Advanced Course Computer Science

Music Processing

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Tempo and Beat Analysis

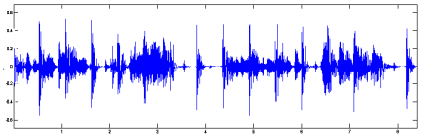
Introduction

Musical Properties:

- Harmony
- Melody
- Rhythm
- Timbre

Introduction

Perception of Rhythm:

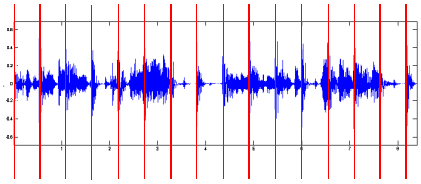


1. Musical accents → Beats
2. Regular intervals, periodicity → Tempo

Tapping your Foot

Introduction

Perception of Rhythm:



1. Musical accents → Beats
2. Regular intervals, periodicity → Tempo

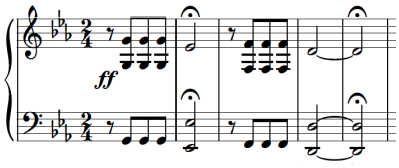
Tapping your Foot

Examples: Strong or weak rhythm?

- Queen – Another One Bites The Dust
- Shostakovich – 2nd Waltz
- Beethoven – Pathetique
- Beethoven – Symphony No. 5
- Borodin – String Quartet No. 2

Musical Timings

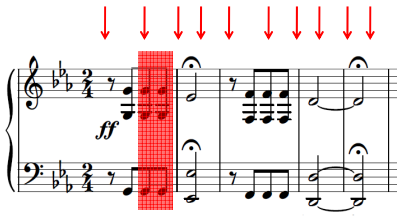
Musical tempo may differ from perceived tempo!



Musical Timings

Tempo and beat analysis on different time scales:

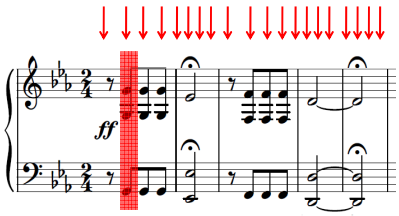
Tactus (beat) Level



Musical Timings

Tempo and beat analysis on different time scales:

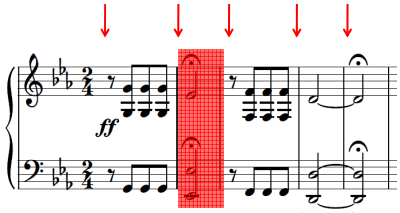
Tatum (*temporal atom*) Level



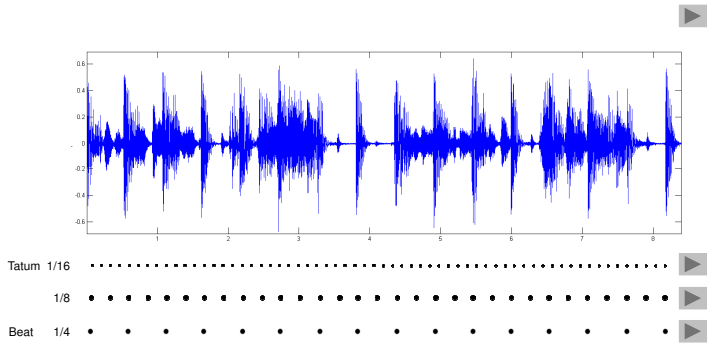
Musical Timings

Tempo and beat analysis on different time scales:

Measure Level



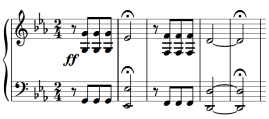
Beat



Beat Tracking

1. Impulse Extraction
2. Periodicity Analysis

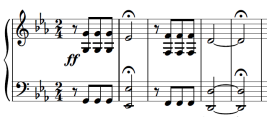
3. Musical Tempo Estimation
4. Tracking *the* Beat



Beat Tracking

1. Impulse Extraction — Signal Processing
2. Periodicity Analysis

3. Musical Tempo Estimation — Musical Knowledge
4. Tracking *the* Beat

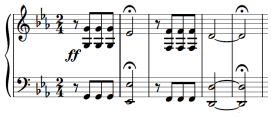


Impulse Extraction

- Musical Accents

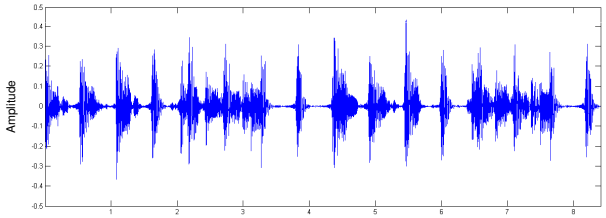
Onsets:
- The exact time, a note is hit
- One of the three parameters defining a note (pitch, onset, duration)

- Change of perceived properties of sound:
  - Loudness
  - Pitch
  - Timbre



Impulse Extraction

- Rectification
- Smoothing
- Differentiation
- Half wave rectification



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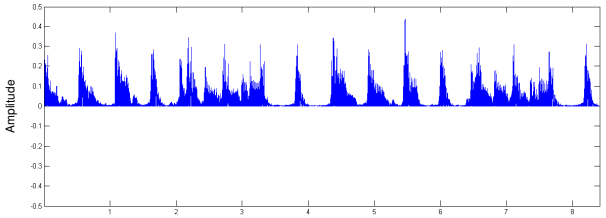

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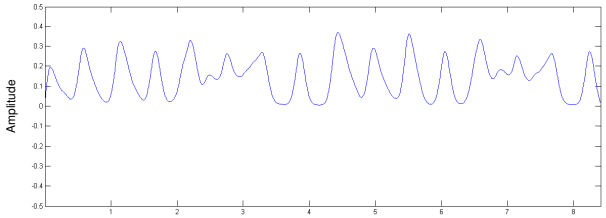

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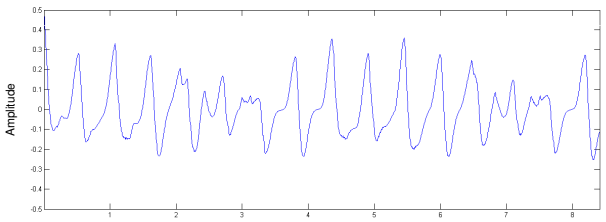

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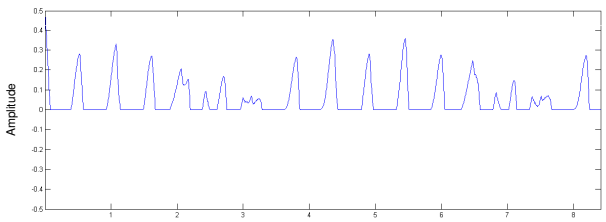
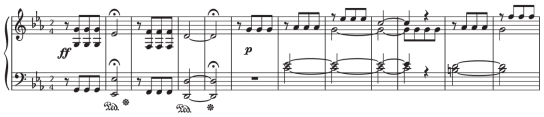
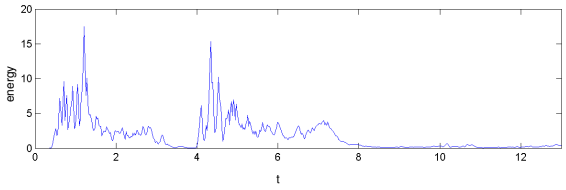


Classical Music





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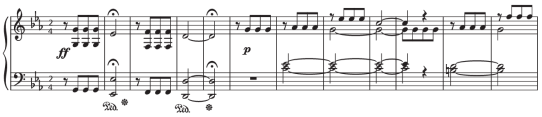
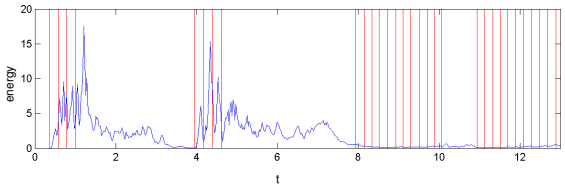
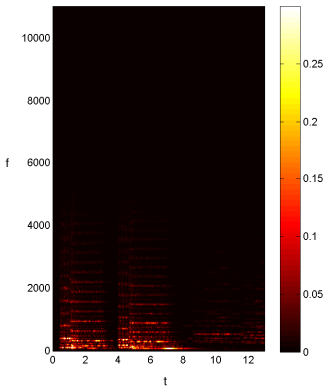




Extraction of Transients

spectrogram $|X|$

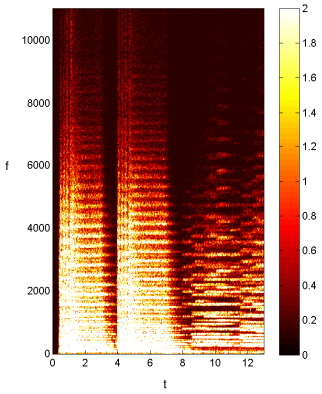


1. **Spectrogram**
2. Log compression
3. Differentiation
4. Integration

capture spectral changes:
- *loudness*
- *pitch*
- *timbre*

Extraction of Transients

Compressed spectrogram Y



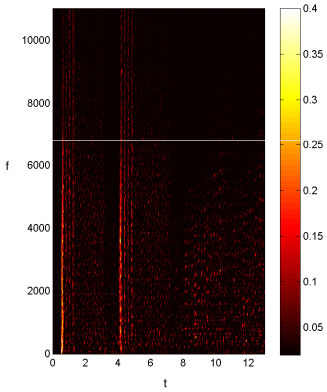
1. Spectrogram
2. **Log compression**
3. Differentiation
4. Integration

$$Y = \log(1 + C \cdot |X|)$$

- *human sensation*
- *enhances low intensity values*
- *high frequency content*
- *reduces influence of amplitude modulation*

Extraction of Transients

Spectral difference

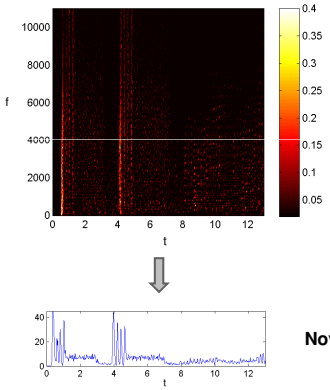


1. Spectrogram
2. Log compression
3. **Differentiation**
4. Integration

- *measure of change*
- *only positive intensity changes*
- *relative difference function*

Extraction of Transients

Spectral difference

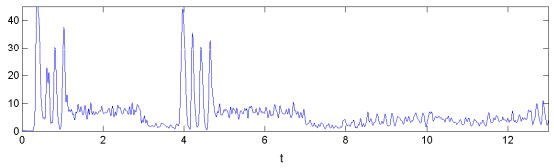


1. Spectrogram
2. Log compression
3. Differentiation
4. **Integration**

Novelty Curve

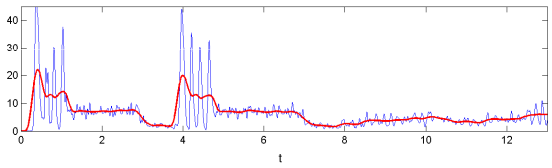
Postprocessing

Novelty Curve



Postprocessing

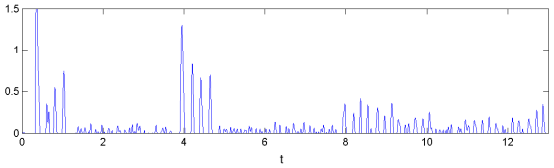
Novelty Curve



Subtraction of Local Average

Novelty Curve

Novelty Curve



Novelty Curve

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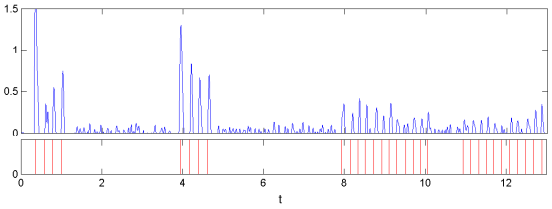
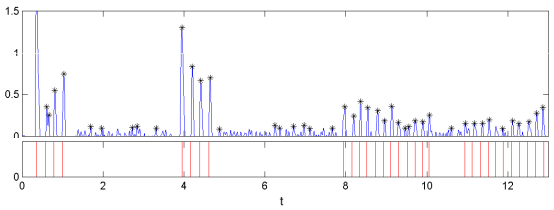


Peak Picking

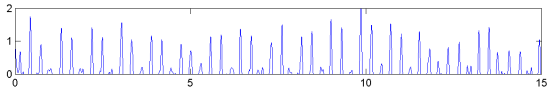
Peaks as note onset candidates:

Novelty Curve

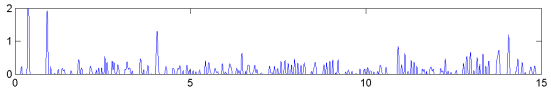


Examples

Shostakovich – 2nd Waltz

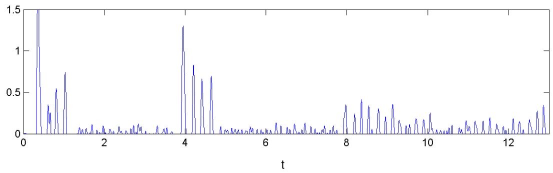


Borodin – String Quartet No. 2



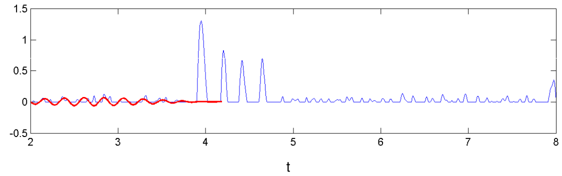
Periodicity Estimation

Reveal periodic structure of novelty curve
Frequency / Tempo



Fourier Analysis

Sinusoidal kernels
30 to 600 BPM, 0.5 to 10 Hz



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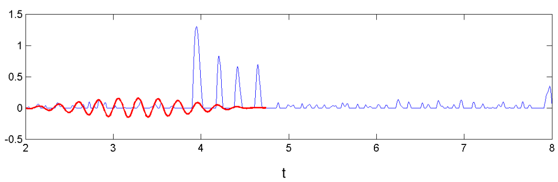

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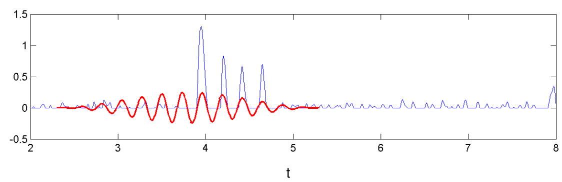

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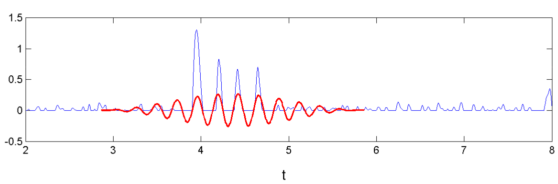

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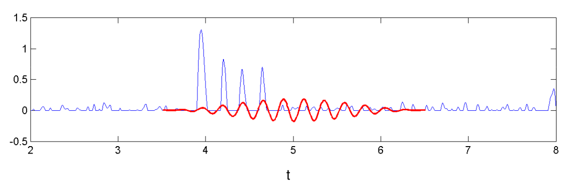

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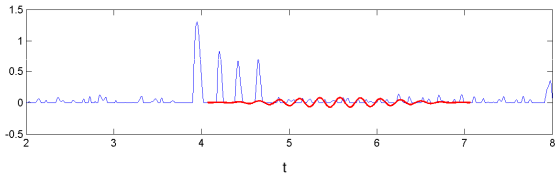

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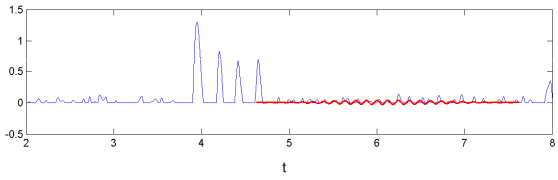

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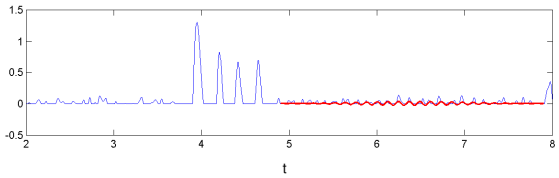
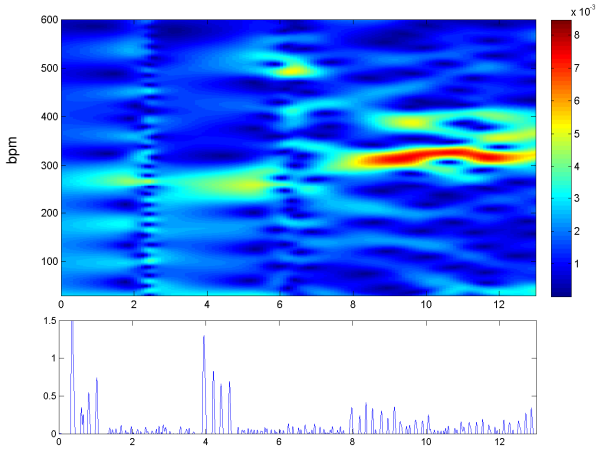


Tempogram



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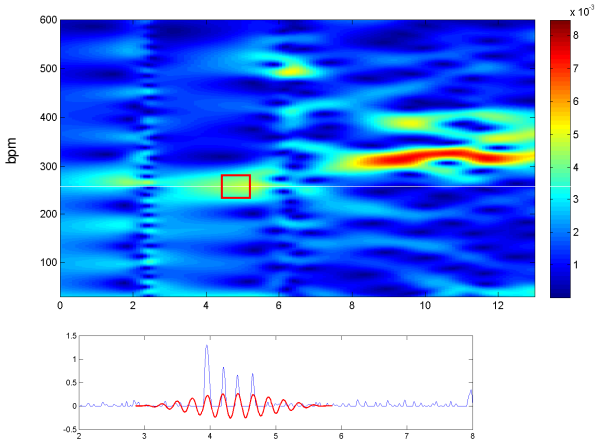
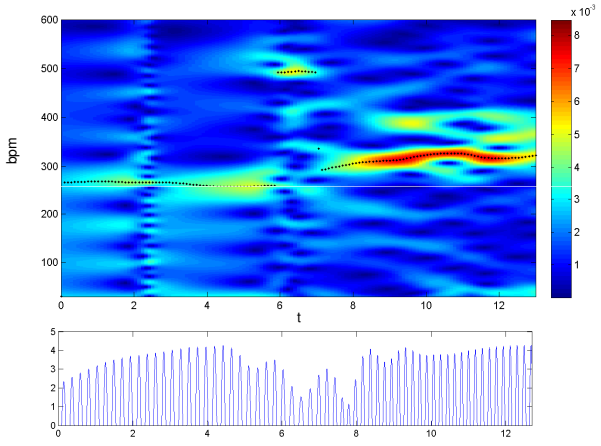


Tempogram: Optimal Periodicity Kernels



Examples:

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- Shostakovich – 2nd Waltz
- Beethoven – Symphony No. 5
- Borodin – String Quartet No. 2

Summary

1. Impulse Extraction
   - Novelty curve (something is changing, note onsets)
   - Indicates note onset candidates
   - Hard task for non-percussive instruments (strings)
2. Periodicity Analysis
   - Fourier analysis
   - Detect ***a*** tempo (the dominant)
3. Musical Tempo Estimation
   - Define ***the*** tempo (quarter beats per minute)
   - Musical knowledge needed (meter, time signature, …)
4. Tracking *the* Beat
   - Find most likely beat positions