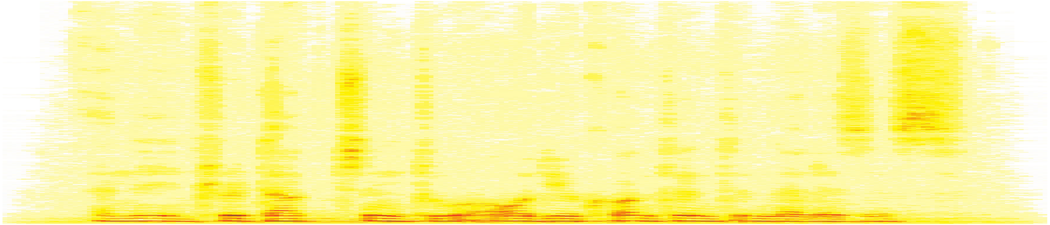
Introduction to Audio Content Analysis

Module 7.1: Audio-to-Audio & Audio-to-Score Alignment

alexander lerch



Georgia Tech Center for Music Technology
College of Design

introduction
overview

corresponding textbook section

Chapter 7: Alignment (pp. 146–150)

- **lecture content**
  - Audio-to-Audio alignment
    - use cases
    - features
    - distance measures
    - typical accuracy
  - Audio-to-Score alignment
- **learning objectives**
  - elaborate on possible use cases for audio-to-audio alignment
  - give examples for features and distance measures for alignment
  - discuss differences between audio-to-audio and audio-to-score alignment

introduction

overview

corresponding textbook section

Chapter 7: Alignment (pp. 146–150)

- **lecture content**
  - Audio-to-Audio alignment
    - use cases
    - features
    - distance measures
    - typical accuracy
  - Audio-to-Score alignment
- **learning objectives**
  - elaborate on possible use cases for audio-to-audio alignment
  - give examples for features and distance measures for alignment
  - discuss differences between audio-to-audio and audio-to-score alignment

audio-to-audio alignment
introduction

- **objective**
  - align two sequences of audio
- **use cases**
  - *quick browsing* for certain parts in recordings
  - *timing adjustment* (backing vocals, loops, . . .)
  - *automated dubbing*
  - *musicological analysis* (timing of several performances)
- **processing steps**
  - extract suitable features
  - compute distance matrix
  - compute alignment path

audio-to-audio alignment
introduction

Georgia Tech Center for Music Technology College of Design

- **objective**
  - align two sequences of audio
- **use cases**
  - *quick browsing* for certain parts in recordings
  - *timing adjustment* (backing vocals, loops, . . .)
  - *automated dubbing*
  - *musicological analysis* (timing of several performances)
- **processing steps**
  - extract suitable features
  - compute distance matrix
  - compute alignment path

audio-to-audio alignment
introduction

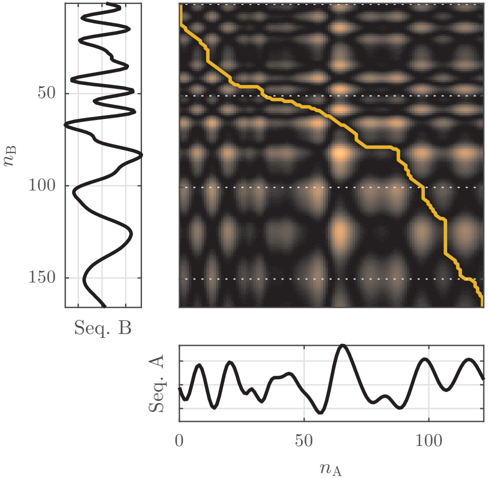
- **objective**
  - align two sequences of audio
- **use cases**
  - *quick browsing* for certain parts in recordings
  - *timing adjustment* (backing vocals, loops, . . .)
  - *automated dubbing*
  - *musicological analysis* (timing of several performances)
- **processing steps**
  - extract suitable features
  - compute distance matrix
  - compute alignment path

audio-to-audio alignment

alignment path computation

Georgia Tech Center for Music Technology College of Design

→ prerequisite: Module 7.0—Dynamic Time Warping



matlab source: matlab/displayDtw.m

audio-to-audio alignment
features

- **use case examples**
  - **quick browsing** — find the same part across files
    ⇒ use *pitch based* features
  - **timing adjustment** — backing vocals to lead vocals
    ⇒ use *intensity based* features
  - **automated dubbing** — same speaker several recordings
    ⇒ use *intensity based* and *timbre based* features
- **feature categories**
  - **intensity**: energy, onset probability, . . .
  - **tonal**: pitch chroma, . . .
  - **timbral**: MFCCs, spectral shape, . . .

  plot from[1]

[1] H. Kirchhoff and A. Lerch, "Evaluation of Features for Audio-to-Audio Alignment," *Journal of new music research*, vol. 40, no. 1, pp. 27–41, 2011. DOI: 10.1080/09298215.2010.529917.

audio-to-audio alignment

features

Georgia Tech Center for Music Technology College of Design

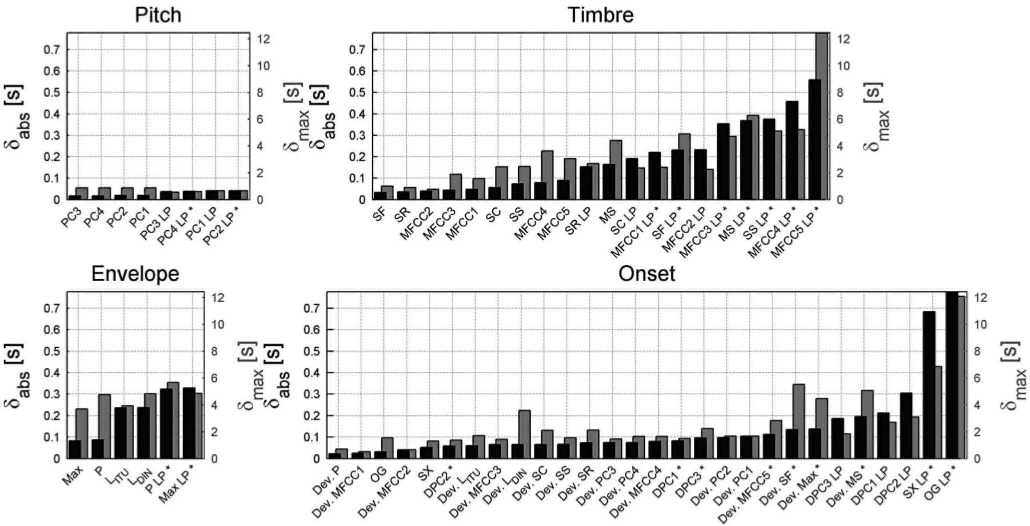
- **use case examples**
  - **quick browsing** — find the same part across files
    $\Rightarrow$ use *pitch based* features
  - **timing adjustment** — backing vocals to lead vocals
    $\Rightarrow$ use *intensity based* features
  - **automated dubbing** — same speaker several recordings
    $\Rightarrow$ use *intensity based* and *timbre based* features
- **feature categories**
  - **intensity**: energy, onset probability, ...
  - **tonal**: pitch chroma, ...
  - **timbral**: MFCCs, spectral shape, ...

plot from[1]

[1] H. Kirchhoff and A. Lerch, "Evaluation of Features for Audio-to-Audio Alignment," *Journal of new music research*, vol. 40, no. 1, pp. 27–41, 2011. DOI: 10.1080/09298215.2010.529917.

audio-to-audio alignment

features



audio-to-audio alignment

compute distance matrix — distance measures

- typical distance measures
  - *Euclidean distance*: $d_{\mathrm{E}}(s) = \sqrt{\sum\limits_{j=0}^{11}\left(\nu_{\mathrm{e}}(j) - \nu_{\mathrm{t,s}}(j)\right)^2}$
  - *Manhattan distance*: $d_{\mathrm{M}}(s) = \sum\limits_{j=0}^{11}\left|\nu_{\mathrm{e}}(j) - \nu_{\mathrm{t,s}}(j)\right|$
  - *Cosine distance*: $d_{\mathrm{C}}(s) = 1 - \left(\frac{\sum\limits_{j=0}^{11}\nu_{\mathrm{e}}(j)\cdot\nu_{\mathrm{t,s}}(j)}{\sqrt{\sum\limits_{j=0}^{11}\nu_{\mathrm{e}}(j)^2}\sqrt{\cdot\sum\limits_{j=0}^{11}\nu_{\mathrm{t,s}}(j)^2}}\right)$
  - *Kullback-Leibler divergence*: $d_{\mathrm{KL}}(s) = \sum\limits_{j=0}^{11}\nu_{\mathrm{e}}(j)\cdot\log\left(\frac{\nu_{\mathrm{e}}(j)}{\nu_{\mathrm{t,s}}(j)}\right)$
- data-driven approach: train classifier with 2-class problem[1]

[1] H. Kirchhoff and A. Lerch, "Evaluation of Features for Audio-to-Audio Alignment," *Journal of new music research*, vol. 40, no. 1, pp. 27–41, 2011. DOI: 10.1080/09298215.2010.529917.

audio-to-audio alignment

compute distance matrix — distance measures

- typical distance measures
  - *Euclidean distance*: $d_\mathrm{E}(s) = \sqrt{\sum\limits_{j=0}^{11} \left(\nu_\mathrm{e}(j) - \nu_\mathrm{t,s}(j)\right)^2}$
  - *Manhattan distance*: $d_\mathrm{M}(s) = \sum\limits_{j=0}^{11} \left|\nu_\mathrm{e}(j) - \nu_\mathrm{t,s}(j)\right|$
  - *Cosine distance*: $d_\mathrm{C}(s) = 1 - \left(\frac{\sum\limits_{j=0}^{11} \nu_\mathrm{e}(j)\cdot\nu_\mathrm{t,s}(j)}{\sqrt{\sum\limits_{j=0}^{11} \nu_\mathrm{e}(j)^2}\sqrt{\cdot\sum\limits_{j=0}^{11} \nu_\mathrm{t,s}(j)^2}}\right)$
  - *Kullback-Leibler divergence*: $d_\mathrm{KL}(s) = \sum\limits_{j=0}^{11} \nu_\mathrm{e}(j)\cdot\log\left(\frac{\nu_\mathrm{e}(j)}{\nu_\mathrm{t,s}(j)}\right)$
- data-driven approach: train classifier with 2-class problem[1]

[1] H. Kirchhoff and A. Lerch, "Evaluation of Features for Audio-to-Audio Alignment," *Journal of new music research*, vol. 40, no. 1, pp. 27–41, 2011. DOI: 10.1080/09298215.2010.529917.

audio-to-audio alignment

compute distance matrix — distance measures

- typical distance measures
  - *Euclidean distance*: $d_\mathrm{E}(s) = \sqrt{\sum\limits_{j=0}^{11}\left(\nu_\mathrm{e}(j) - \nu_\mathrm{t,s}(j)\right)^2}$
  - *Manhattan distance*: $d_\mathrm{M}(s) = \sum\limits_{j=0}^{11}\left|\nu_\mathrm{e}(j) - \nu_\mathrm{t,s}(j)\right|$
  - *Cosine distance*: $d_\mathrm{C}(s) = 1 - \left(\frac{\sum\limits_{j=0}^{11}\nu_\mathrm{e}(j)\cdot\nu_\mathrm{t,s}(j)}{\sqrt{\sum\limits_{j=0}^{11}\nu_\mathrm{e}(j)^2}\sqrt{\cdot\sum\limits_{j=0}^{11}\nu_\mathrm{t,s}(j)^2}}\right)$
  - *Kullback-Leibler divergence*: $d_\mathrm{KL}(s) = \sum\limits_{j=0}^{11}\nu_\mathrm{e}(j)\cdot\log\left(\frac{\nu_\mathrm{e}(j)}{\nu_\mathrm{t,s}(j)}\right)$
- data-driven approach: train classifier with 2-class problem[1]

[1] H. Kirchhoff and A. Lerch, "Evaluation of Features for Audio-to-Audio Alignment," *Journal of new music research*, vol. 40, no. 1, pp. 27–41, 2011. DOI: 10.1080/09298215.2010.529917.

audio-to-audio alignment

compute distance matrix — distance measures

Georgia Tech Center for Music Technology College of Design

- typical distance measures
  - *Euclidean distance*: $d_\mathrm{E}(s) = \sqrt{\sum\limits_{j=0}^{11}\left(\nu_\mathrm{e}(j) - \nu_\mathrm{t,s}(j)\right)^2}$
  - *Manhattan distance*: $d_\mathrm{M}(s) = \sum\limits_{j=0}^{11}\left|\nu_\mathrm{e}(j) - \nu_\mathrm{t,s}(j)\right|$
  - *Cosine distance*: $d_\mathrm{C}(s) = 1 - \left(\frac{\sum\limits_{j=0}^{11}\nu_\mathrm{e}(j)\cdot\nu_\mathrm{t,s}(j)}{\sqrt{\sum\limits_{j=0}^{11}\nu_\mathrm{e}(j)^2}\sqrt{\cdot\sum\limits_{j=0}^{11}\nu_\mathrm{t,s}(j)^2}}\right)$
  - *Kullback-Leibler divergence*: $d_\mathrm{KL}(s) = \sum\limits_{j=0}^{11}\nu_\mathrm{e}(j)\cdot\log\left(\frac{\nu_\mathrm{e}(j)}{\nu_\mathrm{t,s}(j)}\right)$
- data-driven approach: train classifier with 2-class problem[1]

[1] H. Kirchhoff and A. Lerch, "Evaluation of Features for Audio-to-Audio Alignment," *Journal of new music research*, vol. 40, no. 1, pp. 27–41, 2011. DOI: 10.1080/09298215.2010.529917.

audio-to-audio alignment

compute distance matrix — distance measures

Georgia Tech | Center for Music Technology | College of Design

- typical distance measures
- data-driven approach: train classifier with 2-class problem[1]

b_{orig} \ $b_{stretch}$	34	35	36	37	38	39	40	41
34	0	1	1	1	1	1	1	1
35	1	0	1	1	1	1	1	1
36	1	0	1	1	1	1	1	1
37	1	1	0	0	1	1	1	1
38	1	1	1	1	0	0	1	1
39	1	1	1	1	1	1	0	1
40	1	1	1	1	1	1	1	0
41	1	1	1	1	1	1	1	0

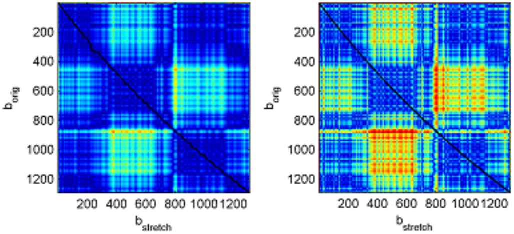
[1] H. Kirchhoff and A. Lerch, "Evaluation of Features for Audio-to-Audio Alignment," *Journal of new music research*, vol. 40, no. 1, pp. 27–41, 2011. DOI: 10.1080/09298215.2010.529917.

audio-to-audio alignment

compute distance matrix — distance measures

Georgia Tech Center for Music Technology College of Design

- typical distance measures
- data-driven approach: train classifier with 2-class problem[1]

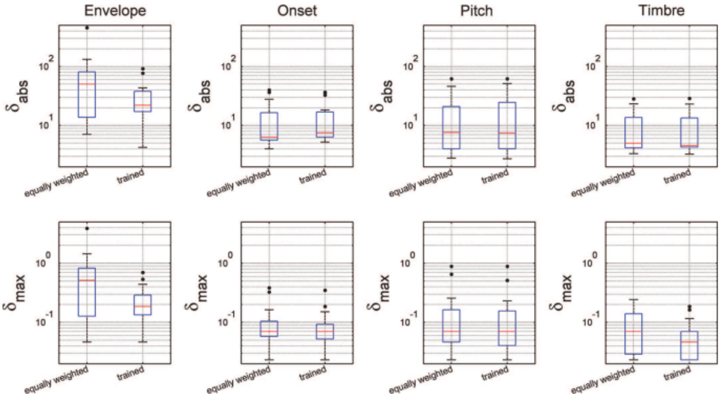


[1] H. Kirchhoff and A. Lerch, "Evaluation of Features for Audio-to-Audio Alignment," *Journal of new music research*, vol. 40, no. 1, pp. 27–41, 2011. DOI: 10.1080/09298215.2010.529917.

audio-to-audio alignment

typical results

Georgia Tech Center for Music Technology College of Design



originals **synced**

left: instrumental

right: a capella

2

[2] H. Kirchhoff and A. Lerch, "Evaluation of Features for Audio-to-Audio Alignment," *Journal of new music research*, vol. 40, no. 1, pp. 27–41, 2011. DOI: 10.1080/09298215.2010.529917.

audio-to-score alignment
overview

- **objective**
  - align an audio sequence with a score sequence
- **use cases**
  - score viewer
  - music education
  - identify matching score/audio via cost function
  - musicological analysis
- **processing steps**
  - see audio-to-audio alignment

audio-to-score alignment

overview

- **objective**
    - align an audio sequence with a score sequence
- **use cases**
    - score viewer
    - music education
    - identify matching score/audio via cost function
    - musicological analysis
- **processing steps**
    - see audio-to-audio alignment

audio-to-score alignment

overview

- **objective**
  - align an audio sequence with a score sequence
- **use cases**
  - score viewer
  - music education
  - identify matching score/audio via cost function
  - musicological analysis
- **processing steps**
  - see audio-to-audio alignment

audio-to-score alignment
challenges

- features from **different domains** (no timbre and proper loudness information in the score)
  - *approach 1*: convert score into audio-like representation
    - MIDI-to-audio
    - use model for harmonics and ADSR
  - *approach 2*: convert audio into score-like representation
    - audio-to-MIDI
    - pitch chroma
    - event-based segmentation
- pauses and rests
  - DTW algorithm has no graceful way of dealing with pauses

audio-to-score alignment
challenges

- features from **different domains** (no timbre and proper loudness information in the score)
  - *approach 1*: convert score into audio-like representation
    - MIDI-to-audio
    - use model for harmonics and ADSR
  - *approach 2*: convert audio into score-like representation
    - audio-to-MIDI
    - pitch chroma
    - event-based segmentation
- pauses and rests
  - DTW algorithm has no graceful way of dealing with pauses

summary
lecture content

- **audio-to-audio alignment**
  1. extract features
  2. create distance matrix with suitable distance measure
  3. use DTW to find alignment path
  4. (use time-stretching to actually align the sequences)

- **audio-to-score alignment**
  1. extract usually pitch-based features
  2. distance measure
  3. use DTW, HMM, etc to extract alignment path