SAMA

Signal, Audio & Music Analysis

Today's agenda

- Surface overview of **computational rhythm analysis**
  - Which subtopics would you like us to study further?
- Plan for 2019:
  - What signal/audio/music analysis topics to study?
  - Would you like to present anything?
  - Spring schedule: Frequency? Dates?

Perspective taken

- Providing a mindmap of computational research in rhythm analysis in general

- Presenting general underlying concepts
    - Particular focus for illustrative purpose
- Introducing techniques/methodologies
- Synthetic (and shallow) understanding of the state of the art
    - Entry points for subsequent deeper studies

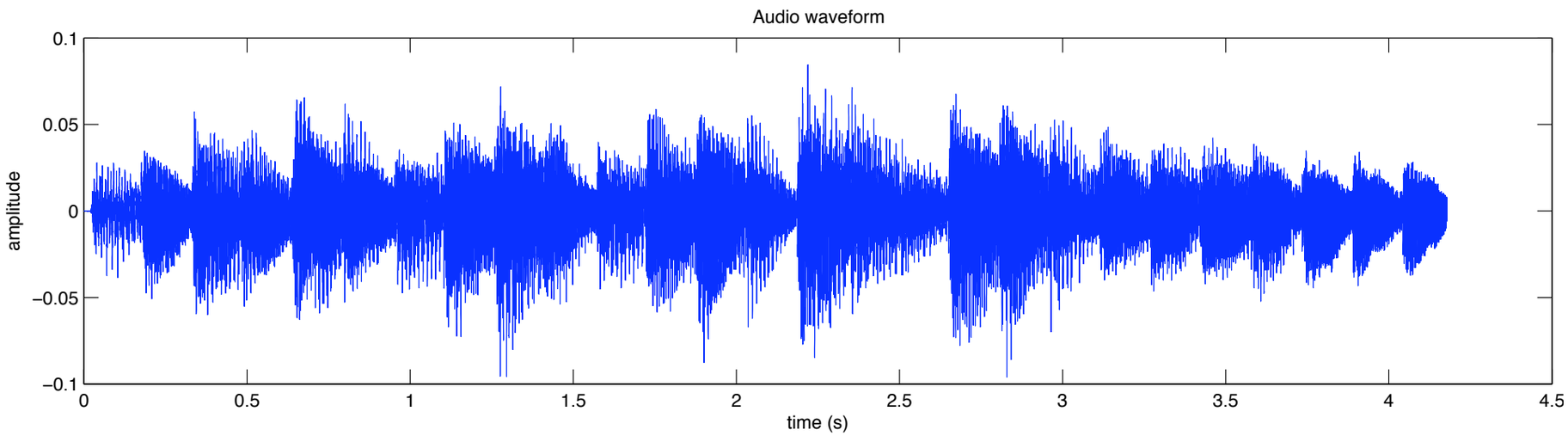
Rhythm analysis

- Rhythmical events: detection and characterisation (attack)
- Inferring rhythmical/metrical structure
  - Periodicity
  - Tracking metrical structure
  - Tempo estimation vs. Beat tracking, downbeat tracking
- Audio/score alignment
- Performance analyse: tempo variation
- Pulse clarity, syncopation
- Rhythmic similarity

Event detection

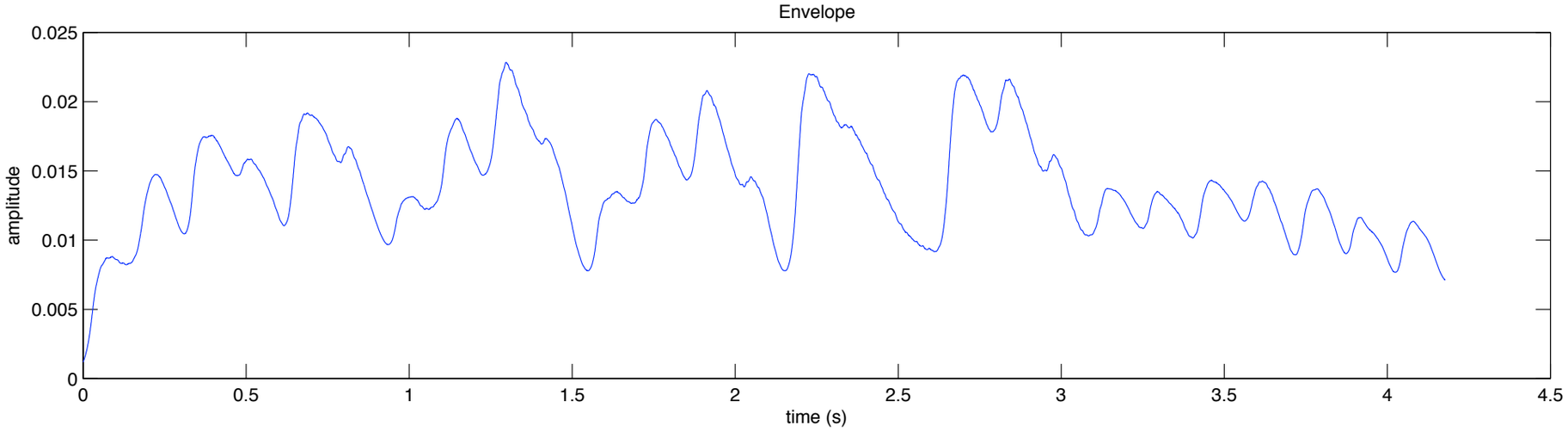
- What is the sound/music characteristic of a rhythmic event?
- Dynamics
- Significant increase of amplitude/energy
- “Phenomenal accent” (Klapuri 2006)

Event detection
Global dynamics

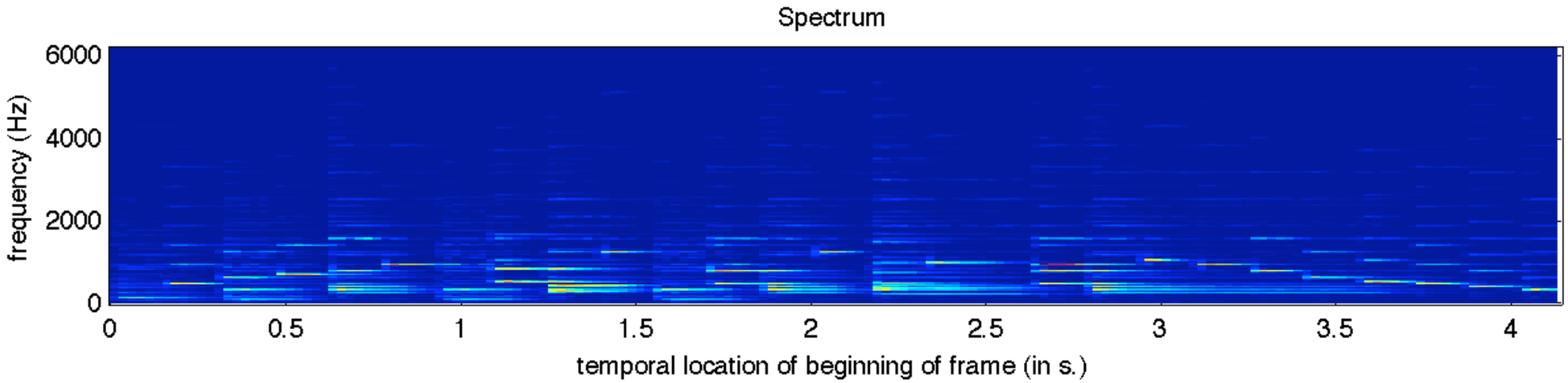


- Envelope: Outer shape of waveform, long-term dynamic evolution

- Peaks: burst of energy, percussive events

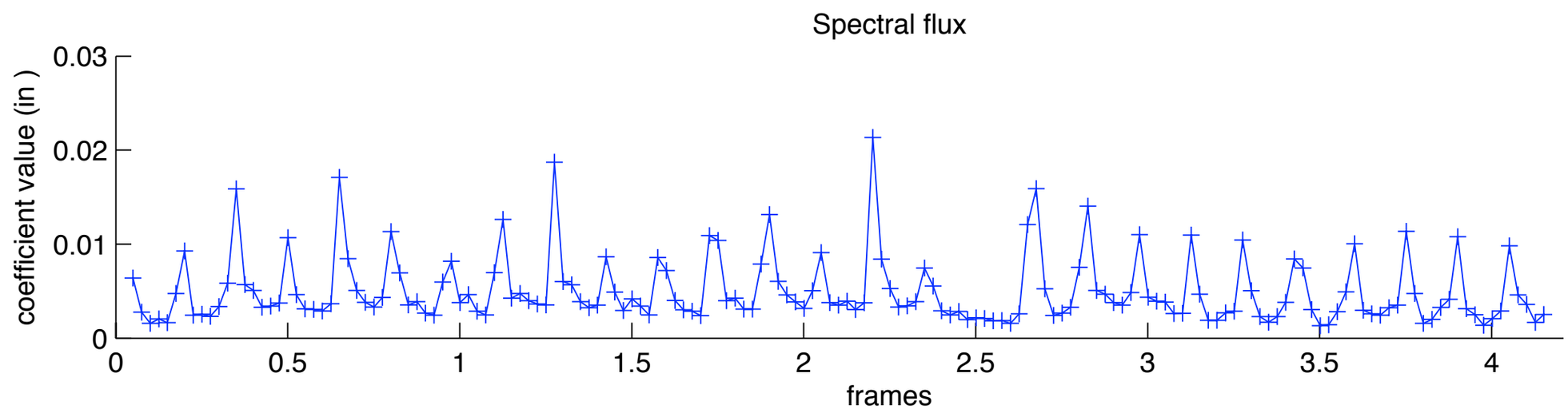


Event detection
Spectral changes

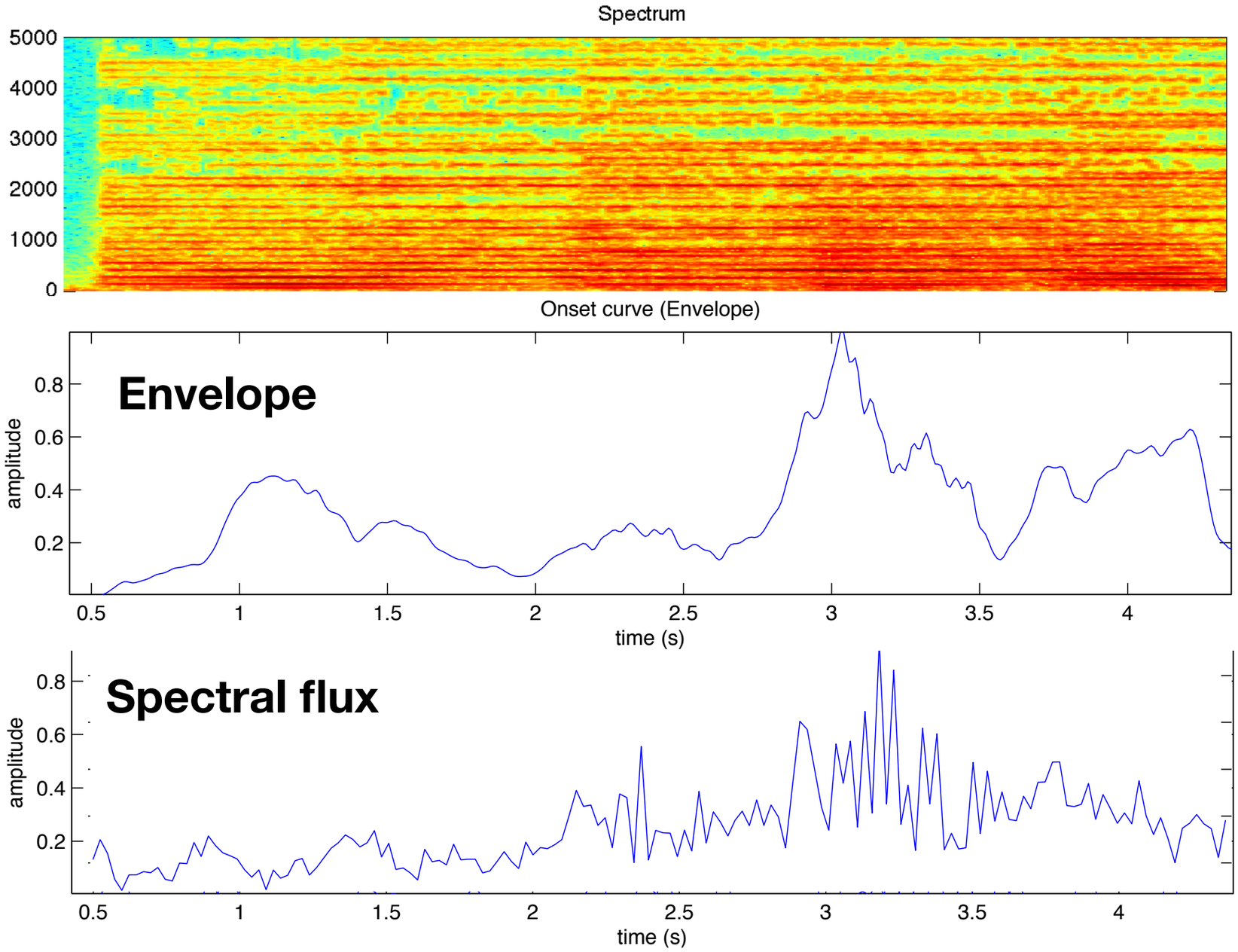


- Spectral flux: difference between successive frames

- Peaks: spectral discontinuities



Event detection
Spectral changes



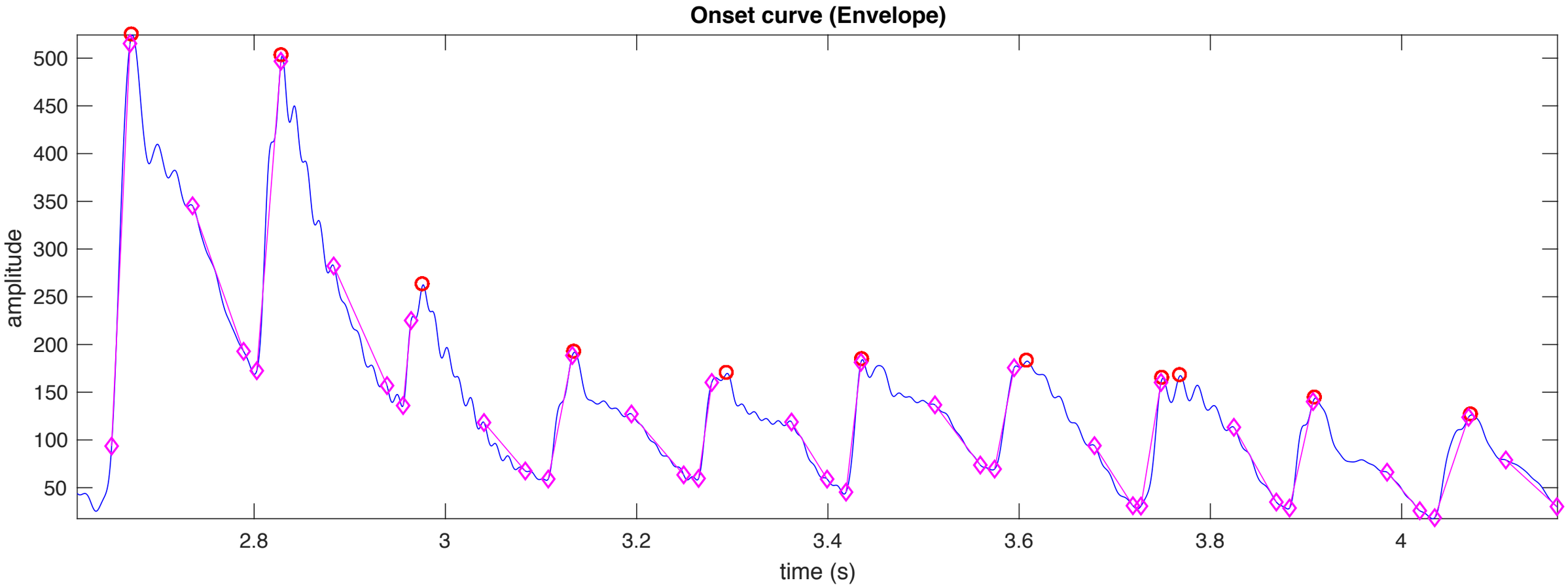
- Spectral flux does not always work.

- Search on narrow frequency regions: Goto, 2001; Lartillot, 2013

Event detection

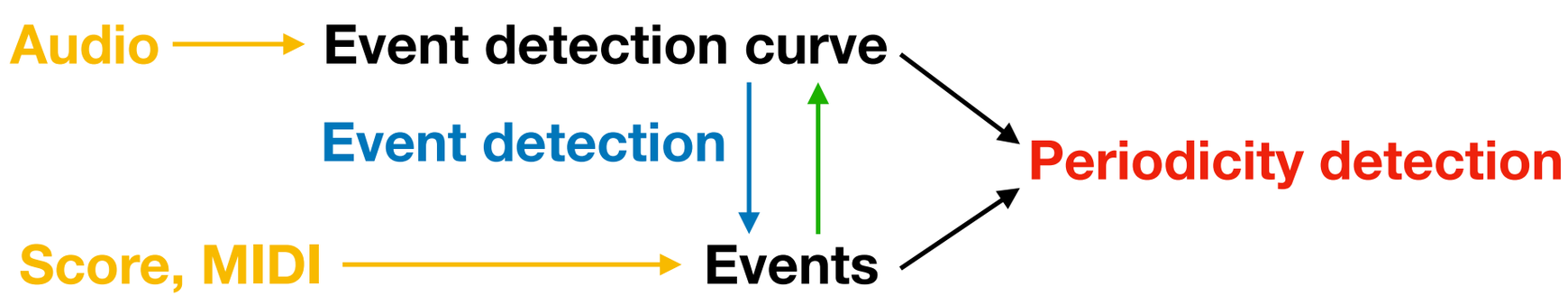
- Anything can be a rhythmical event:
    - Change of dynamics
    - Spectral changes
    - Change of chords
    - Phase based novelty (Müller)
- Both in audio recordings and scores, MIDI files.

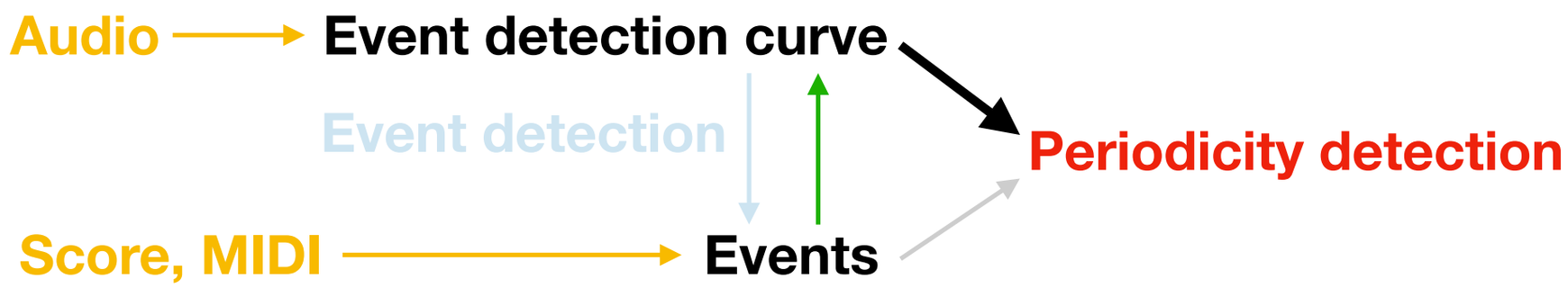
Attack characterisation



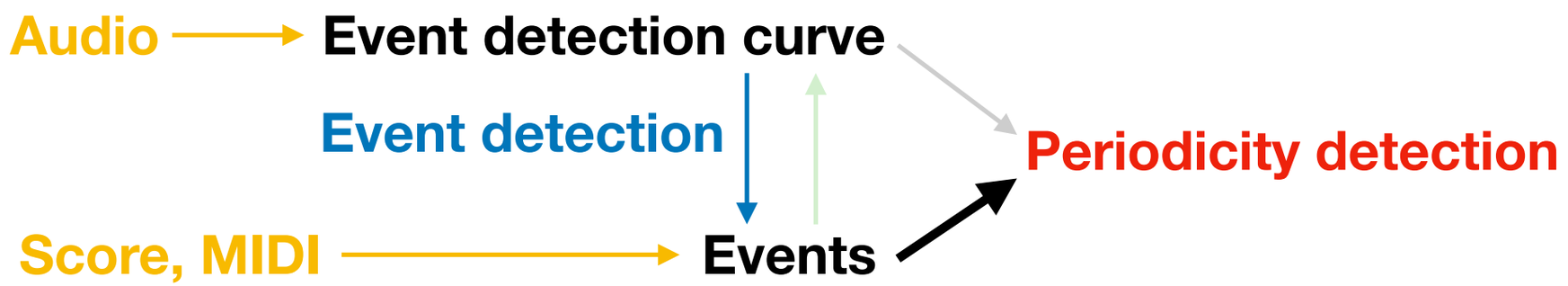
- TIME project

Periodicity

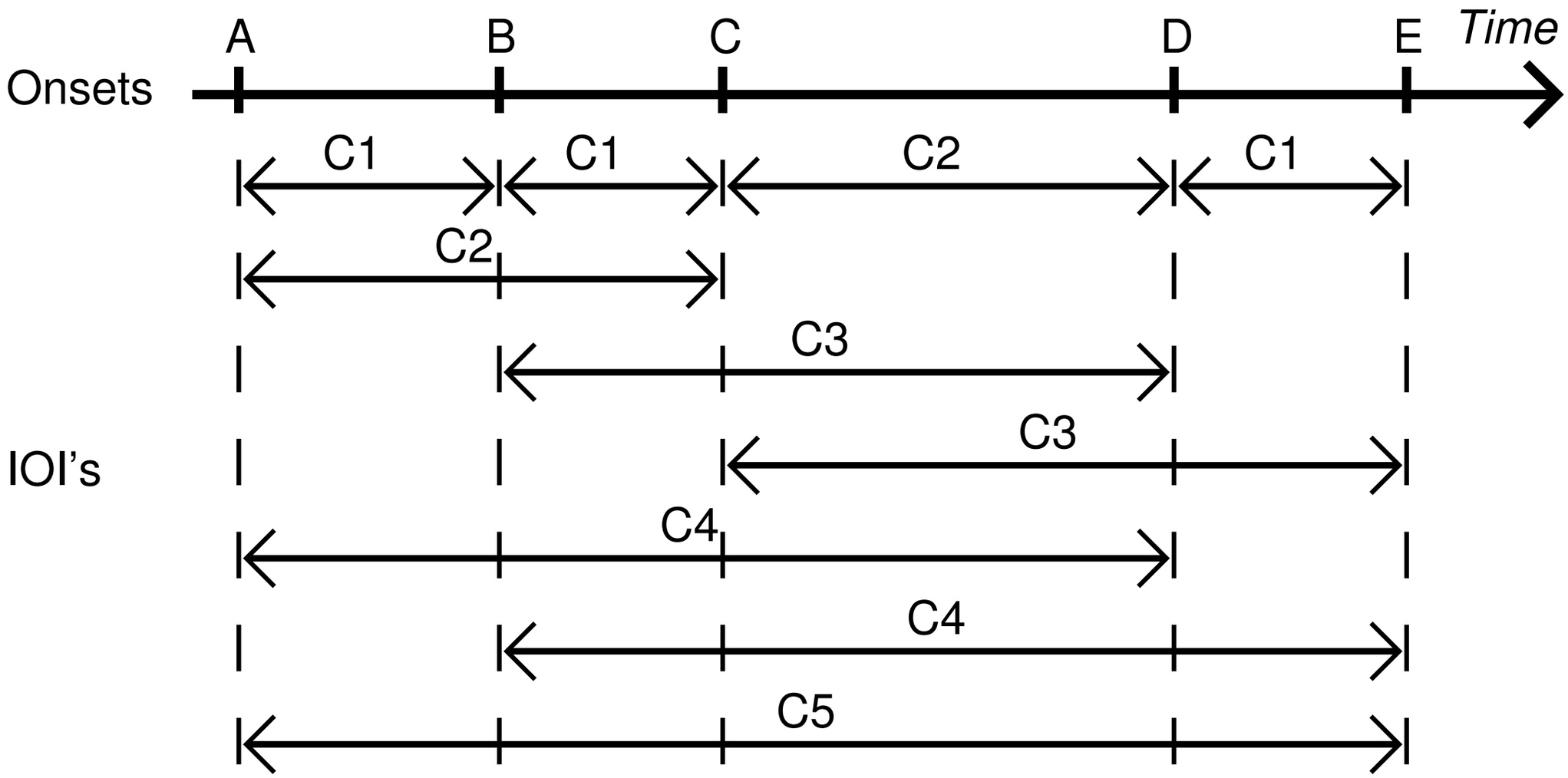




- Signal processing:
  - Spectrum (Fourier Transform)
  - Autocorrelation function
  - Comb filters (Scheirer 1998)
  - wavelets
- Neural network



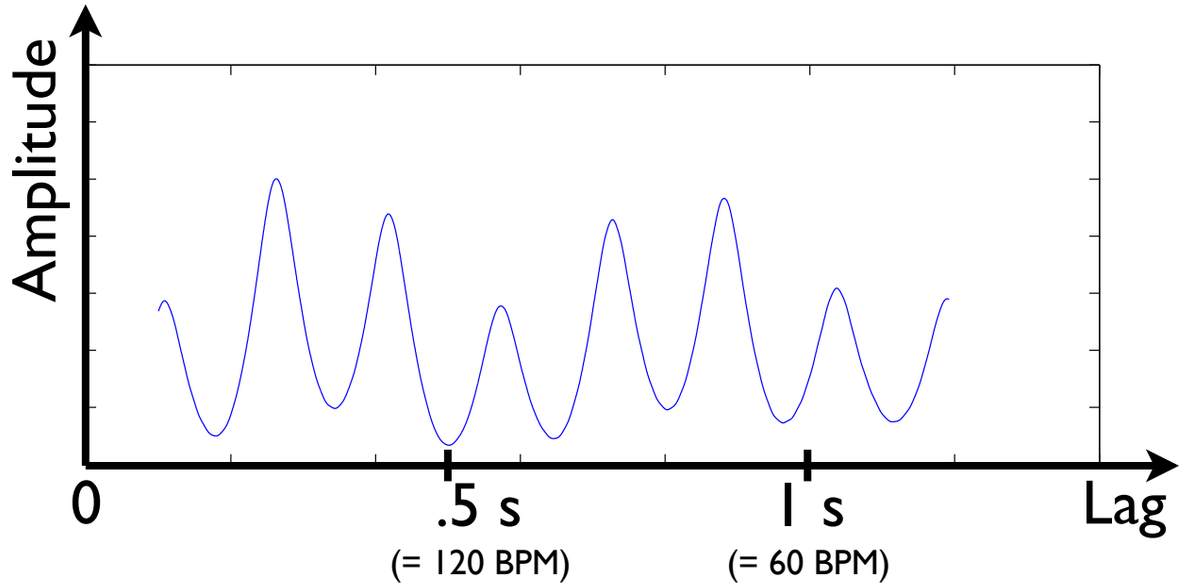
- Inter-Onset Intervals Clustering (Dixon 2007)

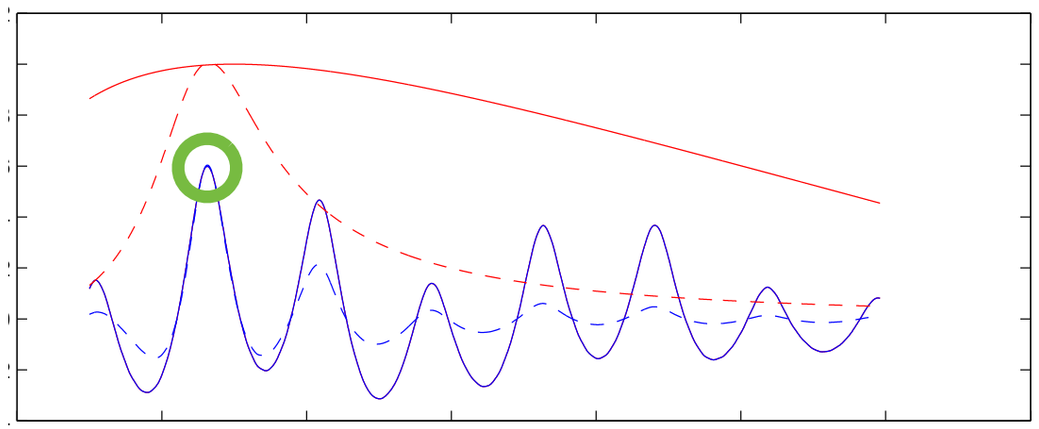


Tempo estimation

- Emphasis on the best perceived tempi

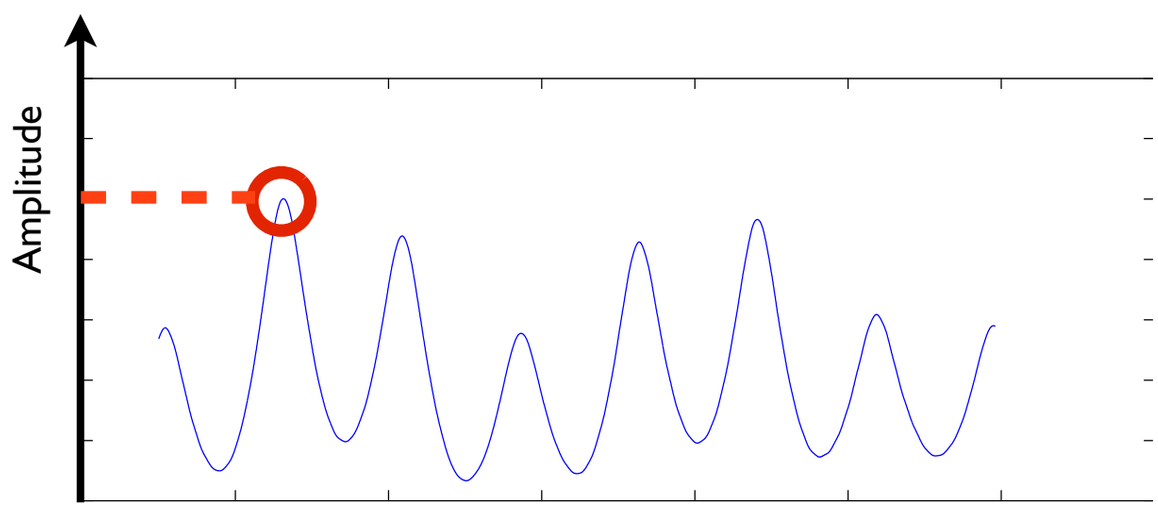
- Resonance curve (Toiviainen & Snyder, 2003)



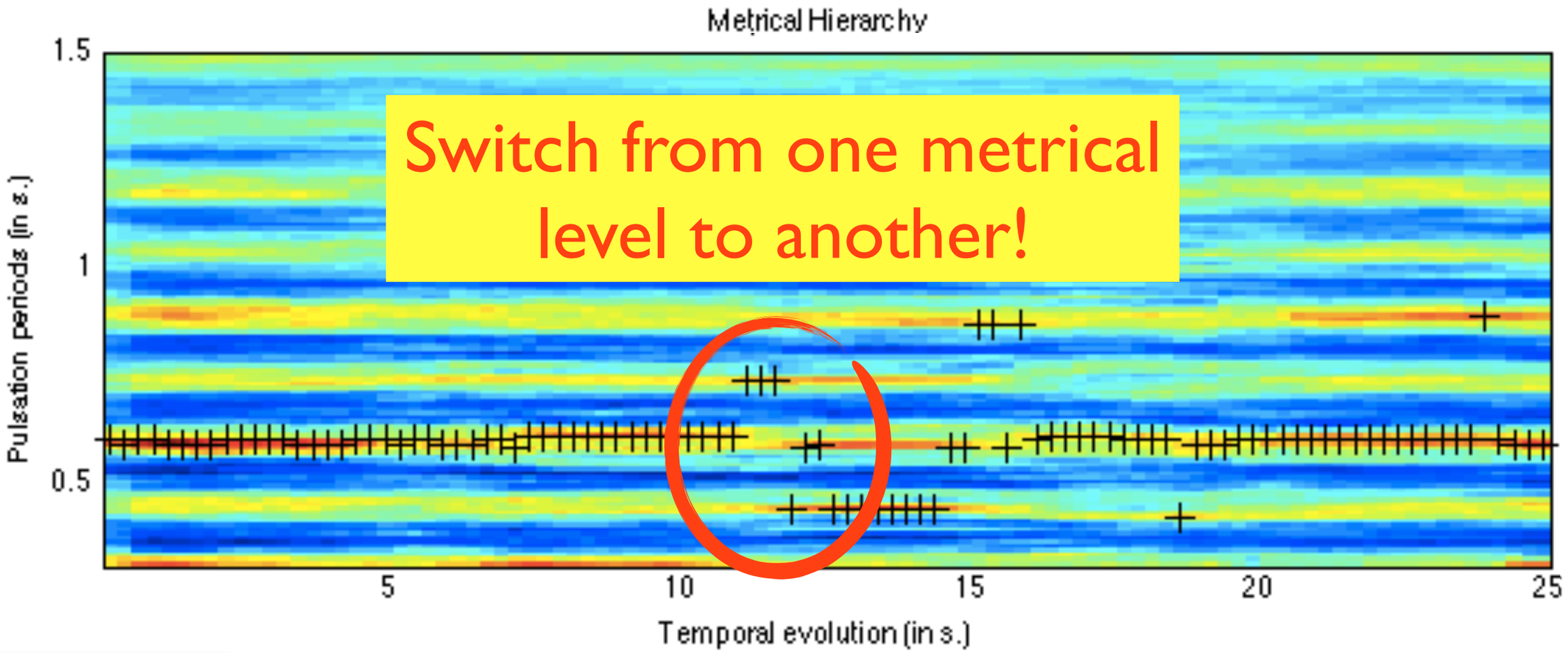


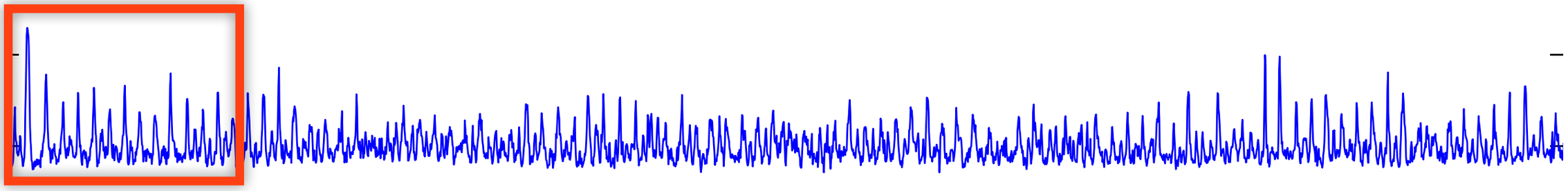
Pulse clarity

- Beat strength (Tzanetakis 2002): variability of the autocorrelation function across time
- Pulse clarity (Lartillot 2008): salience of periodicity, measured from autocorrelation function



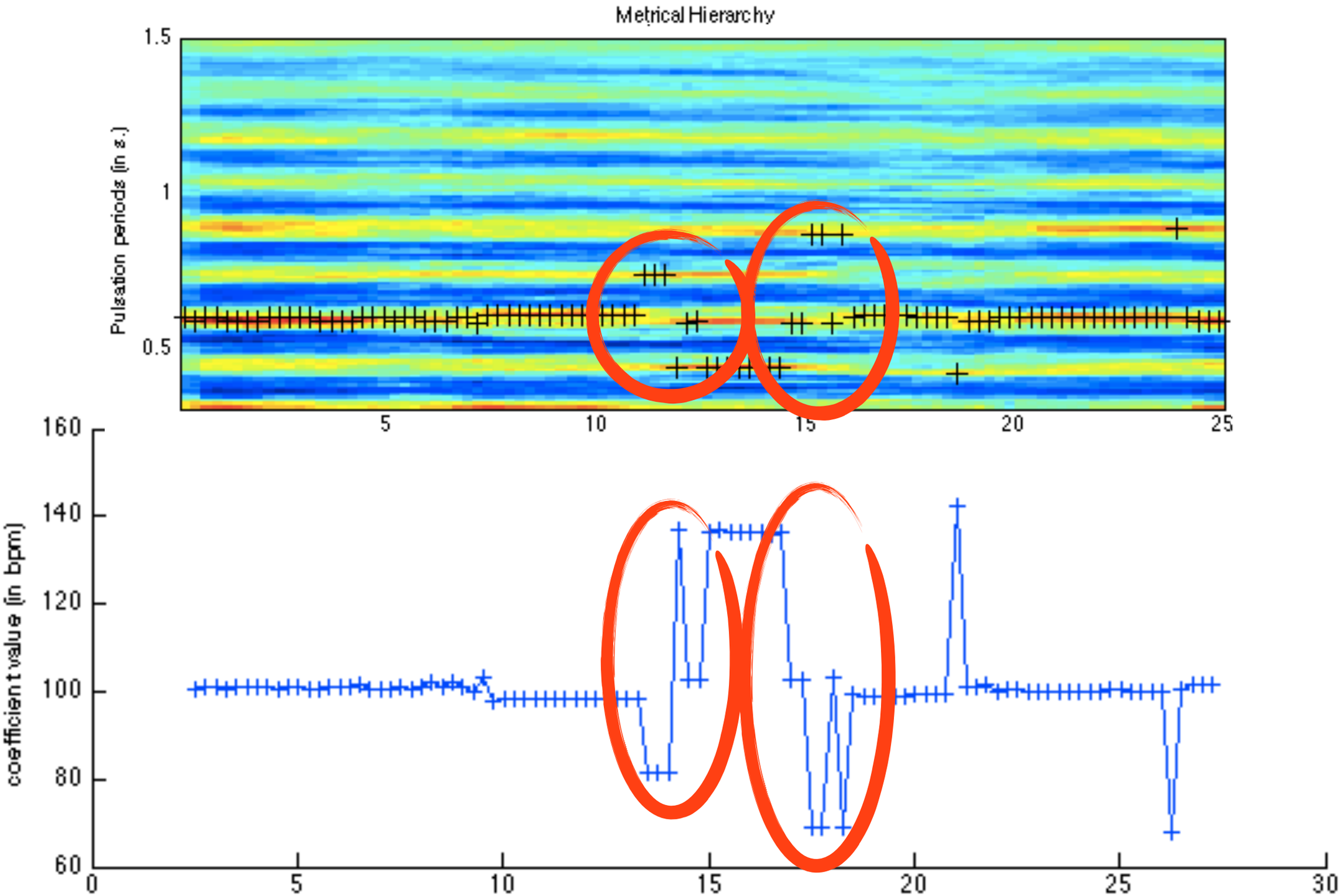
Tempo estimation: “Octave error”





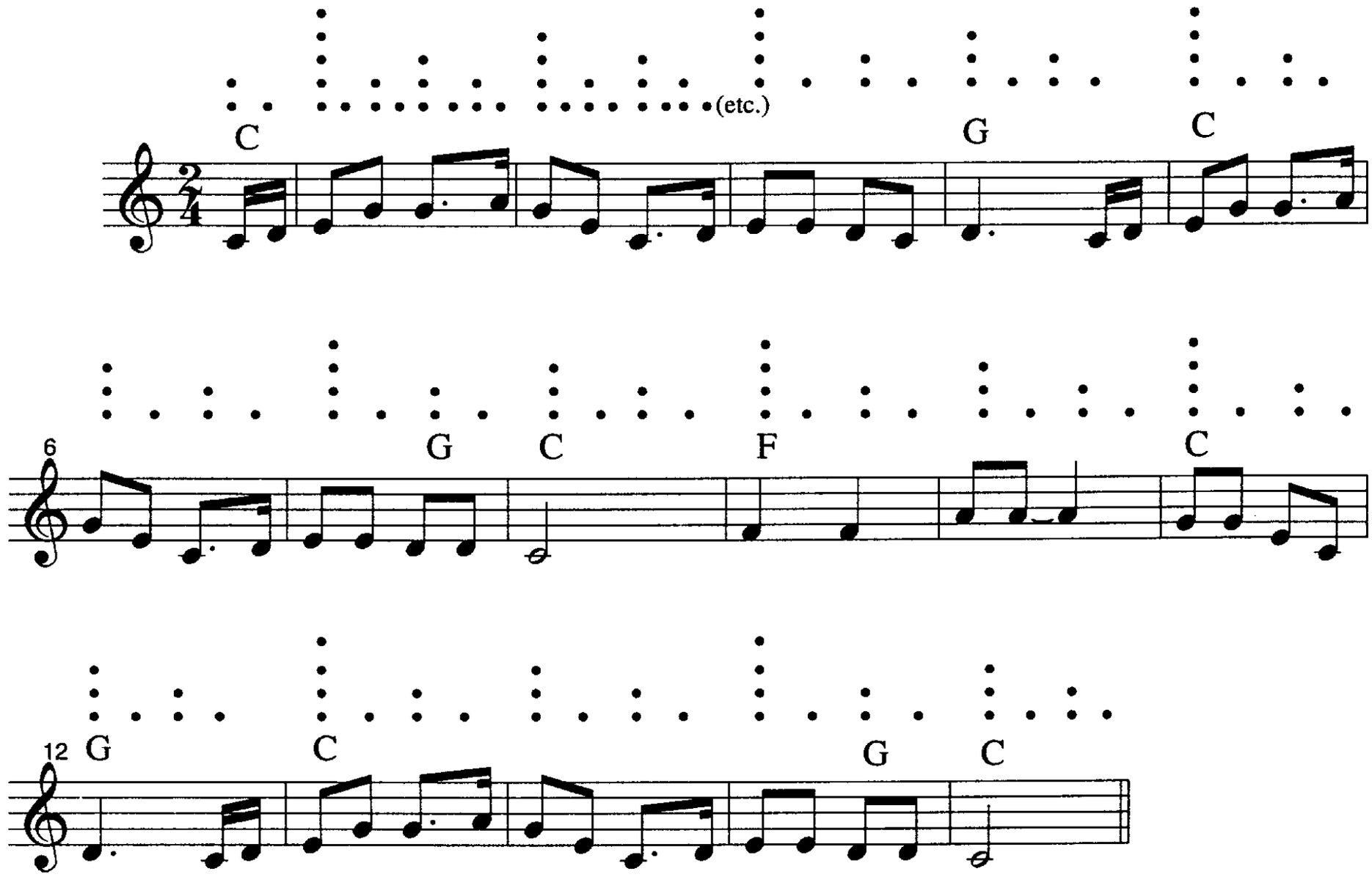
J.S. Bach, *Brandenburg concert No.2 in F Major*, BWV 1047, 1st mvt

Tempo estimation: “Octave error”



Metrical structure

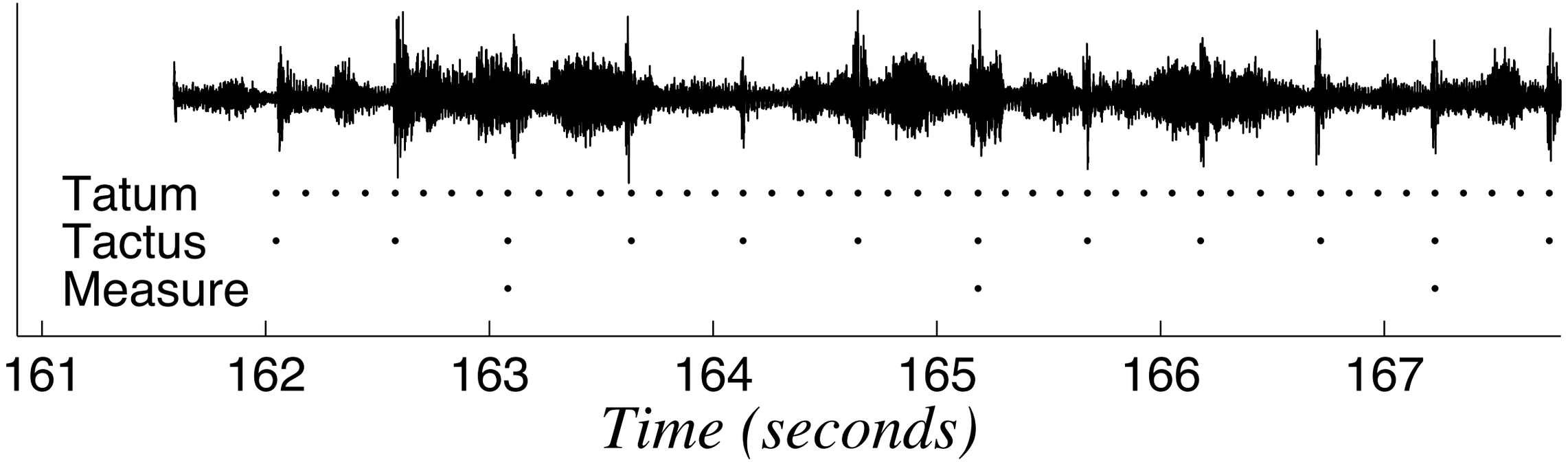
- *Generative Theory of Tonal Music* (GTTM, Lerdahl & Jackendoff)



Metrical structure

- Preference rules (Temperley 1999)
  - Event rule: prefer a structure that aligns beats with event onsets
  - Length rule: prefer a structure that aligns strong beats with onsets of longer events
  - Regularity rule: prefer beats at each level to be maximally evenly spaced

Metrical structure

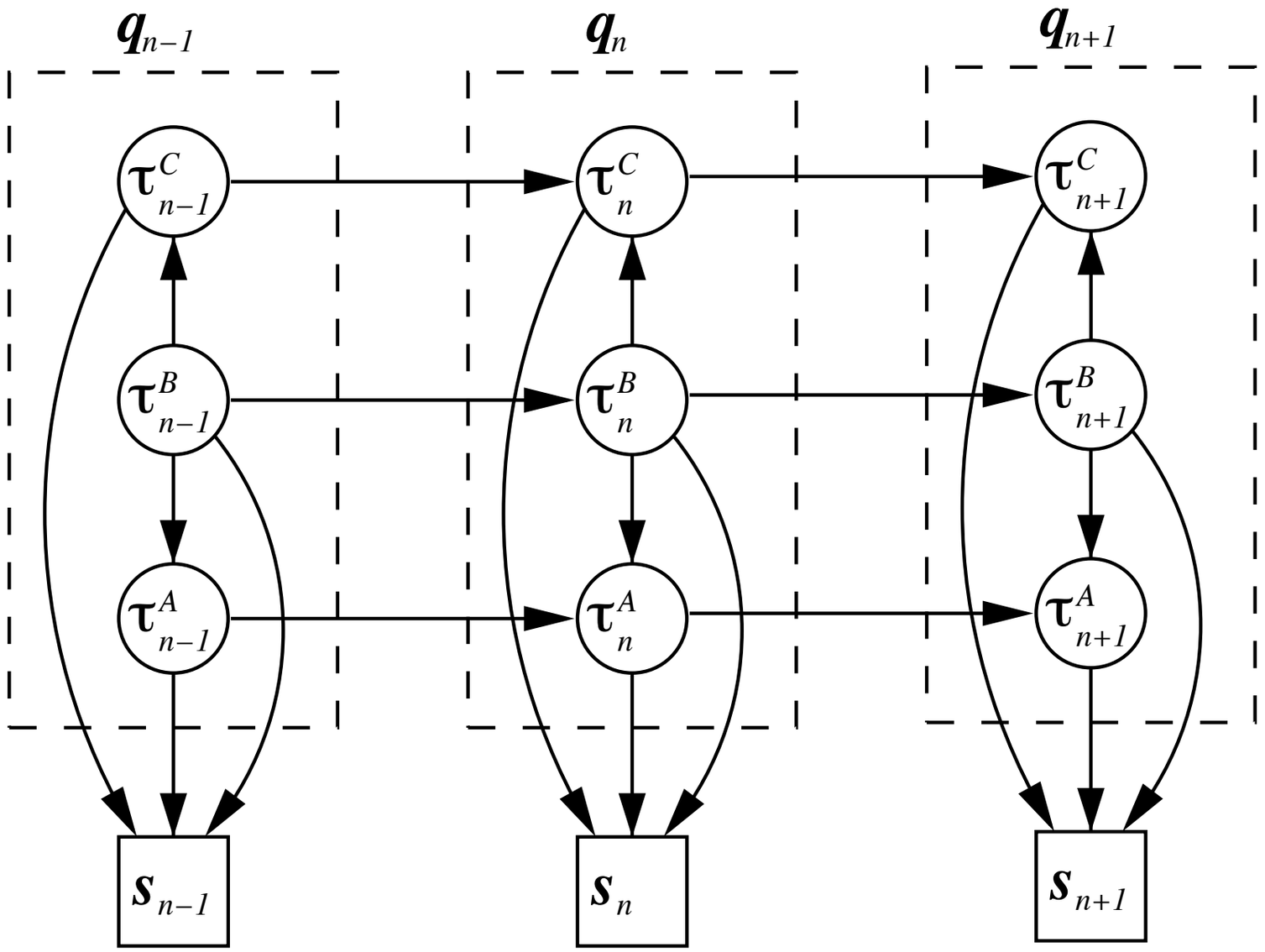


- *Tatum* = temporal atom, or tick
- *Tactus*: preferred, primary, metrical level: tempo, beat, «foot tapping»
- Measure/Bar: indicates time signature

Klapuri 2006

Metrical structure
Probabilistic state-space models

Hidden
(estimated)
metrical structure



C: measure

B: tactus

A: tatum

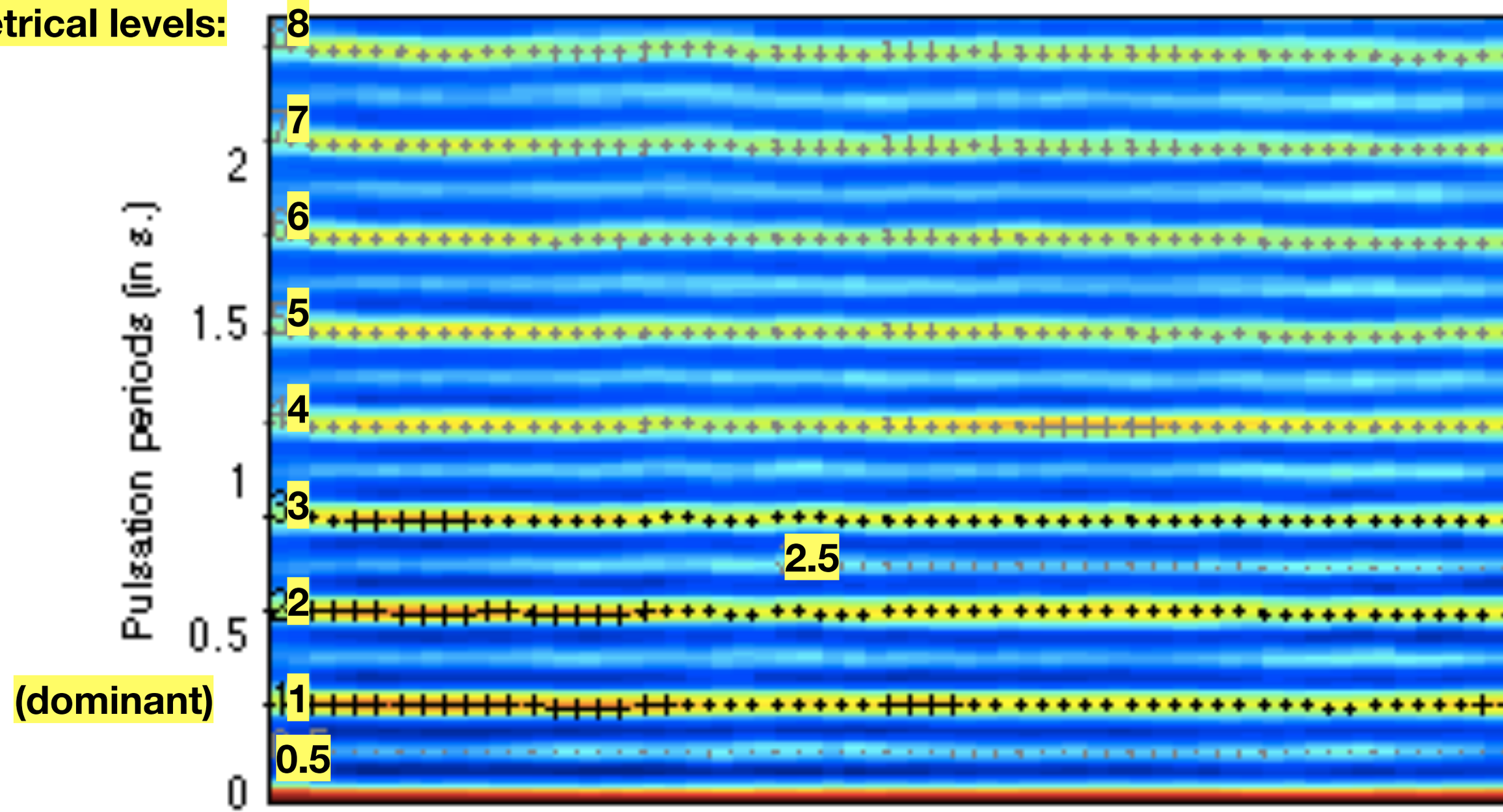
Observed
autocorrelation

- Modelling dependencies between successive instants, using Hidden Markov Model (HMM).

Klapuri 2006

Metrical structure

- Tracking all metrical levels (mirmetre, Lartillot)



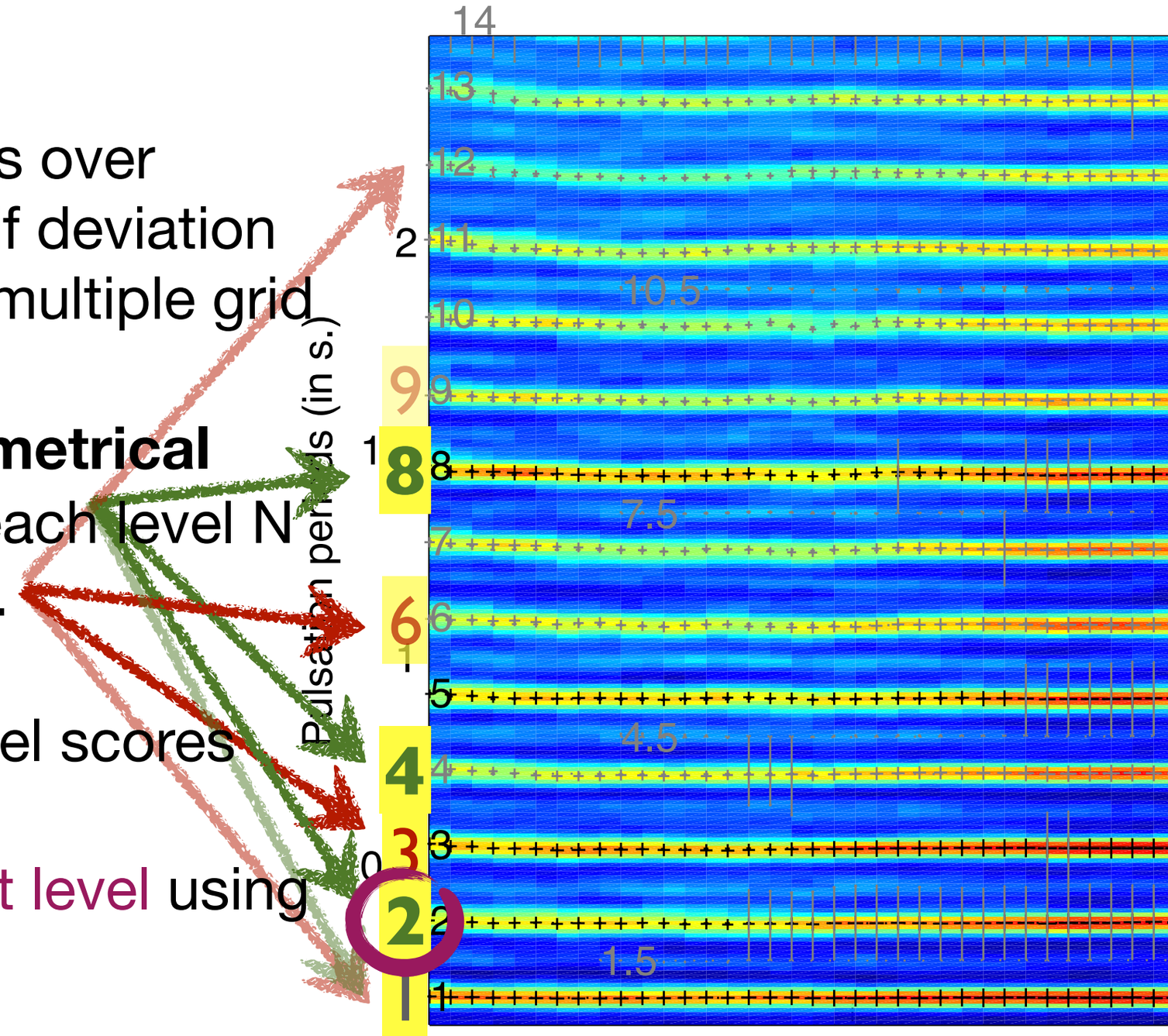
Tempo estimation

- Metrical level **score** = ∑ autocorrelation values over frames, plus a penalty if deviation of periodicity from the multiple grid

- Construct all possible **metrical hierarchies** (in which each level N is multiple of level N-1).

- Hierarchy score = ∑ level scores

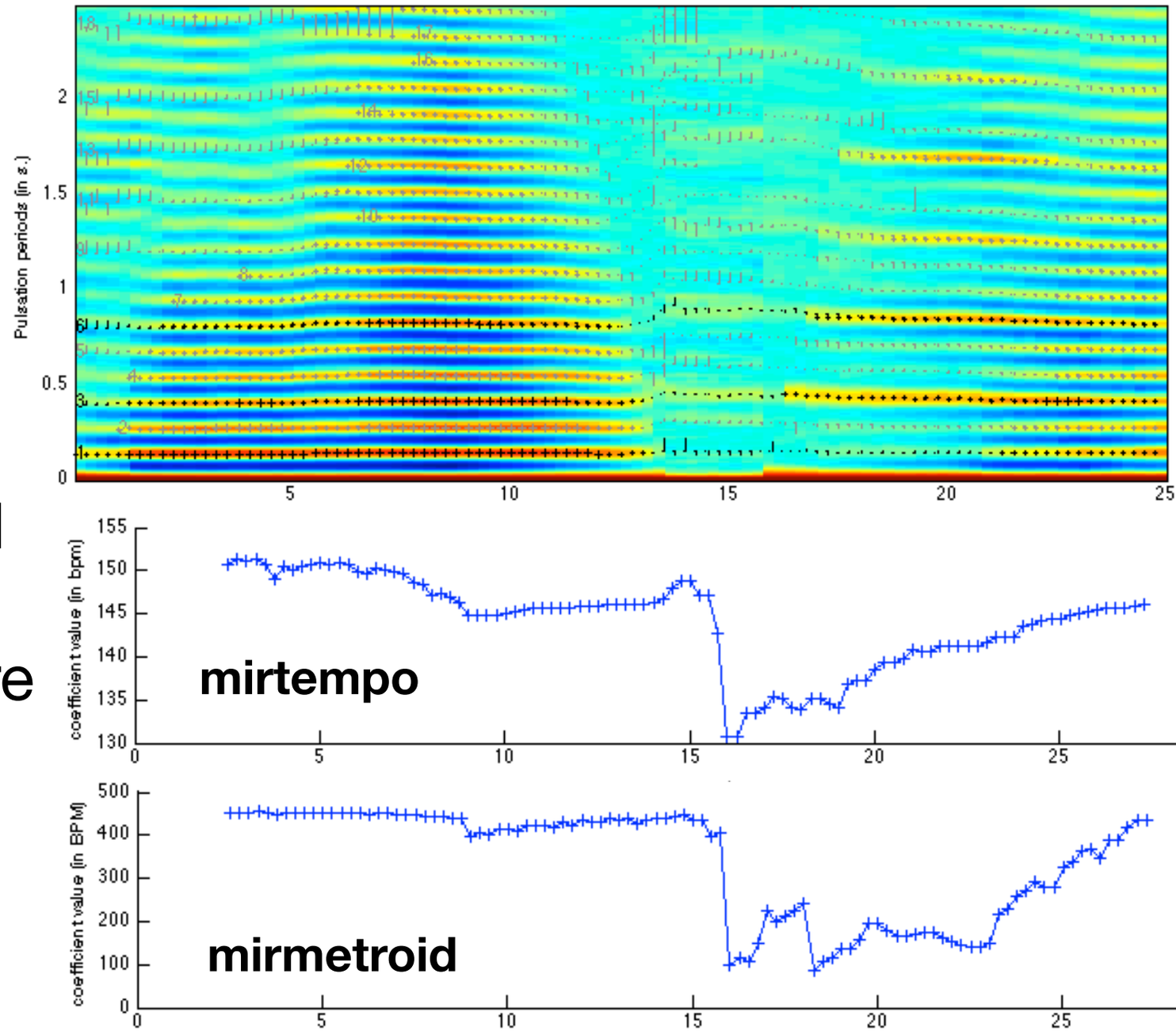
- In best hierarchy, select level using resonance curve.



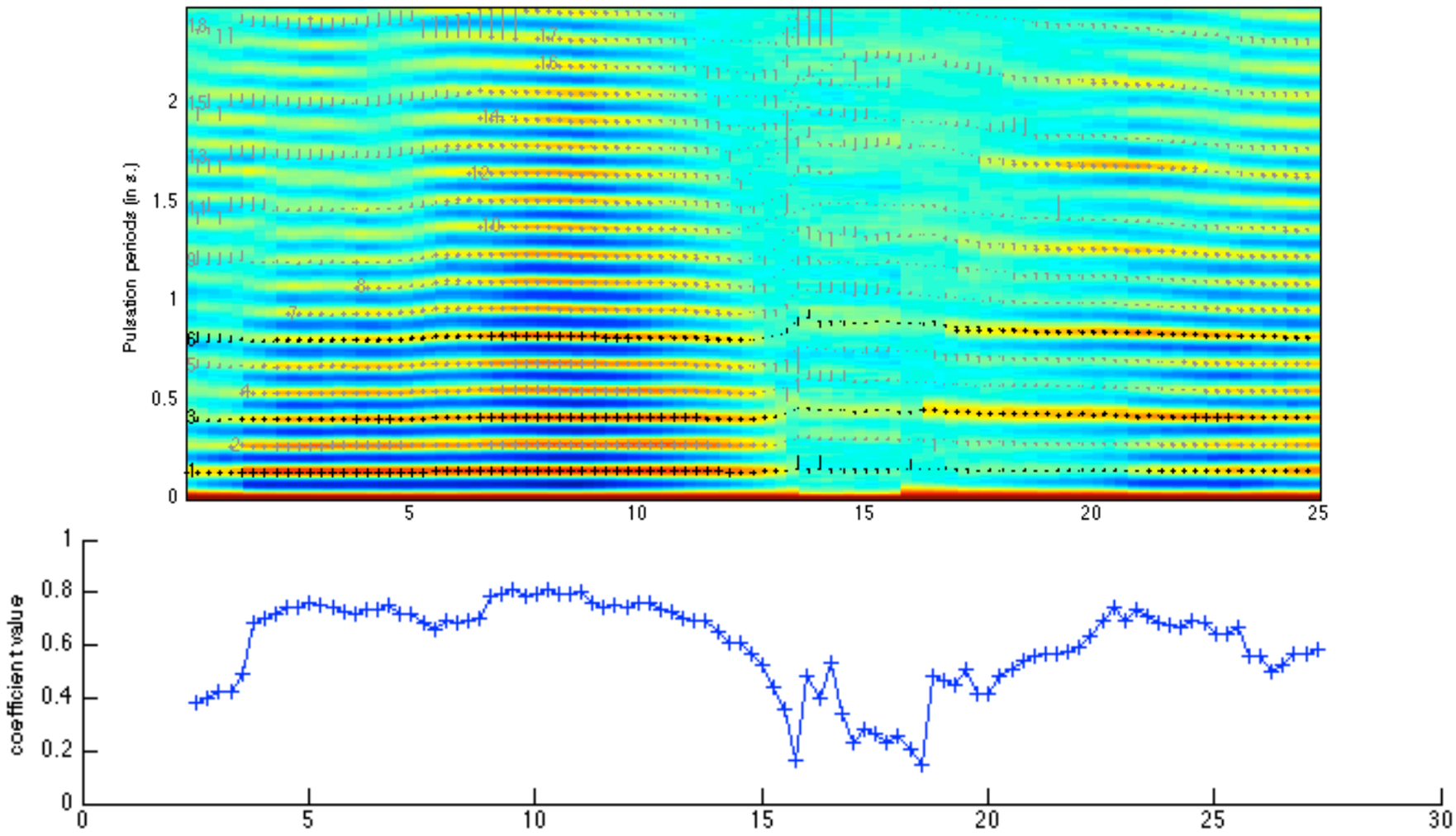
mirtempo('Metre'), Lartillot

Global metrical activity

- **Dynamic metrical centroid** (mirmetroid)
  - Centroid of periodicities of a selection of metrical levels (using their autocorrelation score as weights)
- Expressed in BPM



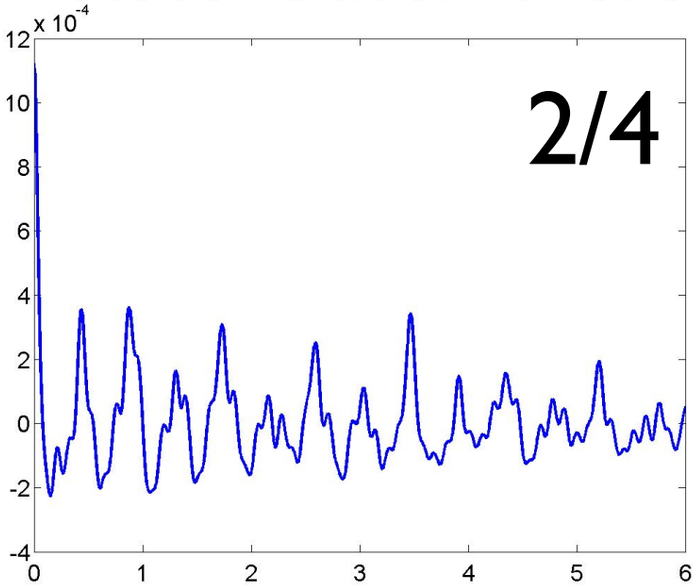
Metrical strength

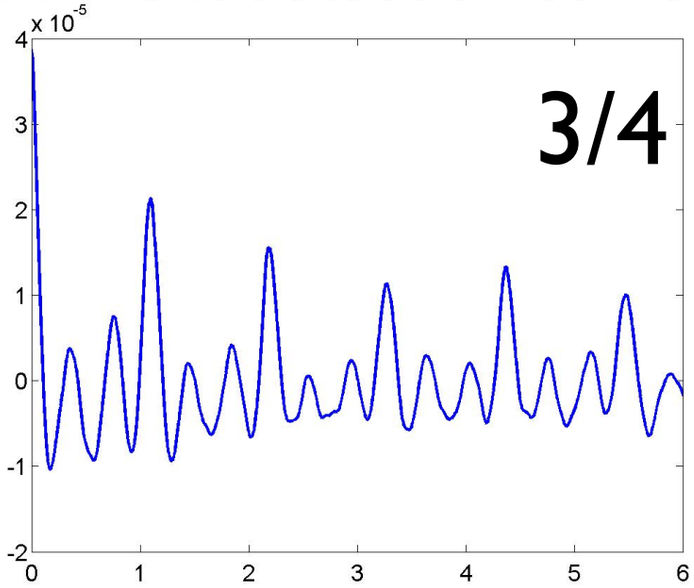


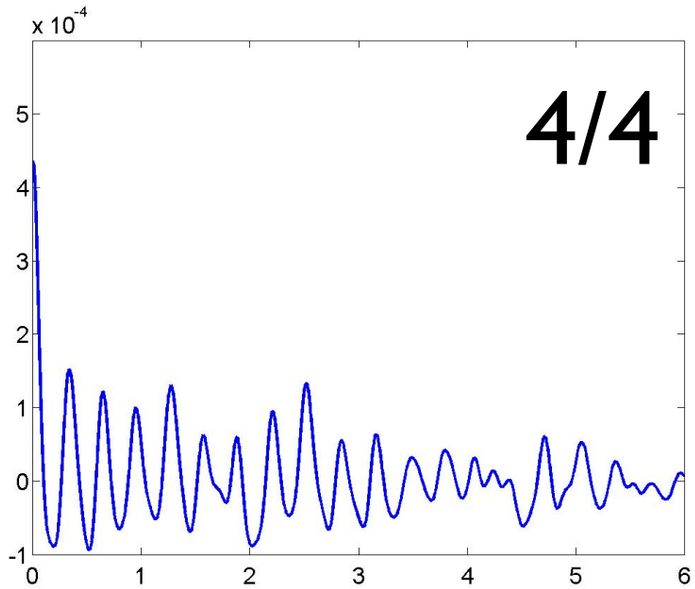
- Summation of autocorrelation scores of selected metrical levels.

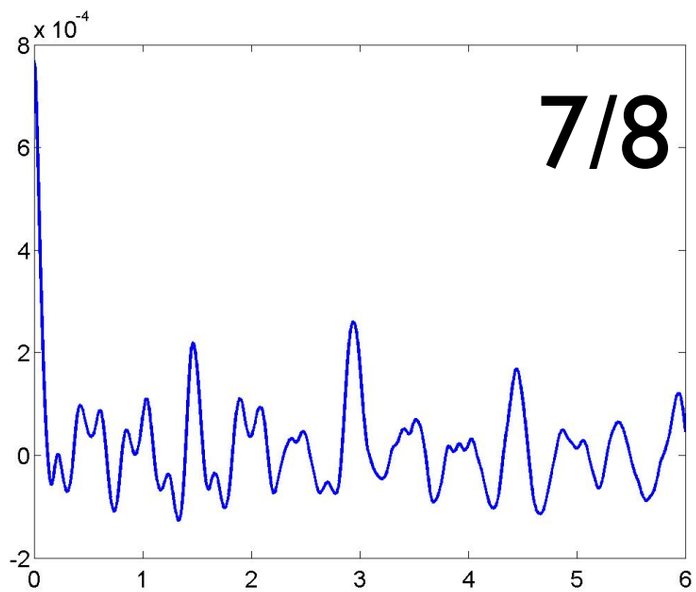
Meter identification

Autocorrelation function from event detection curves



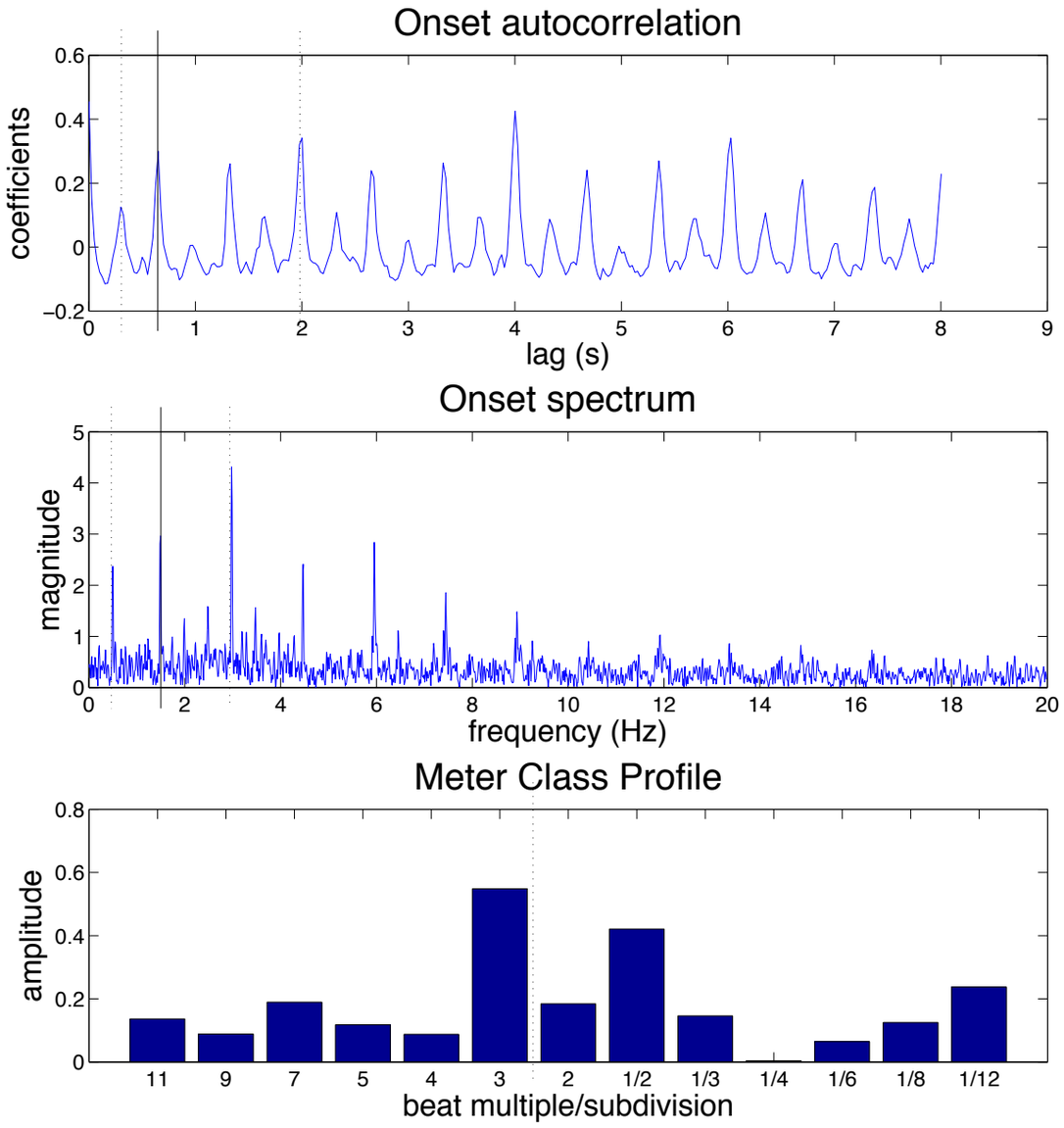


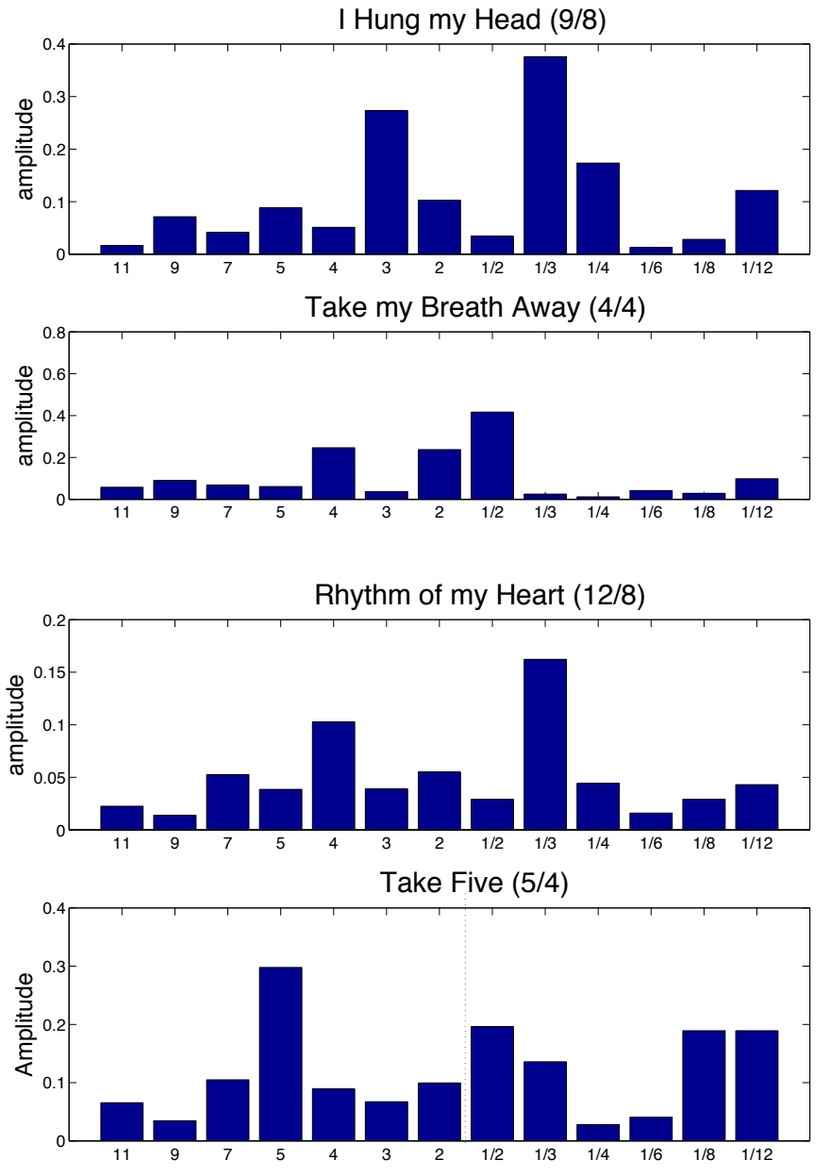




- Machine learning (linear discriminant function, Toiviainen & Eerola, 2006; SVM, Gouyon & Dixon, 2004)

Meter description

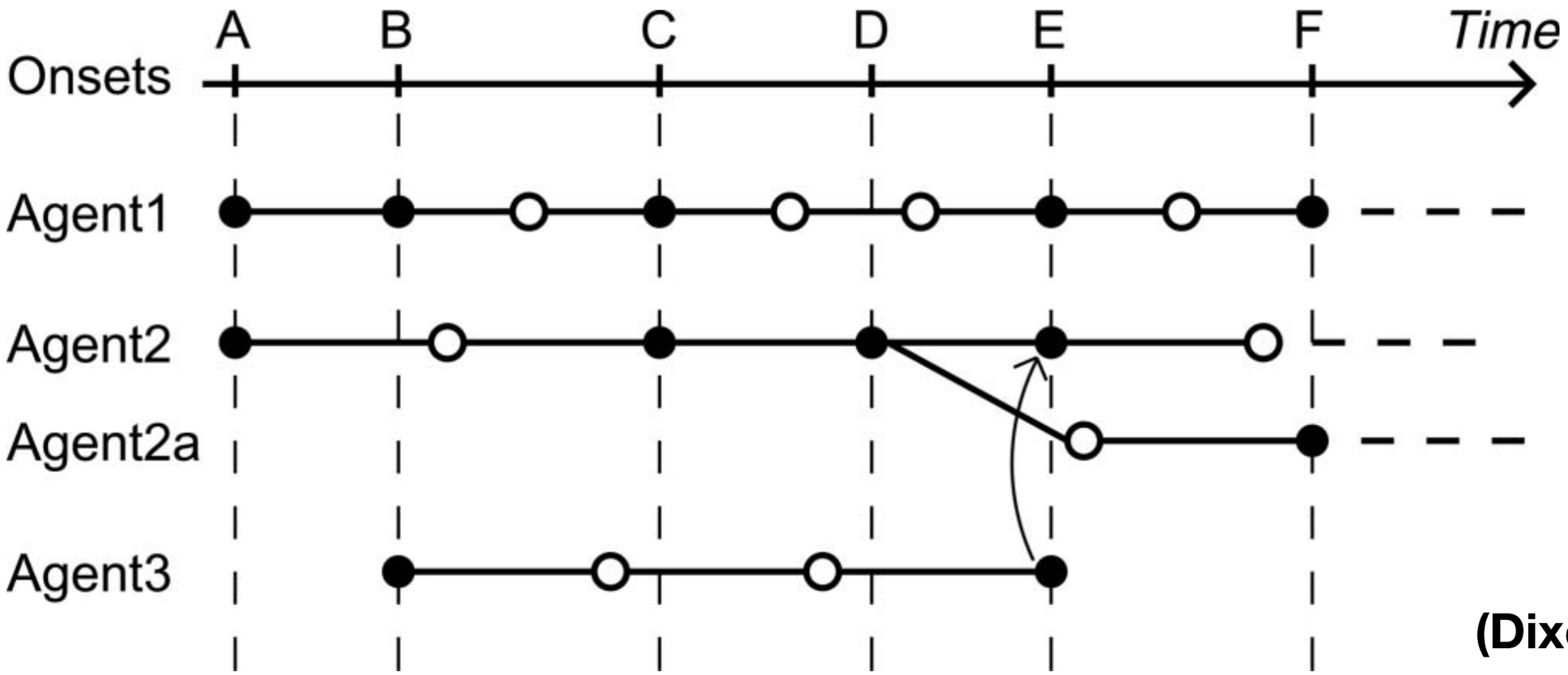




Meter Class Profile, Robine et al., 2009

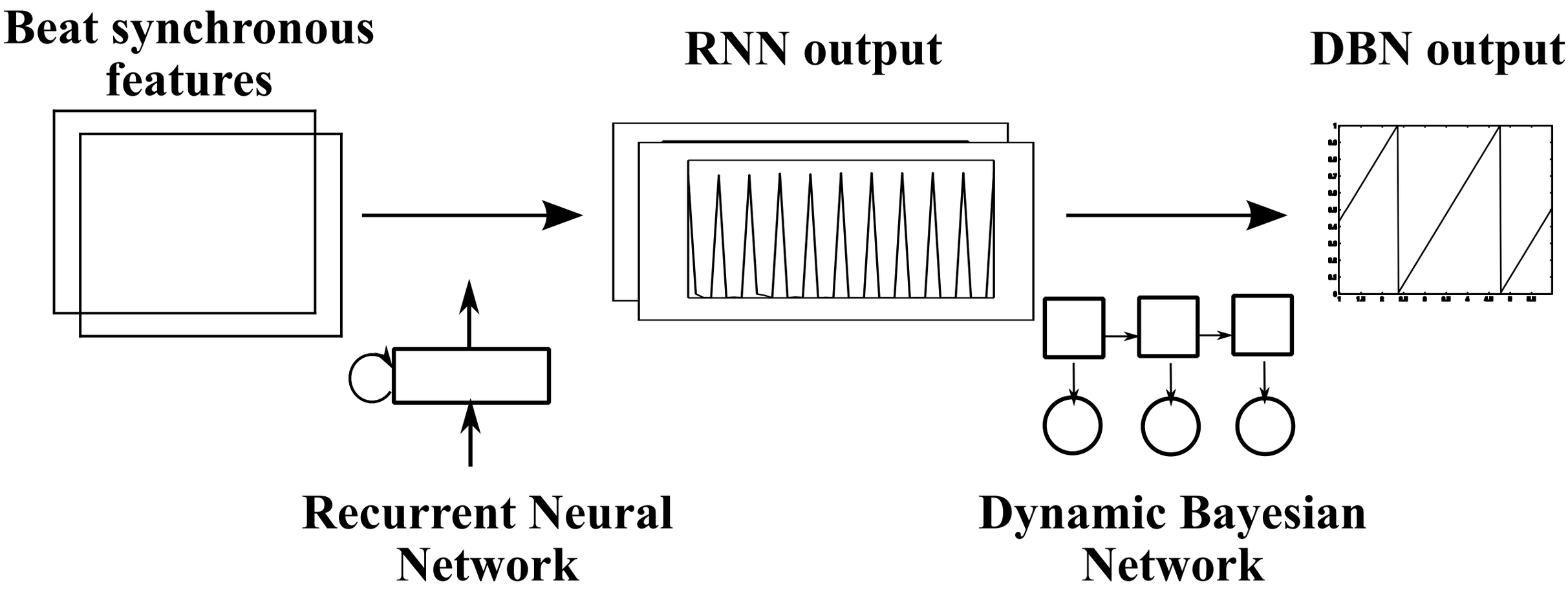
Beat tracking

- Finding the actual temporal position of beats
- Each agent locked on a particular tempo obtained from tempo estimation.



(Dixon, 2007)

Downbeat tracking



Krebs 2016

Audio/score alignment

Performance analysis

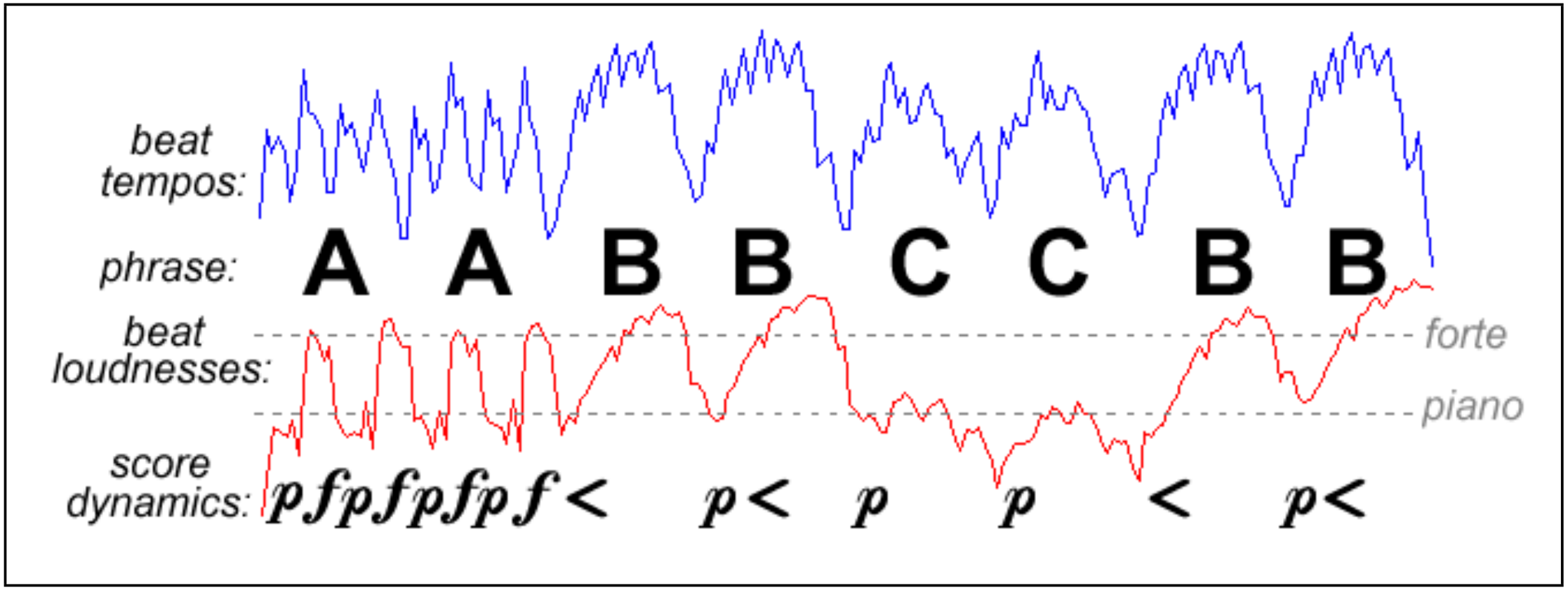


Figure 1. Average tempo and dynamic graphs for 35 performances of mazurka in B minor, 30/2.

Sapp 2007

Syncopation

- Longuet-Higgins 1982
- Koops 2015: Corpus-Based Rhythmic Pattern Analysis of Ragtime Syncopation
-

Rhythmic similarity

- Panteli 2014: Modeling rhythm similarity for EDM
  - Attack characterisation
  - Periodicity: Characterisation of autocorrelation function
  - Metrical distribution: Syncopation, symmetry, density, …

Rhythm analysis

- Rhythmical events: detection and characterisation (attack)
- Inferring rhythmical/metrical structure
  - Periodicity
  - Tracking metrical structure
    - Tempo estimation vs. Beat tracking, downbeat tracking
- Audio/score alignment
- Performance analyse: tempo variation
- Pulse clarity, syncopation, groove
- Rhythmic similarity
- **Asymmetric meter**
- **Complexity in genres (romantic rubato, jazz, EDM, …)**
- **Limitations of methods for particular types of music, importance of dance**

SAMA topics

- Periodicity detection in signals (spectrum, autocorrelation, etc.)
- Attacks (TIME project)?
- Parncutt’s paper suggested by Georgios
- Physical / cognitive, **auditory models** / corporeal / phenomenal/social entrainment
- motion/sound signal analysis (ex PQoM), motion template
- Spatialisation in rhythm/meter and more generally; sonic/movement environment
- Real-time, predictive models
- Neuroscience data jockeying

Don’t forget to register to the SAMA mailing list

Cf. SAMA page in RITMO website