Synchronizing Audio Signals
-
via Landmark Cross Correlation

by Lea N. Possberg

Seminar: Speech Processing

November 30, 2017

Motivation

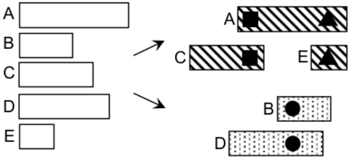

Figure: Clustering and Synchronization (Bryan, Smaragdis, Mysore, 2012)

Cross Correlation Function R

$$R_{f,g}(\tau) = \sum_{t=-\infty}^{\infty} f^*(t)g(\tau + t)$$

What does R do?

Video

(https://www.youtube.com/watch?v=L6YJqhbsuFY)

Cross Correlation Function R - Landmark Signals

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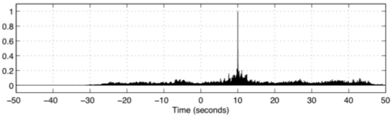
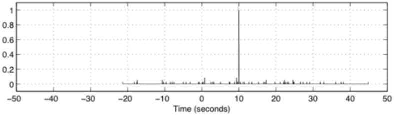
Landmark Signals - Why?



(a) Normalized absolute time-domain cross-correlation.



(b) Normalized landmark cross-correlation.

Figure: Absolute vs. Landmark Cross Correlation (Bryan, Smaragdis, Mysore, 2012)

Generating Landmark Signals - How?

Follow Steps 1-4

1. Take the Short Time FT of a given audio signal

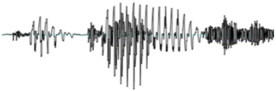


Figure: Given audio signal

$\xrightarrow{\text{STFT}}$

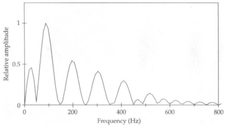


Figure: Spectrum

(Images: Wagner, 2017)

2. Identify frequency peaks and create landmark tuple

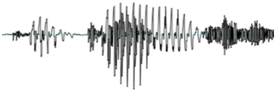
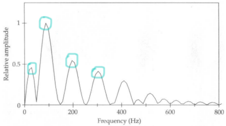


Figure: Given audio signal

STFT
⟶



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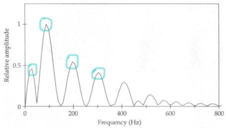

Figure: Spectrum

$$\text{landmark} = (\text{frequency}, \text{timevalue}) = (f_1, t_1)$$

"time idexed frequency value"

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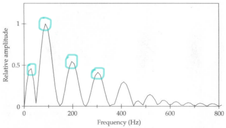

Figure: Spectrum

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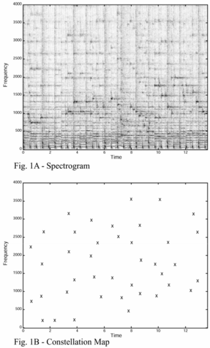

Figure: Spectrogram (Wang, 2003)

3. Pair landmarks with nearest other landmarks

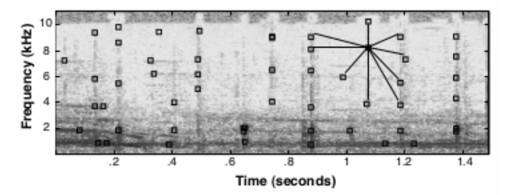

Figure: Spectrogram (Kennedy, Naaman, 2009)

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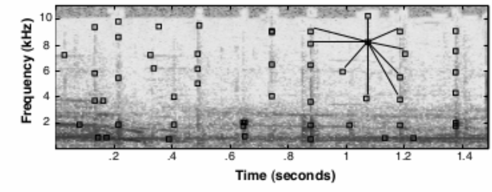

Figure: Spectrogram (Kennedy, Naaman, 2009)

$$\text{landmark-pair} = \text{landmark} = (\text{frequency}, \text{frequency}, \text{timevalue})$$
$$= (f_1, f_2, t_2 - t_1)$$

"time indexed landmark"

4. Hash each landmark and create feature vector

$$hash : landmark \rightarrow integer$$

$$(f_1, f_2, t_2 - t_1) \mapsto 2$$

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Understanding R

$$\boxed{\begin{pmatrix} 0 \\ 1 \\ \dots \\ 0 \end{pmatrix} = L(t=6)}$$

$$R_{L_i,L_j}(\tau) = \sum_{t=-\infty}^{\infty} L_i(t)^T L_j(\tau + t)$$

Understanding R

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"Amout of matching landmarks in both signals at one point in time"

"Total amount of matching landmarks for one time shift τ"

Understanding R

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Synchronizing both signals

$$\hat{\tau}_{ij} = arg \max_{\tau} R_{L_i, L_j}(\tau)$$

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"time offset to align both signals L_i and L_j"

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- 2 loops over t, τ $\longrightarrow$ $\mathbf{O(n^2)}$

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- use FFT: no need to loop over t anymore, only 1 loop over τ $\longrightarrow$ $\mathbf{O(n \log n)}$

FFT of the two signals

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Frequency Domain: $FFT(f^*) * FFT(g)$

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2. Reduce costs by transforming absolute signals f, g to Landmark signals L_i, L_j
3. Reduce complexity by applying the FFT to both signals before multiplying them, then apply IFFT to the result

Sources

"Clustering and Synchronizing Multi-Camera Video via Landmark Cross-Correlation", Bryan, Smaragdis, Mysore, 2012

https://www.youtube.com/watch?v=L6YJqhbsuFY

Wagner, 2017 (Lecture "Phonetik und Phonologie" Slides "Akustische Phonetik")

"An Industrial-Strength Audio Search Algorithm", Wang, 2003

"Less Talk, More Rock: Automated Organization of Community-Contributed Collections of Concert Videos", Kennedy and Naaman, 2009