Multimedia Systems

IV. Music Information Retrieval

4.3. Rhythm

António Sá Pinto

FEUP – 2019/2020

Agenda

- Musical context
- Novelty Detection
- Tempo induction
- Beat tracking, downbeat tracking
- Evaluation
- Rhythm
- Creative use of MIR and Rhythm

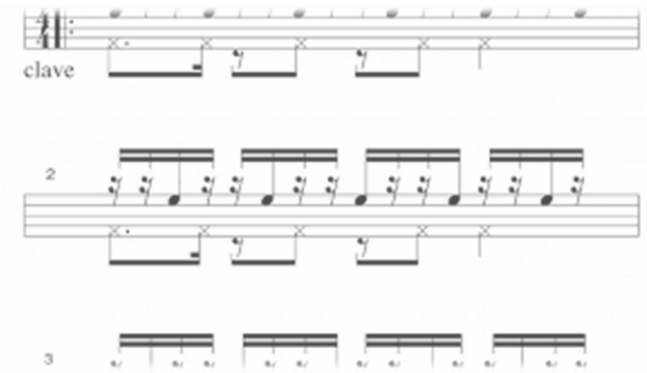
Musical context

Rhythm

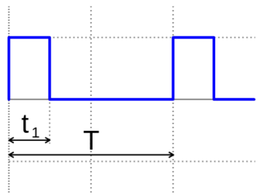
Tempo

Measure (Metre)

Beat (Pulse)



Musical context



Beat (Pulse)

Measure (Metre)

Tempo

Rhythm

- is one of a series of regularly recurring, precisely equivalent ["undifferentiated"] stimuli.
- consists of beats in a (repeating) of identical yet distinct periodic short-duration stimuli perceived as points in time occurring at the mensural level; (Wikipedia)
- is typically what listeners entrain* to as they tap their foot or dance along with a piece of music; (Handel, 1989)
- Like the tick of a metronome or a watch, pulses mark off equal units in the temporal continuum.
- *Beat is the “heartbeat” of music;*

Musical context

Beat (Pulse)

Measure (Metre)

Tempo

Rhythm

- is the measurement of the number of pulses between more or less regularly recurring accents.
- there can be no meter without an underlying pulse to establish the units of measurement.
- Marks the (high-level) periodicity of rhythm.
- is the reocurring pattern (measure/bar/metre) of strong/weak beats.

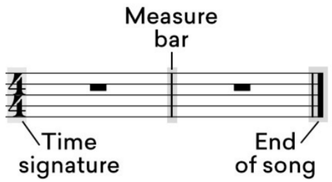
Musical context

Beat (Pulse)

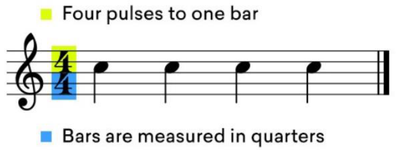
Measure (Metre)

Tempo

Rhythm

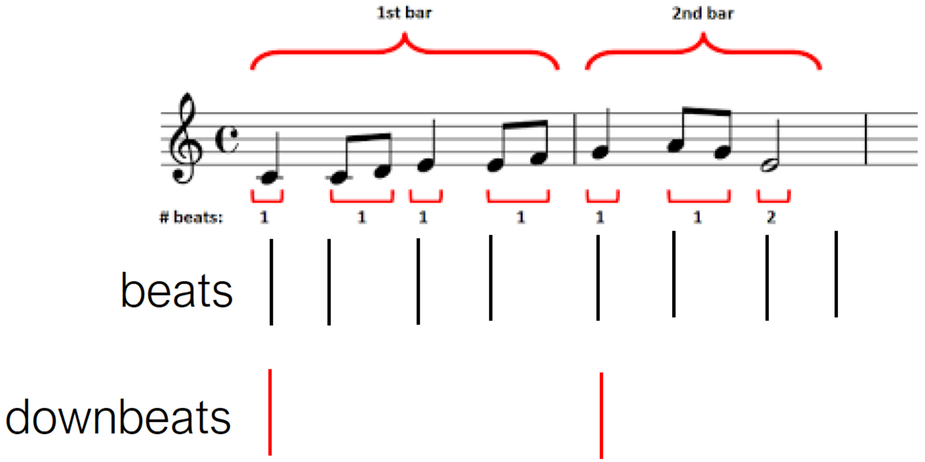


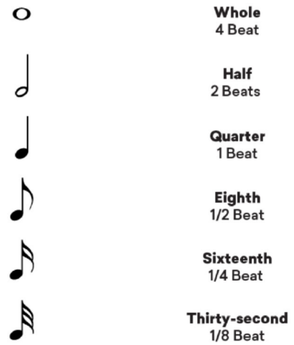
What does the time signature mean?



$\frac{3}{4}$ Three pulses to one bar
Bars are measured in fourths

$\frac{6}{8}$ Six pulses to one bar
Bars are measured in eighths





Musical context

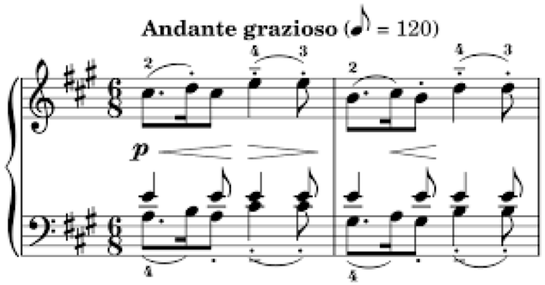
Beat (Pulse)

Measure (Metre)

Tempo

Rhythm

- the speed of the beat(pulse).
- The inverse of the beat period, usually measured in **b**eats **p**er **m**inute (bpm).



Larghissimo	**very, very slow**	**< 19 bpm**
Grave	**slow and solemn**	**20-40**
Lento	**slowly**	**40-45**
Largo	**broadly**	**45-50**
Larghetto	**rather broadly**	**50-55**
Adagio	**slow and stately**	**55-65**
adagietto	**rather slow**	**65-69**
Andante moderato	**a bit slower than andante**	**69-72**
Andante	**at walking pace**	**73-77**
Andantino	**slightly faster than andante**	**78-83**
Marcia moderato	**moderately, march**	**83-85**
Moderato	**moderately**	**86-97**
Allegretto	**moderately quick**	**98-109**
Allegro	**fast, quick and bright**	**109-132**
Vivace	**lively and fast**	**132-140**
Vivacissimo	**very fast and lively**	**140-150**
Presto	**very fast**	**168-177**
Prestissimo	**extremely fast**	**>178**

Musical context

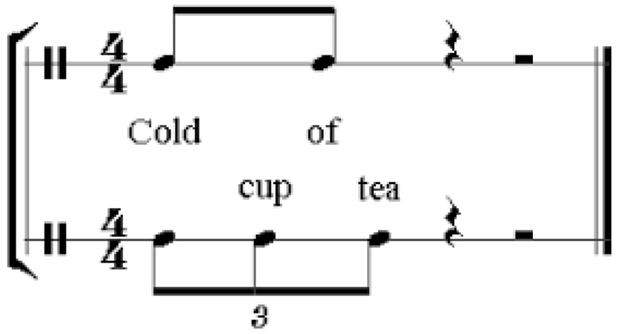
Beat (Pulse)

Measure (Metre)

Tempo

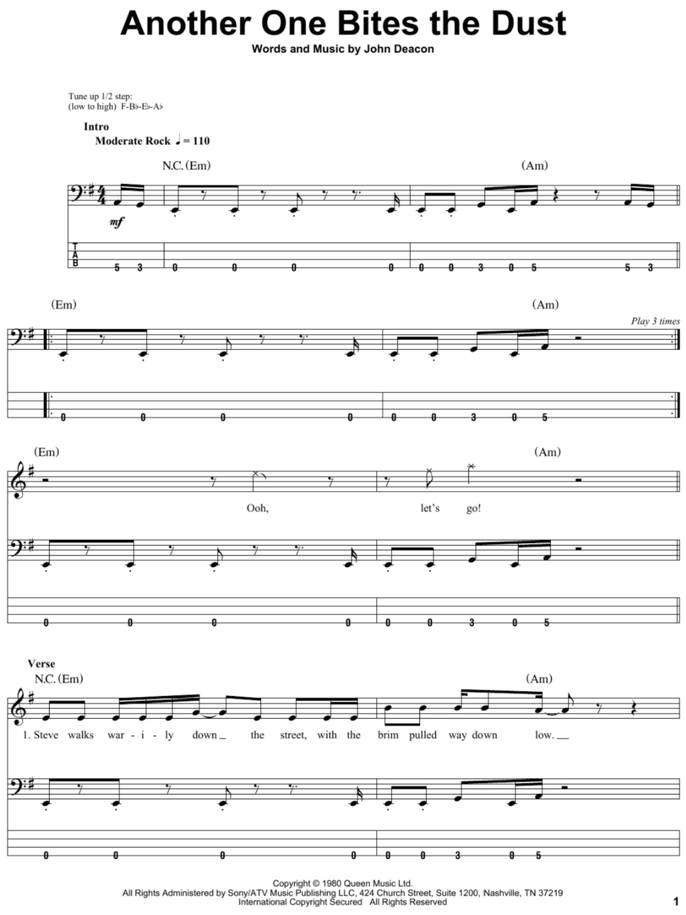
Rhythm

- is the pattern of regular or irregular pulses caused in music by the occurrence of strong and weak beats.
- Is the patterns of long and short sounds and silences in music over the steady background of the beat.



Musical context

- Beat (Pulse)
- Measure (Metre)
- Tempo
- Rhythm
- **Examples**



Another One Bites the Dust

Words and Music by John Deacon

Tune up 1/2 step:
(low to high) F-B♭-E♭-A♭

Intro
Moderate Rock ♩ = 110

N.C. (Em) (Am)

mf

(Em) (Am)

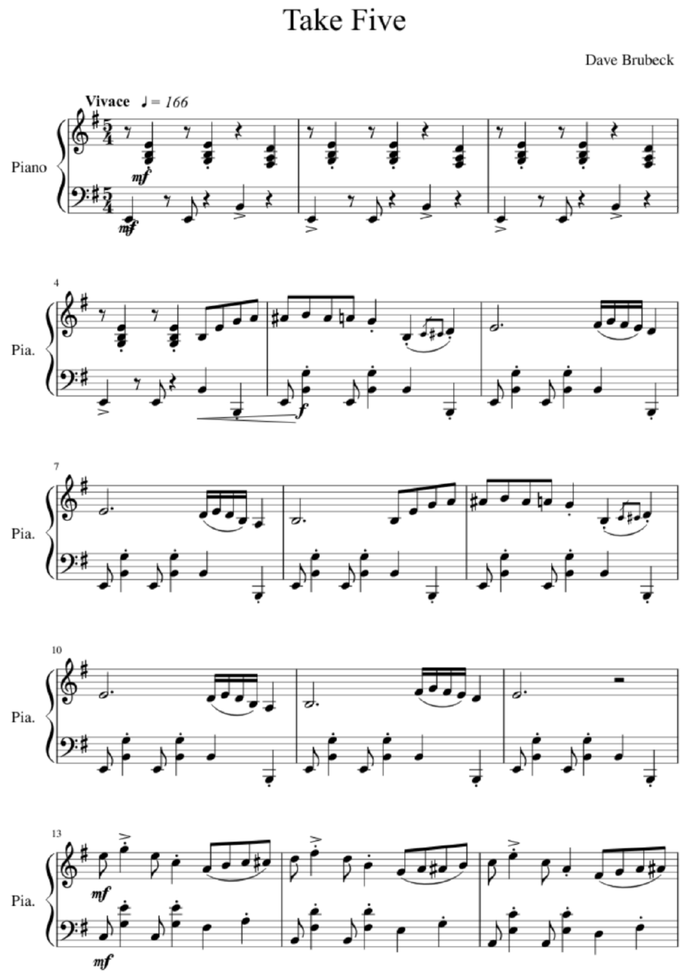
Play 3 times

(Em) (Am)

Ooh, let's go!

Verse
N.C. (Em) (Am)

1. Steve walks war - i - ly down the street, with the brim pulled way down low.



Take Five

Dave Brubeck

Vivace ♩ = 166

Piano

mf

4

Pia.

7

Pia.

10

Pia.

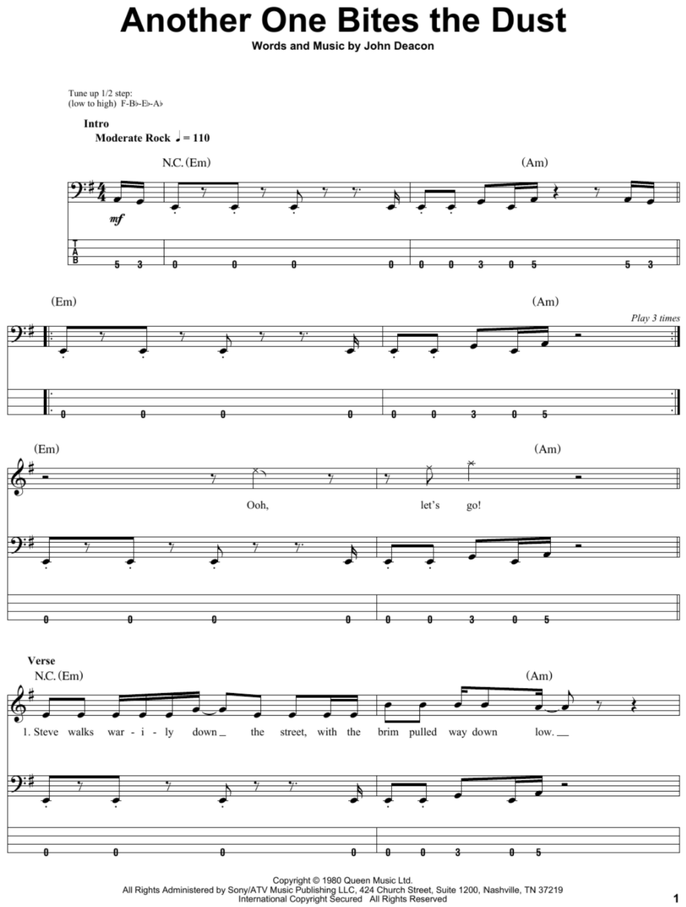
13

Pia.

mf

Musical context

- Beat (Pulse)
- Measure (Metre)
- Tempo
- Rhythm
- Examples



Another One Bites the Dust

Words and Music by John Deacon

Tune up 1/2 step:
(low to high) F-B♭-E♭-A♭

Intro

Moderate Rock ♩ = 110

N.C. (Em) (Am)

mf

(Em) (Am)

Play 3 times

(Em) (Am)

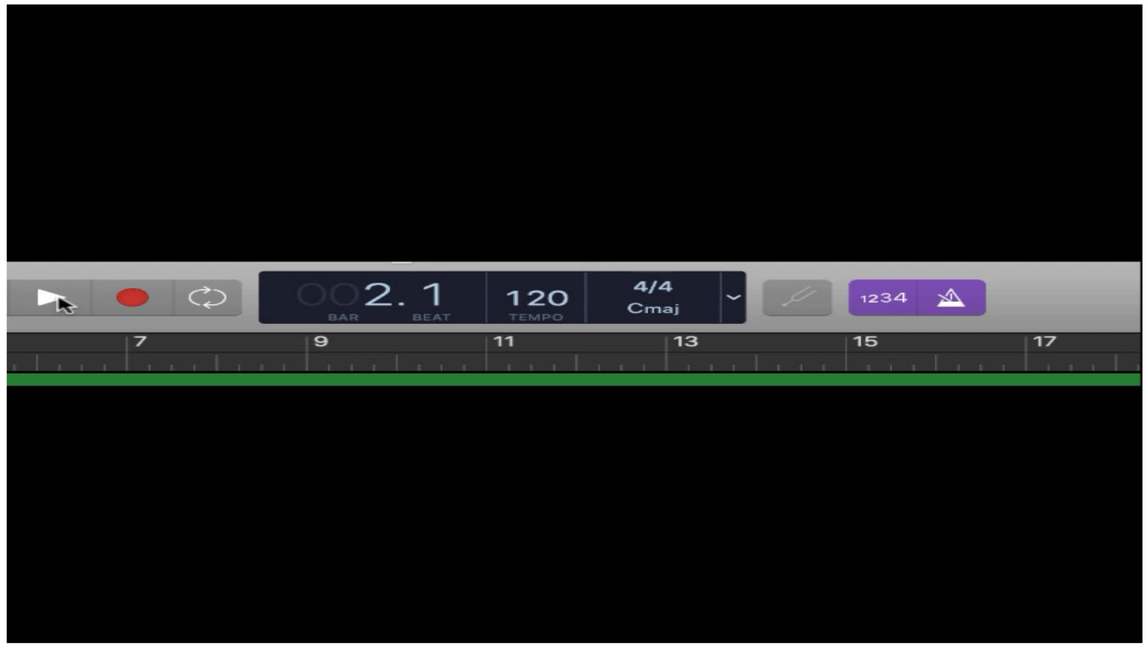
Ooh, let's go!

Verse

N.C. (Em) (Am)

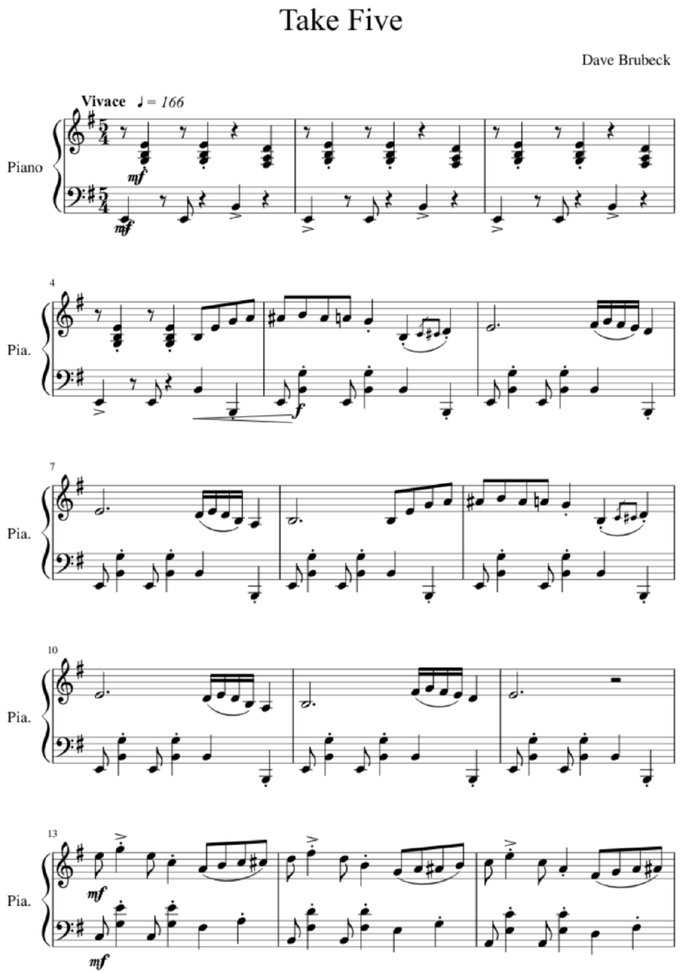
1. Steve walks war - i - ly down the street, with the brim pulled way down low.

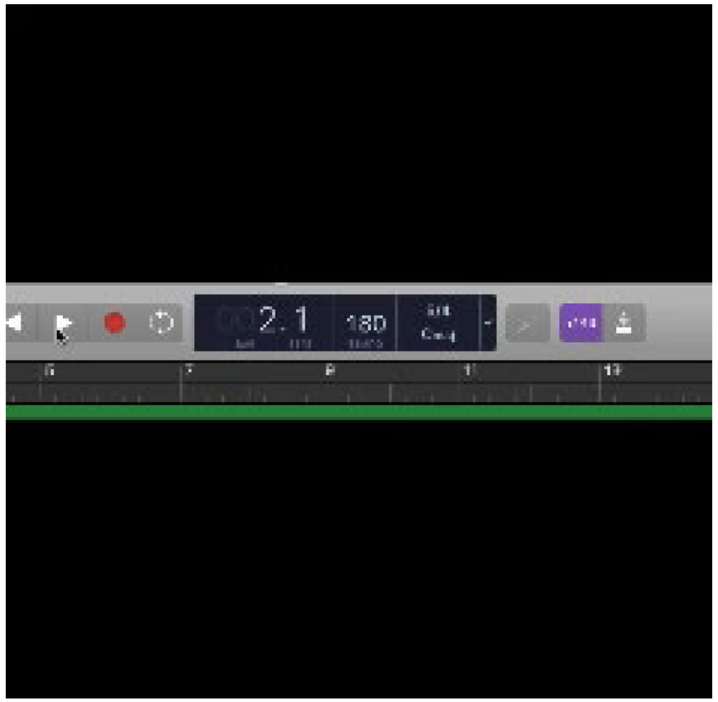
1



Musical context

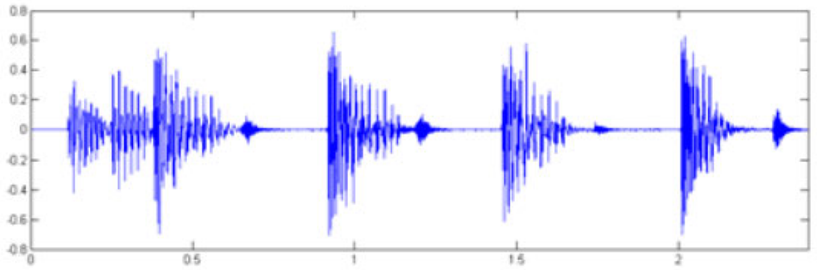
- Beat (Pulse)
- Measure (Metre)
- Tempo
- Rhythm
- Examples





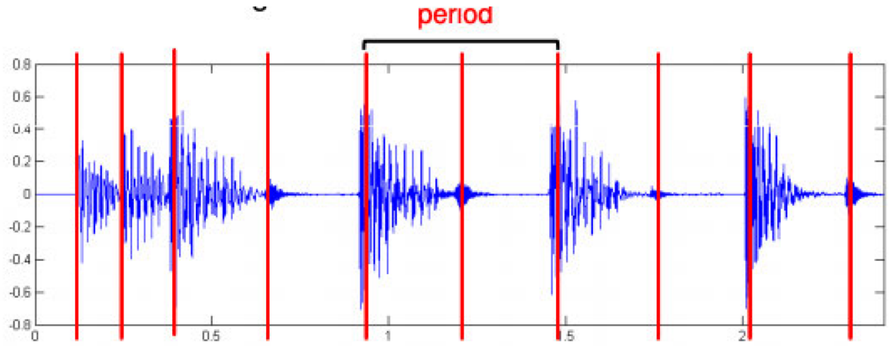
Introduction

- **Tempo** and **beat** are fundamental properties of music
- The **beat** provides the temporal framework of music (musical meaningful time axis)
  - *a second is not relevant in musical time, a beat is*

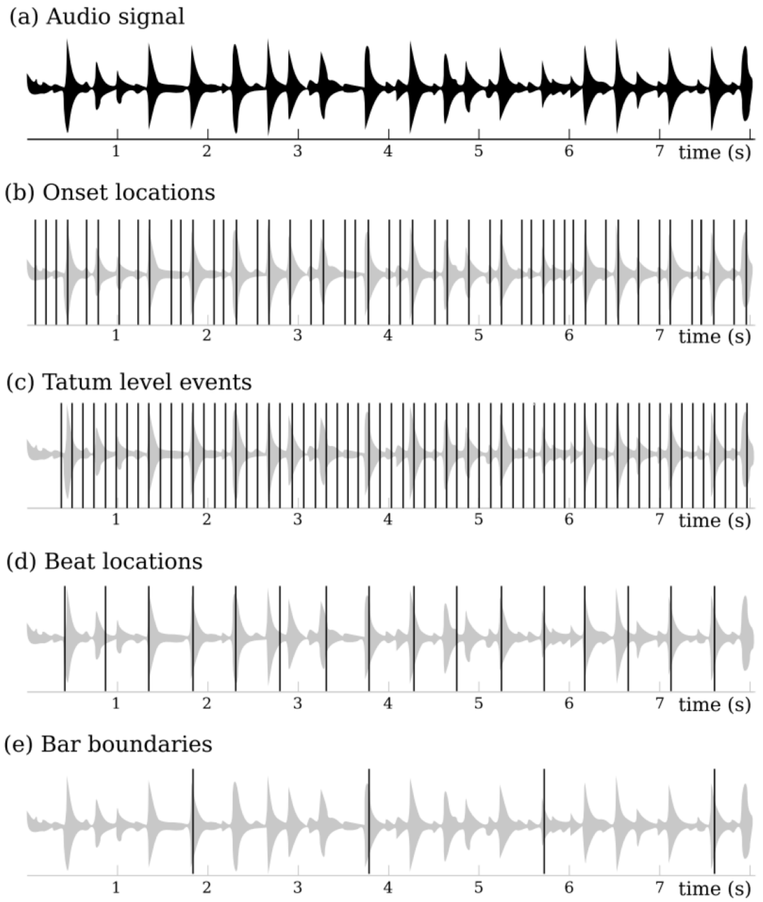


Motivation

- **Find periodicities!**
- As opposed to finding pitch:
  - Detail level (not on signal directly, but more high level)

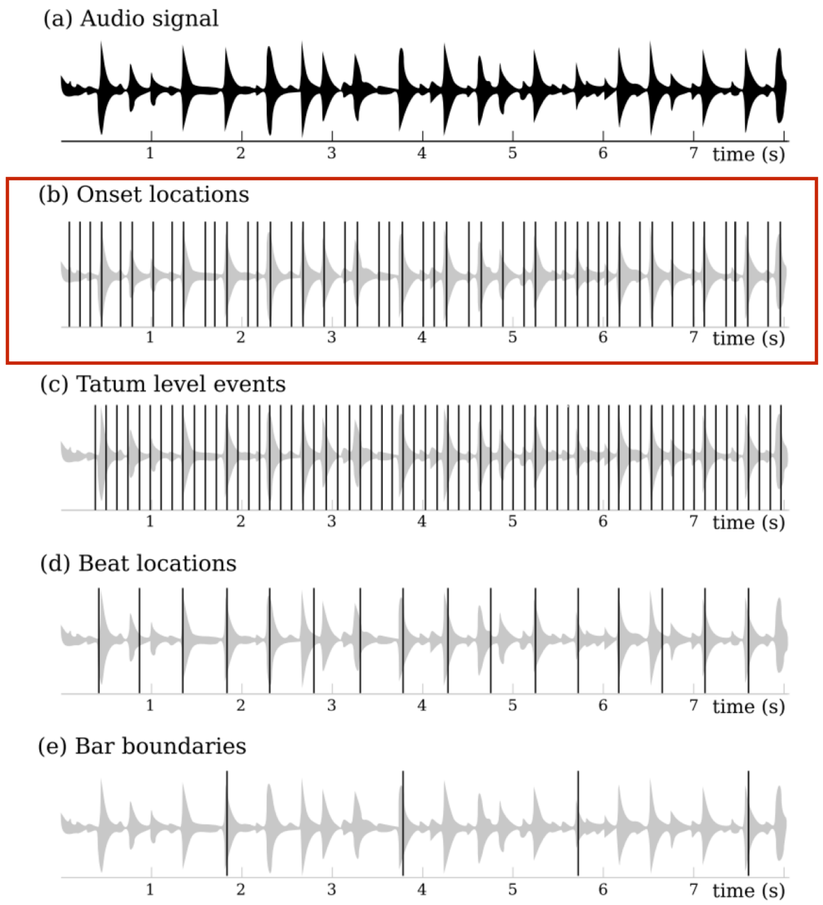


Motivation



- onsets - start times of note events
- *tatum* - fastest level
- beat - comfortable tapping level *(tactus)*
- downbeats - grouping beats into bars (*measure)*

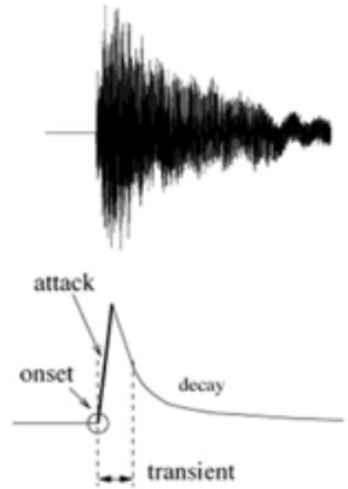
Motivation



- **onsets** - start times of note events
- tatum - fastest level
- beat - comfortable tapping level
- downbeats - grouping beats into bars

Onsets

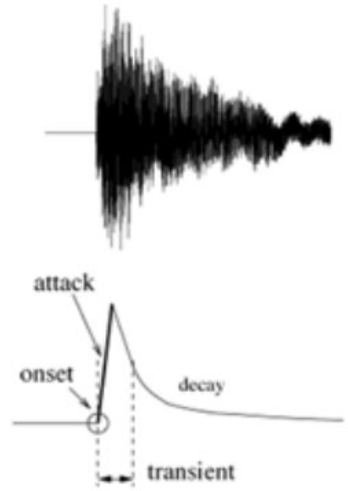
- Finding start times of perceptually relevant acoustic events in music signal;
- Onset is the time position where a note is played
- Onset typically goes along with a change of the signal's properties:
  - Energy / loudness
  - Pitch or Harmony



[Bello et al., IEEE-TASLP 2005]

Onsets

- **Novelty**
- Lot’s of different novelty functions
- Energy-Based
- Spectral-Based



[Bello et al., IEEE-TASLP 2005]

Onsets

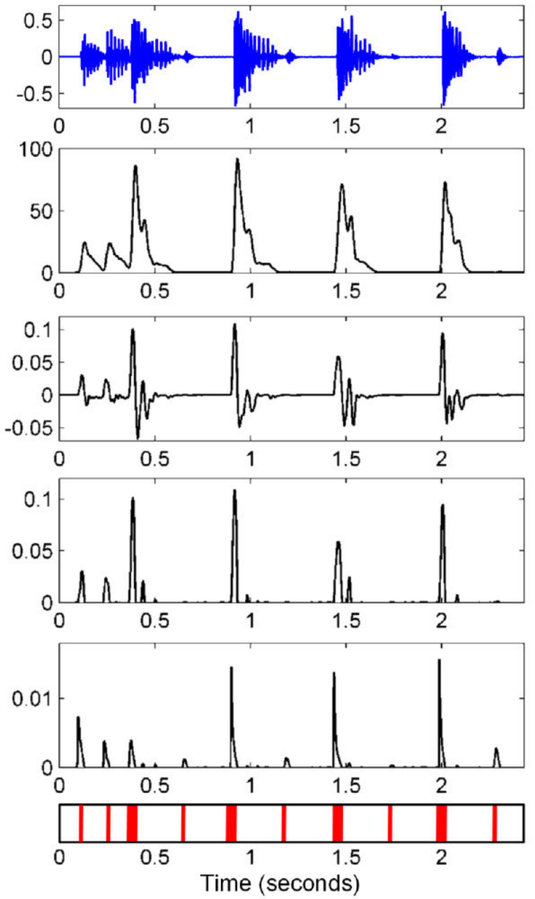
- Novelty
- Lot's of different novelty functions
- Energy-Based
- Spectral-Based

Log-energy-based novelty function:

$$\Delta^{\text{Log}}_{\text{Energy}}(n) = |E^x_h(n+1) - E^x_h(n)|_{\geq 0}$$

Steps

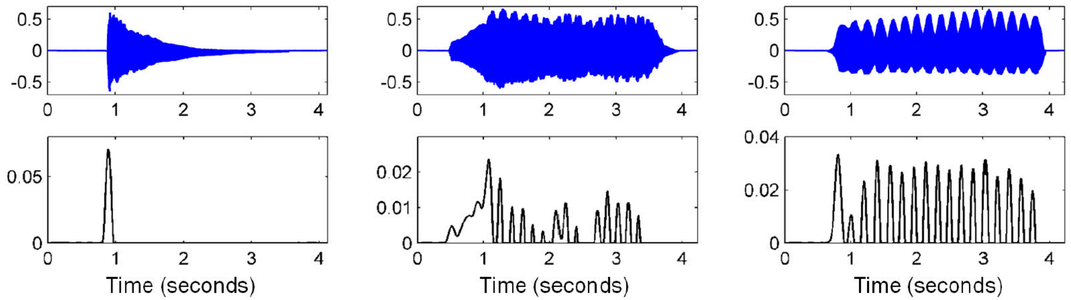
1. Amplitude squaring
2. Windowing
3. Differentiation
4. Half wave rectification
5. Peak picking



Onsets

- Novelty
- Lot’s of different novelty functions
- Energy-Based
- Spectral-Based

- Waveform and energy-based novelty function of the note C4 (261.6 Hz) played by different instruments – piano (left), violin (middle) and flute (right)



From: M. Mueller, *Fundamentals of Music Processing*, Chapter 6, Springer 2015

Onsets

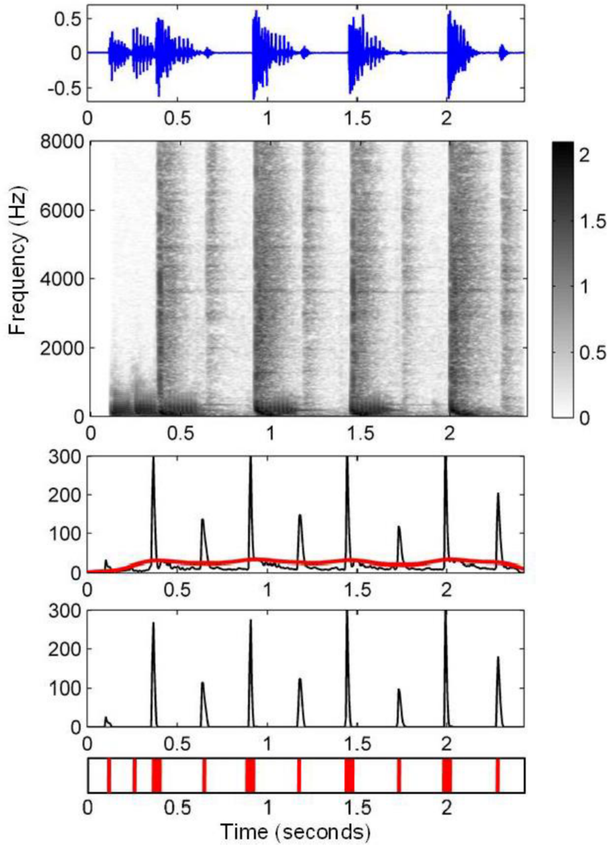
- Novelty
- Lot’s of different novelty functions
- Energy-Based
- Spectral-Based

Spectral flux

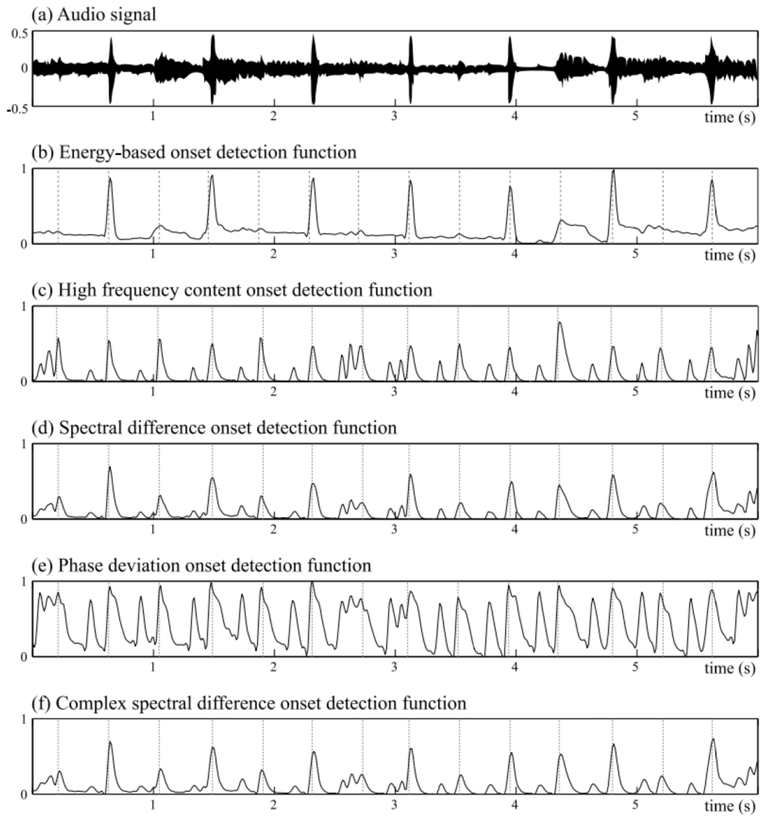
$$\Delta_{\text{Spectral}}(n) := \sum_{k=0}^{K} \left| Y_\gamma(n+1,k) - Y_\gamma(n,k) \right|_{\geq 0}$$

Steps:

1. Spectrogram
2. Logarithmic compressio
3. Differentiation
4. Accumulation
5. Normalization
6. Peak picking

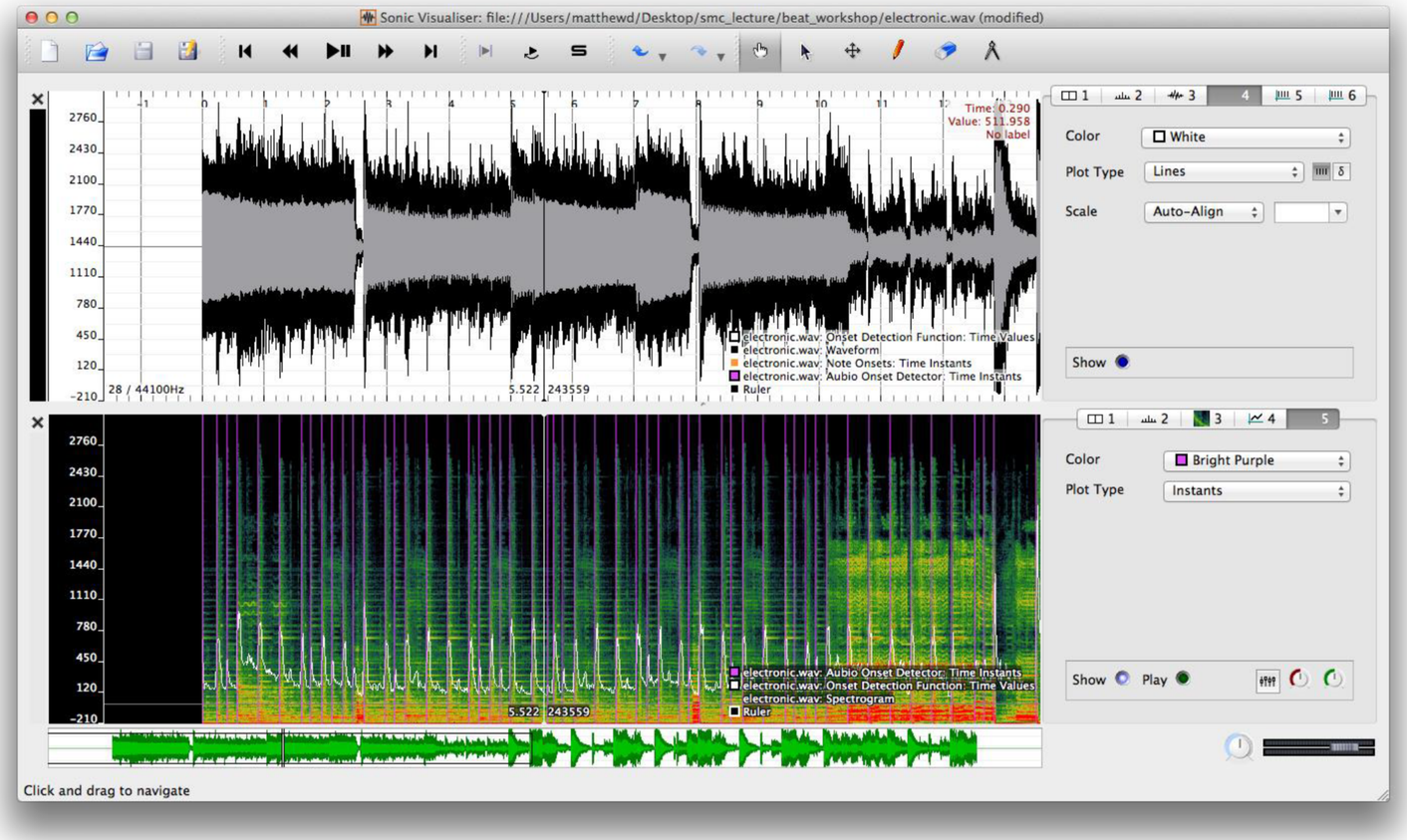


Many different onset detection functions



- There are lots of different onset detection functions
- e.g. using: energy, phase, spectral difference, emphasis on high frequencies
- and more complex approaches to finding onsets: e.g. neural networks, rhythmic information

Onset Example



Onset detection articles

Classical approaches:

J. P. Bello, L. Daudet, S. Abdallah, C. Duxbury, M. Davies, and M. Sandler. "A tutorial on onset detection in music signals" IEEE TSAP, 13(5):1035–1047, Sept. 2005

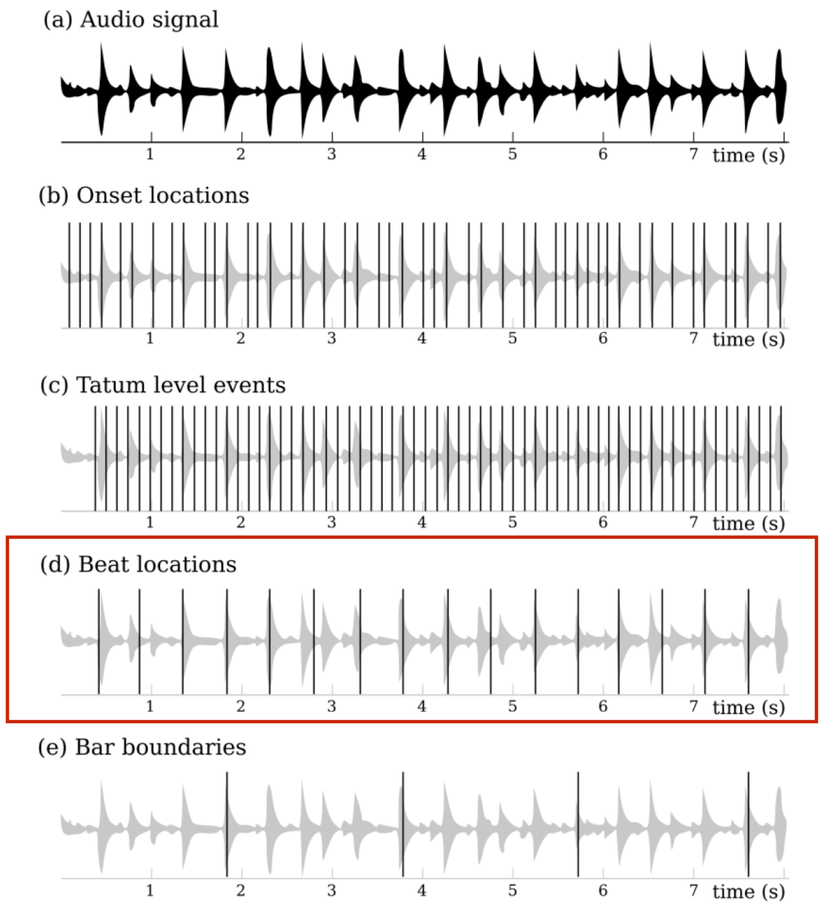
S. Dixon. "Onset detection revisited" In Proc. of DAFx-06, pp 133–137, 2006

Beyond "peak-picking":

F Eyben, S Böck, B Schuller, A Graves. "Universal Onset Detection with Bidirectional Long Short-Term Memory Neural Networks". In Proc. of ISMIR, pp. 589-594, 2010

N. Degara, M. E. P. Davies, A. Pena and M. D. Plumbley, "Onset Event Decoding Exploiting the Rhythmic Structure of Polyphonic Music" IEEE JSTSP, 5(6), pp. 1228-1239, 2011

Musical overview



- onsets - start times of note events
- tatum - fastest level
- **beats** - comfortable tapping level
- downbeats - grouping beats into bars

What is beat tracking?

Beat tracking is the computational task of getting a computer to “**tap its foot**” in time to music

The aim is to reflect the innate human ability to induce and follow a pulse in music

We often to do this without thinking - it's easy, right?

How do we make the computer “**feel the beat**”?

How is beat tracking used?

What are the main applications of beat trackers?

In many music information retrieval (MIR) research tasks: chord detection, structural segmentation, finding cover-songs, music transcription - **analysis in musical time**

And in creative/performance applications: beat-synchronous audio effects, automatic accompaniment, automatic remixing, mashups - **synchronisation is very important**

How is beat tracking done?

In **lots** of ways!

There are probably over 100 “different” beat tracking algorithms out there

Using: comb filters, autocorrelation, neural networks, psychoacoustic models, dynamic programming, particle filters, bayesian models, etc, etc.

Basic approach

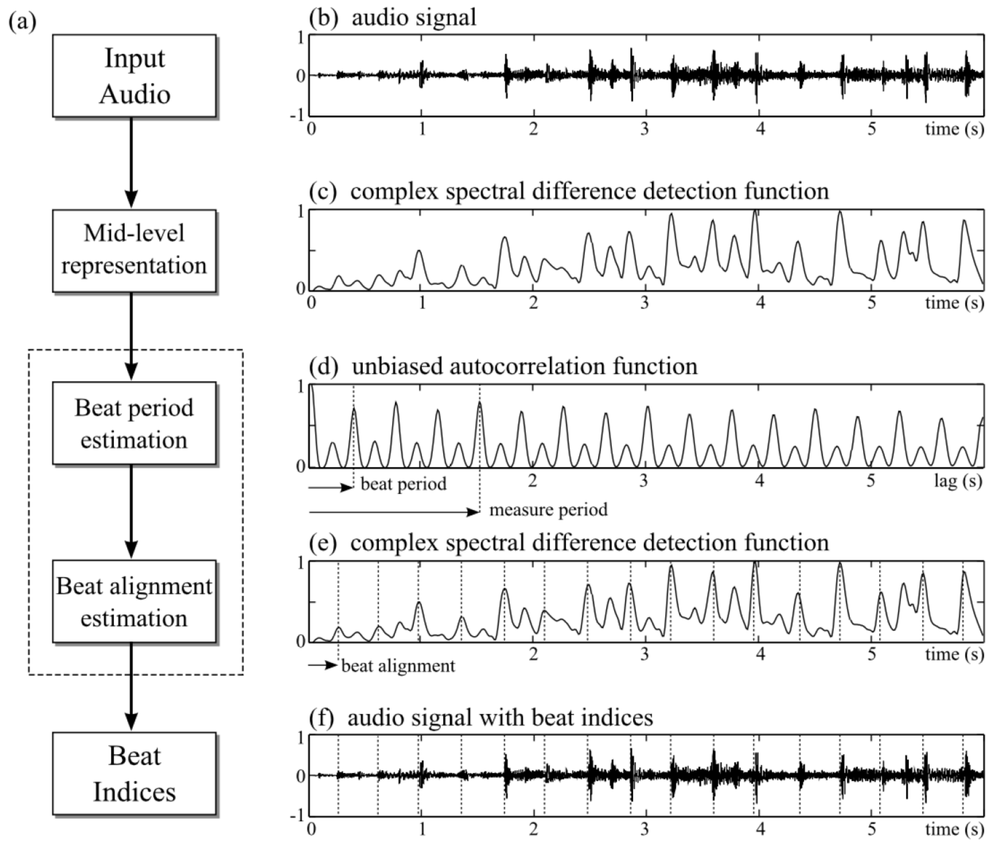
Calculate an **onset detection function**

emphasises locations of start times of events

Estimate **tempo** by some periodicity analysis

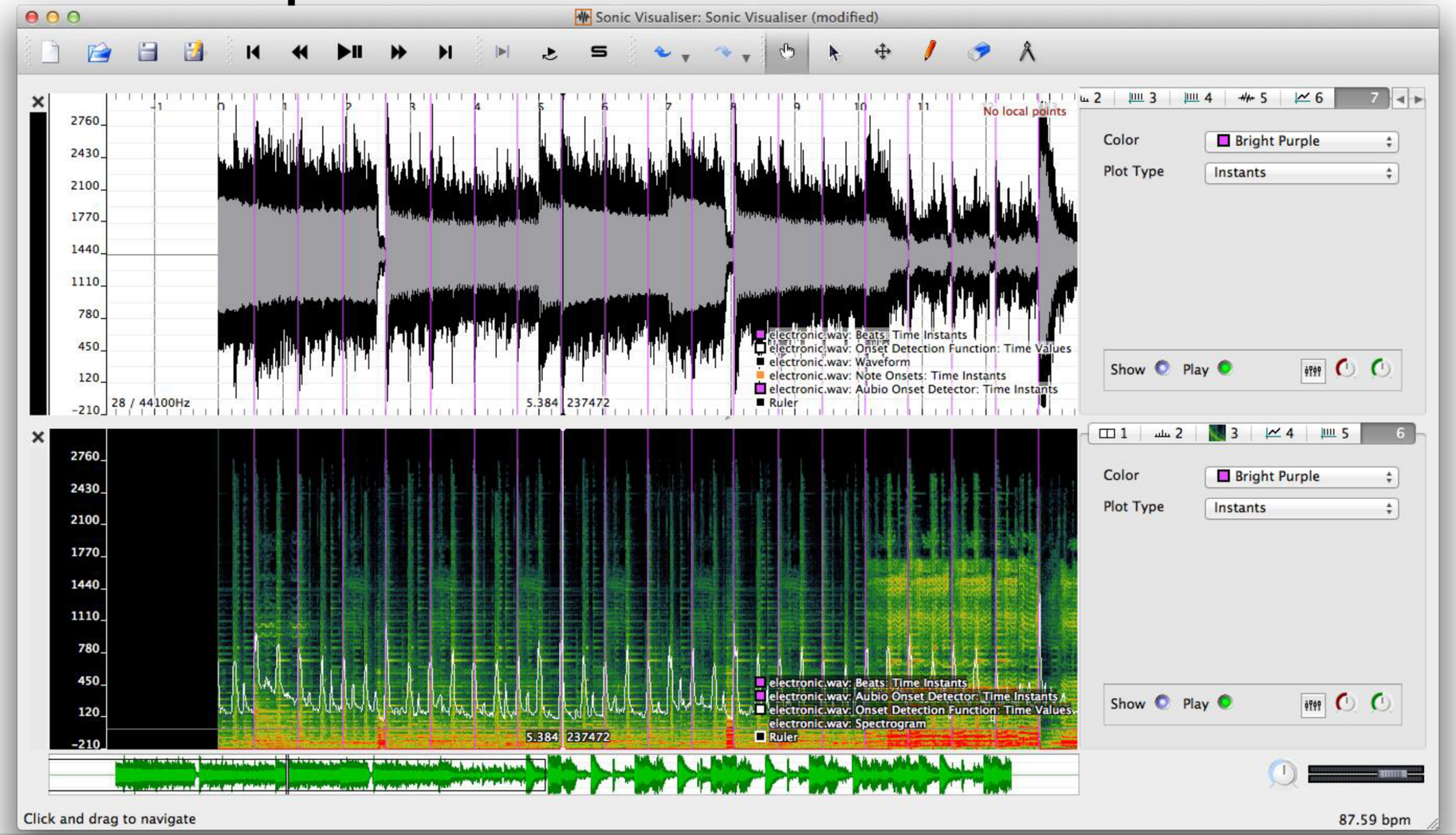
Determine the **phase** of the beats given the periodicity

Basic approach: beat tracking

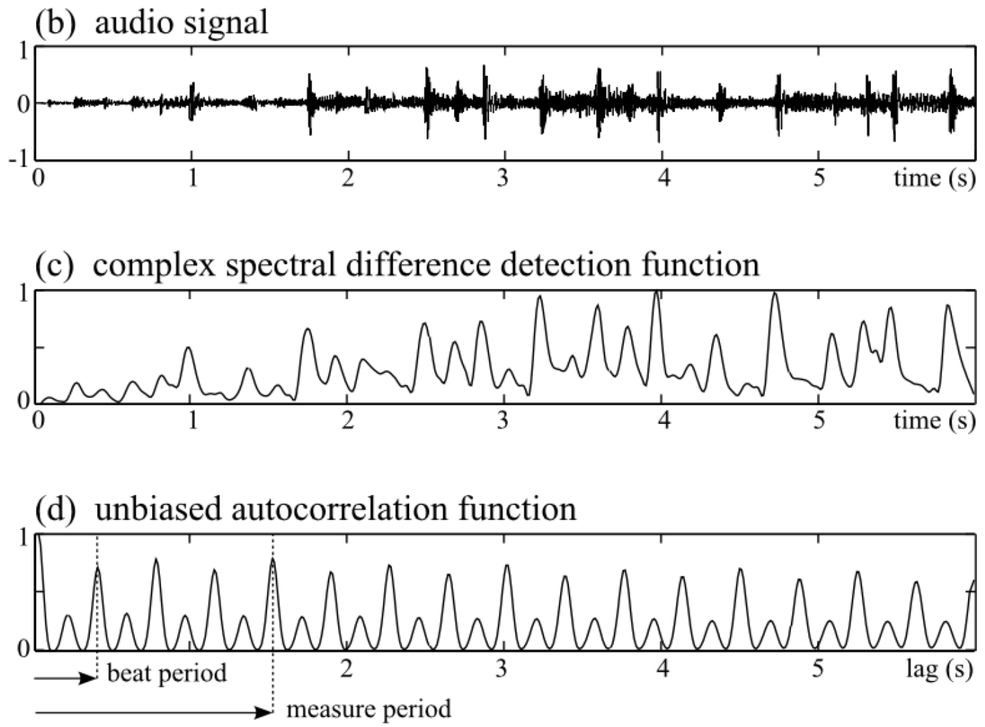


- Transform audio to onset detection function (ODF)
- Look for strongest beat periodicity
- Find periodic peaks in ODF
- Playback beats with audio

Beat Example

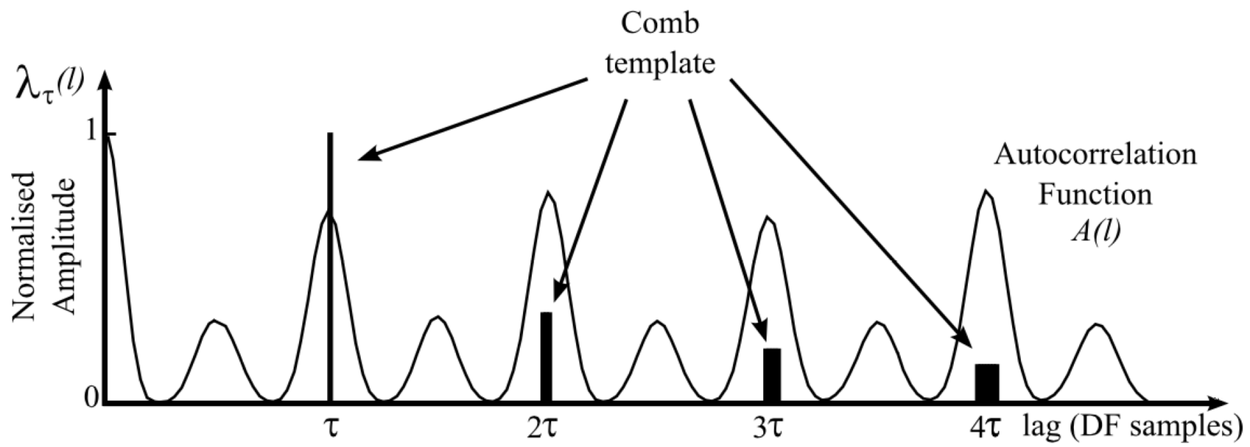


Autocorrelation function (ACF)



- Compare the ODF to a shifted version of itself… for lots of shifts to make the ACF

Finding the beat period



- Which peak in the autocorrelation function is the most likely to represent the beat period in the music?
- The “tempo octave error” is an important problem
- Beat trackers aren’t good at distinguishing between “fast” and “slow” **but** they can confidently say it’s either 70 bpm or 140 bpm

How do we evaluate beat trackers?

Subjectively

By listening back to the beats mixed with the original music signal

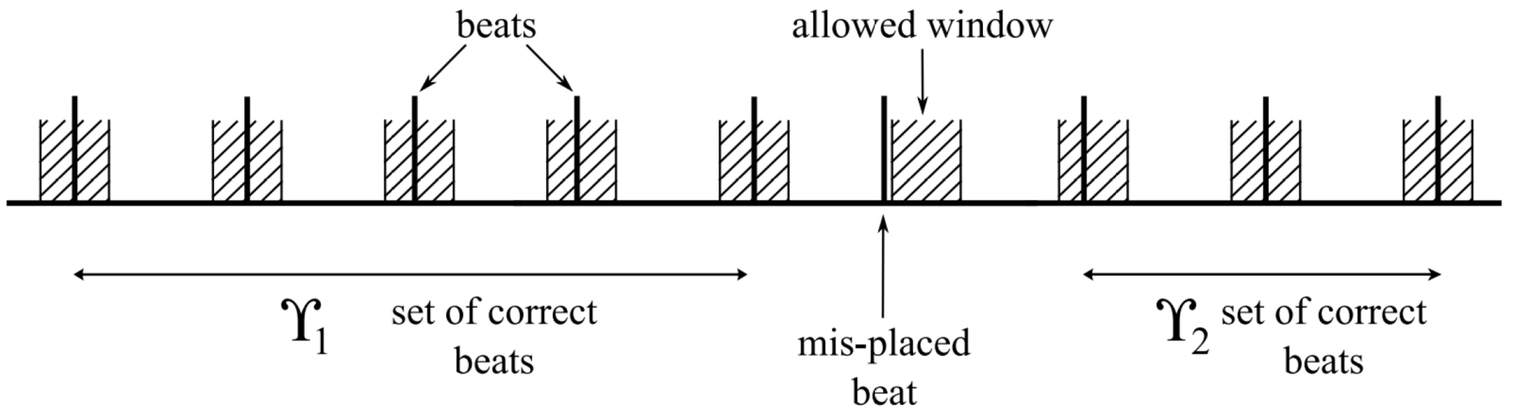
what's good? what's bad?

Objectively

By marking up “ground truth” and comparing to beat estimates

what's good? what's bad?

Objective evaluation



make **tolerance windows** around **ground truth**

count number of correct beats (w/ continuity)

allow different metrical interpretations (e.g. double/half tempo)

Objective evaluation

Beat tracking evaluation scores *(from madmom)*

fmeasure

F-measure.

pscore

P-score.

cemgil

Cemgil accuracy.

goto

Goto accuracy.

information_gain

Information gain.

error_histogram

Error histogram.

global_information_gain

Global information gain.

cmlc

CMLc.

cmlt

CMLt.

amlc

AMLc.

amlt

AMLt.

How good are beat trackers?

Tap Example 1

Tap Example 2

Tap Example 3

How good are beat trackers?

The state of the art is very good for “**easy**” types of music:

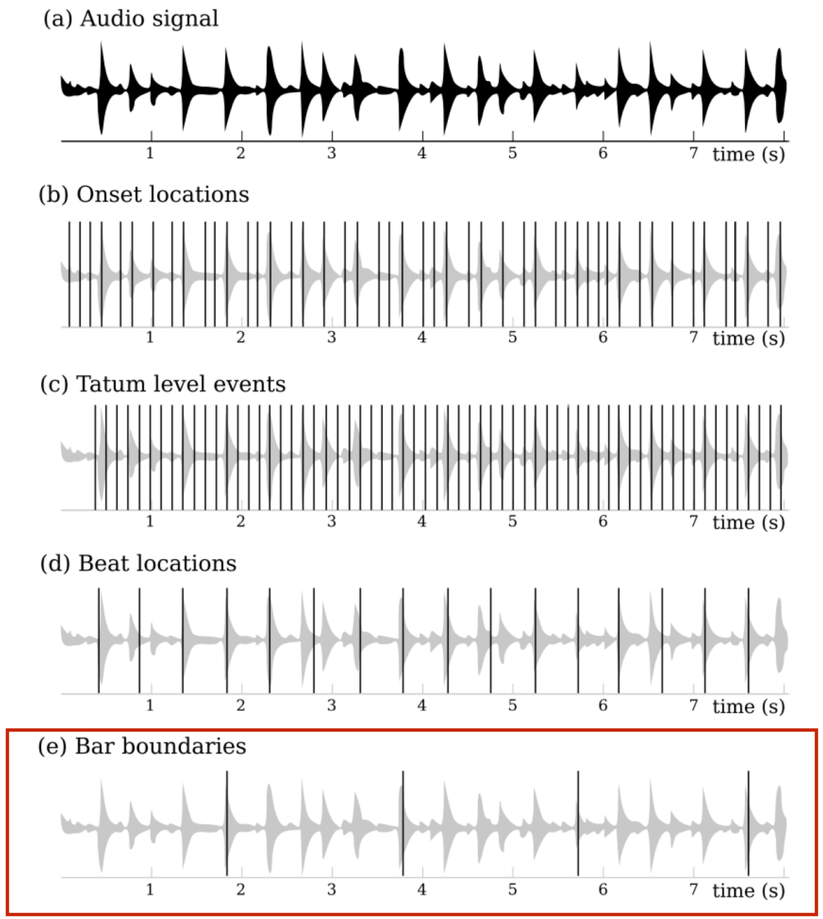
rock/pop, (some) electronic dance music -> steady tempo with strong percussive content

It's not so good for jazz, folk, classical

tempo variations, no drums, changes in metre

How good are human tappers?

Musical overview



- onsets - start times of note events
- tatum - fastest level
- beat - comfortable tapping level
- **downbeats** - grouping beats into bars

(very) basic approach

- Extract beat locations from audio signal

- Create a beat-synchronous spectral representation

- Measure the spectral difference between beat-frames

- Identify beats which give **most spectral change** as the ‘1’

Note:very simplified approach (assumes 4/4)

Other cues for downbeats:

Chord changes

- need chord detection algorithm (see later class!)

Rhythmic patterns

- do we need metre to find rhythm to find metre?

Detected drum patterns (kick + snare structure)

- what if no drums??

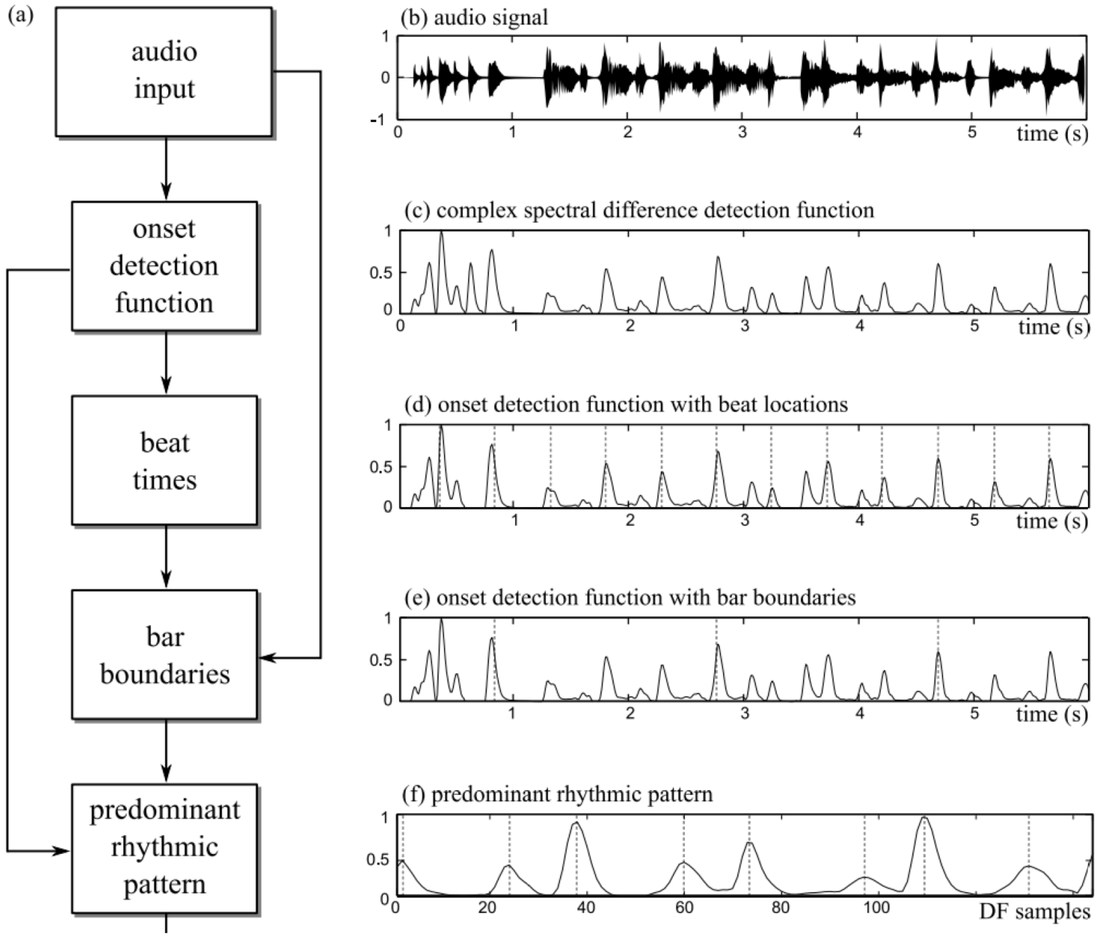
Very challenging problem - style and culturally specific

Rhythmic Patterns

If we know about metre, can we start to characterise rhythm?

If so, this can lead to recognition of musical style by rhythm in certain (restricted) contexts

Basic approach

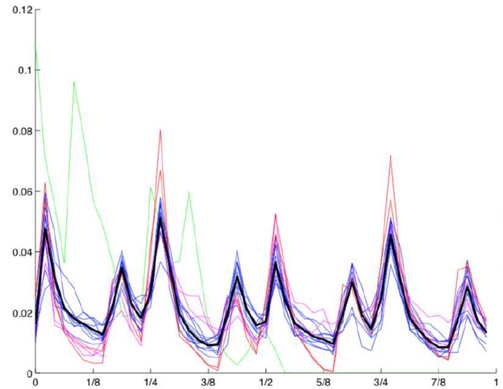


- Given beats and downbeats
- Look at repeated structure of ODF across each of the bars in the music
- Try to summarise to a single rhythmic pattern

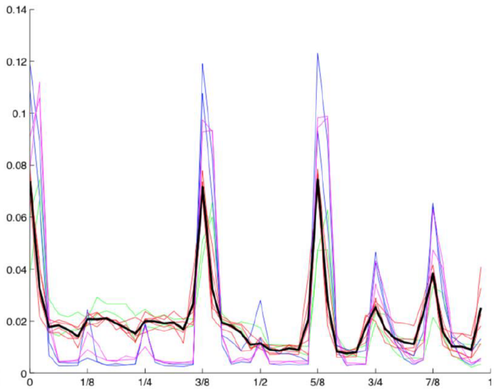
Ballroom dance music classification

Ballroom is strongly defined by tempo and rhythmic structure

Jive



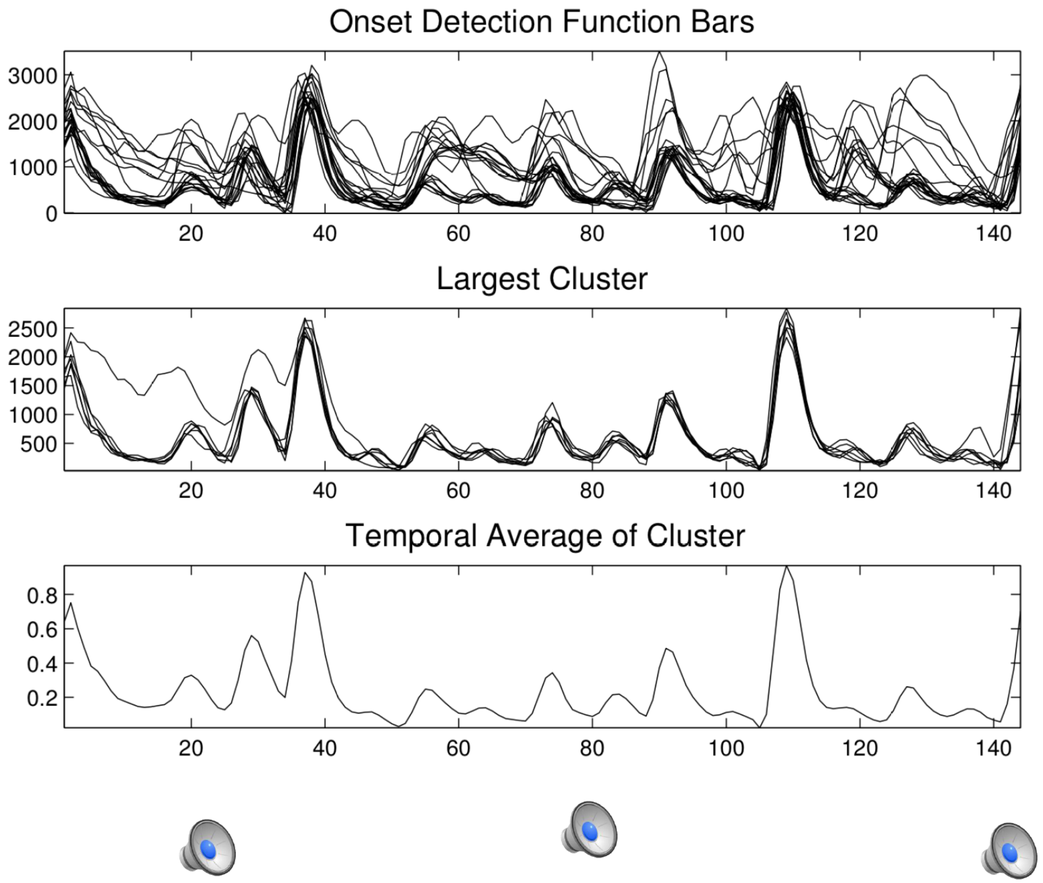
Rumba



- taken from Gouyon and Dixon: http://www.ofai.at/~fabien.gouyon/slides-GouyonDixon-ISMIR06.pdf

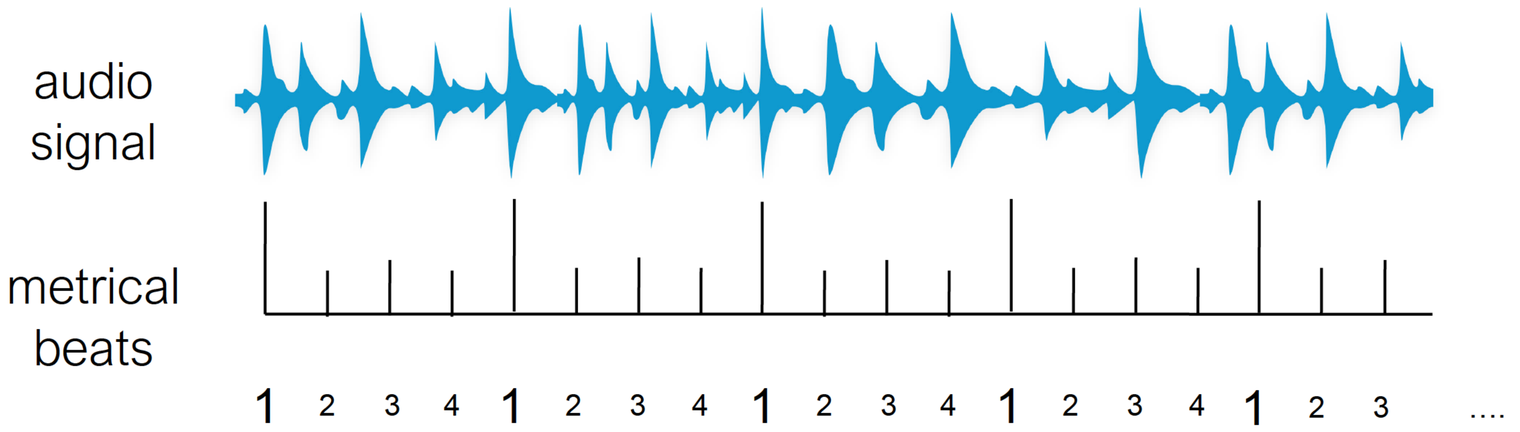
We can also listen to the analysis

Since we can extract beat, downbeat and a rhythmic pattern from music, we can make a kind of “auto drum beat”



Towards creative use of mir and rhythm

Beat and downbeat tracking



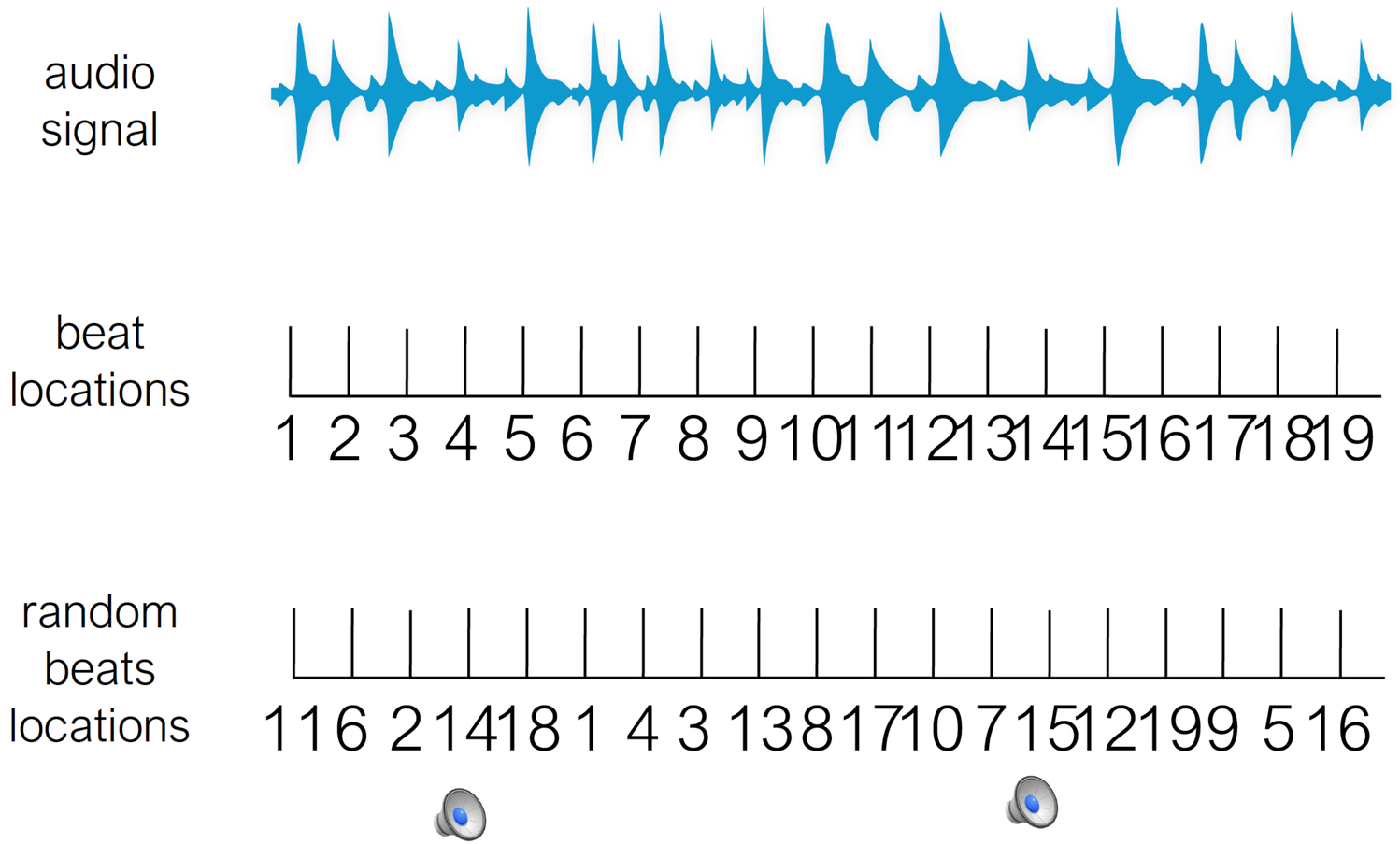
- The “metrical beats” are the main representation we’ll work with for these simply transformations

Beat Tracking

We'll explore:

- scrambling the music in two different ways
- changing the rhythmic structure
- some automatic remixing

Beat Randomizer



Beat Randomizer with Metre

Let's see if we can make the result of the “beat randomizer” a bit more musical

Instead of picking a **totally** random beat each time, we will try to preserve the **metrical structure** by using **downbeat** information

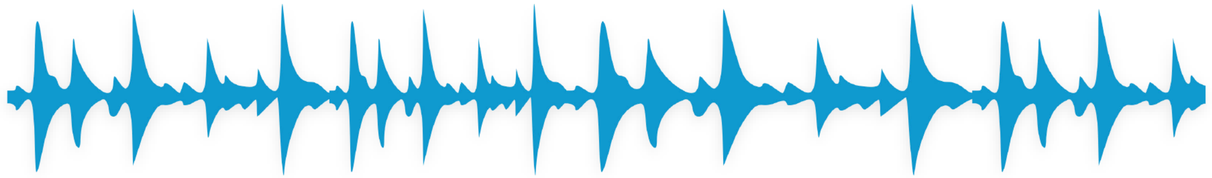
This means we pick a random beat by chose the metrical positions in order

So, we pick a random first beat of each bar, then a random second beat, etc.

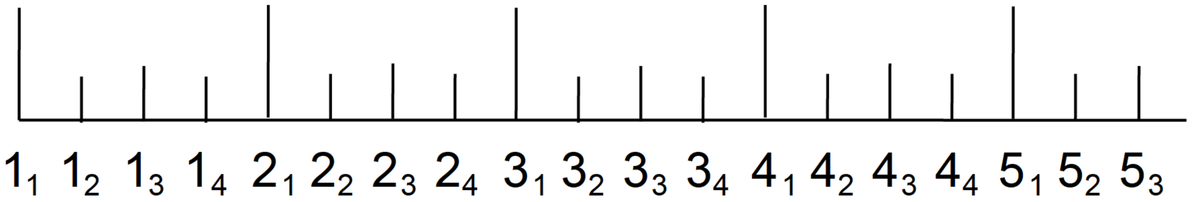
In this way the result is somehow *less* random

Beat Randomizer with Metre

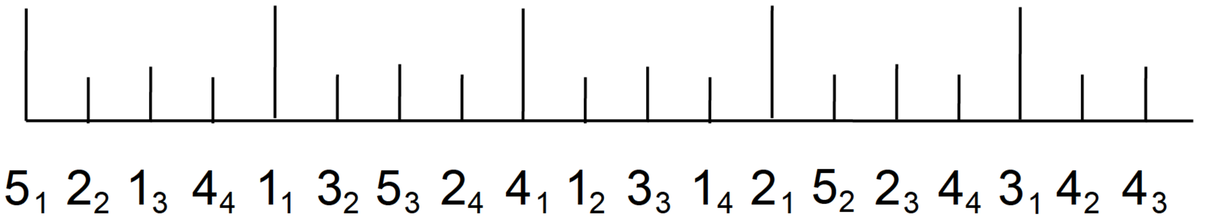
audio signal



metrical beats



random metrical beats



Beat Randomizer with Metre

We can vary number of sub-divisions per beat,

e.g. 2, 4 or 8

Beat Swinger

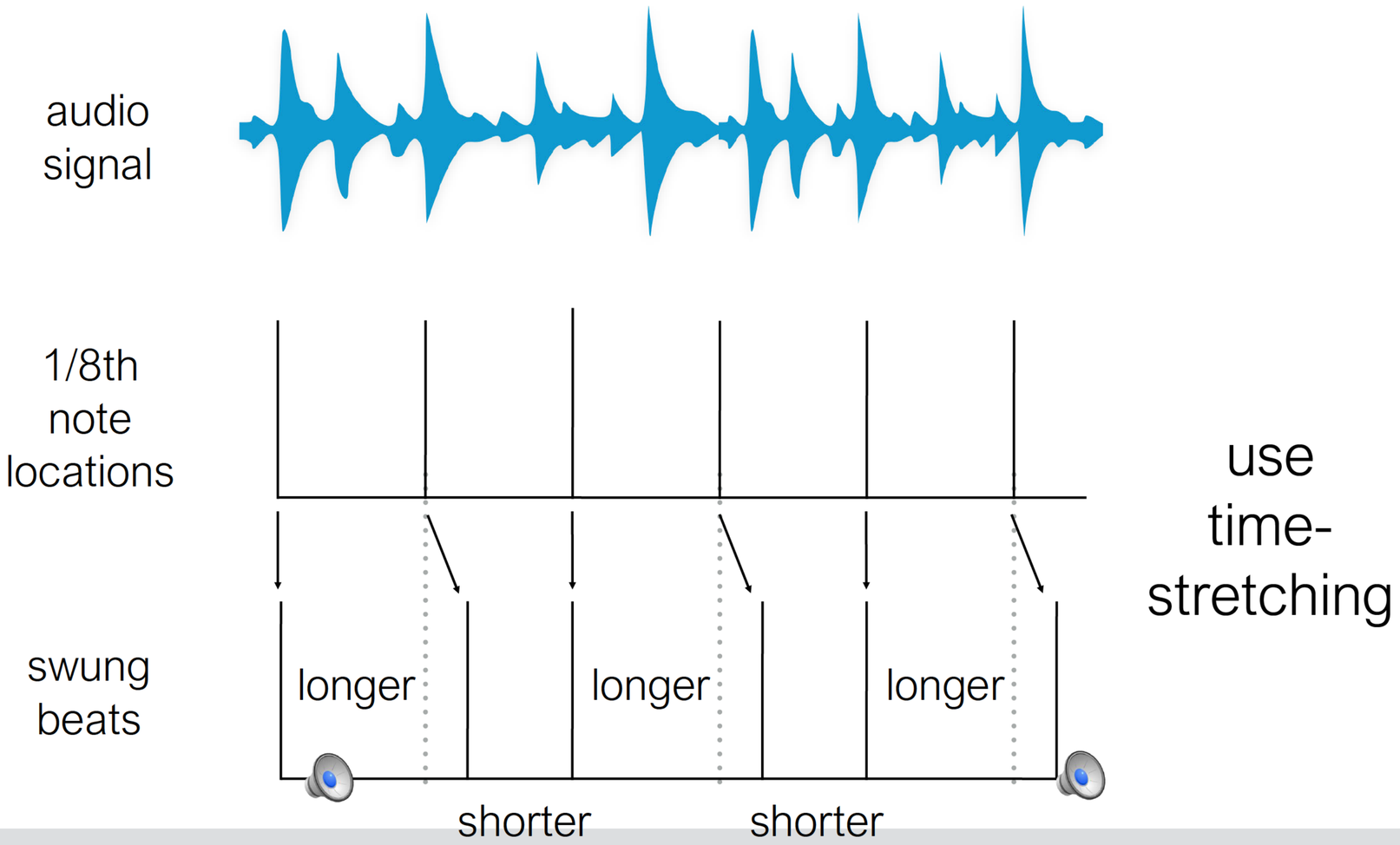
Given the beat times we can use a **time-stretching** tool to alter the rhythmic structure of the music

Time-stretching alters the speed of the music without changing the pitch

To add **swing-feel** we modify the duration of 1/8th notes (i.e. half-beats) in an alternating *long-short* pattern

e.g. we make the first 1/8th note 30% longer and the second one 30% shorter

Beat Swinger



Beat Swinger

To experiment more, we can modify how the beats are sub-divided, and change the stretch factor, e.g.

Best results are obtained through experimentation, and finding the right metrical level to *swing* (normally the fastest)

Beat remixer

If we can modify the timing of beats in music - as shown with the beat swinger, we can apply the same principle for mixing songs together

i.e. we can **beat-match** to make two songs have the same tempo and be synchronised for playback

Instead of a straight beat-matching application, we'll do something a bit different, built around the beat randomizer as well

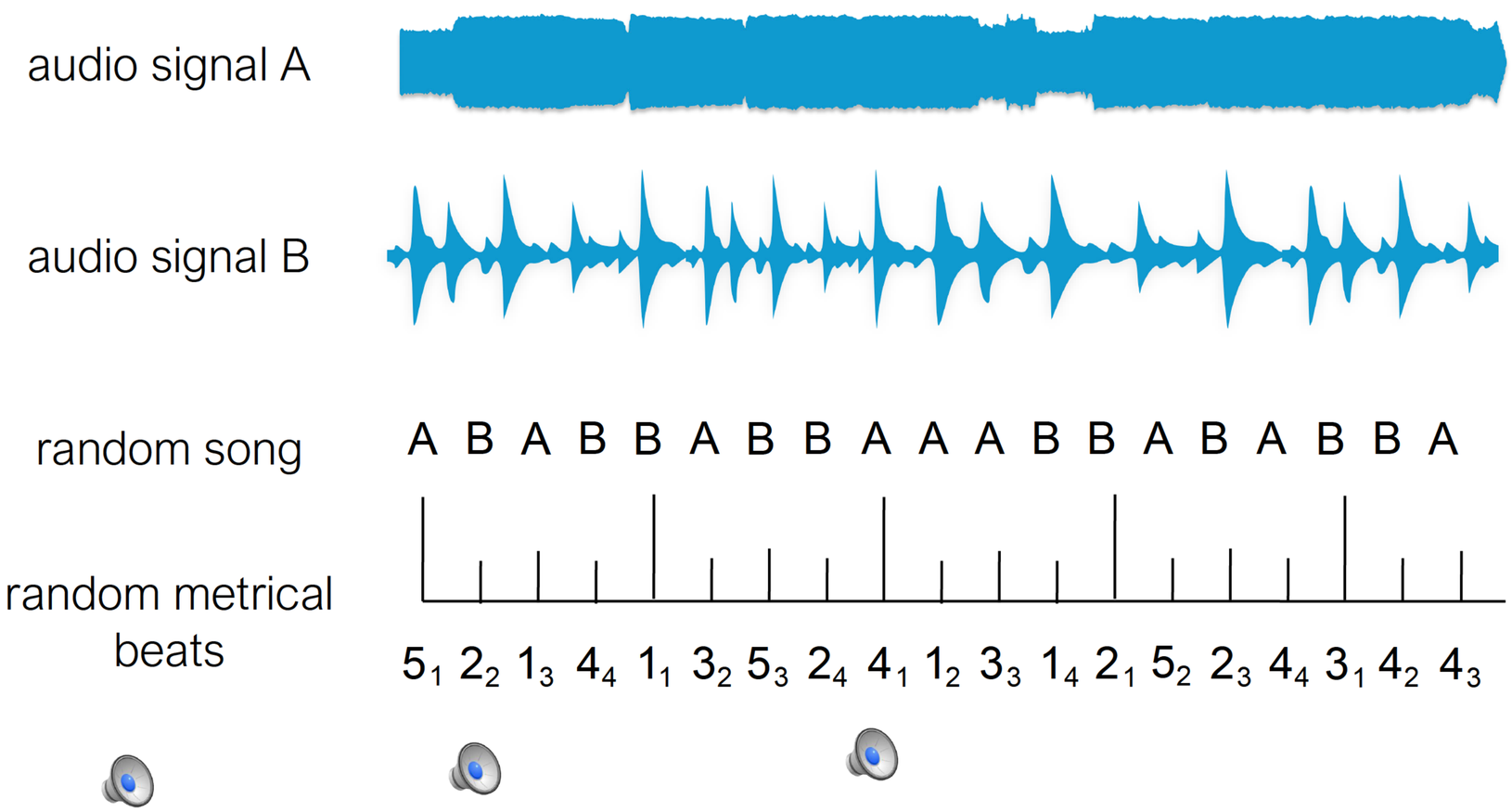
Beat remixer

Given two input music files, we'll follow the
“Beat Randomizer with Metre” process
for each of them

But then, also randomly **switch** between which song we playback at each beat

Making sure that we've **time-stretched** each the beats to be at the same tempo

Beat Remixer



4.3. Rhythm

.