EE269
Signal Processing for Machine Learning

Lecture 3 Part II

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Outline

- Short Time Fourier Transform
- Spectral Descriptors
- Examples

Recap: Continuous Time vs Discrete Fourier Transform

Continuous Time Fourier Transform

$$X_c(f) = \int e^{-j2\pi ft} dt$$

Discrete Fourier Transform

$$X[k] = \sum_{n=0}^{N-1} x[n] e^{-2\pi jkn/N}$$

Short Time Fourier Transform (STFT)

$$X(f,t) = \int w(t-\tau)x(\tau)e^{-j2\pi f\tau}d\tau$$

- $w(t)$: window signal
- Discrete STFT

$$X_{nm} = DFT\{w[nD-k]x[k]\}$$

- D: hop length

Inverting STFT

$$X_{nm} = DFT\{w[nD - k]x[k]\}$$

suppose that

- $\sum_{n=-\infty}^{\infty} w[nD - k] = 1$
  constant overlap-add property: rectangular window, Hanning or Hamming windows satisfy this property
- then signal is recoverable

$$x[k] = \sum_{n} DFT^{-1}\{X_{nm}\}$$

Spectral Descriptors

- spectral centroid
- spectral spread
- spectral skewness
- spectral kurtosis
- spectral entropy
- spectral flatness
- spectral crest
- spectral flux
- spectral slope

$\vdots$

Applications of Spectral Descriptors

- Speaker identification and recognition
- Acoustic scene recognition
- Instrument recognition
- Music genre classification
- Mood recognition
- Voice activity detection

$\vdots$

Spectral Centroid

- spectral centroid μ_1 is the frequency-weighted sum normalized by the unweighted sum

$$\mu_1 = \frac{\sum_{k=b_1}^{b_2} f_k s_k}{\sum_{k=b_1}^{b_2} s_k}$$

  f_k is the frequency in Hz corresponding to bin k

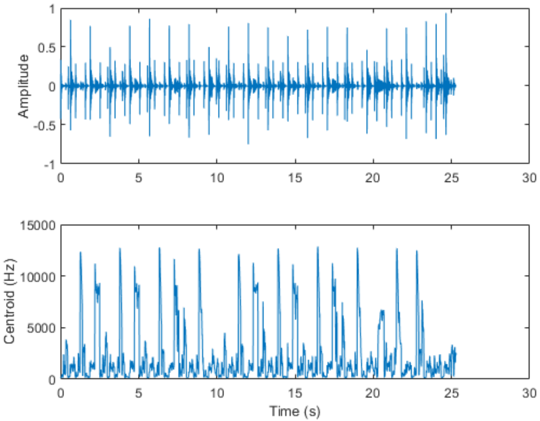
  s_k is the spectral value at bin k

    magnitude spectrum $|X[k]|$ and power spectrum $|X[k]|^2$ are commonly used

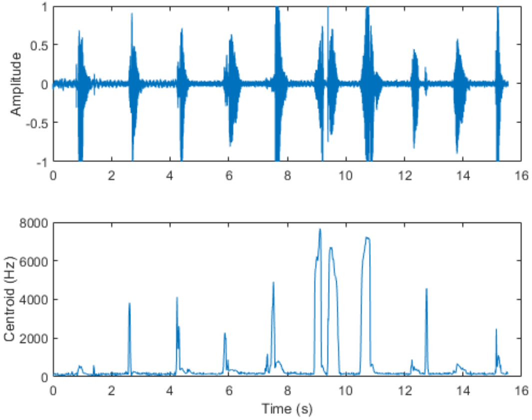
  b_1 and b_2 are band edges, over which to calculate the centroid

Spectral Centroid - Example 1

- represents *center of gravity* of the spectrum, and indicates *brightness*. It is commonly used in music analysis and genre classification.
- for example, the jumps in the centroid corresponding to high hat hits



Spectral Centroid - Example 2



Spectral Spread

- spectral spread μ_2 is the standard deviation around the spectral centroid μ_1
- represents instantaneous bandwidth

$$\mu_2 = \sqrt{\frac{\sum_{k=b_1}^{b_2} (f_k - \mu_1)^2 s_k}{\sum_{k=b_1}^{b_2} s_k}}$$

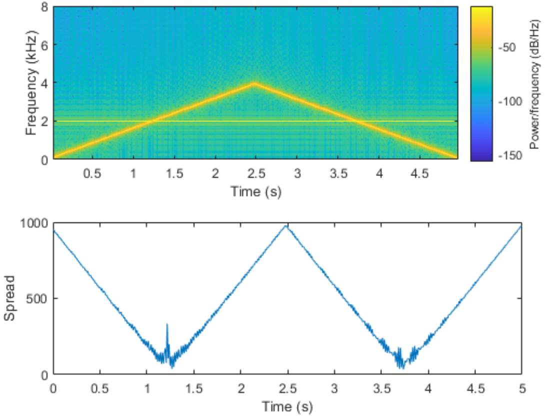
f_k is the frequency in Hz corresponding to bin k

s_k is the spectral value at bin k

b_1 and b_2 are band edges, over which to calculate the spread

μ_1 is the spectral centroid

Spectral Spread - Example



Spectral Kurtosis

- spectral kurtosis μ_4 is the fourth order moment

  measures flatness, or non-Gaussianity of the spectrum around the centroid

  $$\mu_2 = \frac{\sum_{k=b_1}^{b_2} (f_k - \mu_1)^4 s_k}{(\mu_2)^4 \sum_{k=b_1}^{b_2} s_k}$$

  f_k is the frequency in Hz corresponding to bin k

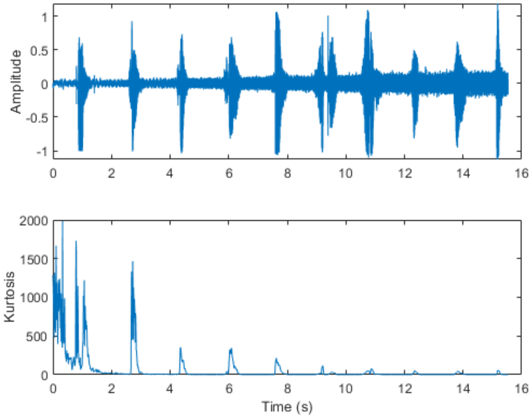
  s_k is the spectral value at bin k

  b_1 and b_2 are band edges, over which to calculate the kurtosis

  μ_1 is the spectral centroid

  μ_2 is the spectral spread

Spectral Kurtosis - Example



Spectral Entropy

- spectral entropy represents the peakiness of the spectrum
  measure of disorder

  $$\text{entropy} = \frac{-\sum_{k=b_1}^{b_k} s_k \log s_k}{\log(b_2 - b_1)}$$

  f_k is the frequency in Hz corresponding to bin k

  s_k is the spectral value at bin k

  b_1 and b_2 are band edges, over which to calculate the entropy
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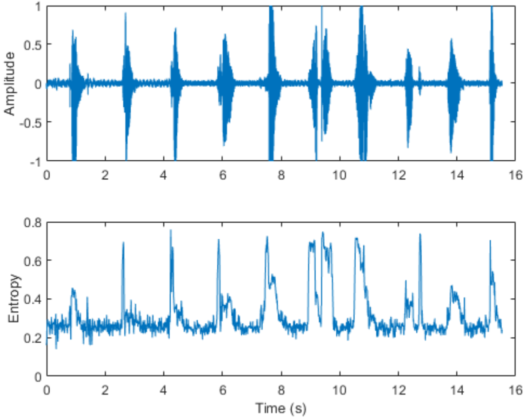
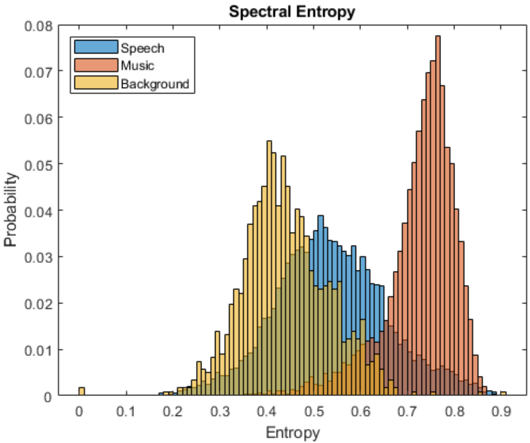
Spectral Entropy - Example 1

- Spectral entropy has been used successfully in voiced/unvoiced decisions for speech recognition



Spectral Entropy - Example 2

- Spectral entropy has also been used to discriminate between speech and music



Spectral Flux

- spectral flux represents the variability of the spectrum over time

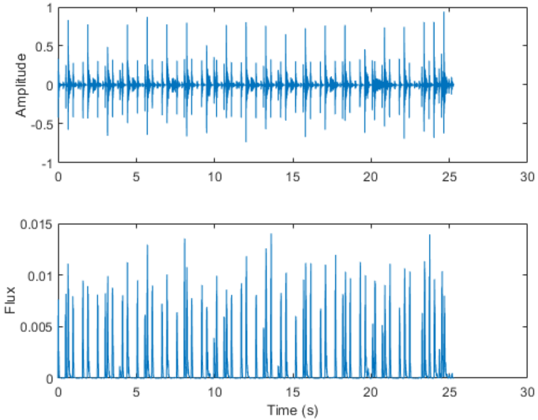
  $$\text{flux} = \left(\sum_{k=b_1}^{b_2} |s_k(t) - s_k(t-1)|^p \right)^{\frac{1}{p}}$$

  s_k is the spectral value at bin k

  b_1 and b_2 are band edges, over which to calculate the spectral flux
- p is the norm type, e.g., $p = 1$ or $p = 2$

Spectral Flux - Example

- For example, the beats in the drum track correspond to high spectral flux



References

- https://www.mathworks.com/help/audio/ug/spectral-descriptors.html
- Murthy, H.a., F. Beaufays, L.p. Heck, and M. Weintraub. "Robust Text-Independent Speaker Identification over Telephone Channels." IEEE Transactions on Speech and Audio Processing. Vol. 7, Issue 5, 1999, pp. 554–568.
- Peeters, G. "A Large Set of Audio Features for Sound Description (Similarity and Classification) in the CUIDADO Project." Technical Report; IRCAM: Paris, France, 2004.
- Grey, John M., and John W. Gordon. "Perceptual Effects of Spectral Modifications on Musical Timbres." The Journal of the Acoustical Society of America. Vol. 63, Issue 5, 1978, pp. 1493–1500.
- S. Zhang, Y. Guo, and Q. Zhang, "Robust Voice Activity Detection Feature Design Based on Spectral Kurtosis." First International Workshop on Education Technology and Computer Science, 2009, pp. 269–272.
- Hansen, John H. L., and Sanjay Patil. "Speech Under Stress: