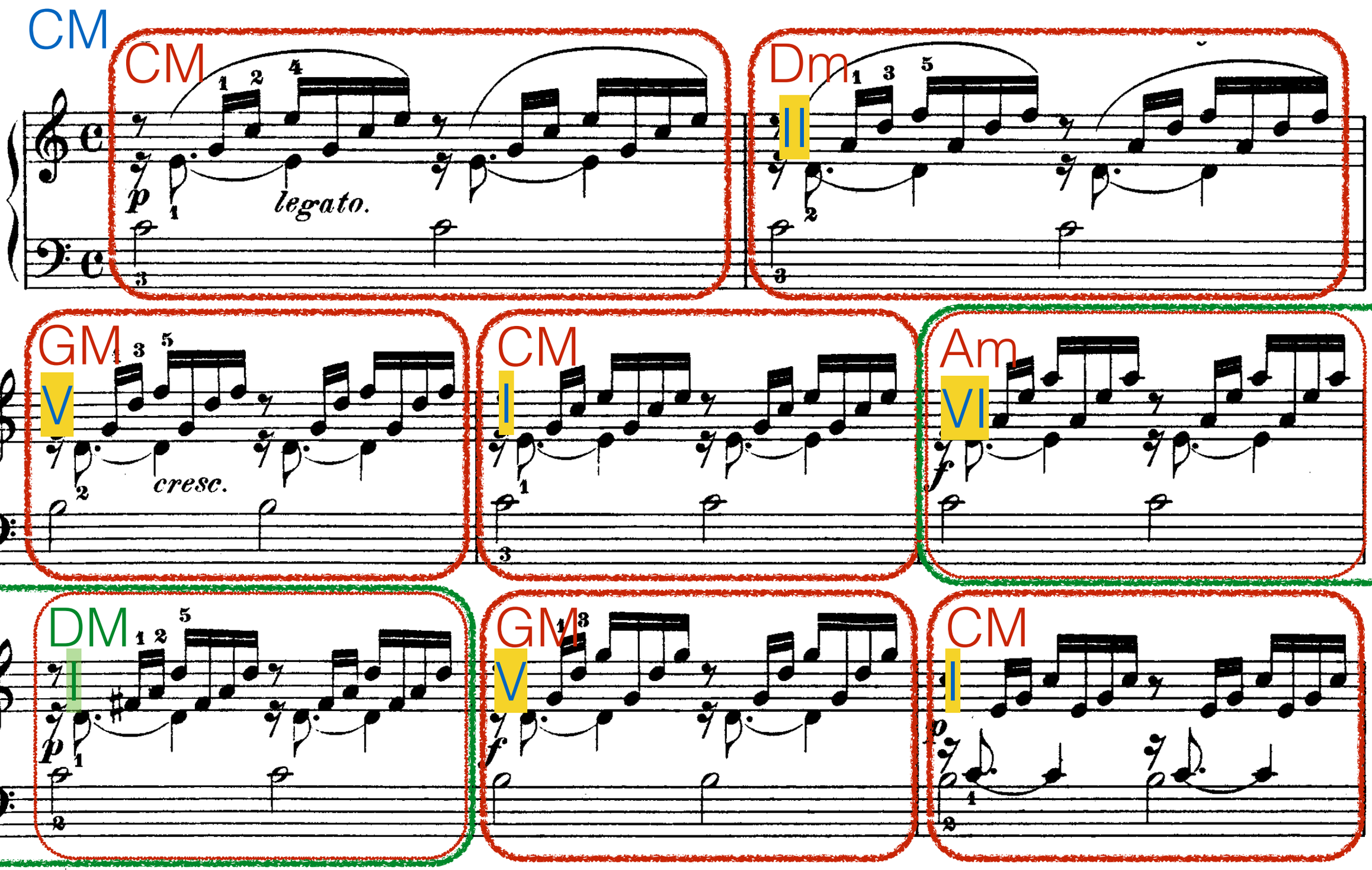


Krumhansl, Cognitive foundations of musical pitch. Oxford UP, 1990.

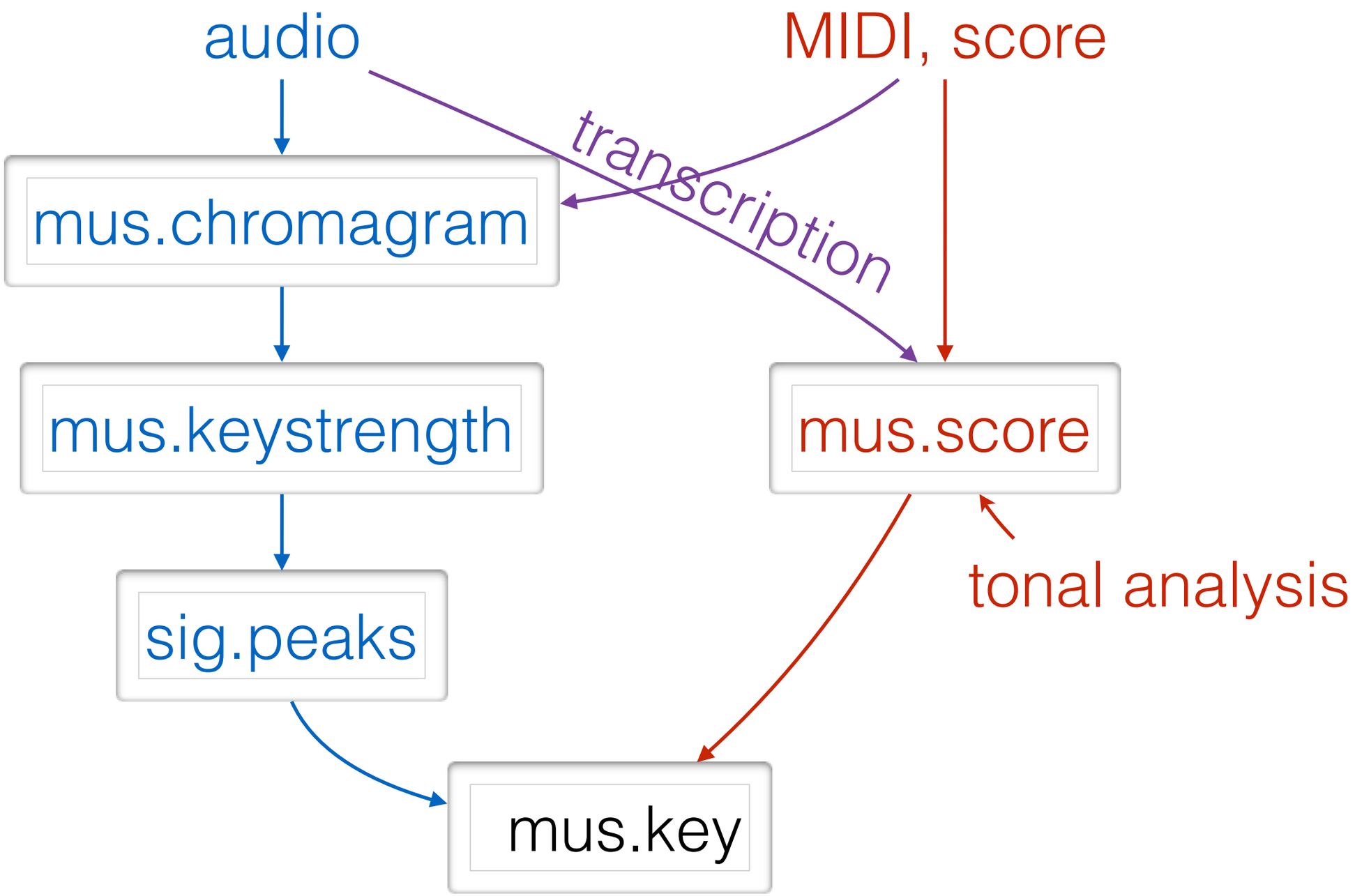
Score-level m/tonal analysis

- Statistical tonal analysis: pitch distribution in frames
  - What if key transition within one single frame?
- Tonality is more than such statistical description:
  - Succession of chords rooted on the scale degrees
  - Standard chord sequences, cadenza formulae
  - Patterns, grouping help emphasise chord changes
  - etc.

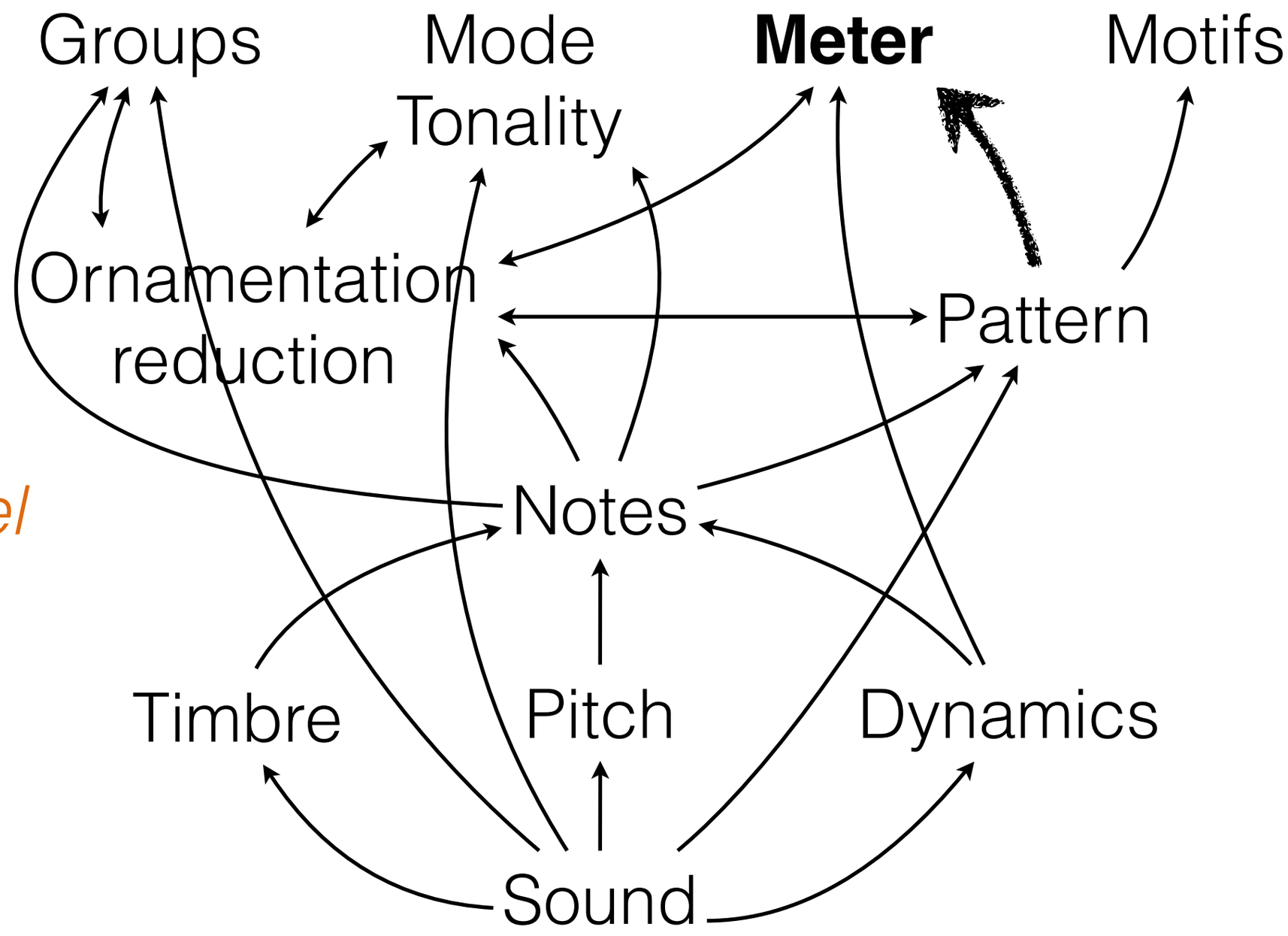
Score-level m/tonal analysis



Audio / symbolic



Structural levels

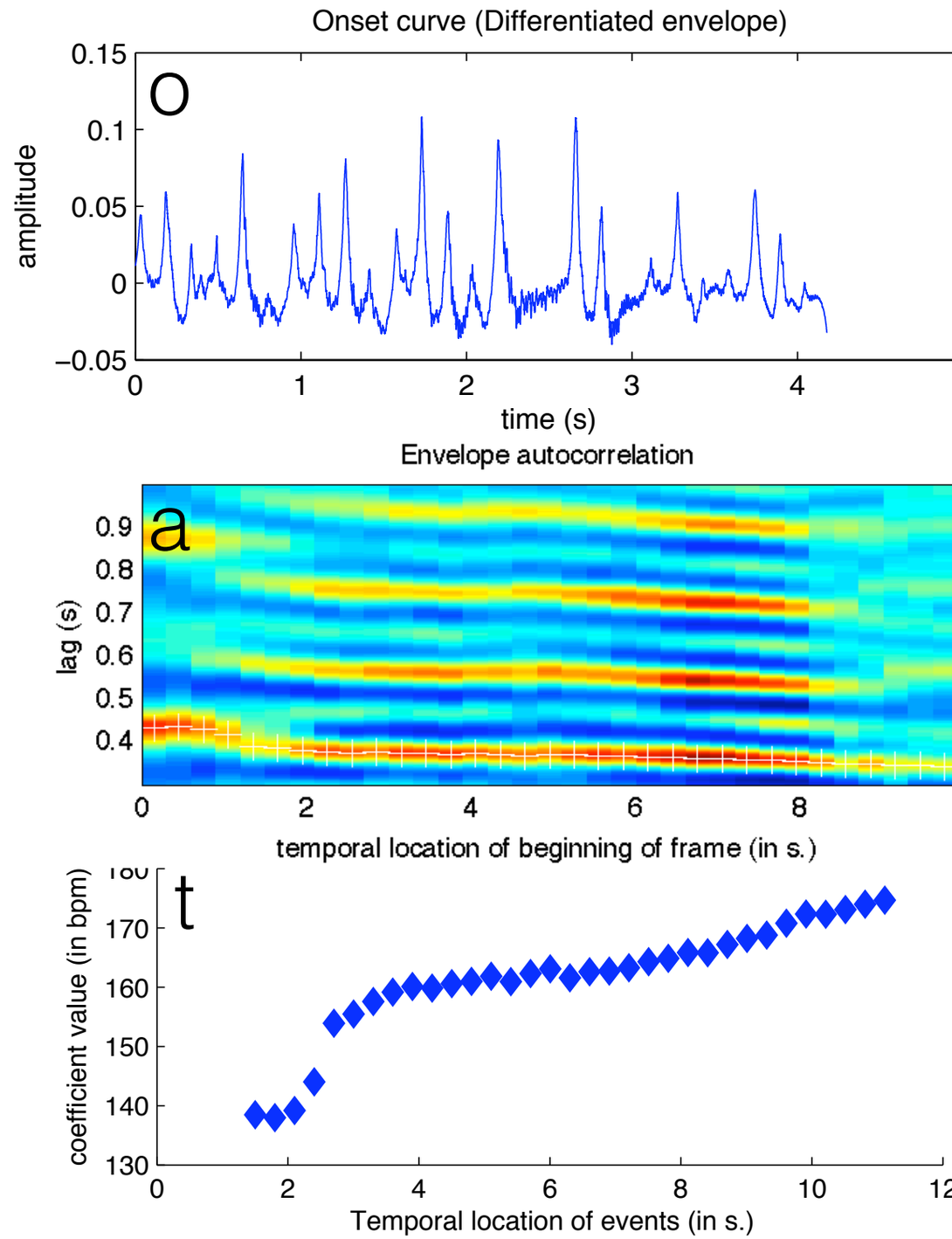


Symbolic level

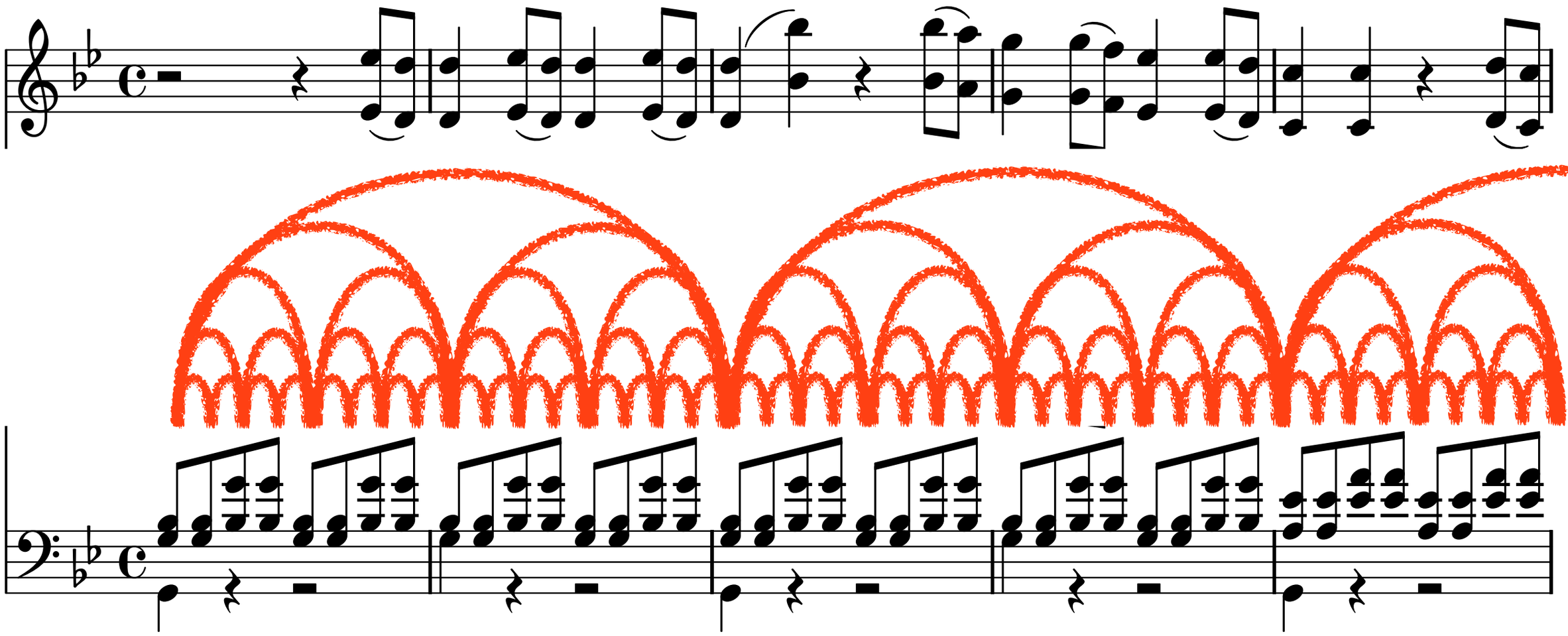
Audio level

Statistical metrical analysis

- *o = aud.envelope('score.mid')*
- *a = mus.autocor(o)*
- *t = mus.tempo(a)*
- *mus.pulseclarity(a)*
- *mus.metre(a)*

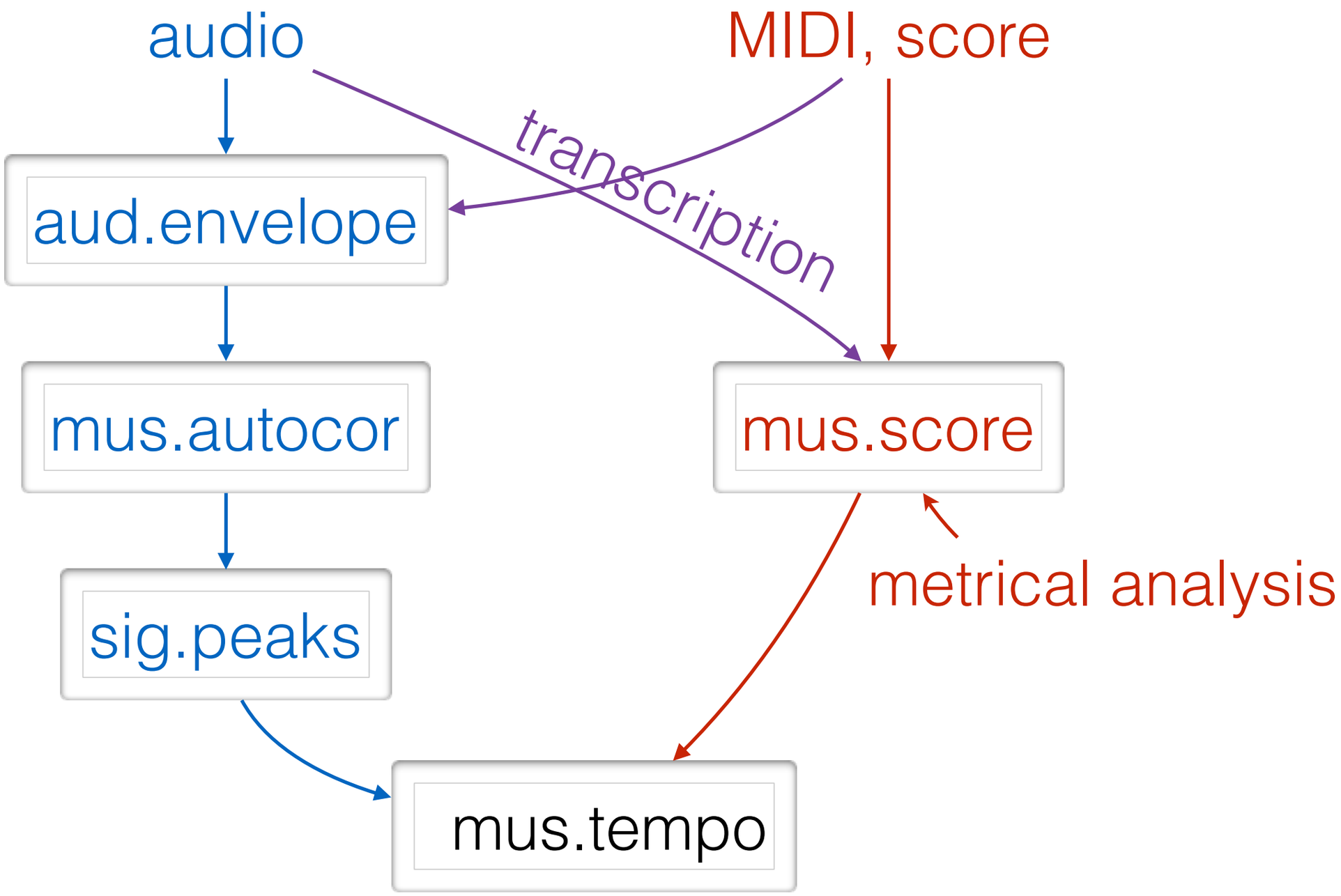


Score-level metrical analysis



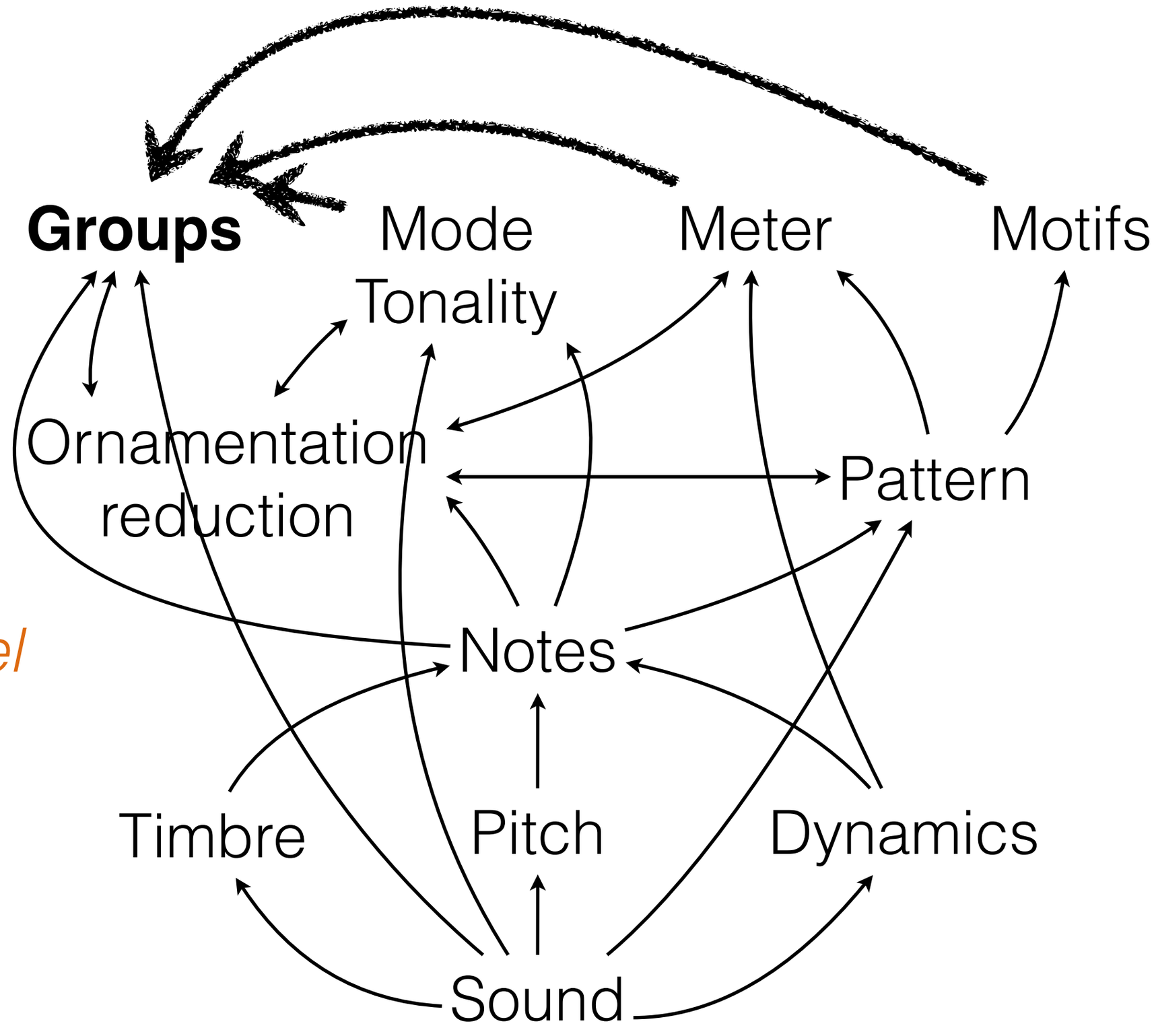
O. Lartillot, “Reflexions towards a generative theory of musical parallelism”, *Musicae Scientiae*, DF 5, 2010.

Audio / symbolic



- In future works, symbolic-based grouping based on combination of different musical factors

Structural levels

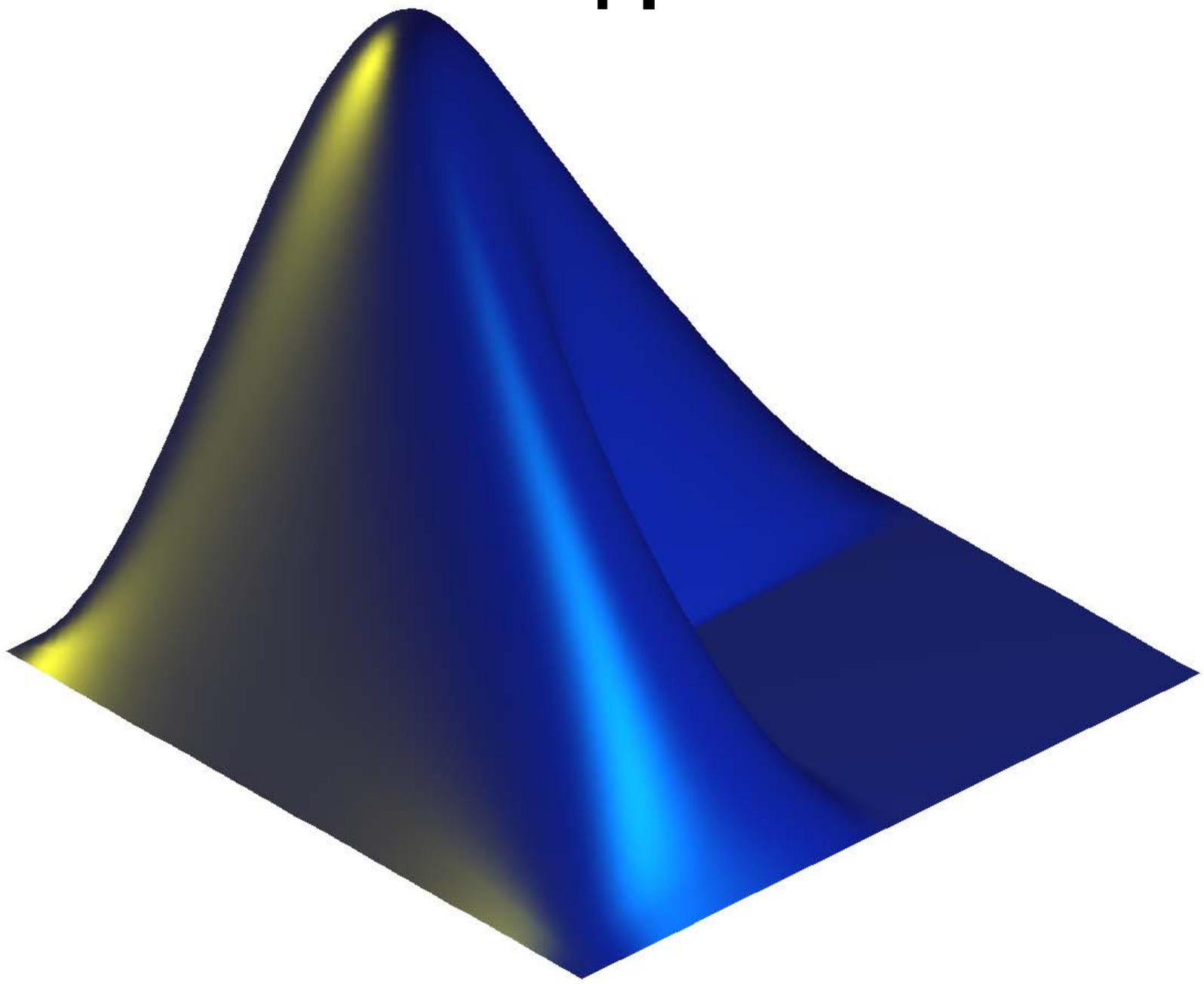


Symbolic level

Audio level


mus.score(..., 'Group')
hierarchical grouping

4.



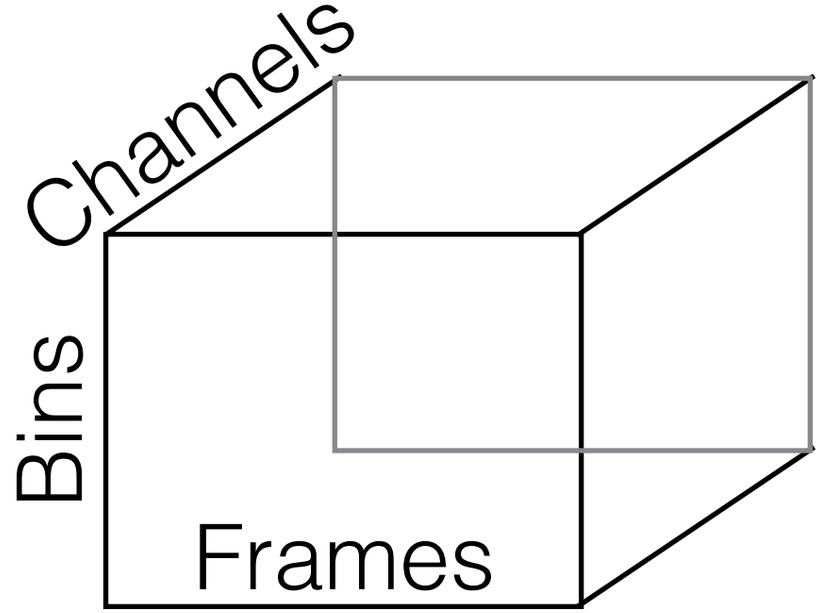
How it works

Matrix convention in *MIRtoolbox*

- In standard *Matlab* code, processing of matrix dimensions makes the code somewhat obscure.

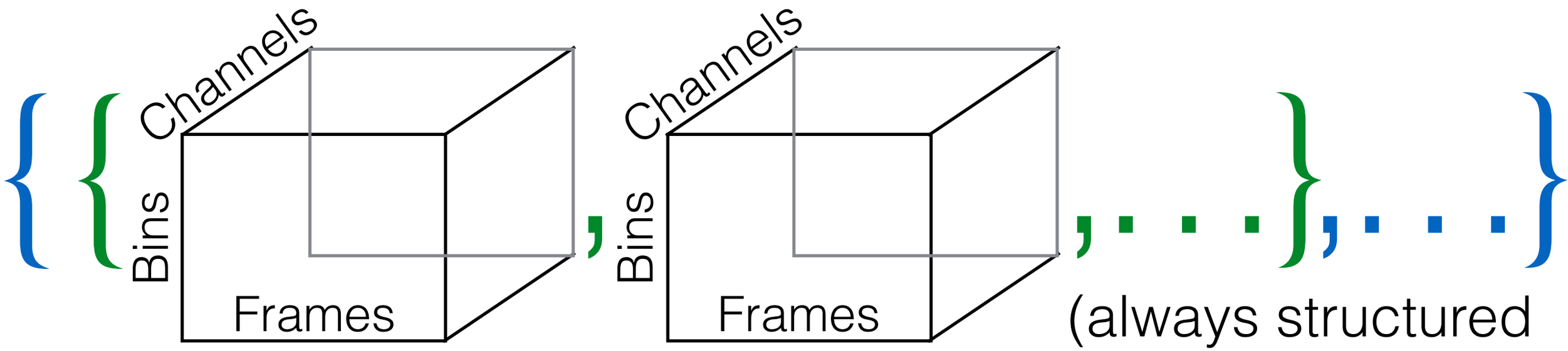
- In *MIRtoolbox*, one single matrix convention:

- This convention should be followed everywhere in the code, and is not explicitly explained to the readers.



Matrix convention in *MIRtoolbox*

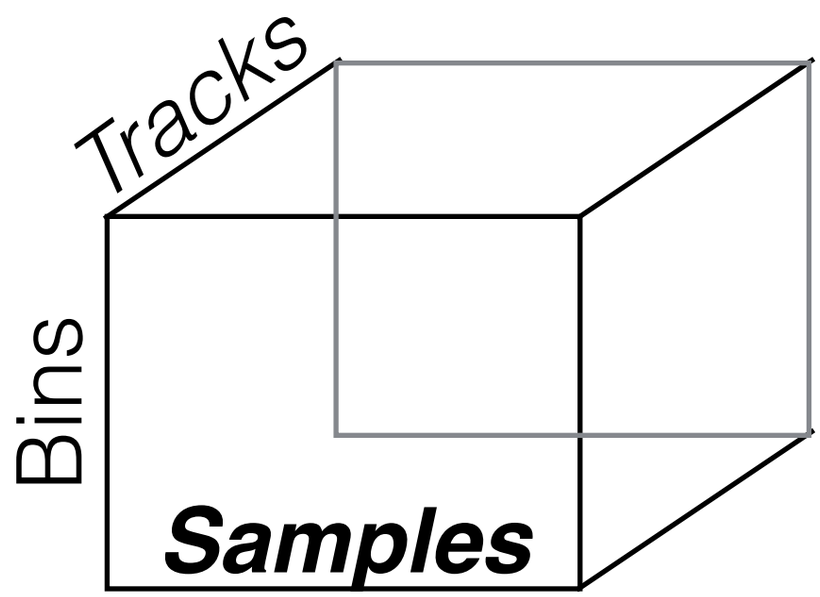
- One single convention that needs to allow complex things such as the data of a batch of audio files that are each segmented.



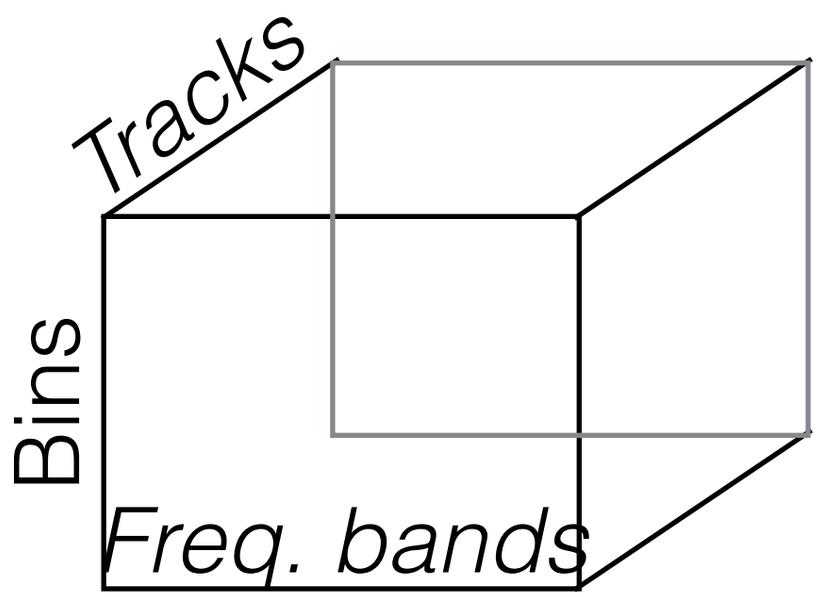
(always structured like this)

Matrix convention in MiningSuite

- There is no more constraint on the choice of dimensions.



{bin, sample, track}

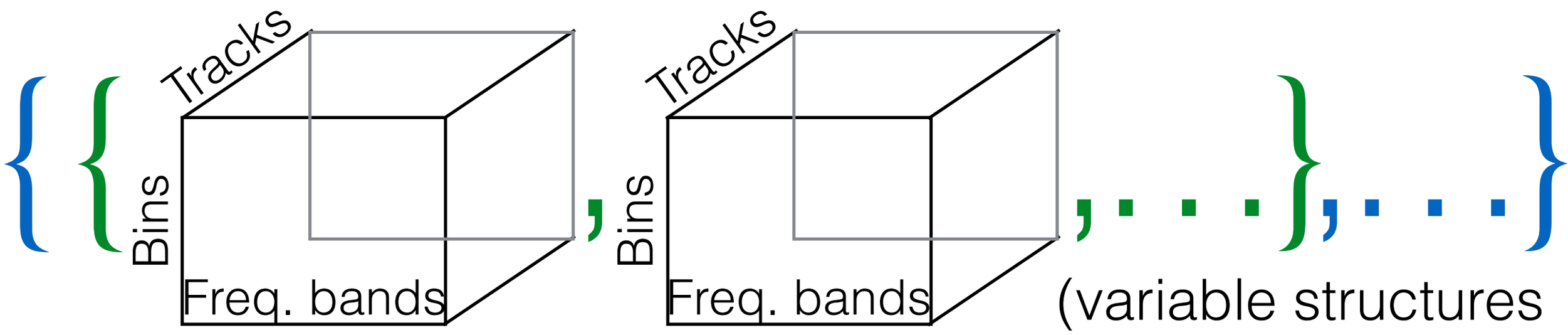


{bin, freqband, track}

- Allows configuration that were not possible in *MIRtoolbox*.

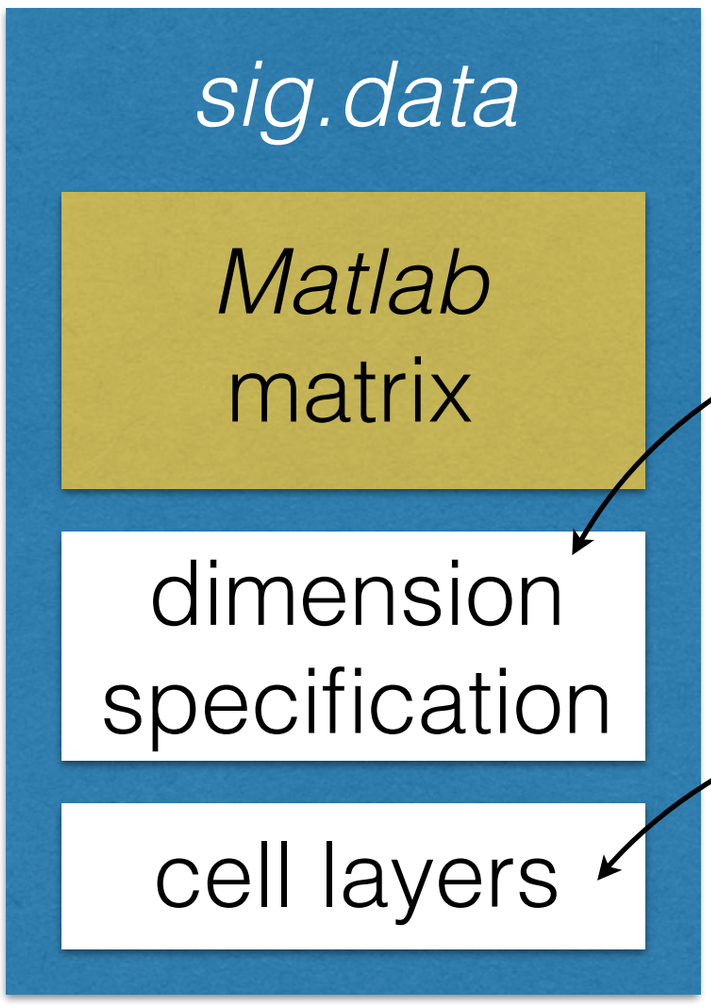
Matrix convention in MiningSuite

- More complex configurations can be freely designed, outside of any “pre-wired” configuration.



sig.data

- New syntactic layer on top of *Matlab* that makes operators' code simpler.



For instance:
{bin,sample,channel}

Indicating if the data is a cell-array, corresponding to batch of audio files, sequence of segmented data, etc.

sig.data

- *x.**size**(‘**sample**’)* gives the number of samples.

- *x.**sum**(‘**channel**’)* sums the matrix along the channel dimension.

- *x**.times**(y)* multiplies two *sig.data* objects, respecting dimension type congruency.

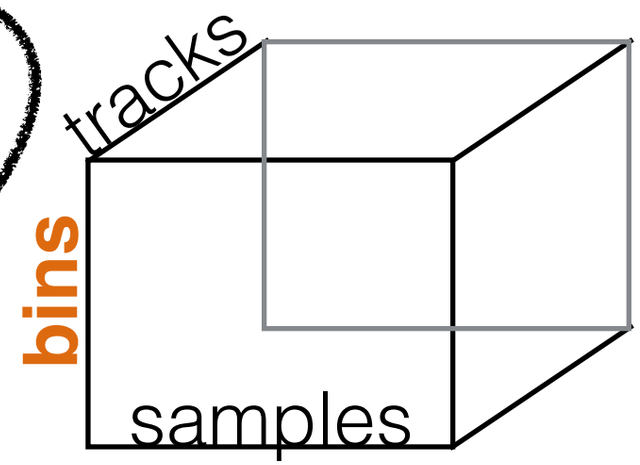
- *x**.apply**(@xcorr,{},{’**sample**’},2)* applies *xcorr* along the sample dimension. The last argument notifies that *xcorr* does not work for matrices with more than 2 dimensions. The extra dimensions are automatically covered via loops.

sig.data

```
function out = routine(d,…)

    e = d.apply(@algo,{…},{‘bin’},2);

    out = {e};

end
```

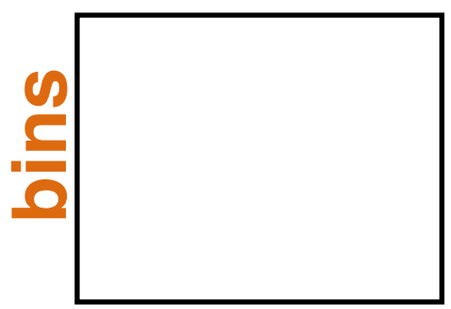
```
function ceps = algo(m,…)
…

    ceps = mfccDCTMatrix * m;

end
```

d:



2 dimensions:

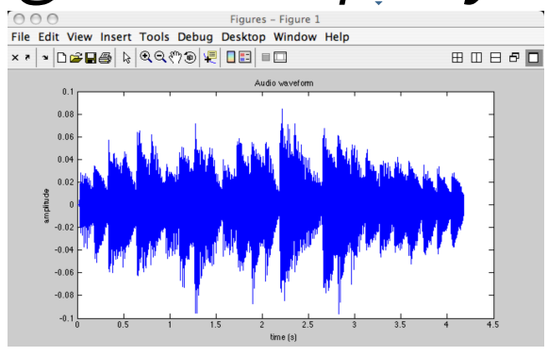
m:



- a = sig.input(‘myfile’, ‘Center’)

sig.signal

sig.signal.display



X axis (bin pos)	*no*
Y axis	
Sample axis	
Frame axis	*no*
Channel axis	*no*
Peaks	
date	15.10.2014
ver	R2014b, MiningSuite 0.8
design	

yname	audio
yunit	
Ydata	
Sstart	0
Srate	44100
Ssize	184269
indices	
precise pos	
precise val	

sig.data

- *Matlab* matrix
- dimension specification
- cell layers

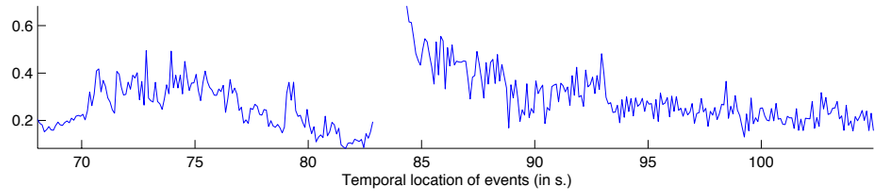
sig.design

```
a = sig.input(‘myfile’, ‘Center’)
```

- b = sig.brightness(a, '**Frame**')

sig.signal

sig.signal.display



X axis (bin pos)	*no*	**yname** **yunit** **Ydata**
Y axis		
Sample axis		**Sstart** 0 **Srate** **40** **Ssize** .05
Frame axis	***no***	
Channel axis	*no*	
Peaks		**indices** **precise pos** **precise val**
date	15.10.2014	
ver	R2014b, MiningSuite 0.8	
design		

brightness

sig.data

Matlab matrix

dimension specification

cell layers

sig.design

b = sig.brightness(a, 'Frame')

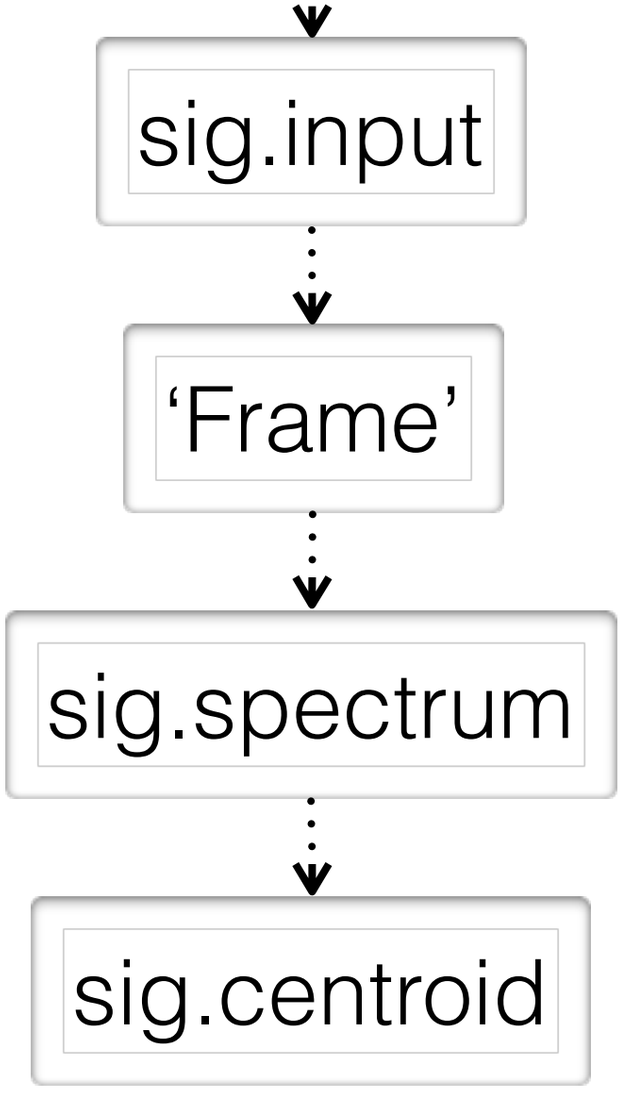
- b = sig.spectrum(a, ‘Frame’)

sig.Spectrum

Information such as time positions are regenerated on the fly.

		sig.axis		*sig.unit*	
X axis		**xname**	frequency	**xname**	Hz’
Y axis		**xstart**	1	**origin**	0
Sample axis		**xunit**		**rate**	10.76
Frame axis	***no***	**yname**	spectrum	**generator**	@..
Channel axis	*no*	**yunit**		**finder**	@..
Peaks		**Ydata**			
date	15.10.2014	**Sstart**	0		
ver	R2014b, MiningSuite 0.8	**Srate**	**40**	**power**	1
design		**Ssize**	.05	**log**	0
		indices		**phase**	*sig.data*
		precise pos			
		precise val			

Data flow graph in MiningSuite

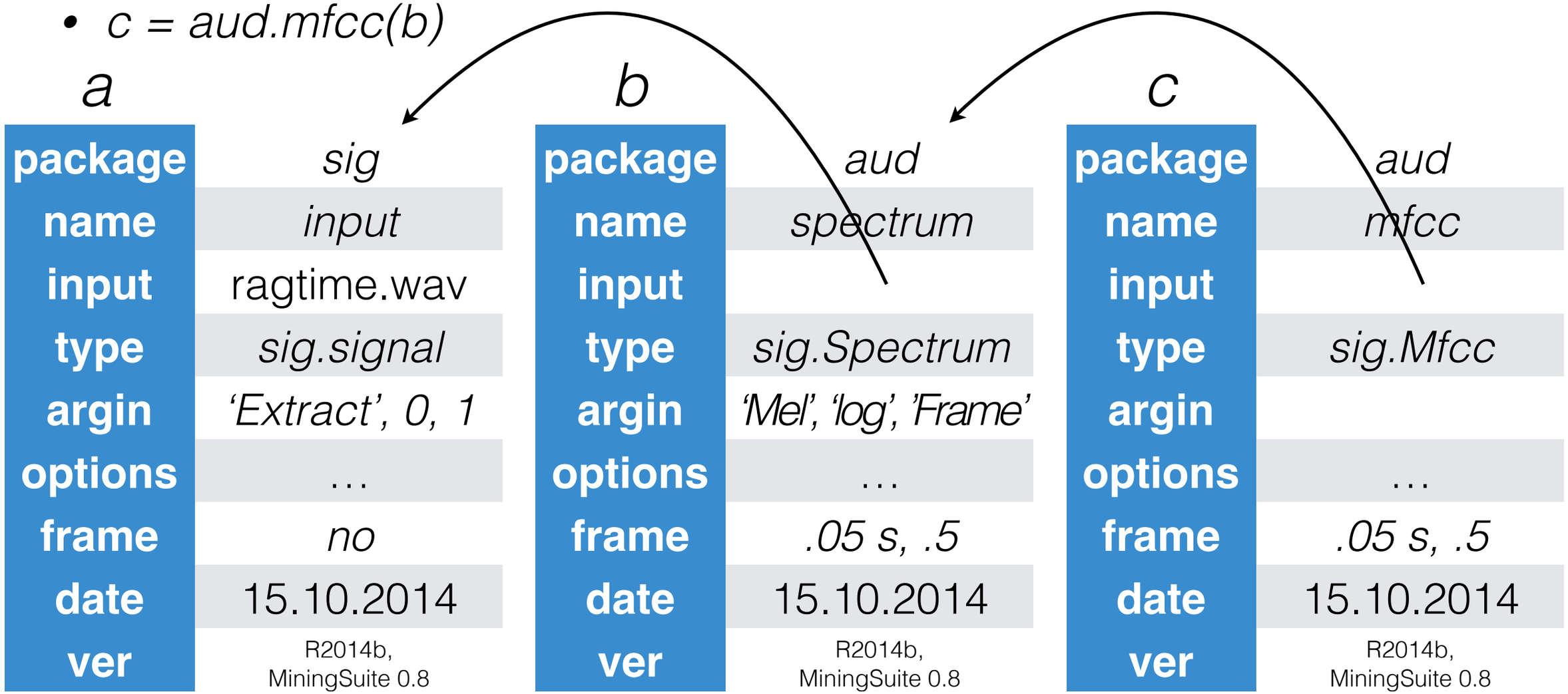


- a = sig.input('bigfile', …);
- s = sig.spectrum(f, 'Frame', …);
- c = sig.centroid(s)

; → No operation is performed.
(The data flow graph is constructed without actual computation.)

sig.design

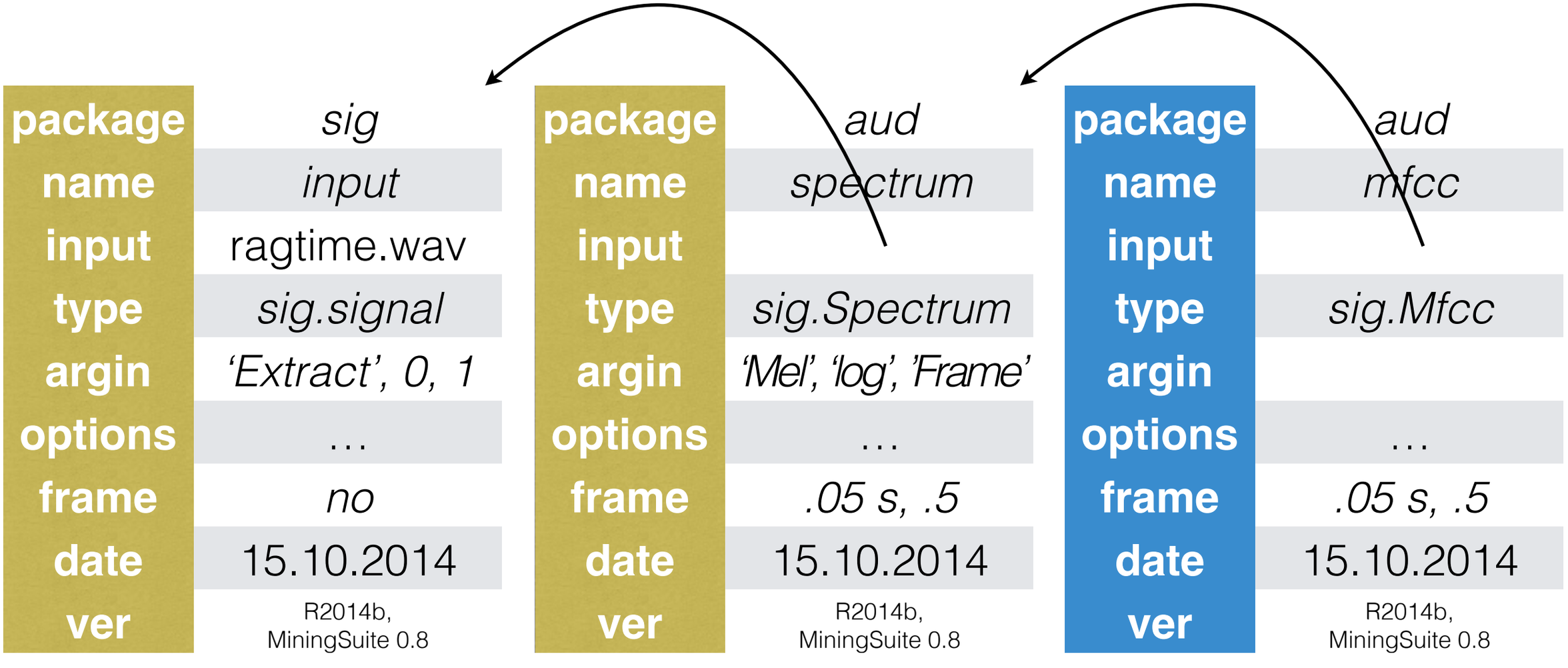
- *a = sig.input('ragtime.wav', 'Extract', 0, 1);*
- *b = aud.spectrum(a, 'Mel', 'log', 'Frame');*
- *c = aud.mfcc(b)*



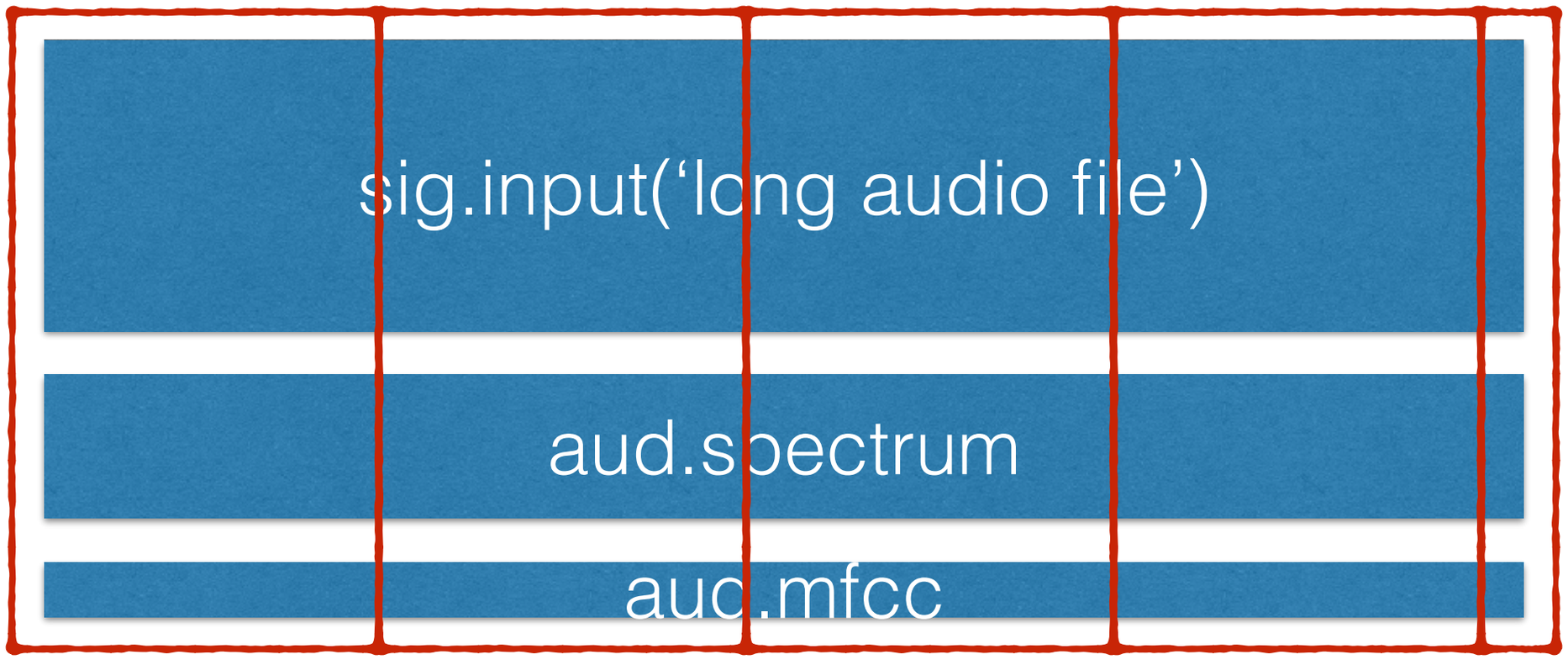
sig.design

- *c = aud.mfcc('ragtime.wav', 'Frame')*

- deploying the implicit data flow prior to the actual operator, during the '**Init**' phase.

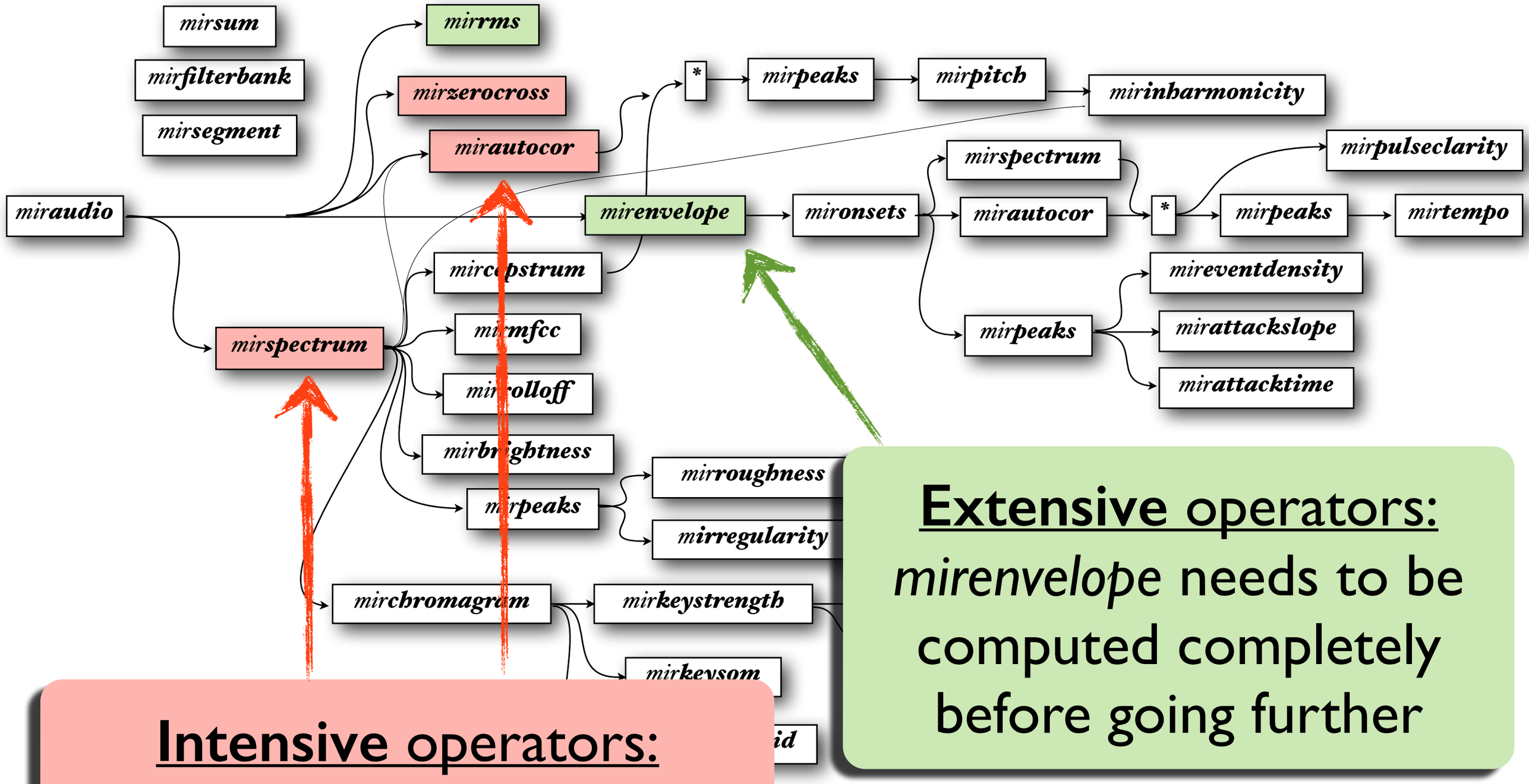


sig.design.eval



- Divide the audio file into successive chunks.
- Compute the whole process on each chunk separately.
- Recombine the final results by concatenation.

when there is **no** frame decomposition



Extensive operators:

mirenvelope needs to be computed completely before going further

Intensive operators:

Chunk decomposition needs to be performed here

mireval

non-frame-based evaluation

- *a = miraudio('Design');*
- *c = mirmfcc(a);*
- *mireval(c,'Folder')*

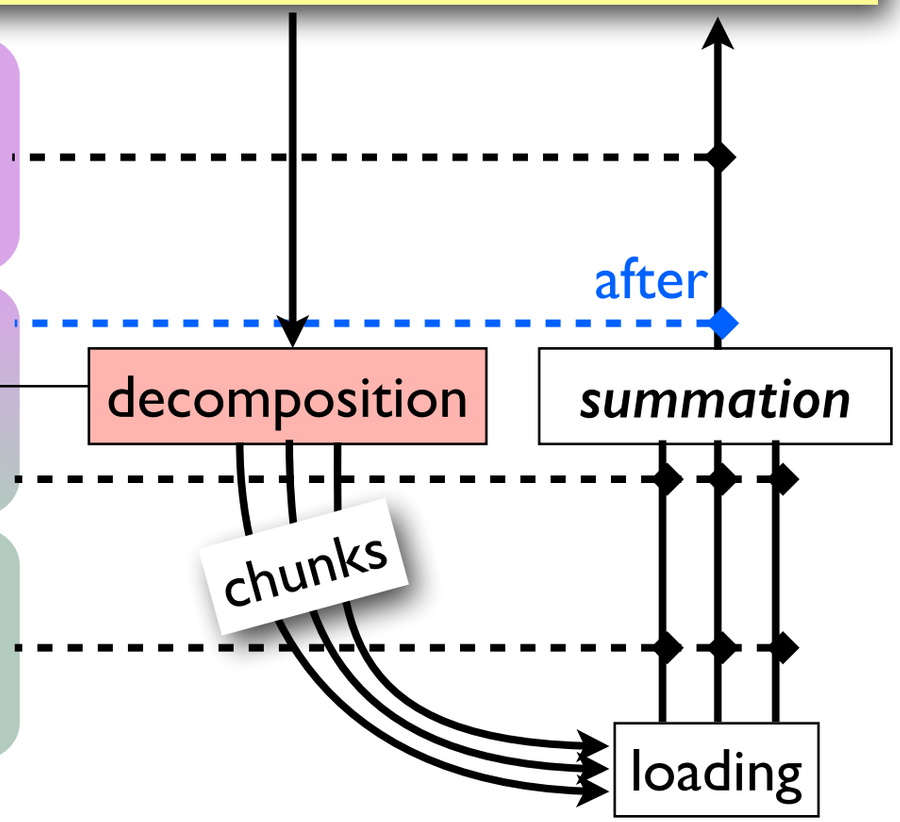
very complex paradigm for a situation not practically usual in MIR. MiningSuite is much more simple

eval_each(c,'song1.wav')

c *@mirdesign type=@mirmfcc*
options: *Rank*=1:13, *Delta*=0, ...

@mirdesign type=@mirspectrum
options: *Win*='*hamming*', ...

a *@mirdesign type=@miraudio*
options: *Sampling*=11025, ...



sig.design.eval('Folder')

- ***a** = aud.mfcc('Folder', …)*
- *d = a**.eval***

- For each separate file in the folder:
    - evaluate the design on that file (using the chunk decomposition)
    - store the results

sig.design.display → *sig.design.eval* → *sig.signal.display*

sig.design object, storing only the data flow graph

- ***a*** *= aud.mfcc('bigfile', …)*
- *d =* ***sig.ans***
- *d = a****.eval****;*
- *d*

sig.design.display = ***sig.design.eval***, which outputs a ***sig.signal*** and calls ***sig.signal.display***

the outputted ***sig.signal***

sig.design.eval outputs a ***sig.signal***

sig.signal.display

sig.operate
operators' main routine

+aud/brightness.m:

```
function varargout = brightness(varargin)
    varargout = sig.operate('aud', 'brightness', options, ...
                                @init, @main, varargin);
end
```

aud.brightness ('ragtime', 'Frame')

sig.operate

- first parses the **arguments** in the call,
- then creates a data flow design:
  - starts with implicit data flow (@init)
  - ends with @main routine.

options specification

my_operator(filename, 'Threshold', 100, 'Normalize')

```
thres.key = 'Threshold';

thres.type = 'Numeric';

three.default = 50;

options.thres = thres;
```

```
norm.key = 'Normalize';

norm.type = 'Boolean';

norm.default = 0;

options.norm = norm;
```

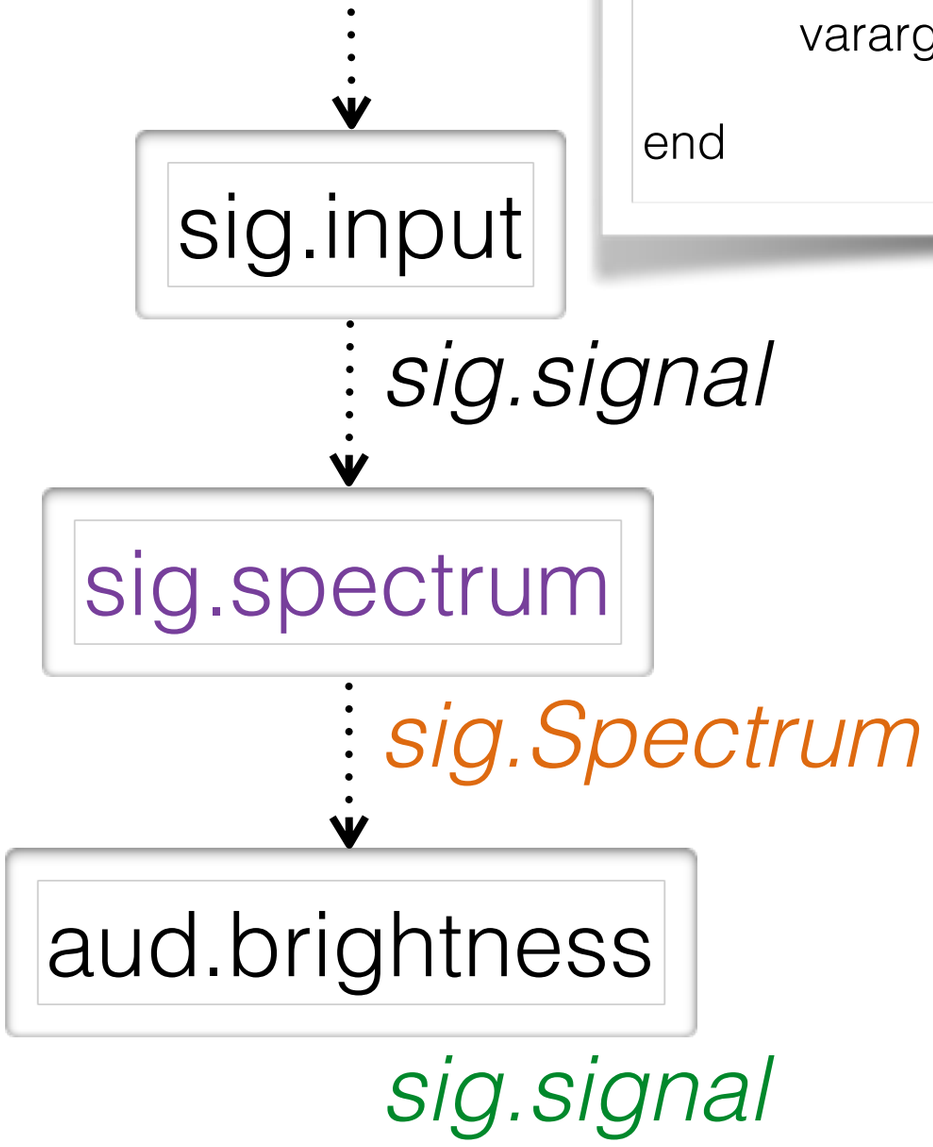
options specification

my_operator(filename, 'Domain','Symbolic')

```
domain.key = 'Domain';

domain.type = 'String';

domain.choice = {'Signal', 'Symbolic'};

domain.default = 'Signal';

options.domain = domain;
```

@init

implicit data flow deployment



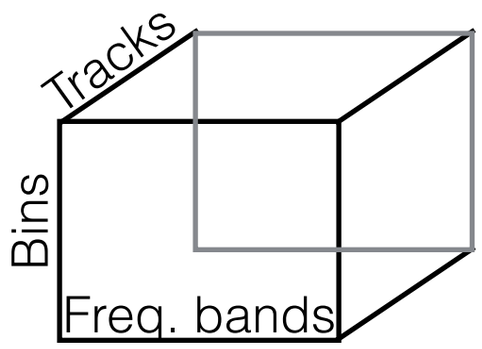

```
function varargout = aud.brightness(varargin)

        varargout = sig.operate('aud','brightness',options,@init,@main,varargin);

end
```

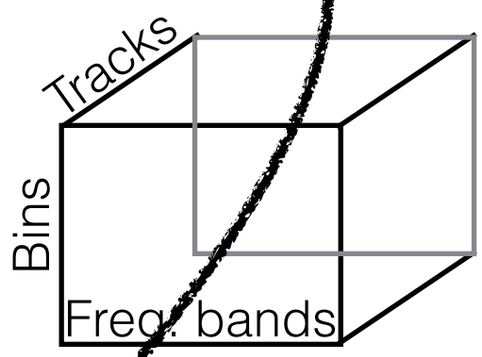
```
function [x type] = init(x,option,frame)

    if ~istype(x,'sig.Spectrum')

        x = sig.spectrum(x);

    end

    type = 'sig.signal';

end
```

```
function varargout = aud.brightness(varargin)

        varargout = sig.operate('aud','brightness',options,@init,@main,varargin);

end
```

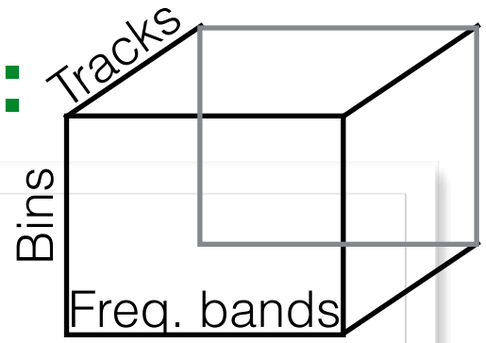
```
function out = main(in,option)

    x = in{1};

    if ~strcmpi(x.yname,'Brightness')

        res = sig.compute(@routine,x.Ydata,x.xdata,option.cutoff);

        x = sig.signal(res,'Name','Brightness','Srate',x.Srate,'Ssize',x.Ssize);

    end

    out = {x};

end
```

```
function out = main(in,option)
...

      res = sig.compute(@routine,x.Ydata,x.xdata,option.cutoff);
```

x.Ydata: { { 

, 

, . . . } , . . . }

d: 


```
function out = routine(d,f,f0)

    e = d.apply(@algo,{f,f0},{'element'},3);

    out = {e};

end
```

sig.compute applies the routine to the successive segments, successive audio files, etc.

```
function out = main(in,option)
...

    res = sig.compute(@routine,x.Ydata,x.xdata,option.cutoff);
```

```
function out = routine(d,f,f0)

  e = d.apply(@algo,{f,f0},{'element'},3);

  out = {e};

end
```

```
function y = algo(m,f,f0)

  y = sum(m(f > f0,:,:)) ./ sum(m);

end
```

sig.data.apply applies the sub-routine algo to the data **properly formatted**, with loops if needed.

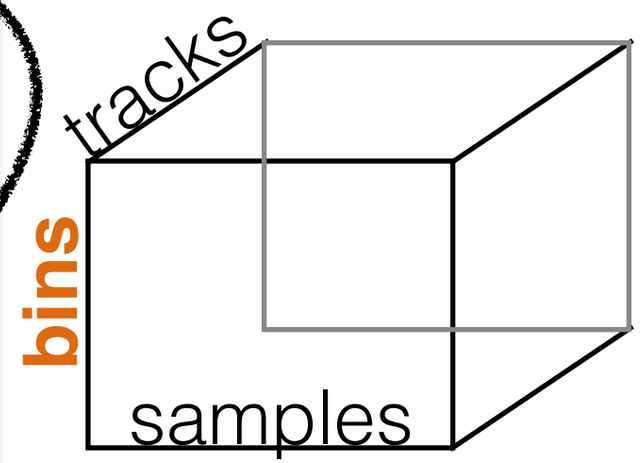
+aud/mfcc.m:

```
res = sig.compute(@routine,x.Ydata,x.xdata,option.cutoff);
```

```
function out = routine(d,…)

    e = d.apply(@algo,{…},{'bin'},2);

    out = {e};

end
```

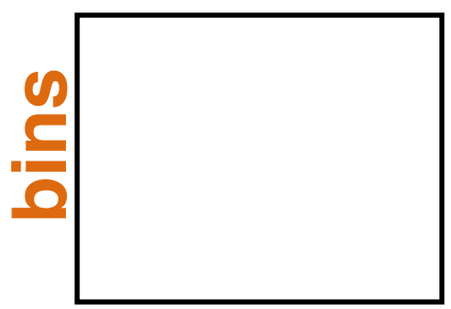
```
function ceps = algo(m,…)
…

    ceps = mfccDCTMatrix * m;

end
```

d:



2 dimensions:

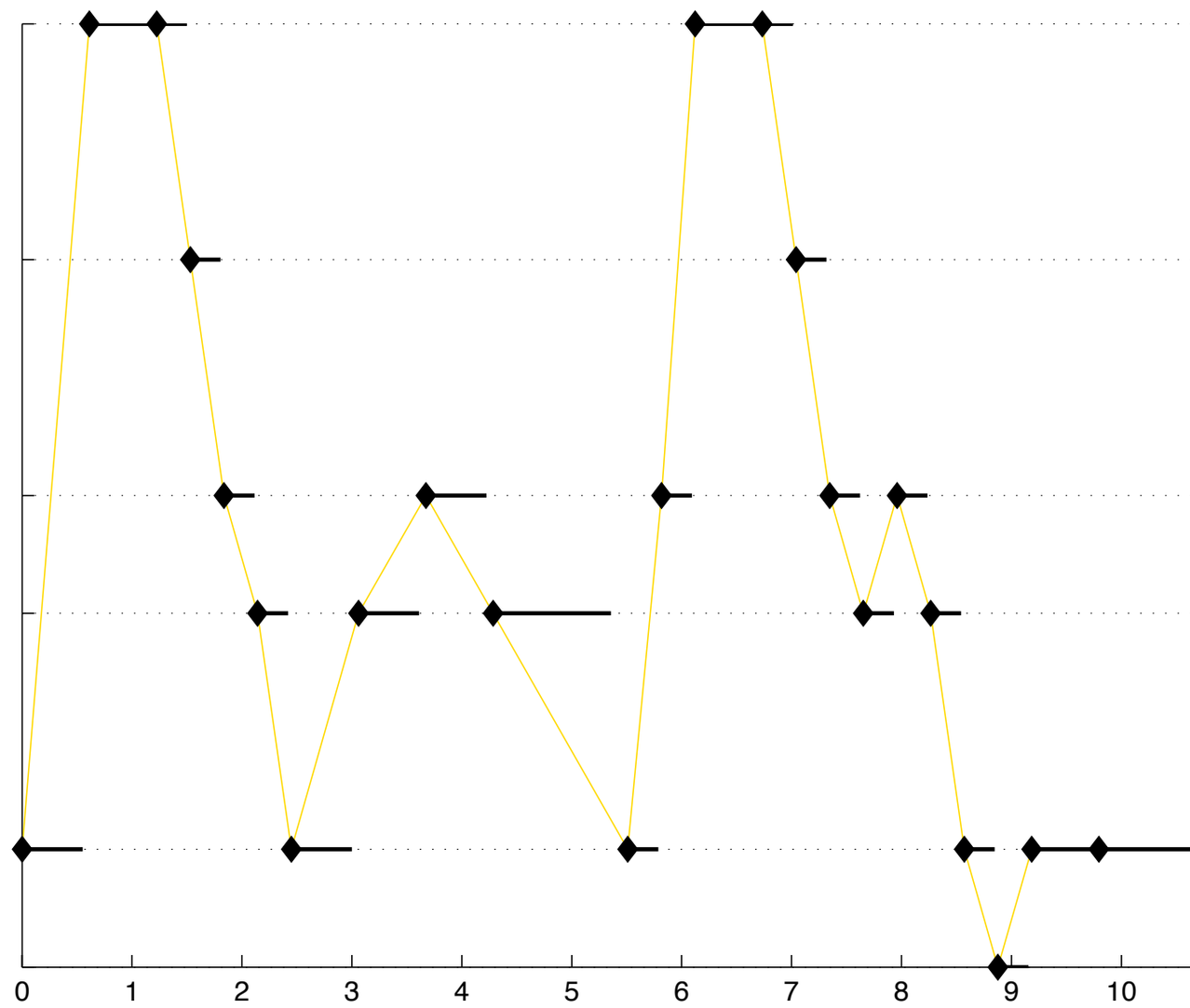
m:



seq.event
note characterization

Each note is a *seq.event*:

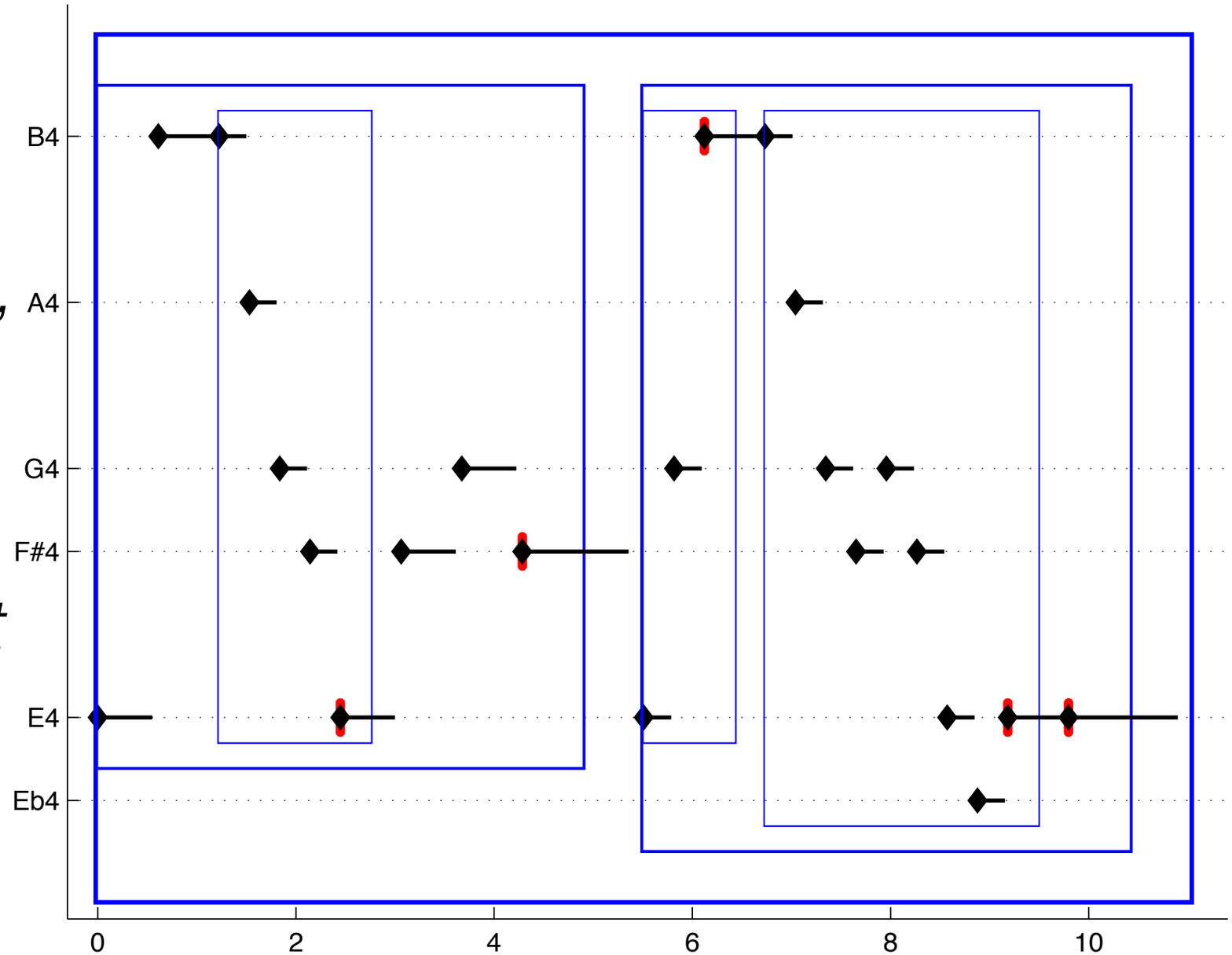
- characterization of the note: musical parameter (instance of class *seq.paramstruct*)
- previous note
- next note



mus.score(…, 'Group') hierarchical grouping

mus.score('laksin.mid', 'Group')

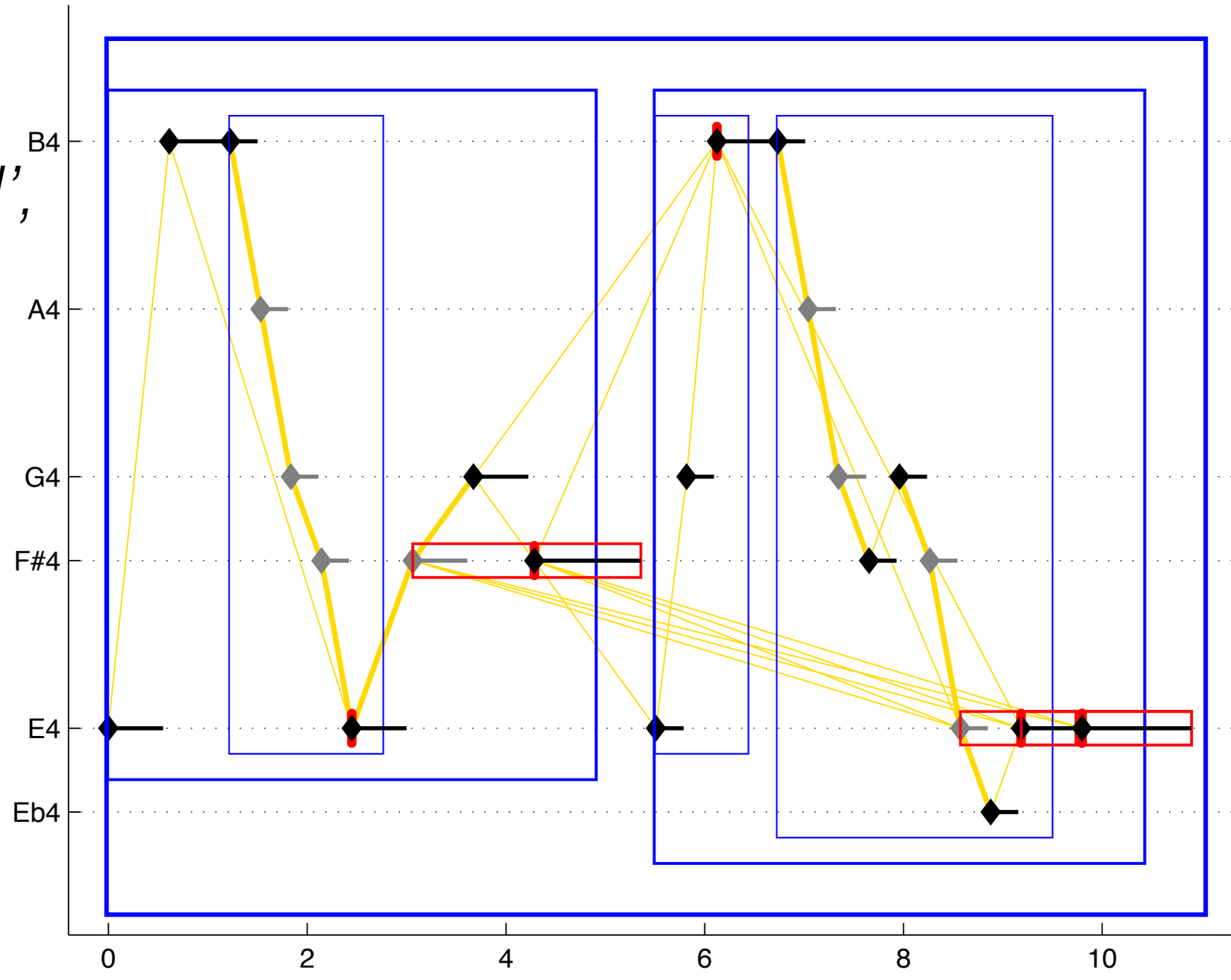
Groups, like notes, are instances of *seq.event*



mus.score(…, 'Reduce') ornamentation reduction

mus.score('laksin.mid', 'Group', 'Reduce')

Each syntagmatic relation between 2 notes is instance of *seq.syntagm*



mus.paramstruct
musical dimensions

each note:

- chromatic pitch

more general

- chromatic pitch class

- diatonic pitch (letter, accident, octave)

- diatonic pitch class

- onset, offset times (in s.)
- metrical position
- channel
- harmony, etc.

interval between notes:

- chromatic pitch interval

- chromatic pitch interval class

- diatonic pitch interval (number, quality)

- diatonic pitch interval class

- gross contour

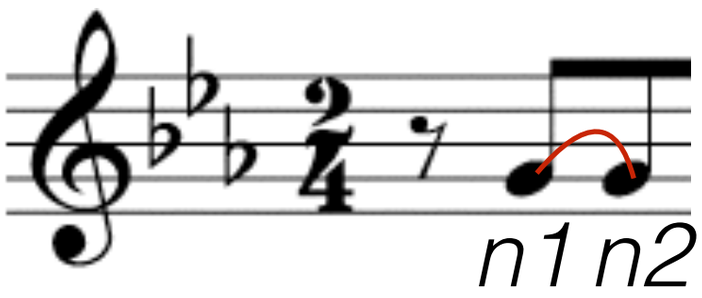
- inter onset interval
- rhythmic value

seq.param
parameter management

- *common(p1,p2)* returns the common parametric description

- *p1.implies(p2)* tests whether *p2* is more general than *p1*

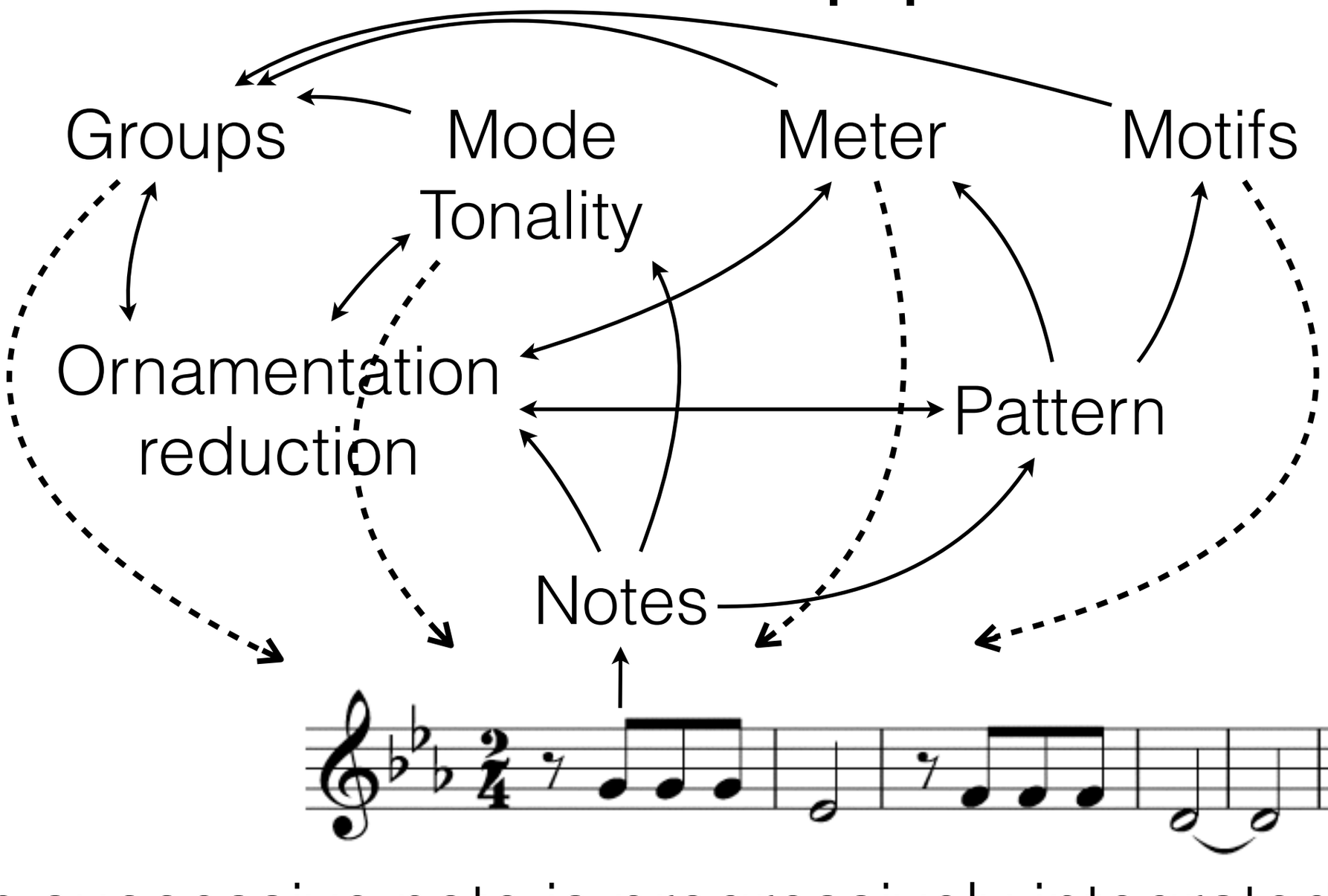
seq.syntagm



s = seq.syntagm(n1,n2)

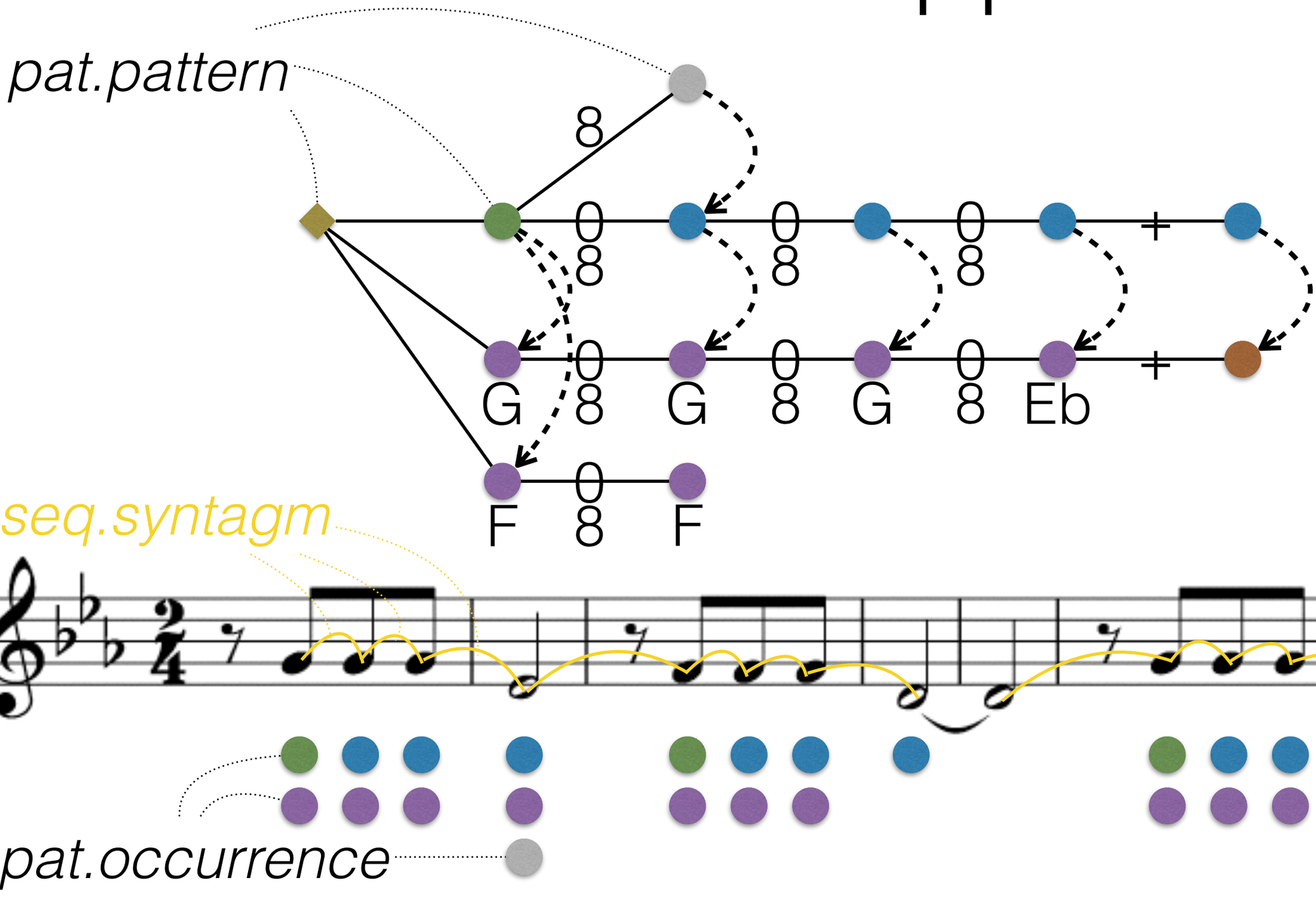
- *s.param* is automatically computed from *n1.param* and *n2.param*

mus.score
incremental approach

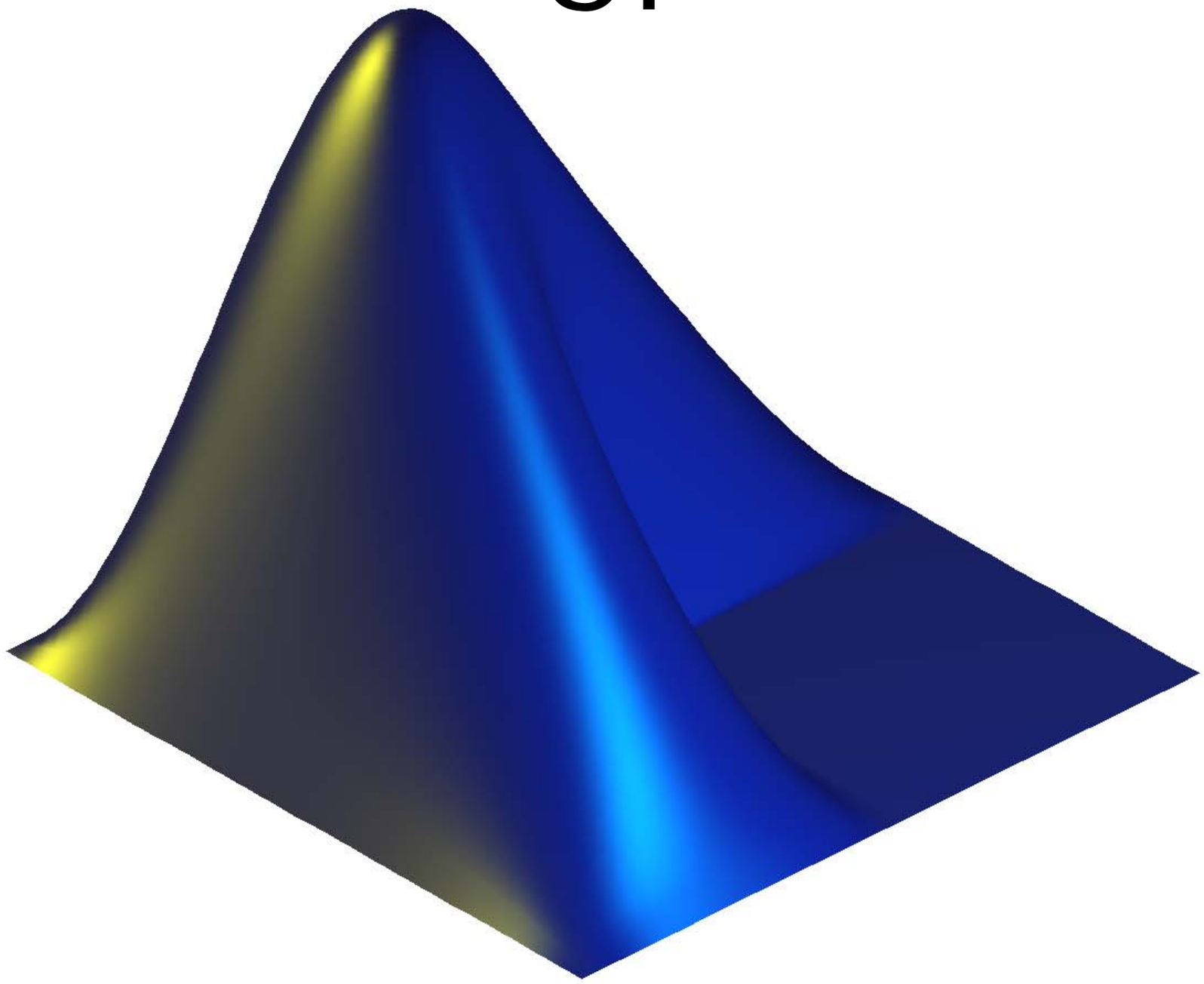


Each successive note is progressively integrated to all musical analyses, driving interdependencies.

mus.score
incremental approach



5.



How you can contribute

https://code.google.com/p/miningsuite/

- All releases, *SubVersion* repository, integrated with code review environment

- User's Manual and documentations in wiki environment

- Mailing lists: news, discussion list related to ongoing development, commits, issues registered and modified, discussion list for users

- Tickets to issue bug reports

Open-source project

- *MIRtoolbox* and initial version of *MiningSuite* is mainly the work of one person. Transition to a tool controlled by a community following standard open-source protocols.

- Whole code should be clearly readable, and be subject to correction/modification/enrichment by open community, after open discussions.

- Further development of the toolbox core (architecture, new perspectives) also subject to open discussion and community-based collaboration.

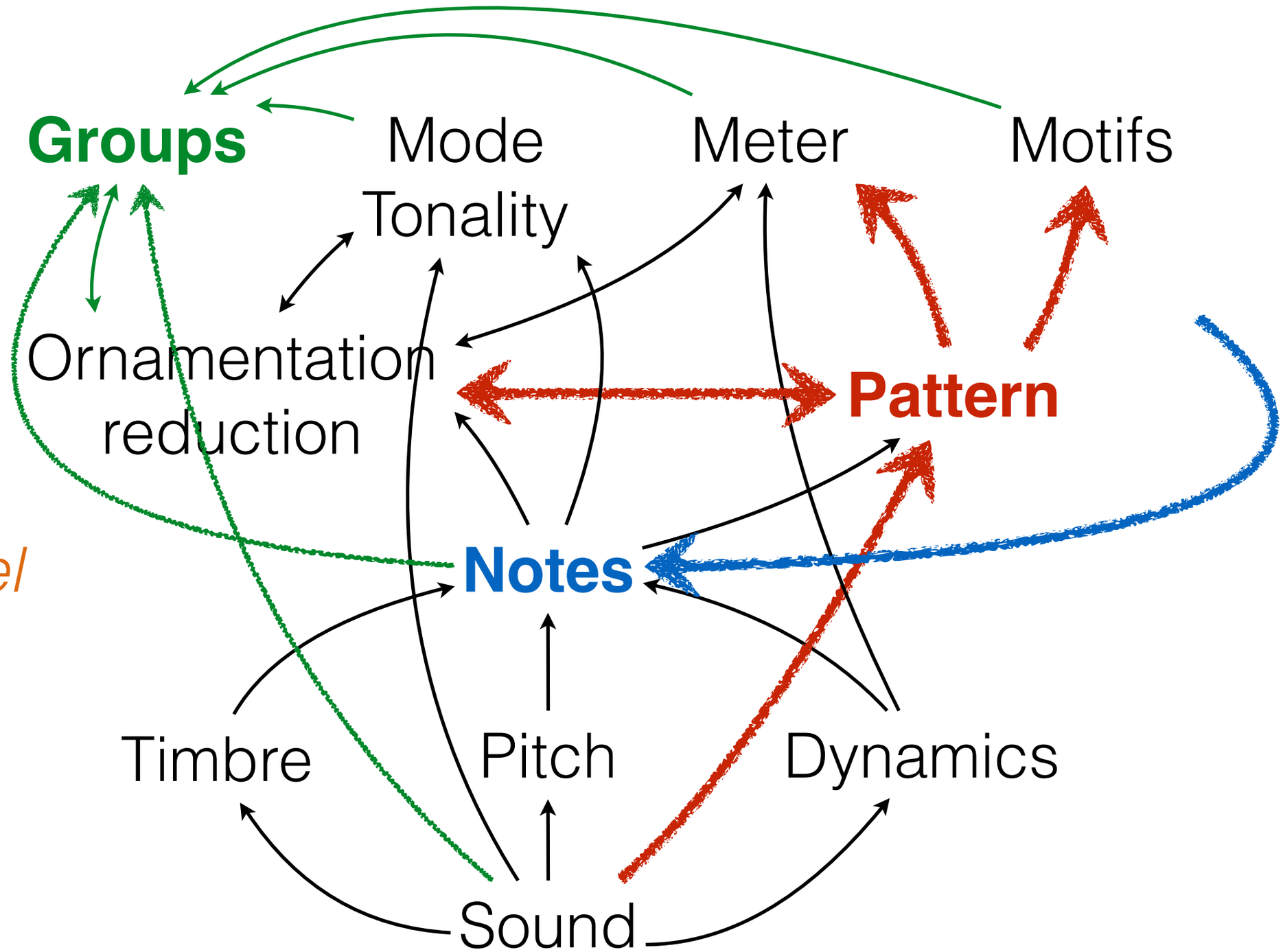
Open-source project Contribution acknowledgement

- Each contributor's participation is acknowledged, in particular in the copyright notice of source files to which he or she contributed.

- Each new model based on particular research is acknowledged in the documentation. In particular, users of the model are asked to cite the related research papers in their own papers.

- High-level musicological analysis refines lower-level transcription.
- Pattern mining is a central process in symbolic-based music analysis.

Structural levels



Symbolic level

Audio level

Future directions (on my side)

- Melodic transformations (ornamentation)
- Modelling form and style
- Metrical, tonal/modal analysis on symbolic domain
- Polyphonic analysis on symbolic domain

Future directions
(We need you!)

- Systematic test to check the validity of the results, to be run before each public version release
    - Measuring and controlling the variations of the results between versions
- Integrating other methods from the MIR literature
- Any other idea?
- We can also discuss about it during ISMIR.

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  - Aalborg University, MusIC group
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- Thanks to *MiningSuite* beta-testers


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University of Jyväskylä
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olbox contributors and u
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233