Introduction to **Audio Content Analysis**

Module 9.3: Onset Detection

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introduction

overview

corresponding textbook section

section 9.3

- **lecture content**
  - detection of the start of musical events
  - fundamental methods for generating a novelty function
  - fundamental methods for peak picking

- **learning objectives**
  - describe the term onset
  - implement an automatic onset detection system

introduction

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section 9.3

- **lecture content**
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- **learning objectives**
  - describe the term onset
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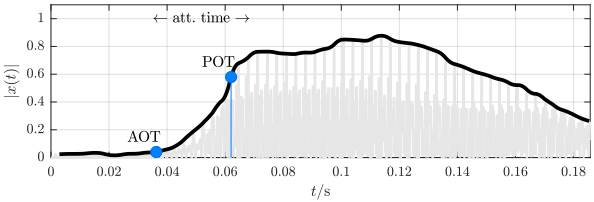
onset detection
problem statement

- **onset**: begin of musical event
- **goal**: detect the point in time of an onset
- **challenges**:
  - which time stamp of the initial attack time actually marks the onset time?
  - *polyphonic* audio signals:
    - unknown number of voices and events
    - multiple onsets occur at "the same" time
    - onset might be obfuscated by other musical content

onset detection
onset time

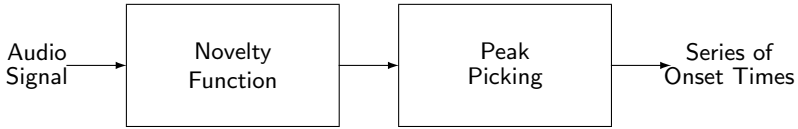
- **note onset time**:
  - time the instrument is *triggered*
- **acoustic onset time**:
  - time of first *measurable* instrument output
- **perceptual onset time**:
  - time the event is *perceived* by listener



matlab source: plotOnset.m

onset detection

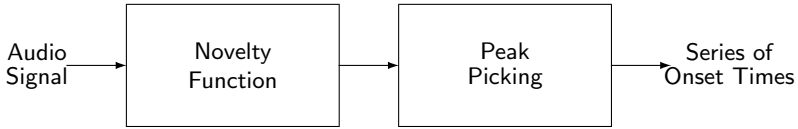
overview



1. **novelty function**
   - measure of probability for new events/signal change over time

2. **peak picking**
   - identify the most likely locations for onsets

onset detection
overview



1 novelty function

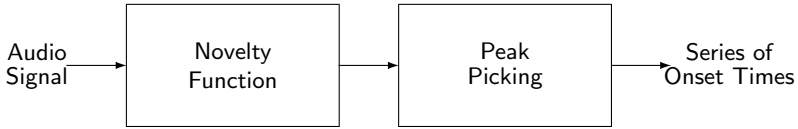
- measure of probability for new events/signal change over time

2 peak picking

- identify the most likely locations for onsets

onset detection

overview



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   - measure of probability for new events/signal change over time

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onset detection
novelty function

- alternative **terms** for *novelty function*
  - detection function
  - difference function

- **processing steps**
  1. extract features
  2. compute derivative
  3. smooth result
  4. apply Half-Wave-Rectification (HWR)

onset detection
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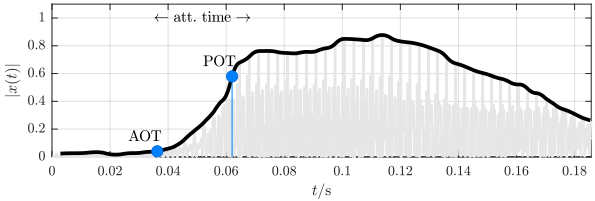
onset detection

novelty function examples 1/3

1. **time domain** example
   - *feature*: time domain envelope
   - *derivative*: slope of envelope
   - *HWR*: only interested in onsets, not offsets



2. **pitch domain**:
   - *feature*: pitch contour
   - *derivative*: changes in pitch

matlab source: plotOnset.m

onset detection
novelty function examples 1/3

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1 **time domain** example

- *feature*: time domain envelope
- *derivative*: slope of envelope
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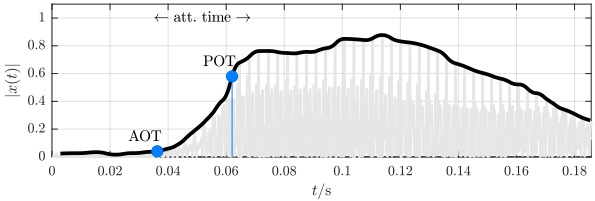
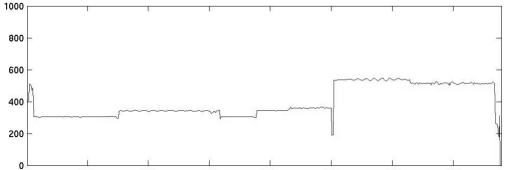


2 **pitch domain**:

- *feature*: pitch contour
- *derivative*: changes in pitch



matlab source: plotOnset.m

[1] N. Collins, "Using a pitch detector for onset detection," in *ISMIR*, 2005, pp. 100–106.

onset detection
novelty function examples 2/3

3. **STFT-based**: compute block difference
   - *flux*
     - $d_{\text{hai}}(n) = \sum_{k=0}^{\mathcal{K}/2-1} \log_2\left(\frac{|X(k,n)|}{|X(k,n-1)|}\right)$
     - $d_{\text{lar}}(n) = \sum_{k=k(f_{\min})}^{k(f_{\max})} \sqrt{|X(k,n)|} - \sqrt{|X(k,n-1)|}$
   - *cosine distance*
   - *complex*

onset detection
novelty function examples 2/3

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onset detection
novelty function examples 2/3

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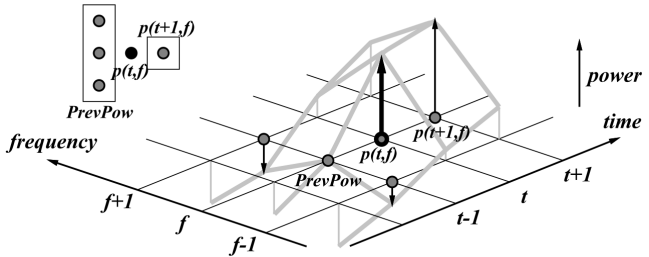
   - *complex*
     - $d_{\mathrm{dux}}(n) = \sum_{k=0}^{\mathcal{K}/2-1} |X(k,n) - X(k,n-1)|$

onset detection
novelty function examples 3/3

3 STFT-based cont'd

- *Goto*-distance[2]
  - higher power than closest preceding and following bins

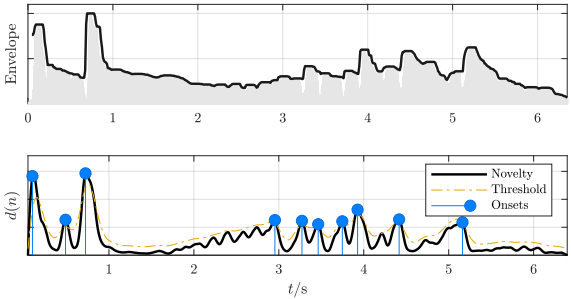
-



[2] M. Goto and Y. Muraoka, "Music Understanding At The Beat Level – Real-time Beat Tracking For Audio Signals," in *Proceedings of the Workshop on Computational Auditory Scene Analysis (IJCAI)*, Aug. 1995.

onset detection
peak picking: introduction

- detect onsets in the smoothed novelty function
- typical **criteria**
  - local maximum & salient peak
  - higher than minimum likelihood
  - not too close to maxima with higher likelihood
  - other options: high attack slope, distance to prev. min, ...



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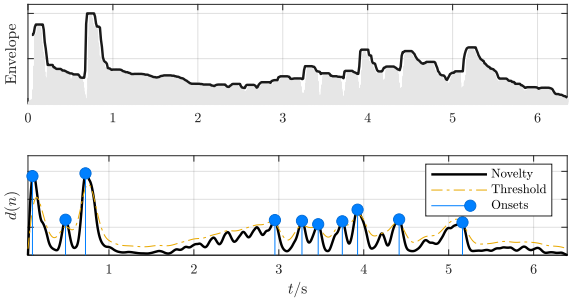


matlab source: plotNovelty.m

onset detection
peak picking: thresholding

- options for thresholding
  - **fixed** threshold

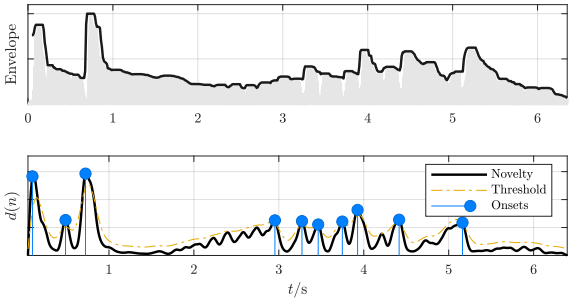
$$G_{d,\mathrm{c}} = \lambda_1$$

  - **smoothed** threshold

$$G_{d,\mathrm{ma}} = \lambda_2 + \sum_{j=0}^{\mathcal{O}-1} b(j) \cdot d(i-j)$$

  - **median** threshold

$$G_{d,\mathrm{me}} = \lambda_2 + \hat{Q}_d(0.5)$$



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onset detection
evaluation

- **goal**
  - compare a series of ground truth onset time stamps with a series of predicted time stamps
- **ground truth annotation** problems
  - deviations between annotators
  - how to annotate quasi-synchronous onsets
- **metrics**
  - measure TP with tolerance range $\Rightarrow$ TP, FN, FP (TN only implicitly)
  - Precision, Recall, F-Measure
  - other metrics
    - mean (absolute) deviation
    - standard deviation
    - max deviation

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summary
lecture content

- **novelty function**
  - measure of unexpectedness - likelihood of an event
    - often a measure similar to flux
- **peak picking**
  - detecting peaks (onsets) in the novelty function
  - usually done by smoothing and adaptive thresholding