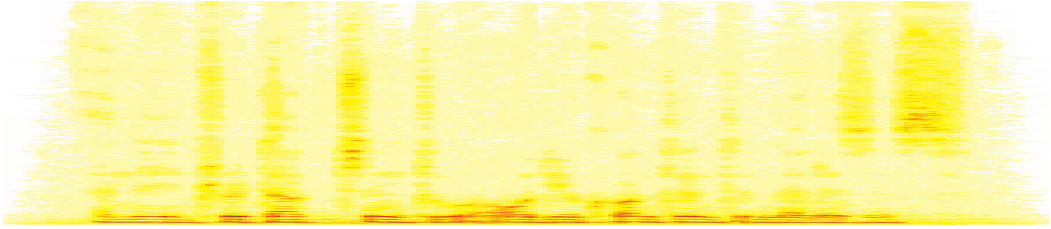
Introduction to Audio Content Analysis

Module 6.2: Tempo Detection

alexander lerch



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introduction

overview

corresponding textbook section

Chapter 6 — Temporal Analysis: pp. 146–148

- **lecture content**
  - introduction to tempo detection and beat tracking
  - overview over basic approaches
  - typical challenges

- **learning objectives**
  - discuss advantages and disadvantages for different approaches to tempo detection and beat tracking
  - summarize the typical challenges of beat tracking systems

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tempo detection & beat tracking

problem statement

- **tempo detection**
  - detect speed of regular pulse (foot-tapping rate)
- **beat tracking**
  - detect the time instances the tempo pulses occur (beat phase)

tempo detection & beat tracking

introduction

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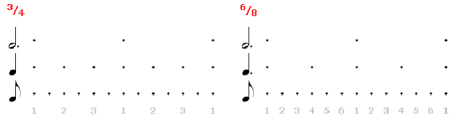
- **objectives**
  1. find the tempo from the novelty function/onsets
  2. find the beat locations

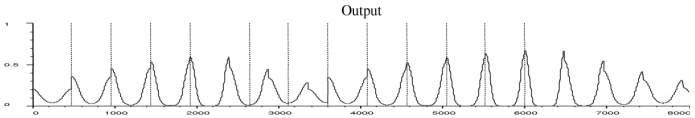
- **systematic problems**:
  1. distinguish *hierarchical levels*
     - meter
     - beat
     - subbeat/tatum
  2. detect *beats without onsets*
  3. recognize *onsets without beats*



tempo detection & beat tracking

oscillator approach

Beat tracking with an oscillator[1]



1. initialize pulse generator (tempo estimate, beat position estimate)
2. predict next beat location with pulse
3. adapt acc. to distance (predicted vs. real onset position)
   - beat period
   - beat phase
4. predict with adapted settings
5. adapt . . .

[1] E. W. Large, "Beat Tracking with a Nonlinear Oscillator," in *Proceedings of the 14th International Joint Conference on Artificial Intelligence (IJCAI)*, Montreal, Aug. 1995.

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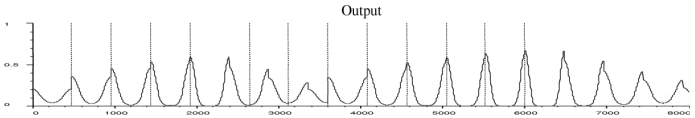

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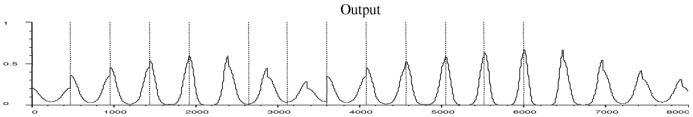

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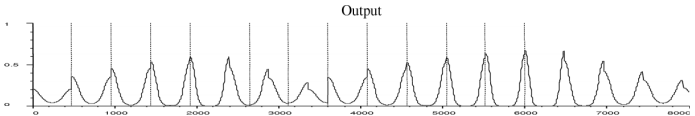

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tempo detection & beat tracking

oscillator approach: initialization

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How to estimate the initial tempo

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oscillator approach: initialization

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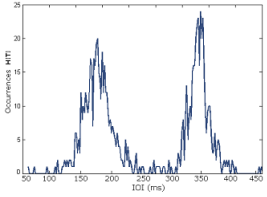
How to estimate the initial tempo

- location of maximum of **ACF of novelty function**
- maximum of **IOI histogram**



- maximum of **beat spectrum/histogram**
- . . .

tempo detection & beat tracking

multi-agent approach

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1. run **multiple beat trackers** with different parameters
   - initial tempo
   - initial beat phase
   - adaptation speed
2. compute reliability/confidence criteria:
   - match beat and onset times
   - tempo stability
   - majority of different agents
   - ...
3. choose **most reliable agent** (or path between agents)

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filterbank approach

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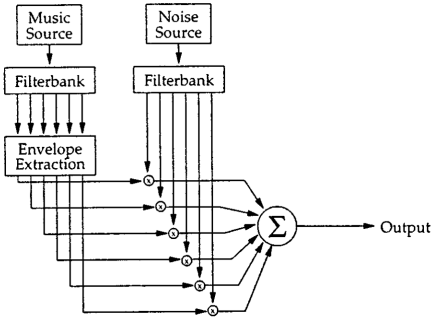
1. design **filterbank** (e.g. comb resonators spaced 1 beat)
2. compute filter output energy
3. pick maximum



plots by Scheirer[2]

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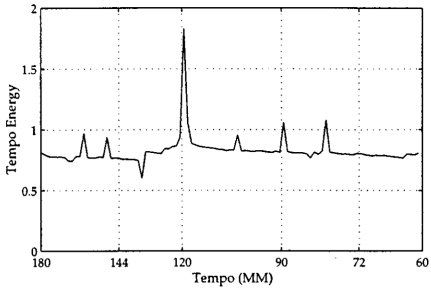

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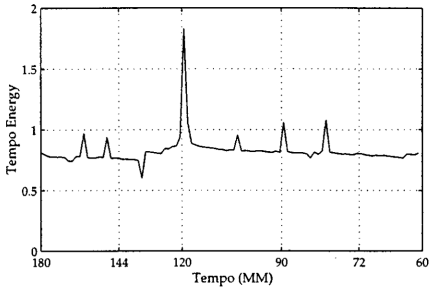

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template-based approach

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1. define set of **template pulses** in all tempi
2. compute CCF between novelty function (or its ACF) and all templates
3. choose template with highest correlation as tempo
4. choose lag with highest correlation as beat phase

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typical problems

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1. tempo: detection of **double/half tempo** (triple, . . .)
2. phase: detection of **off-beats**
3. tempo & phase: strongly depends on **initialization values**
4. tempo & phase: only **slow adaptation** — no sudden tempo changes

challenges with adaptation speed example:

summary

lecture content

- **tempo analysis**
  - similar to pitch detection on a different scale
    - periodicity analysis of novelty function
    - time or spectral domain
- **typical approaches**
  - oscillator
  - histogram/beat spectrum
  - template correlation
- **main challenges**
  - double/half tempo
  - adaptation to sudden tempo changes