CS 583 – Computational Audio

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Lecture 14: Music Information Retrieval & Rhythm Analysis

- Overview of Music Information Retrieval
- Rhythm Analysis: Basic Issues
- Onset Detection

Next Time:

- Beat Detection
- Tempo Estimation
- Higher-level Rhythmic Patterns

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Music Information Retrieval: Overview

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Music Information Retrieval is an interdisciplinary science which attempts to extract interesting and useful information from musical signals using computational tools. Researchers from Electrical Engineering, Computer Science, Musicology, Psychology, and Mathematics apply a variety of techniques in their scientific study of music.

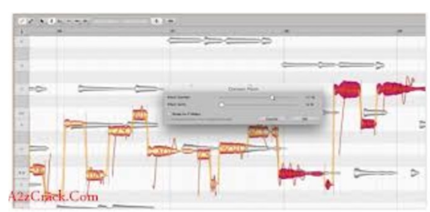
Some Important Areas of Current Interest:

Automatic Feature Extraction (pitch, melody, harmony, rhythm, mood, genre, ...)
Feature Tagging (automatic or manual “ground truth”)
Beat Tracking and Rhythm Analysis
Transcription (melody, chords, score)
Multimodal Synchronization/Alignment
Database Retrieval and search
Fingerprinting and classification
Similarity
Structure Analysis
Performance Analysis …

Applications include many software tools both for the professional community and for the consumer market.

SoundHound

SHAZAM



A good place to start with with Rhythm:

Rhythm (from Greek ῥυθμός, *rhythmos*, "any regular recurring motion, symmetry" (Liddell and Scott 1996)) generally means a "movement marked by the regulated succession of strong and weak elements, or of opposite or different conditions" (Anon. 1971, 2537). This general meaning of regular recurrence or pattern in time can apply to a wide variety of cyclical natural phenomena having a periodicity or frequency of anything from microseconds to millions of years.

U / U / U / U / U /
When I consider how my light is spent,

U / U / U / U / U /
Ere half my days, in this dark world and wide,

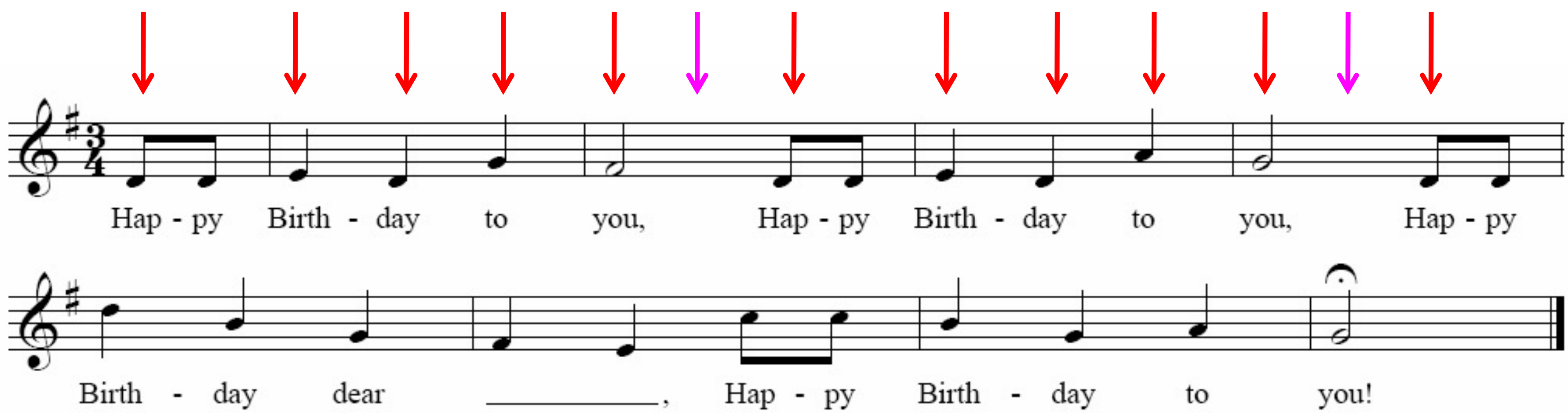
U / U / U / U / U /
And that one Talent which is death to hide,

/ U U / U U U /
Lodged with me useless, though my soul

U /
more bent . . .

We could usefully divide the subject of rhythm into a hierarchy of levels, from the fastest to the slowest divisions of time.

The basic beat is called the Tactus – this is what most people would tap their foot to.



Rhythm Analysis: Introduction

Further Examples:

If I Had You (Benny Goodman)

Shakuhachi Flute

Liszt: Sonetto No. 104 Del Petrarca

Where is the beat? Can you tap your foot to it? What is the meter?

How to find the underlying regular beat which is being varied by the composer and/or performer for expressive effect?

Rhythm Analysis: Introduction

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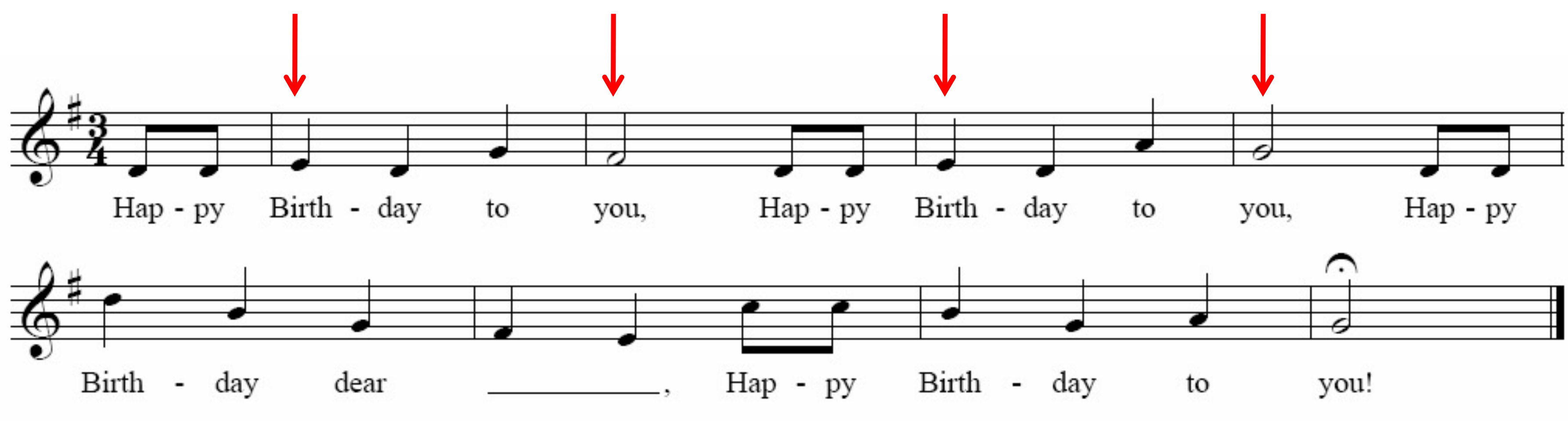
Even when rhythm is regular, there is a complicated semantic problem: rhythm is hierarchical, consisting of many interrelated groupings:

Pulse level: **Measure**



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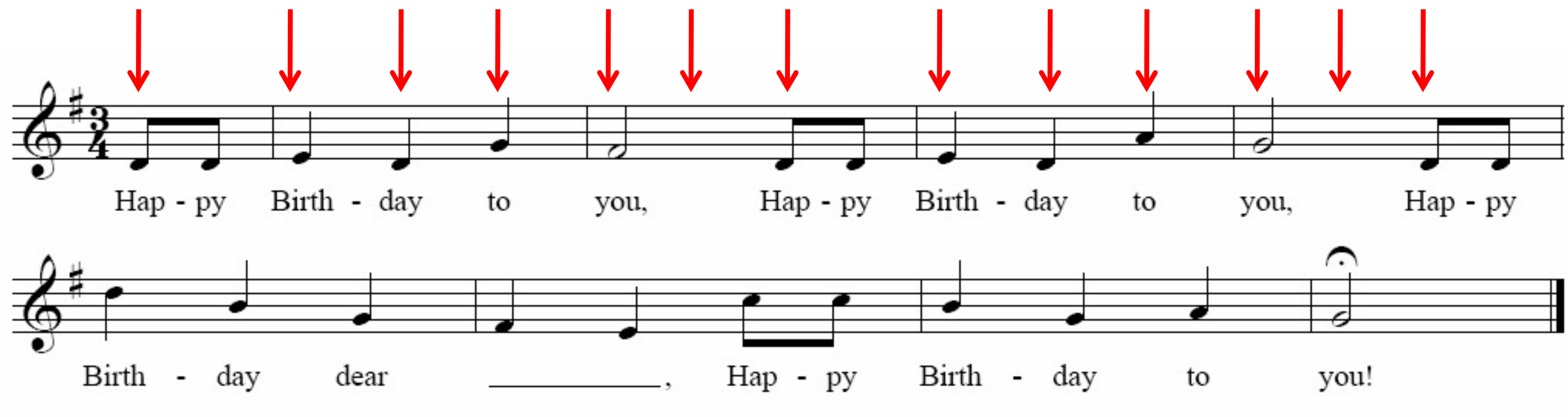
Pulse level: **Tactus (beat)**



Rhythm Analysis: Introduction

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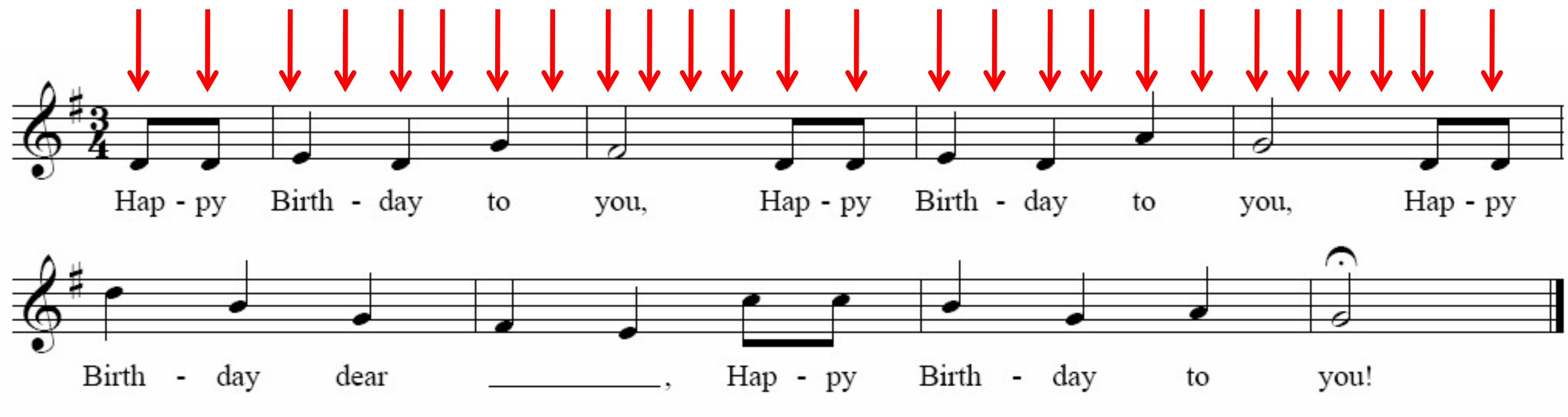
Example: Happy Birthday to you

Pulse level: **Tatum (fastest unit of division)**



Note: "Tatum" was named after Art Tatum, one of the greatest of all jazz pianists, who played a lot of fast notes!

Rhythm Analysis: Introduction

In a sophisticated piece of music, these various levels are exploited by the composer in complicated ways. How should it be notated and described precisely? What is the time signature?

Rhythm Analysis: Introduction

Challenges in beat tracking

- Hierarchical levels often unclear
- Global/slow tempo changes (all musicians do this!)
- Local/sudden tempo changes (e.g. rubato)
- Vague information

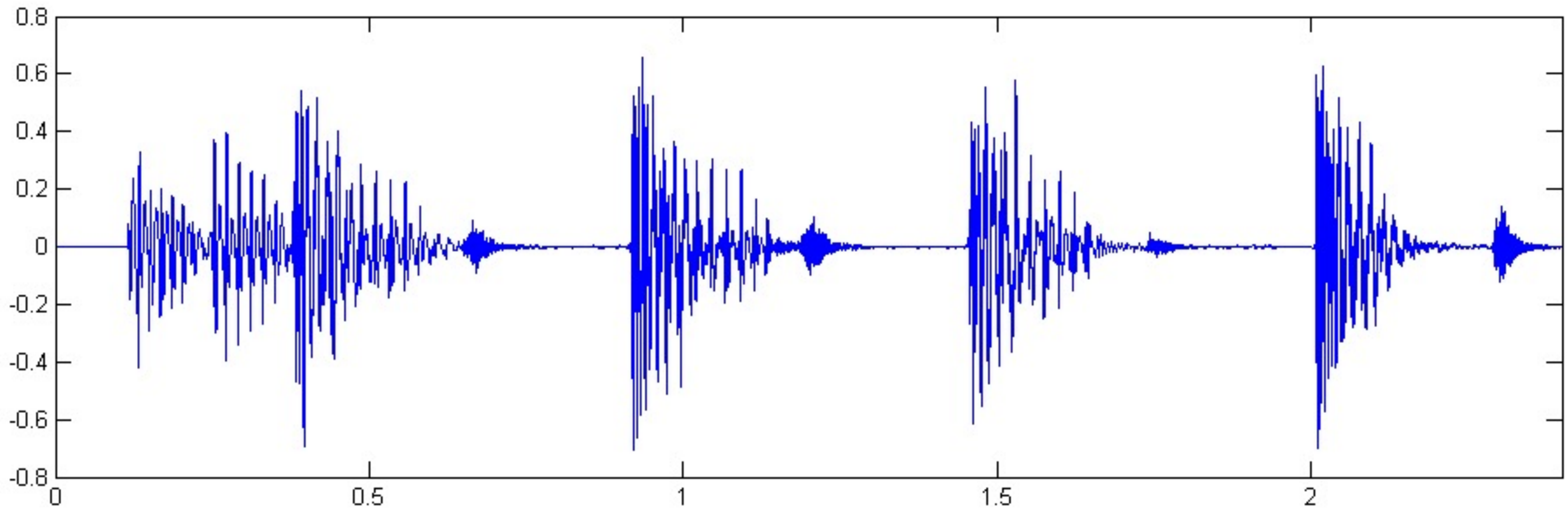
  (e.g., soft onsets, false positives)
- Sparse information: not all beats occur!

  (often only note onsets are used)

Rhythm Analysis: Introduction

Tasks in Rhythm Analysis

- Onset detection
- Beat tracking
- Tempo estimation



Tasks in Rhythm Analysis

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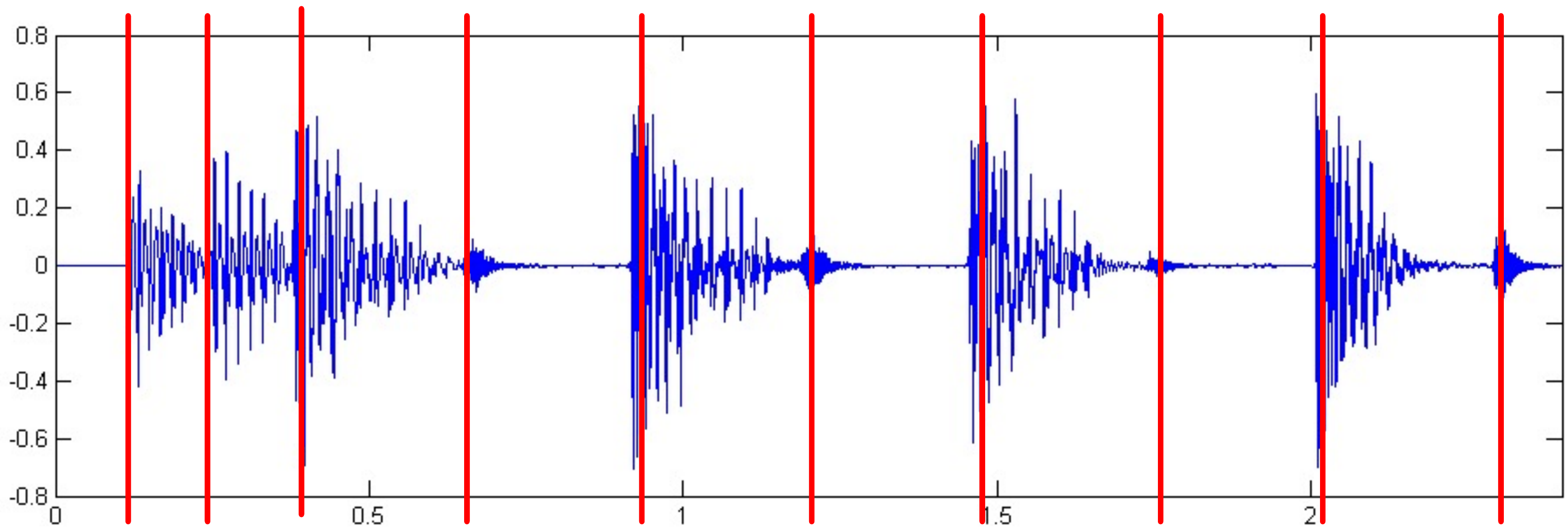
Tasks

- Onset detection
- Beat tracking
- Tempo estimation



Tasks in Rhythm Analysis

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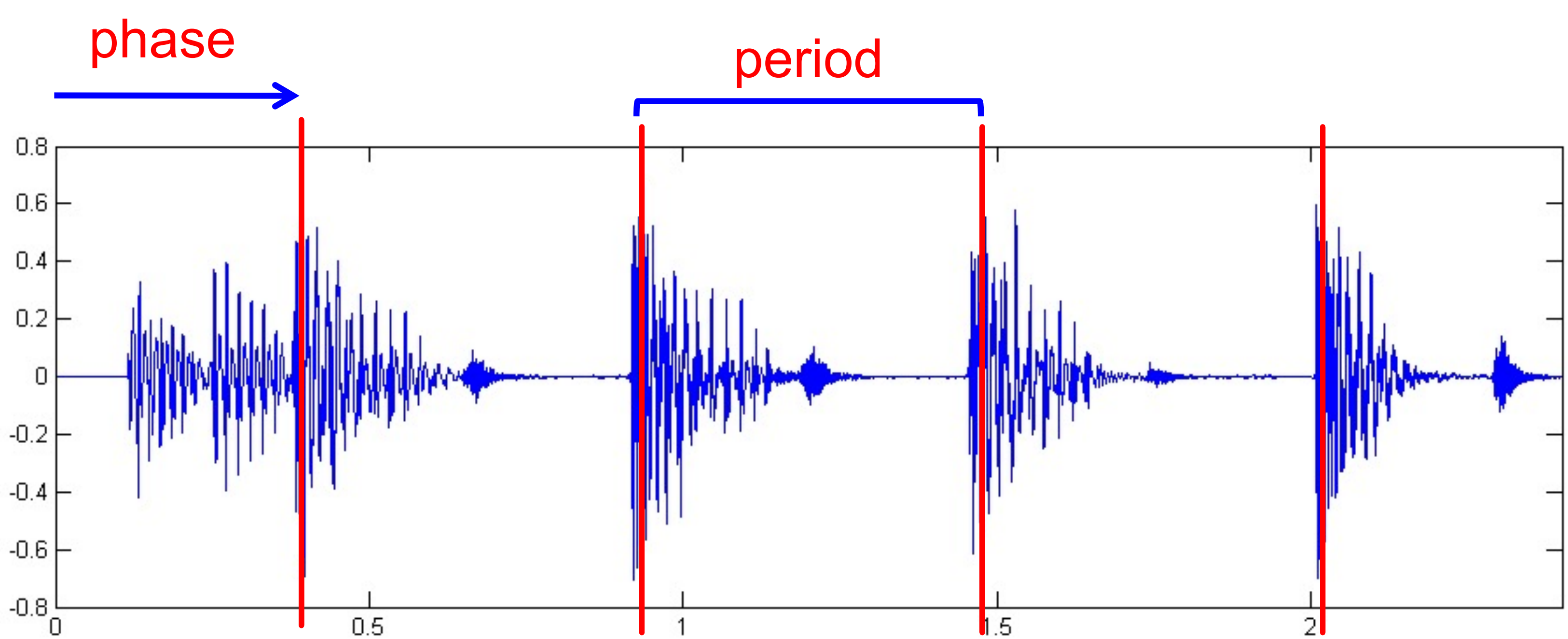
Tasks

- Onset detection
- Beat tracking
- Tempo estimation



Tasks in Rhythm Analysis

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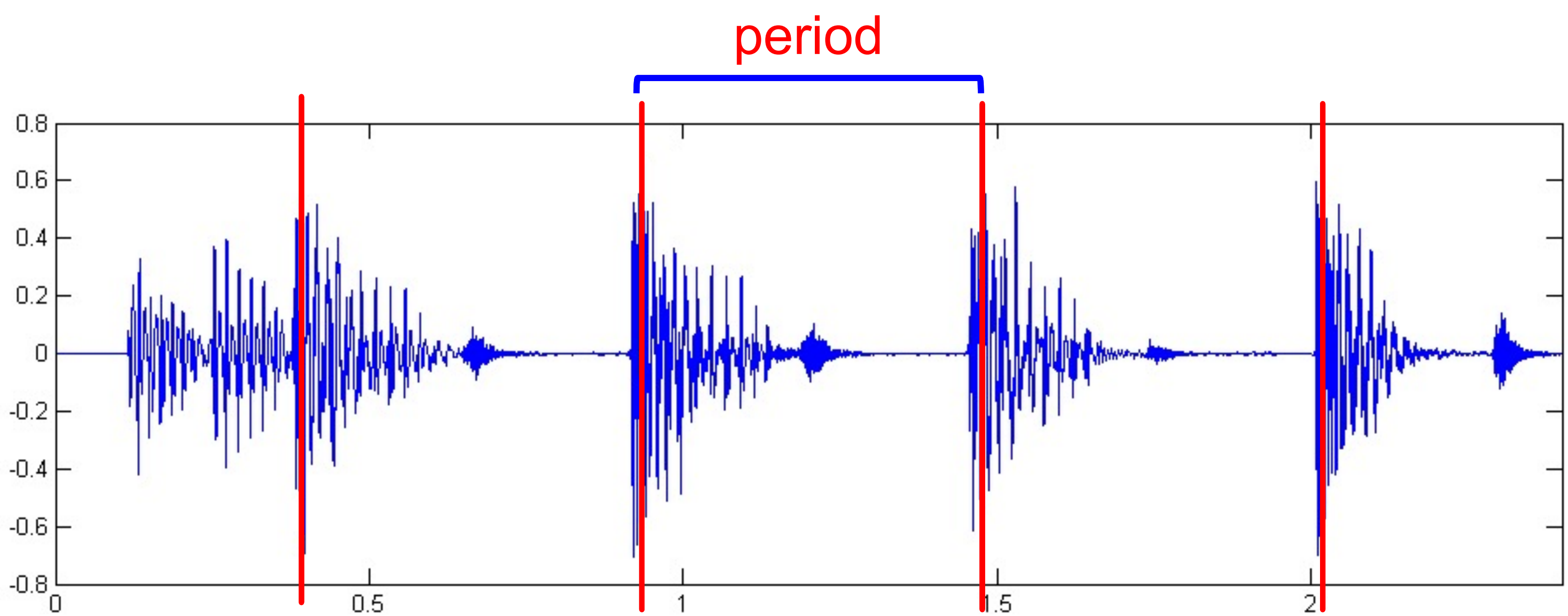
Tasks

- Onset detection
- Beat tracking
- Tempo estimation

Tempo := 60 / period

Beats per minute (BPM)



Onset Detection

- 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 or loudness
  - pitch or harmony
  - timbre

Onset Detection

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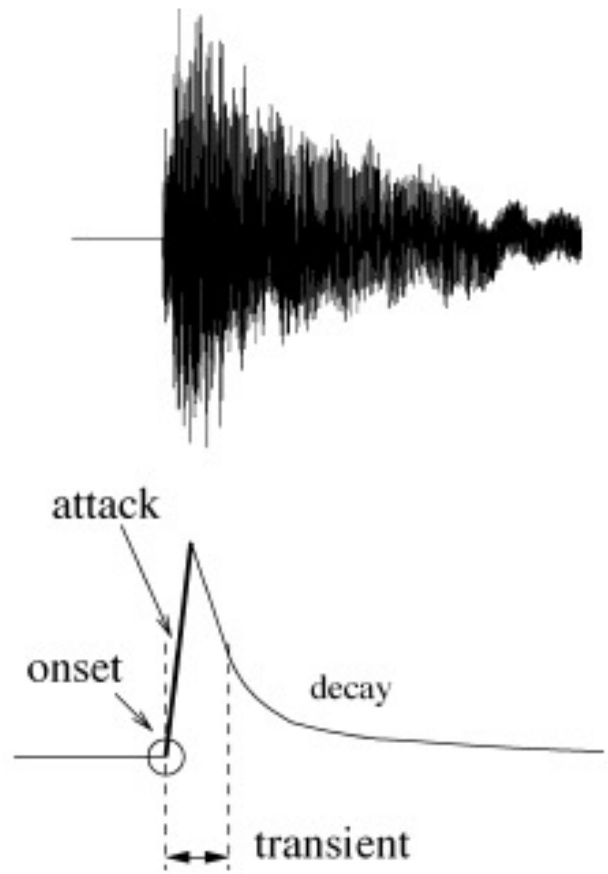

[Bello et al., IEEE-TASLP 2005]

Onset Detection (Amplitude or Energy-Based)

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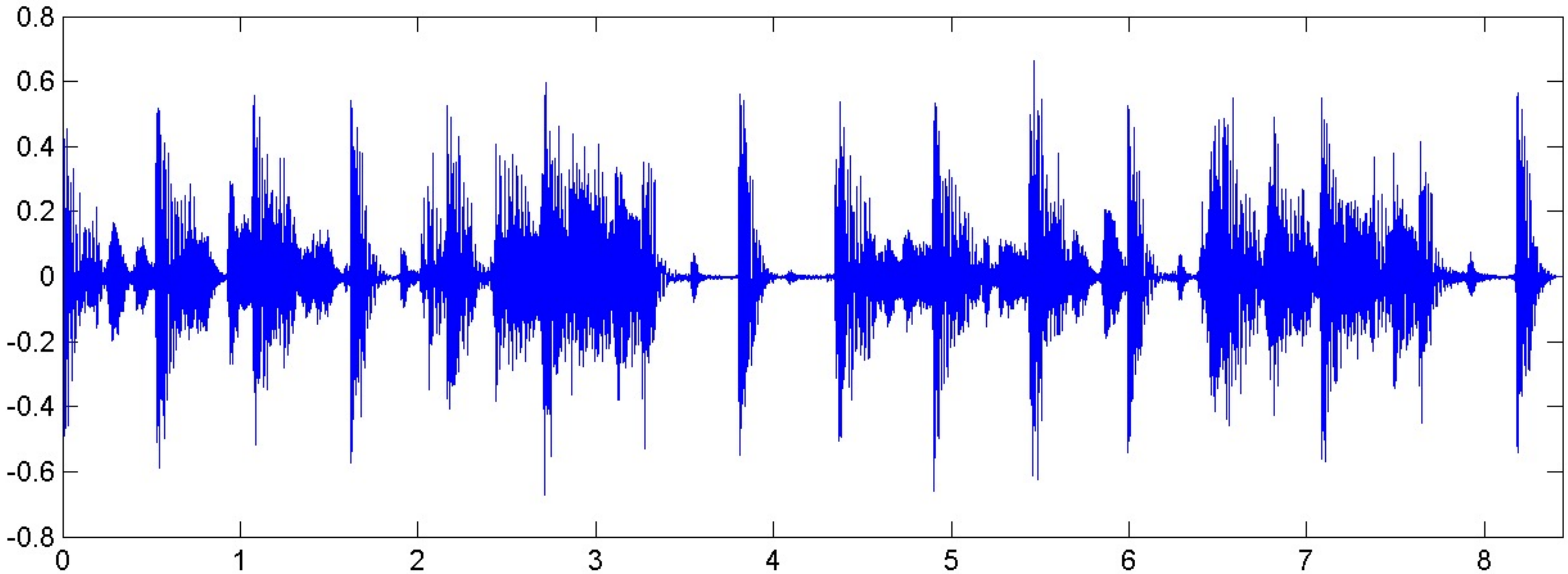
Steps

Waveform



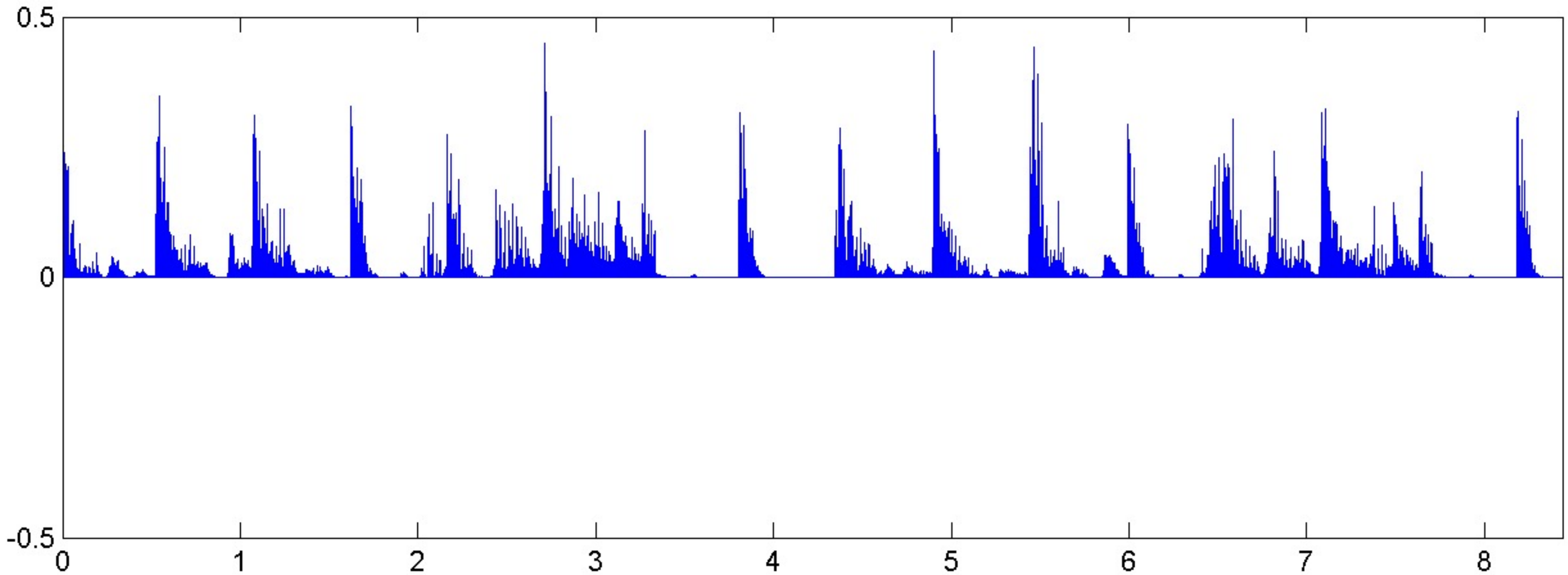
Time (seconds)

Onset Detection (Amplitude or Energy-Based)

Steps

1. Amplitude squaring (full-wave rectification of power signal)

Squared waveform



Time (seconds)

Onset Detection (Amplitude or Energy-Based)

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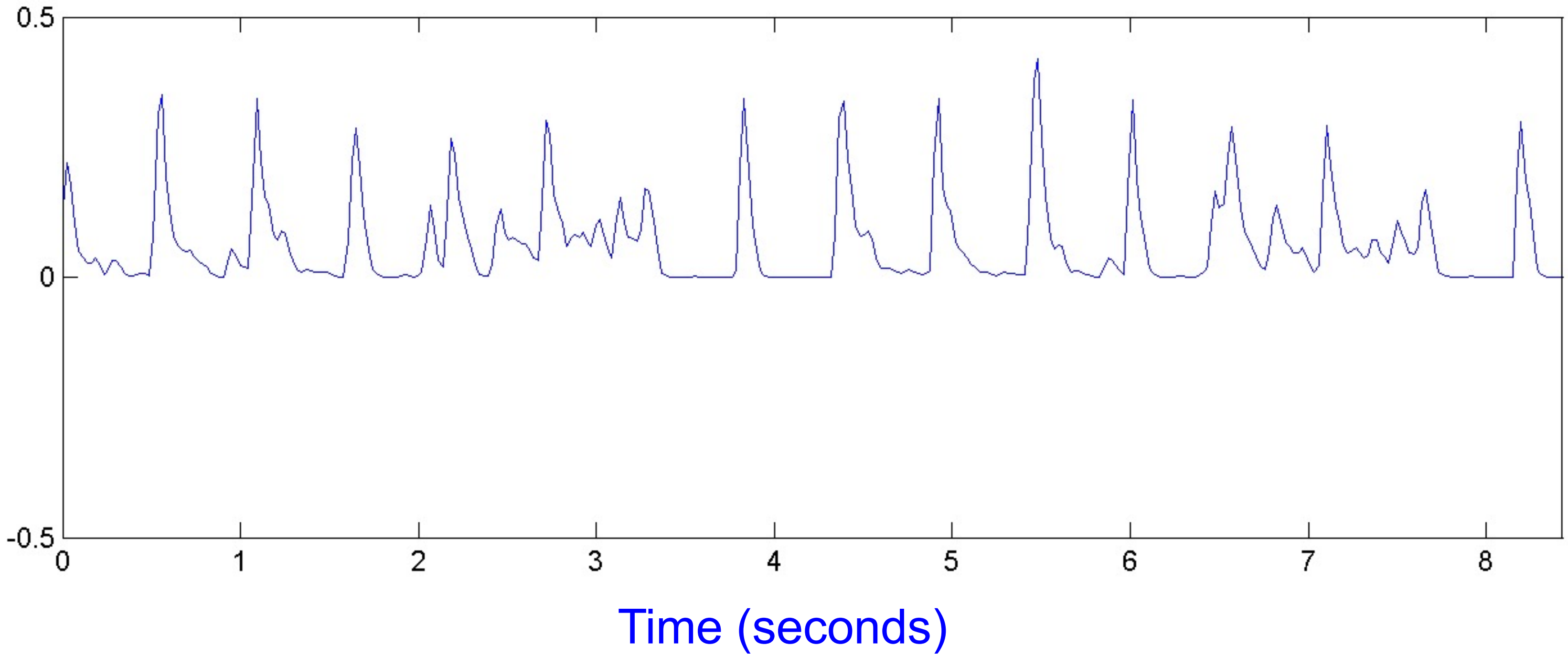
Steps

1. Amplitude squaring (full-wave rectification of power signal)
2. Windowing (taking mean or max in each window): “energy envelope”



Onset Detection (Energy-Based)

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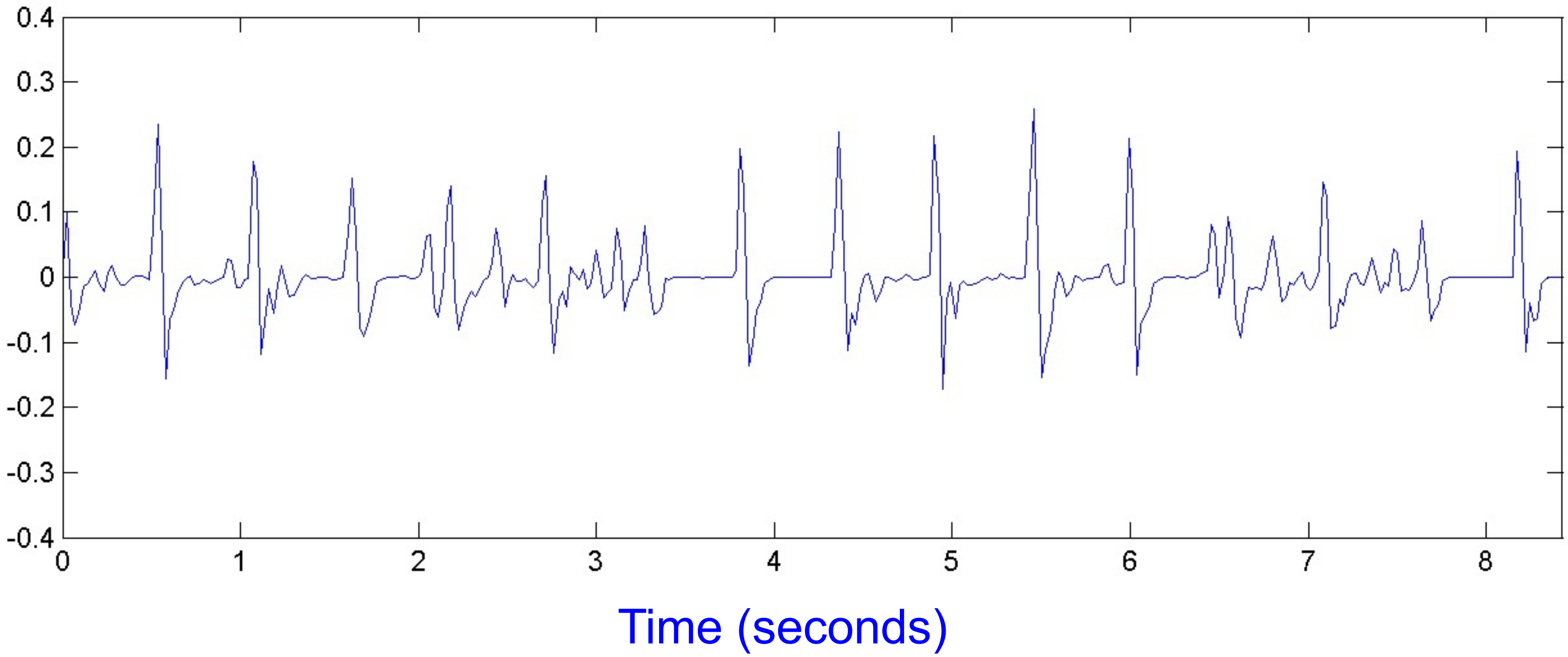
Steps

1. Amplitude squaring (full-wave rectification of power signal)
2. Windowing (taking mean or max in each window) : “energy envelope”
3. Difference Function (using appropriate Distance Function): captures changes in signal energy: “novelty curve.”



Onset Detection (Energy-Based)

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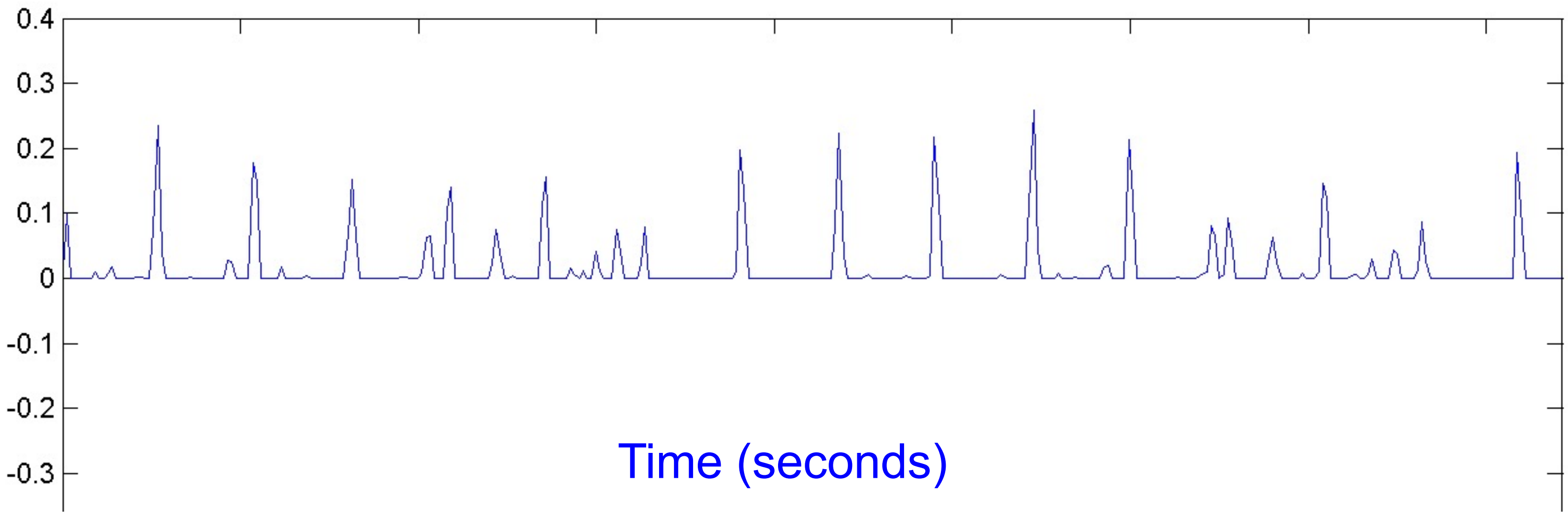
Steps

1. Amplitude squaring (full-wave rectification of power signal)
2. Windowing (taking mean or max in each window) : “energy envelope”
3. Difference Function (using appropriate Distance Function): captures changes in signal energy: “novelty curve.”
4. Half-wave Rectification (negative samples => 0.0): note onsets are indicated by **increases** in energy only.



Onset Detection (Energy-Based)

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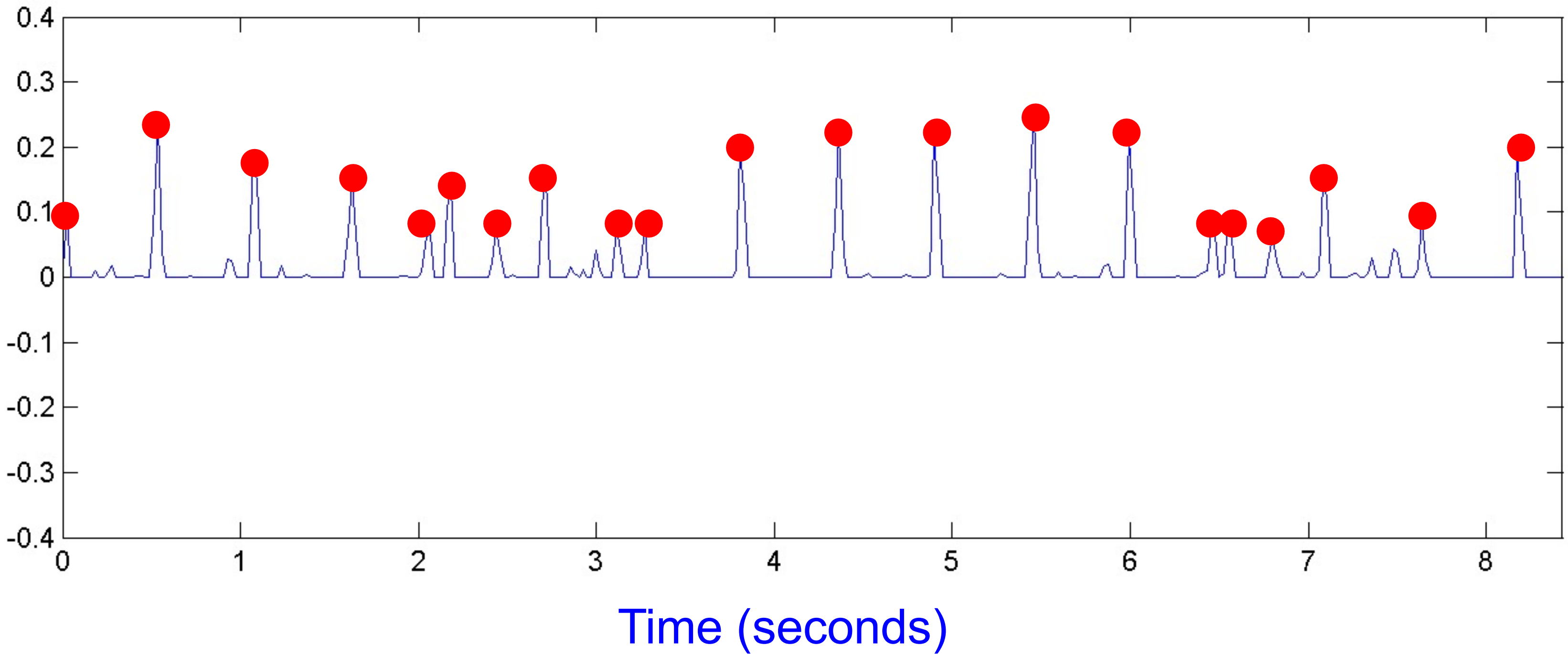
Steps

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

Peak positions indicate note onset candidates



Onset Detection

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- Energy curves often work best for percussive music or very simple signals

- Many instruments have weak note onsets: wind, strings, voice.
  - Example: Shakuhachi Flute

- Biggest problem: pitch or timbre changes (corresponding to note onset) may not correlate with energy changes, e.g., a singer may change the loudness without changing pitch/note, or change pitch/note without appreciable change in loudness.

- More refined methods needed that capture changes in energy spread over the spectrum

[Bello et al., IEEE-TASLP 2005]

Onset Detection

Let's look at an implementation on this in a Jupyter notebook….