Mel-Frequency Cepstral Coefficients Explained Easily

Valerio Velardo

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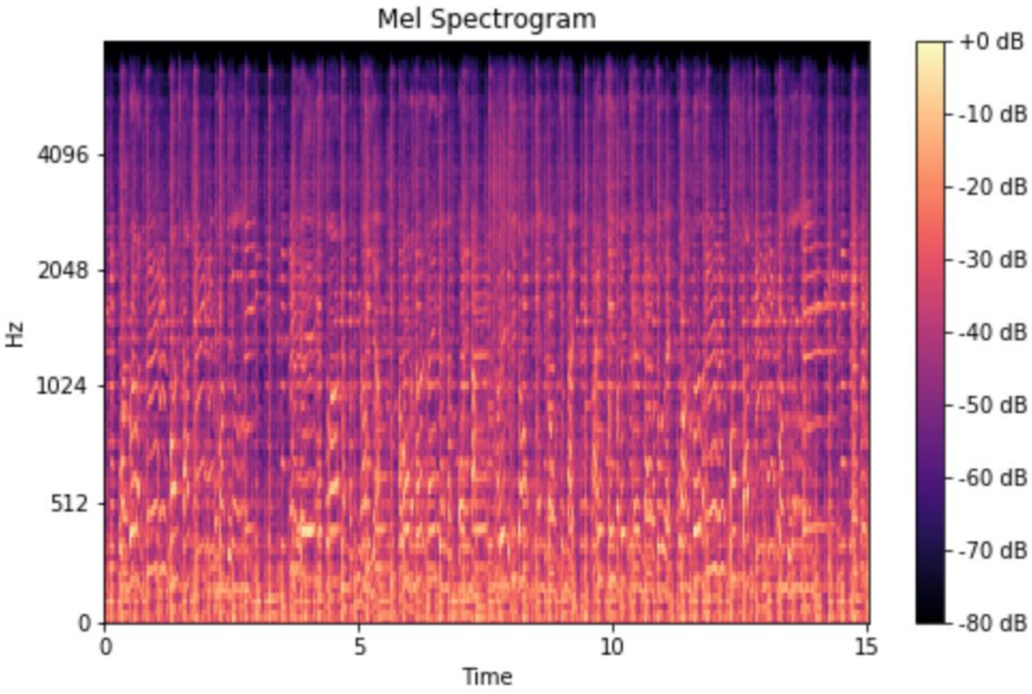
Previously...



Mel Spectrogram
4096
2048
Hz
1024
512
0
0
5
10
15
Time
+0 dB
-10 dB
-20 dB
-30 dB
-40 dB
-50 dB
-60 dB
-70 dB
-80 dB

Mel-Frequency Cepstral Coefficients

Mel-Frequency Cepstral Coefficients

Mel-Frequency Cepstral Coefficients

Mel-Frequency Cepstral Coefficients

Cepstrum

Cepstrum

Cepstrum

Spectrum

Cepstrum

$\Downarrow$

Spectrum

Cepstrum

Spectrum

Quefrency

Liftering

Rhamonic

Cepstrum	Quefrency	Liftering	Rhamonic
Spectrum	Frequency	Filtering	Harmonic

An historical note on Cepstrum

- Developed while studying echoes in seismic signals (1960s)
- Audio feature of choice for speech recognition / identification (1970s)
- Music processing (2000s)

Computing the cepstrum

$$C(x(t)) = F^{-1}[log(F[x(t)])]$$

Computing the cepstrum

Time-domain
signal

$$C(\boxed{x(t)}) = F^{-1}[log(F[\boxed{x(t)}])]$$

Computing the cepstrum

Time-domain signal

Spectrum

$$C(x(t)) = F^{-1}[log(F[x(t)])]$$

Computing the cepstrum

$$C(\overbrace{x(t)}^{\text{Time-domain signal}}) = F^{-1}[\underbrace{log(\overbrace{F[x(t)]}^{\text{Spectrum}})}_{\text{Log spectrum}}]$$

Computing the cepstrum

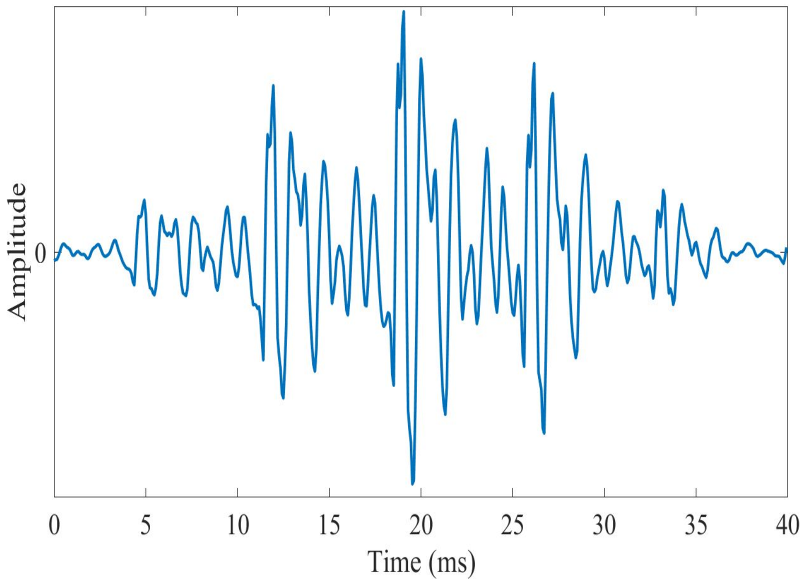
$$C(\overbrace{x(t)}^{\text{Time-domain signal}}) = \underbrace{F^{-1}[\underbrace{log(\overbrace{F[x(t)]}^{\text{Spectrum}})}_{\text{Log spectrum}}]}_{\text{Cepstrum}}$$

Spectrum
of
a spectrum

Cepstrum

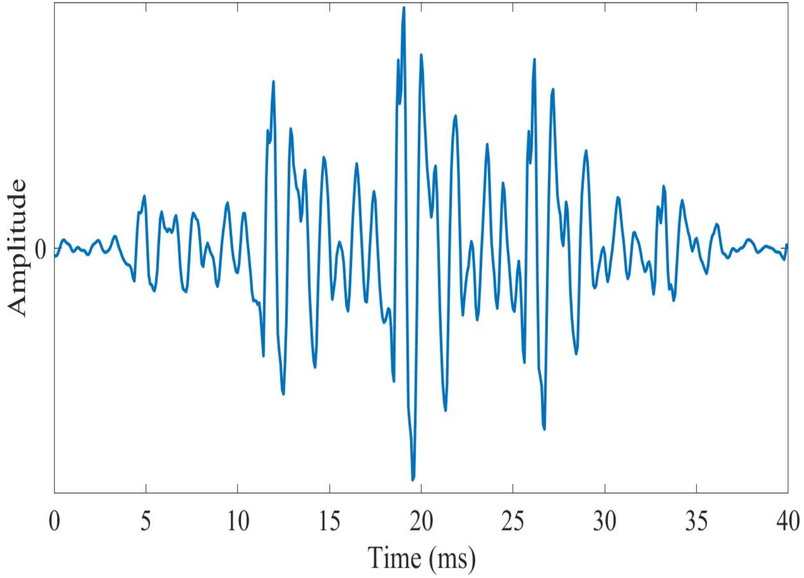
Visualising the cepstrum

Signal



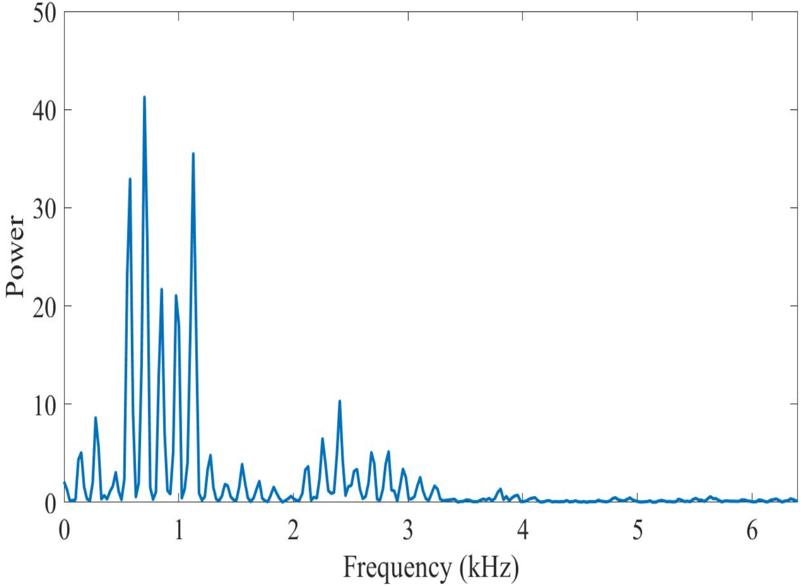
Visualising the cepstrum

Signal



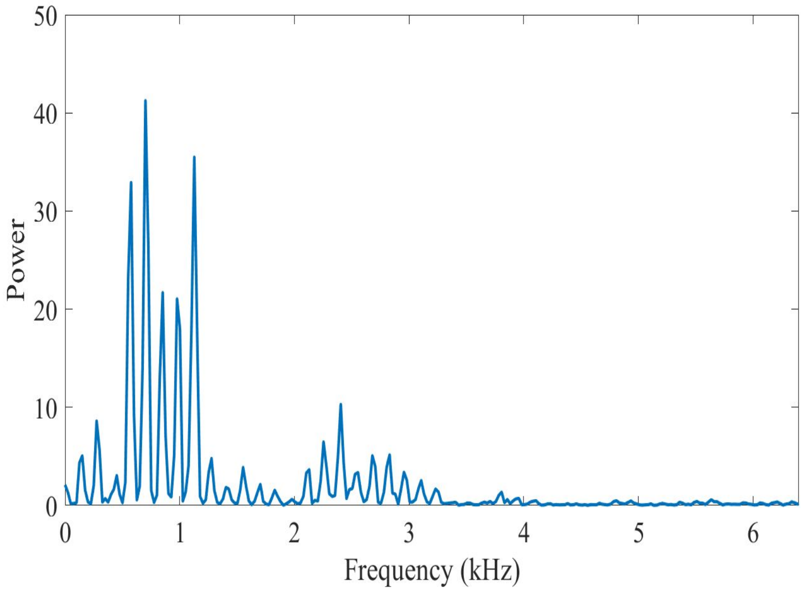
DFT

Power spectrum



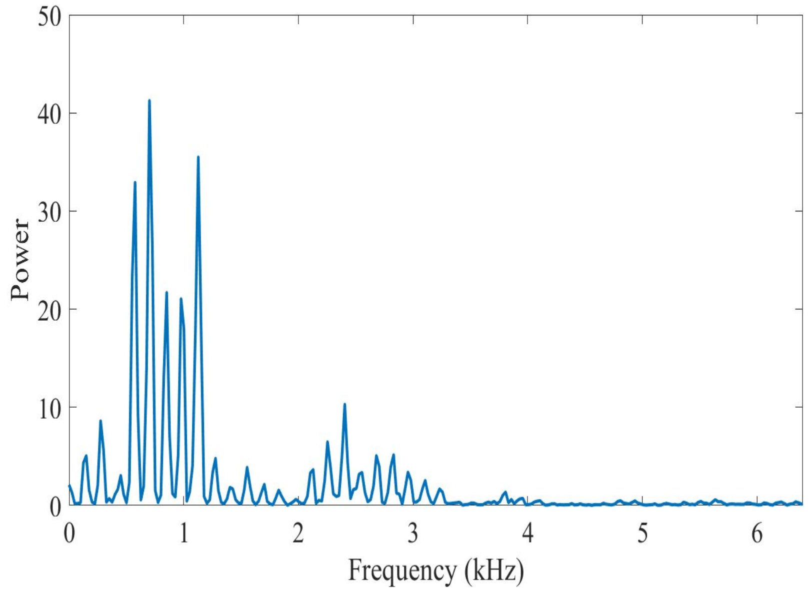
Visualising the cepstrum

Power spectrum

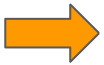


Visualising the cepstrum

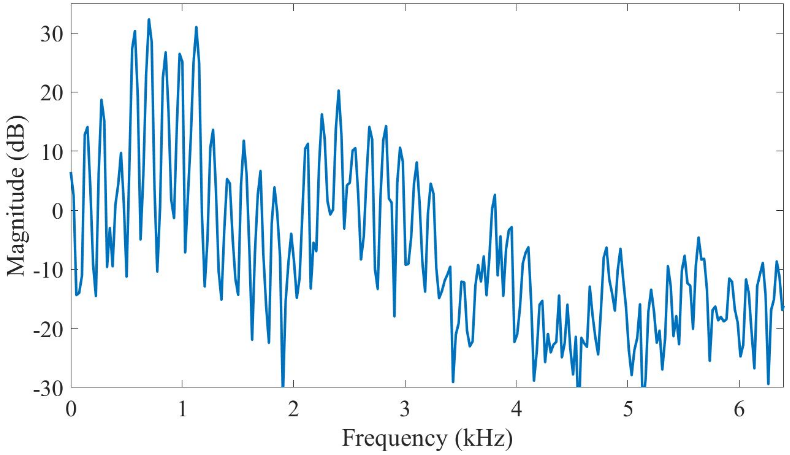
Power spectrum



log

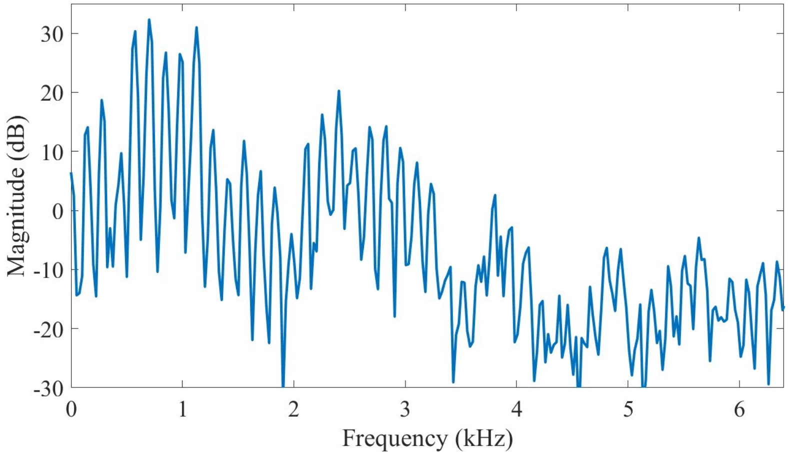


Log power spectrum



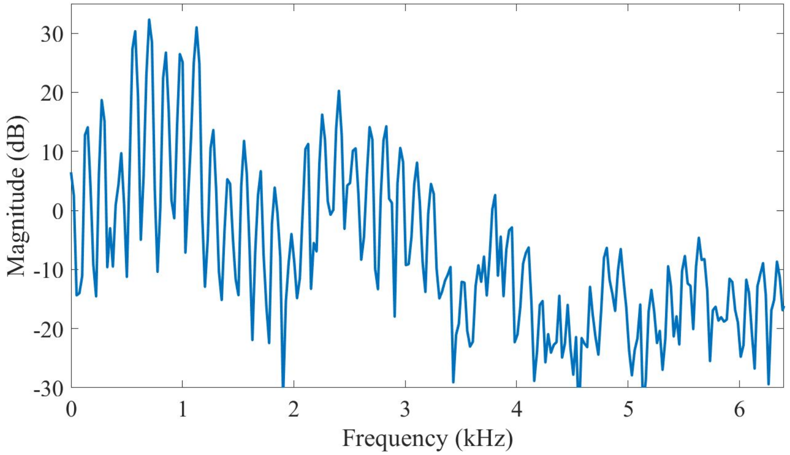
Visualising the cepstrum

Log power spectrum



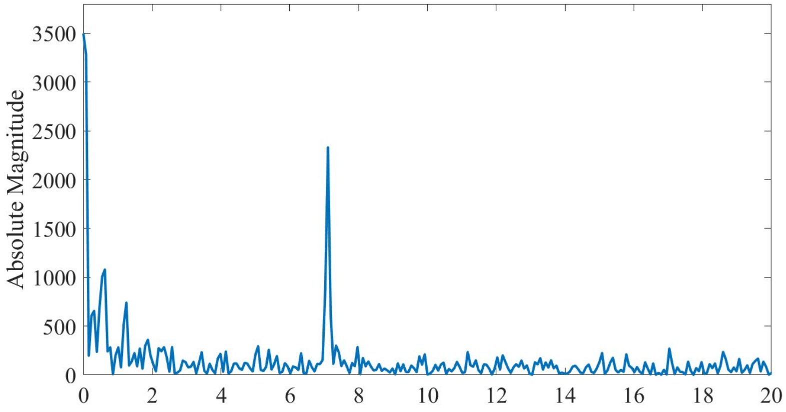
Visualising the cepstrum

Log power spectrum



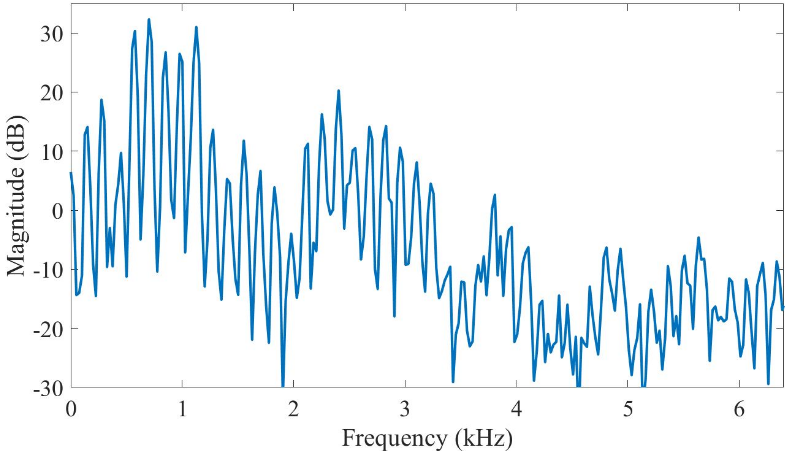
IDFT

Cepstrum



Visualising the cepstrum

Log power spectrum



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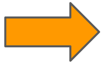
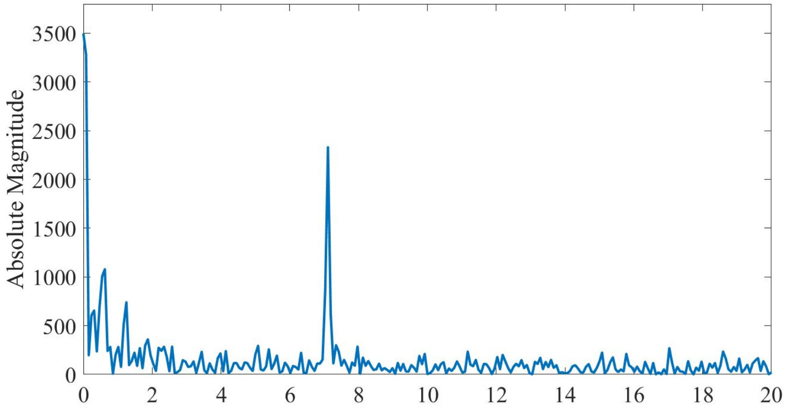


Cepstrum



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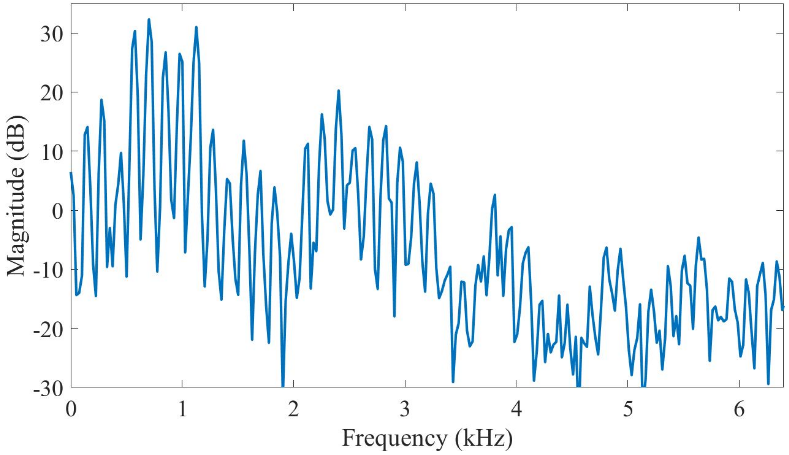
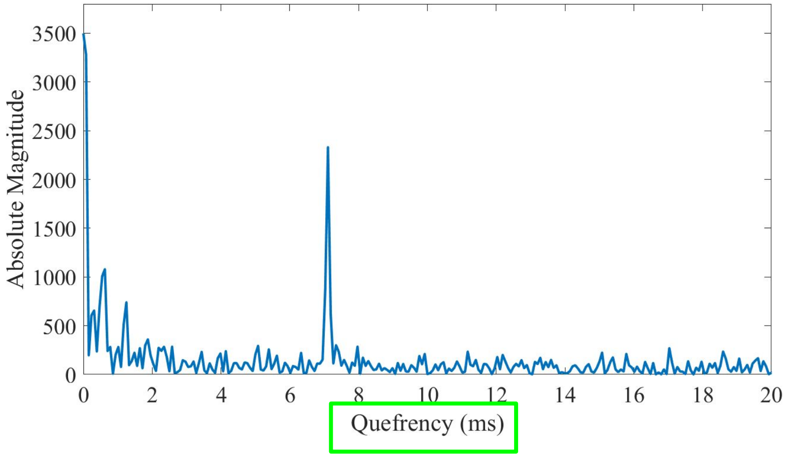
Visualising the cepstrum

Log power spectrum

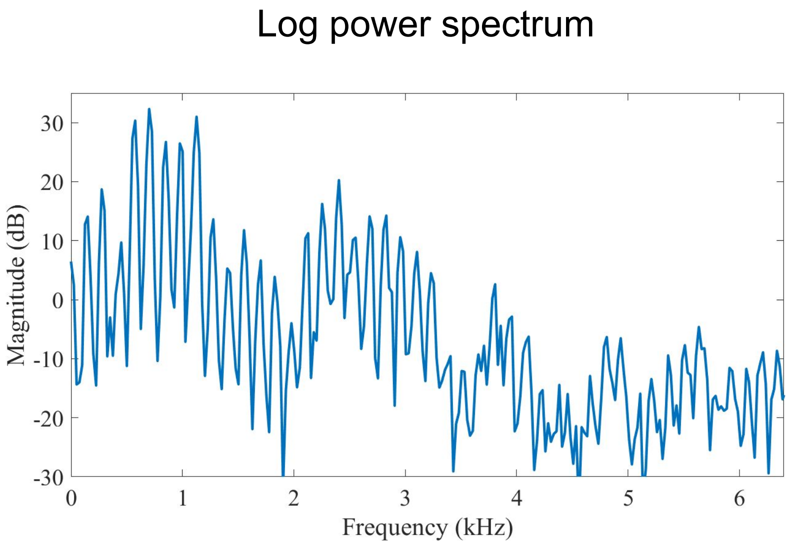


IDFT

Cepstrum



Visualising the cepstrum



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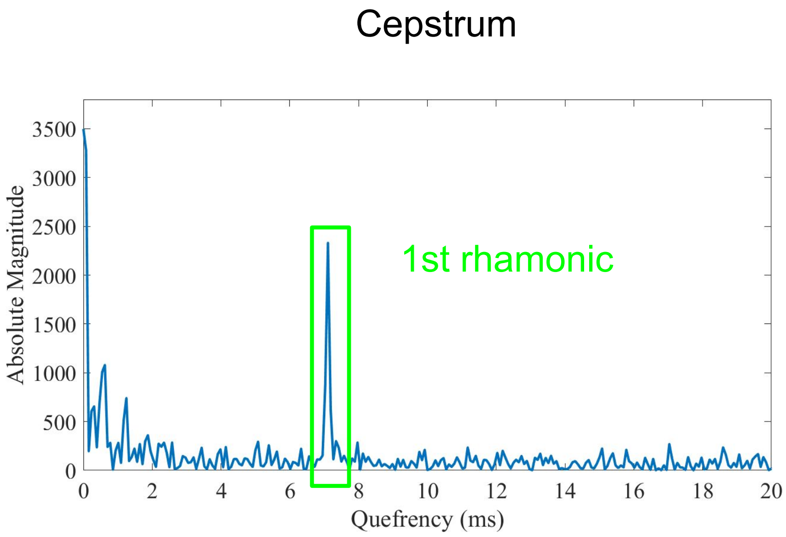
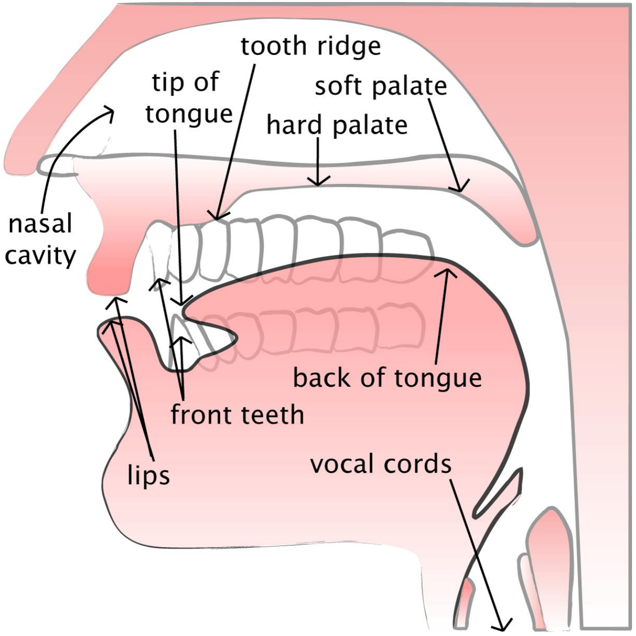


The vocal tract



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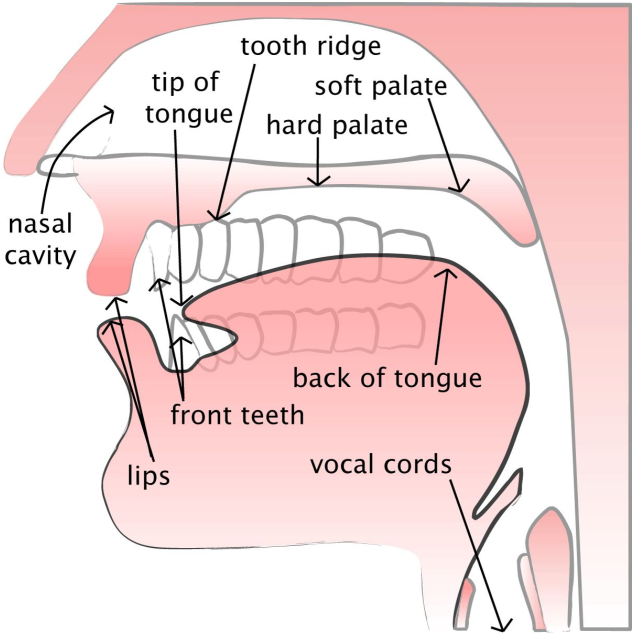
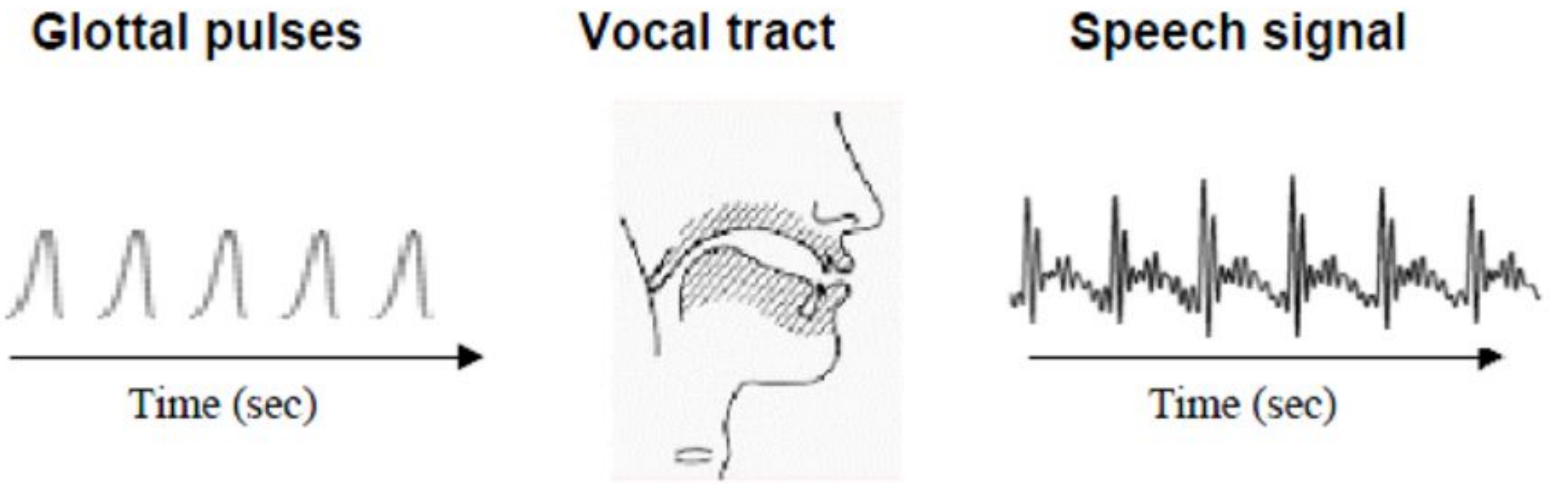


Vocal tract acts as a filter

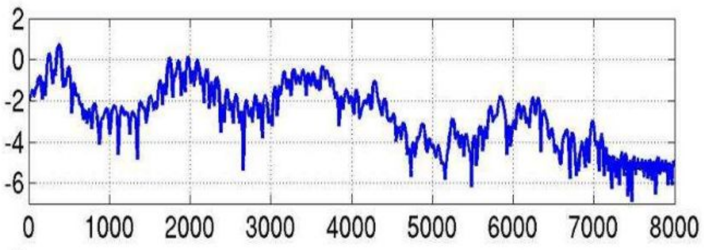
Speech generation



Understanding the cepstrum

Log-spectrum

dB



Hz

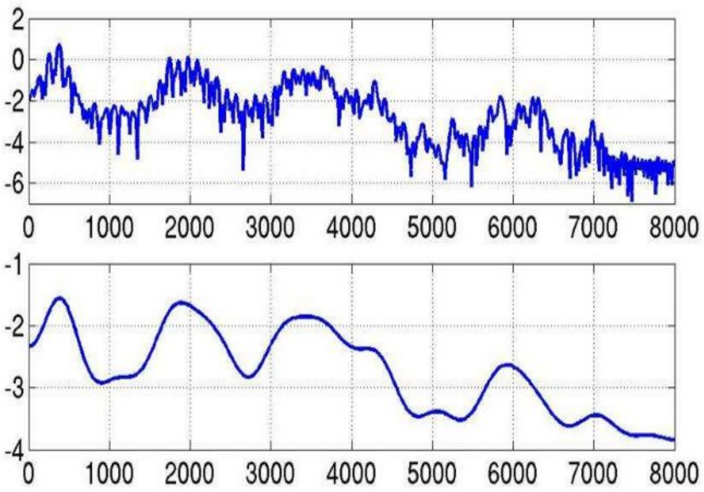
Speech

Understanding the cepstrum

Log-spectrum

dB

Speech



Spectral envelope

Hz

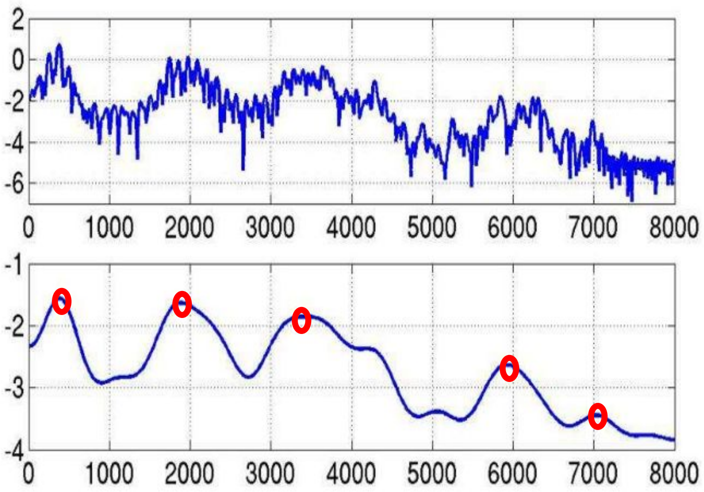
Understanding the cepstrum

Log-spectrum

dB

Speech

Spectral envelope

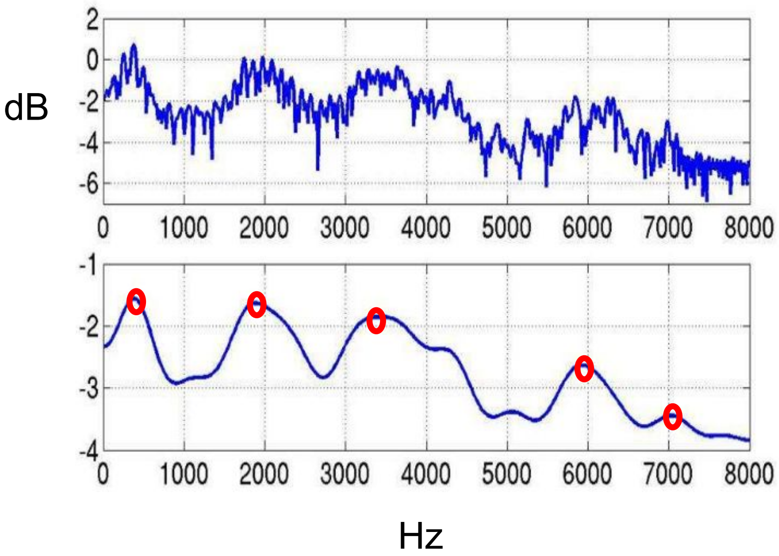


Hz

Understanding the cepstrum

Log-spectrum

Spectral envelope



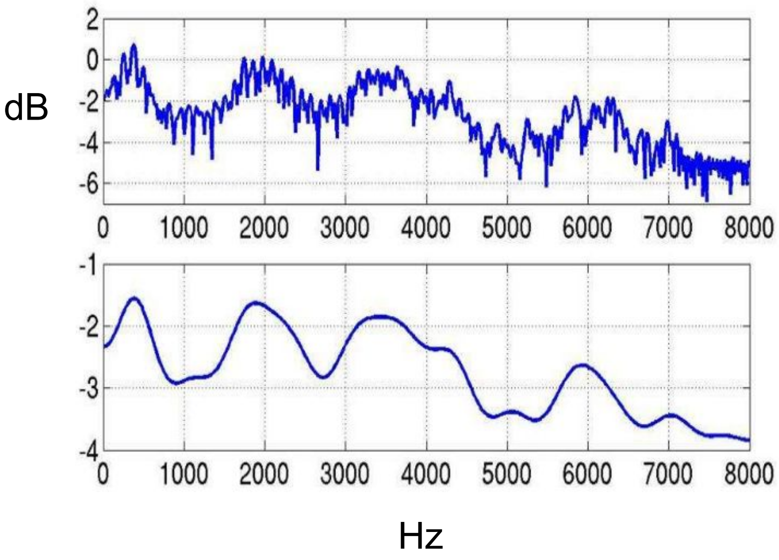
Speech

Formants = Carry identity of sound

Understanding the cepstrum

Log-spectrum

Spectral envelope



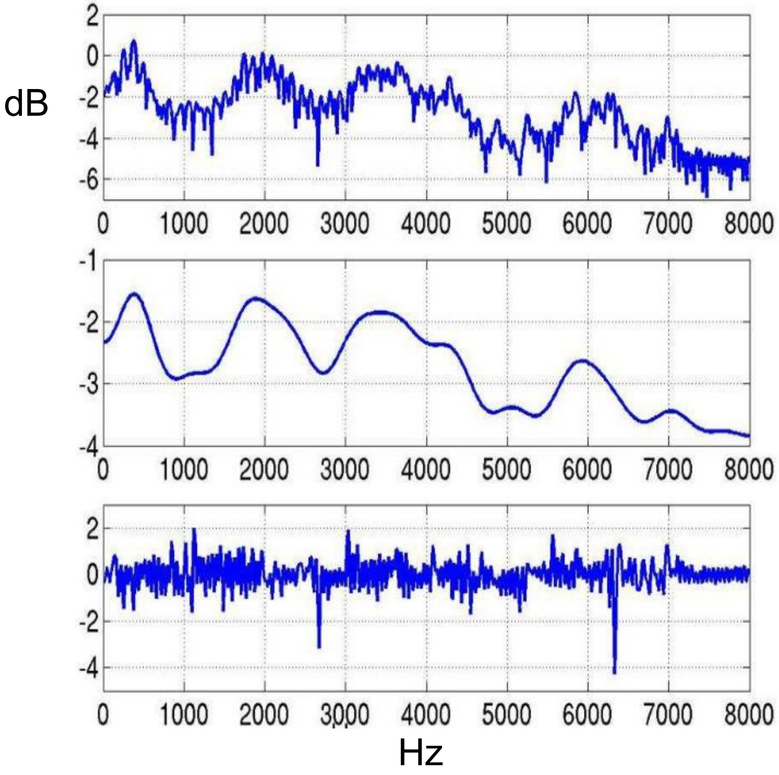
Speech

Vocal tract frequency response

Understanding the cepstrum

Log-spectrum

Spectral envelope



Speech

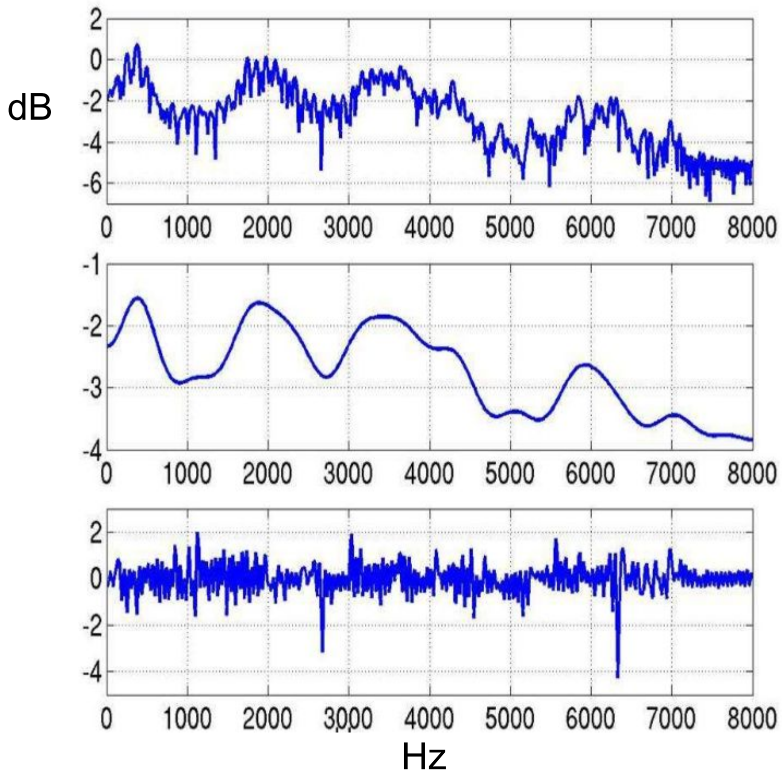
Vocal tract frequency response

Understanding the cepstrum

Log-spectrum

Spectral envelope

Spectral detail



Speech

Vocal tract frequency response

Understanding the cepstrum

Log-spectrum

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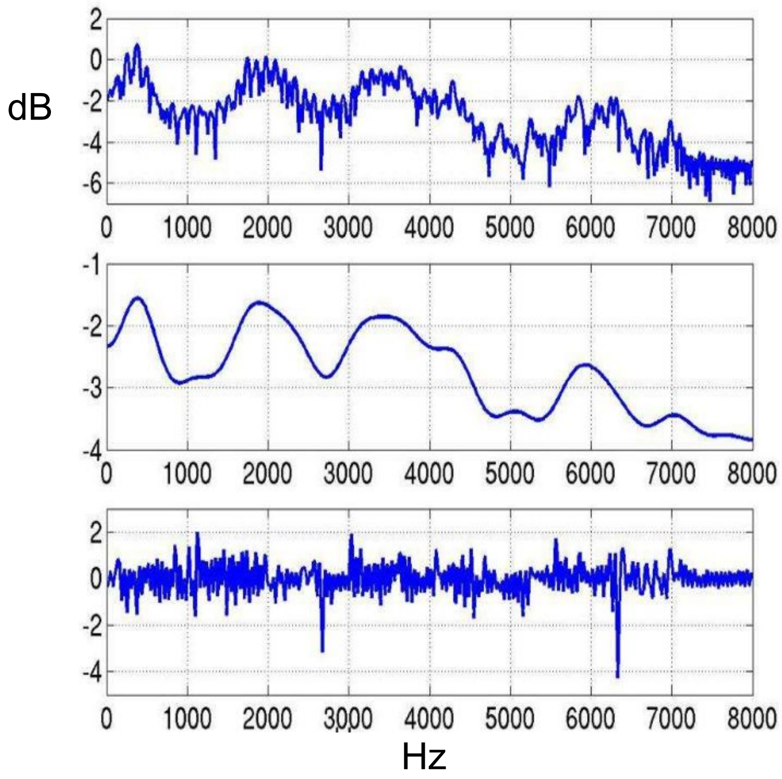
Spectral detail



Speech

Vocal tract frequency response

Glottal pulse

Speech

=

Convolution of vocal tract frequency response with glottal pulse

Formalising speech

$$x(t) = e(t) \cdot h(t)$$

Formalising speech

$$x(t) = e(t) \cdot h(t)$$

$$X(t) = E(t) \cdot H(t)$$

Formalising speech

$$X(t) = E(t) \cdot H(t)$$

Formalising speech

$$X(t) = E(t) \cdot H(t)$$

$$\Downarrow$$

$$log(X(t)) = log(E(t) \cdot H(t))$$

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$$\Downarrow$$

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$$\Downarrow$$

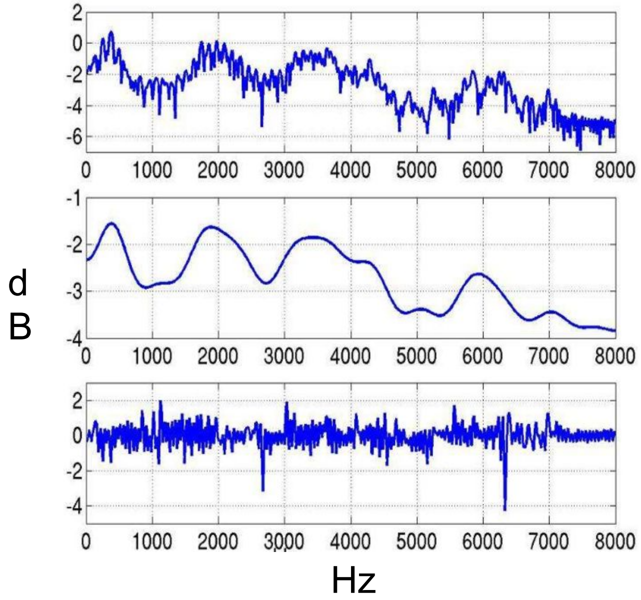
$$log(X(t)) = log(E(t)) + log(H(t))$$

Formalising speech

$$log(X(t)) = log(E(t)) + log(H(t))$$

Formalising speech

$$\boxed{log(X(t))} = \boxed{log(E(t))} + \boxed{log(H(t))}$$

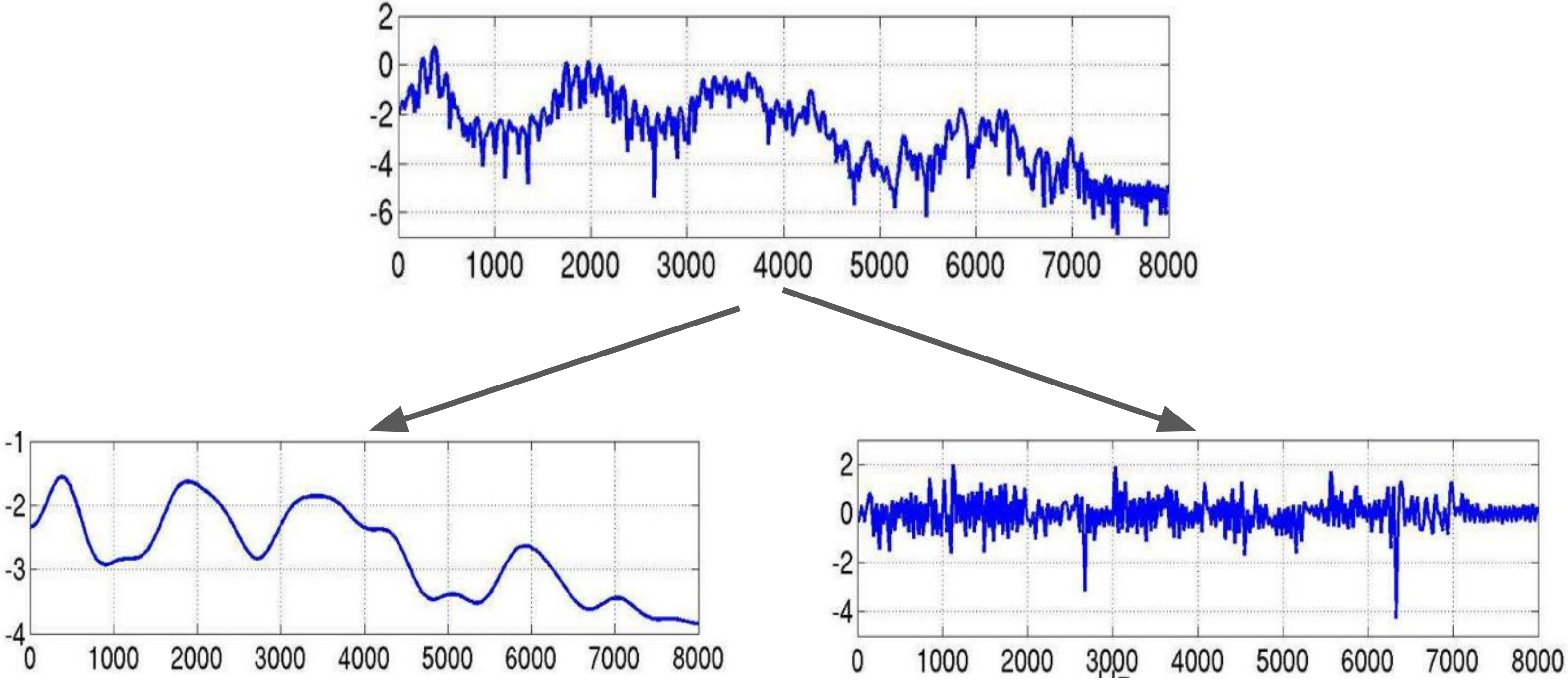


Speech

Vocal tract frequency response

Glottal pulse

The goal: Separating components



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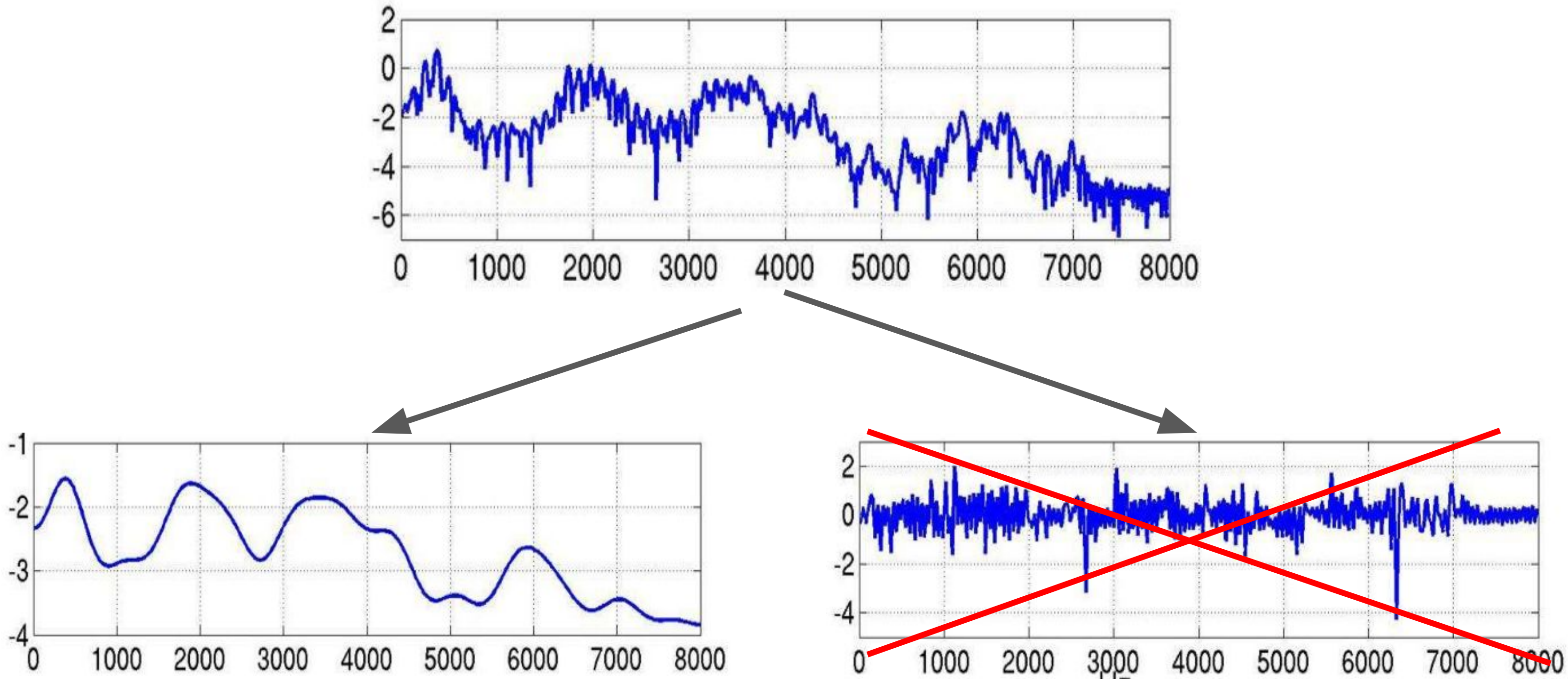
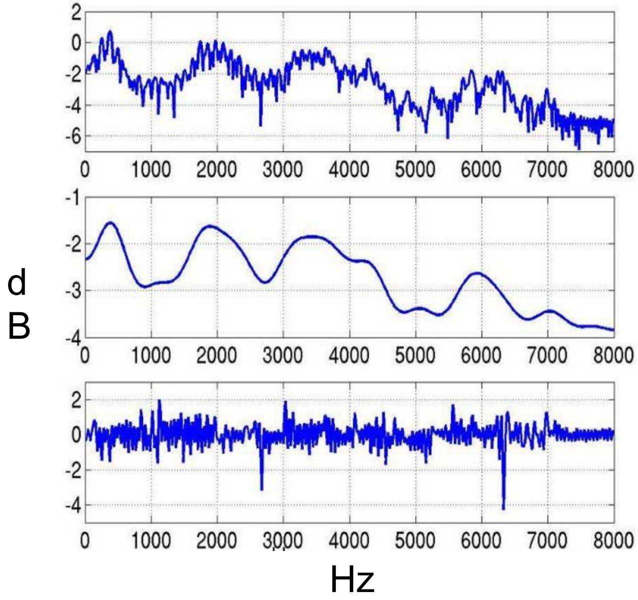


Separating components

$$log(X(t)) = log(E(t)) + log(H(t))$$



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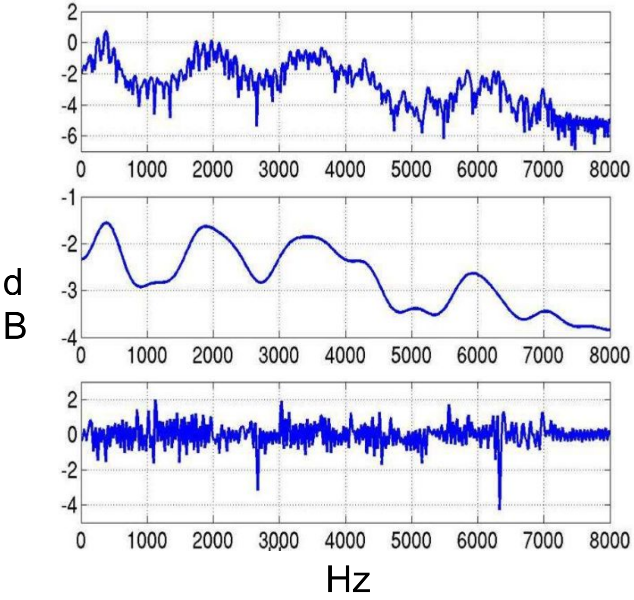
IDFT

quefrency



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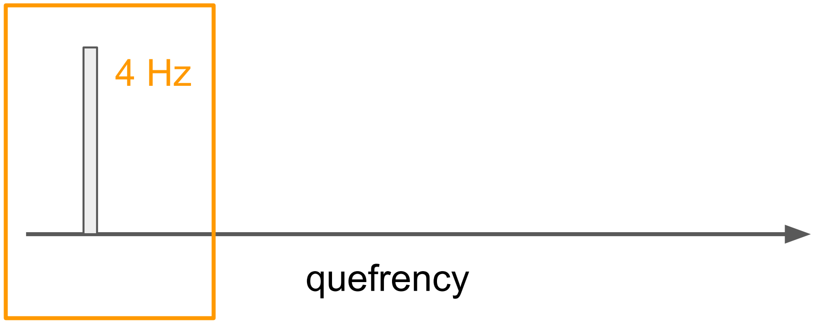

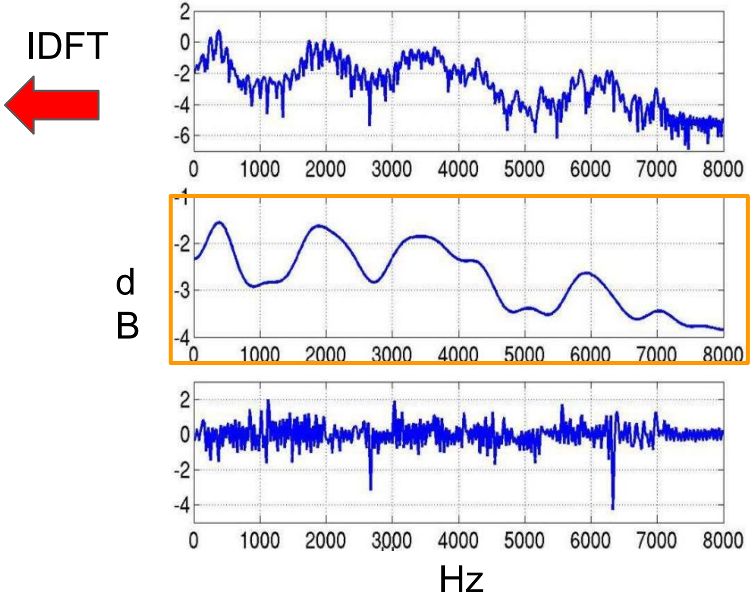

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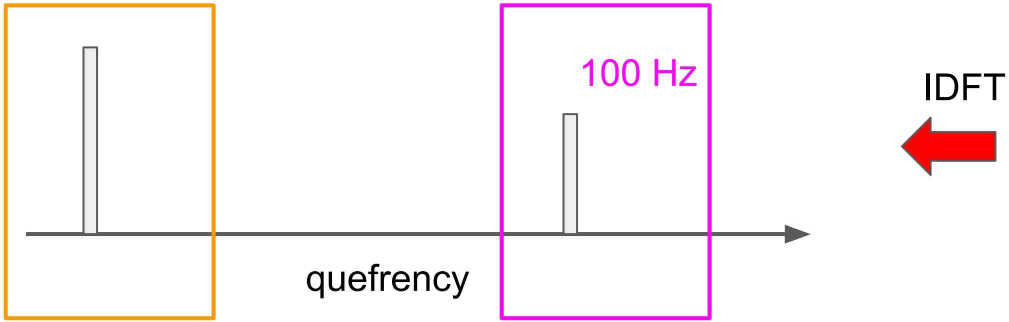

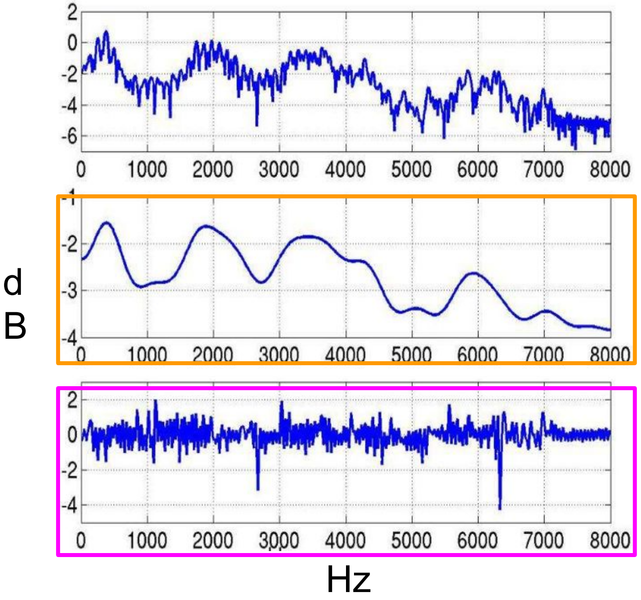

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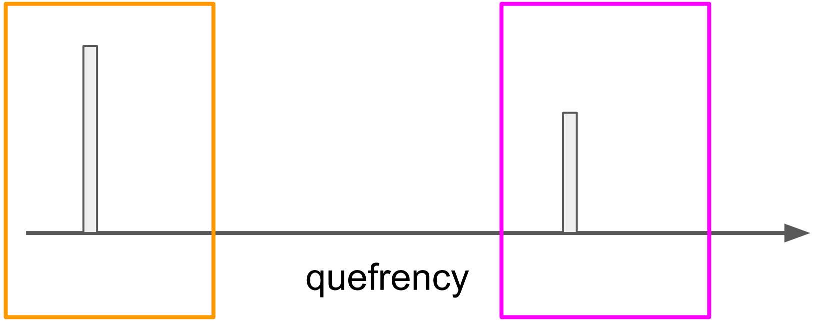
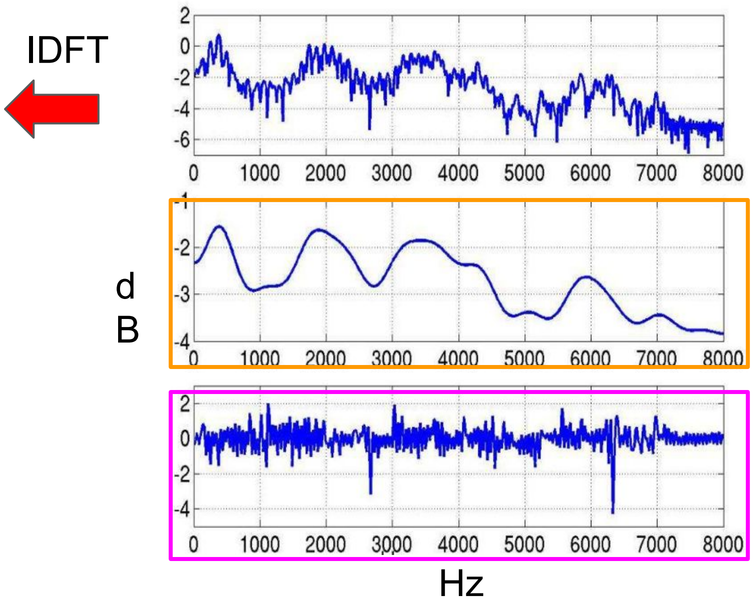


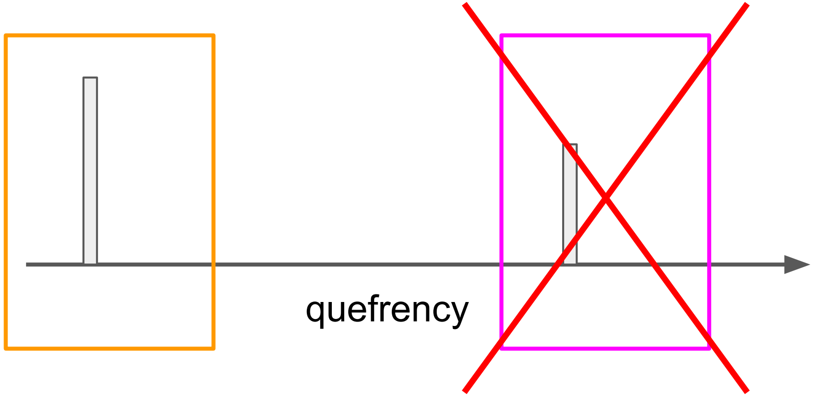


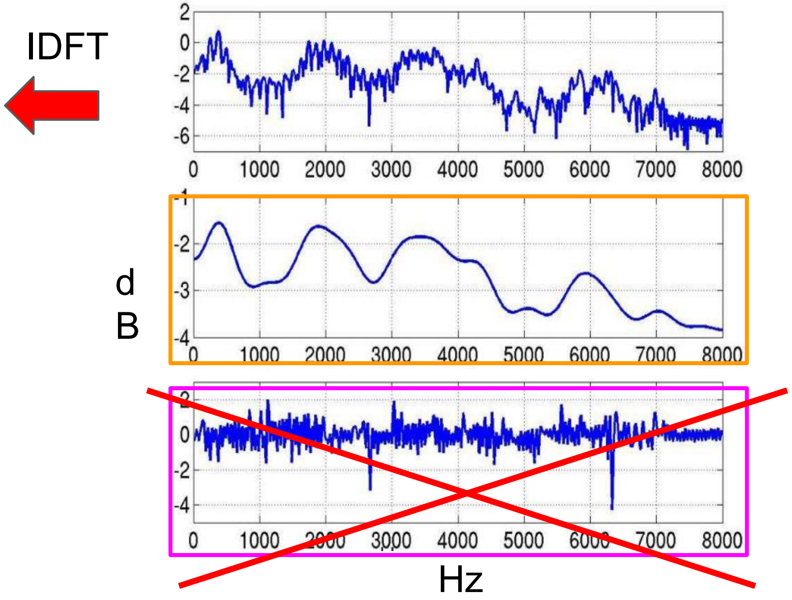
$$X(t) = \boxed{E(t)} + \boxed{H(t)}$$


filtering
liftering
JAKE-CLARK.TUMBLR
imgflip.com

Separating components

$$log(X(t)) = log(E(t)) + log(H(t))$$



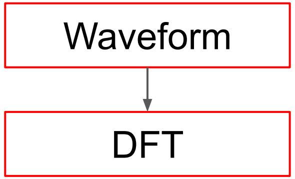


$$X(t) = \boxed{\cancel{E(t)}} + \boxed{H(t)}$$

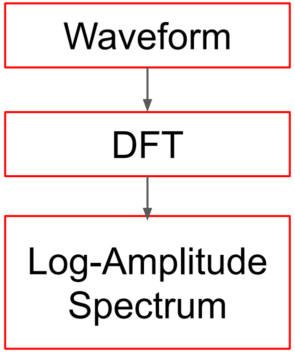
Computing Mel-Frequency Cepstral Coefficients

Waveform

Computing Mel-Frequency Cepstral Coefficients



Computing Mel-Frequency Cepstral Coefficients



Computing Mel-Frequency Cepstral Coefficients

Waveform

↓

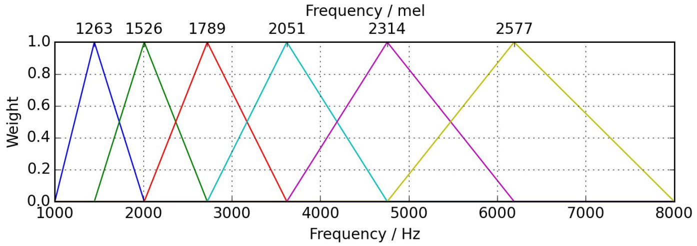
DFT

↓

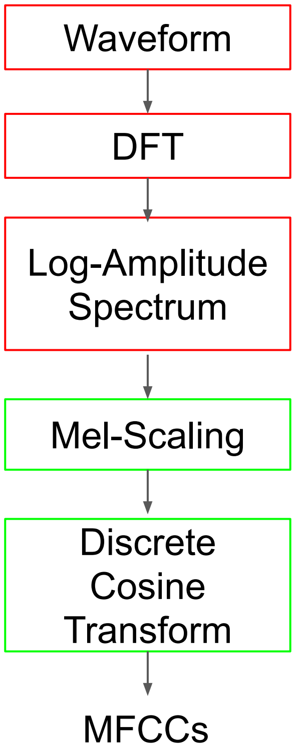
Log-Amplitude Spectrum

↓

Mel-Scaling



Computing Mel-Frequency Cepstral Coefficients



Why Discrete Cosine Transform?

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- Simplified version of Fourier Transform

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- Get real-valued coefficient

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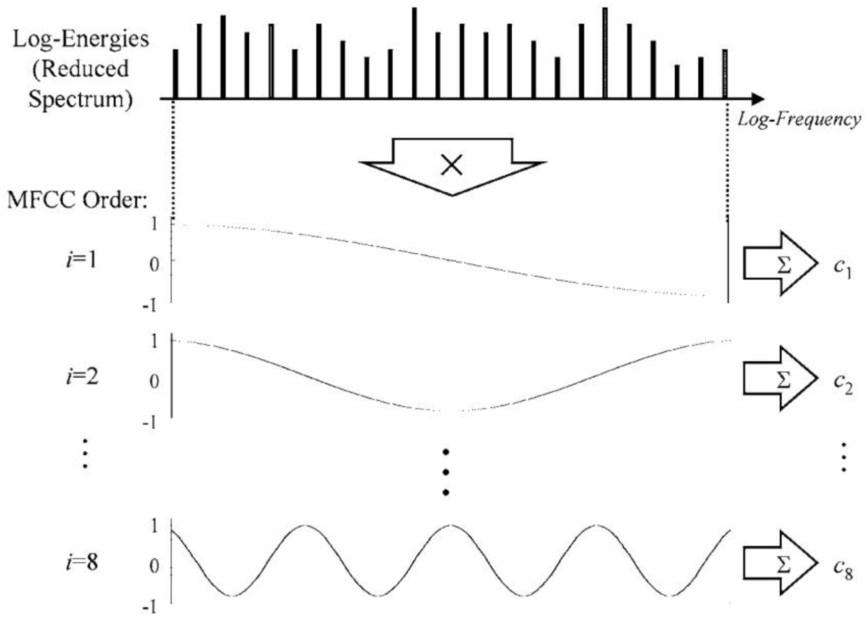
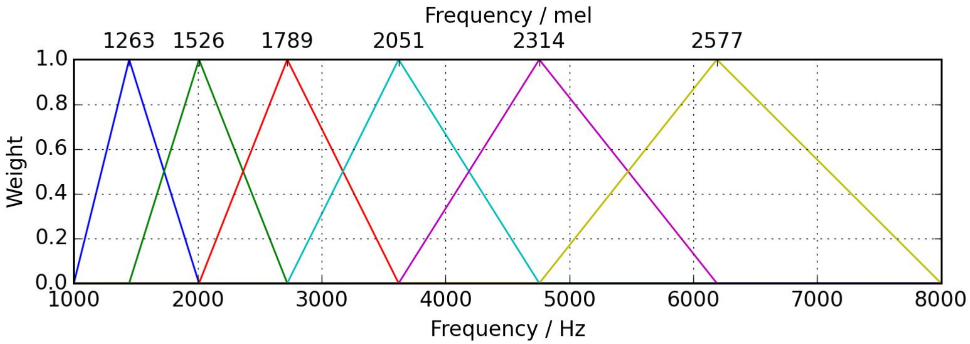


Why Discrete Cosine Transform?

- Simplified version of Fourier Transform
- Get real-valued coefficient
- Decorrelate energy in different mel bands



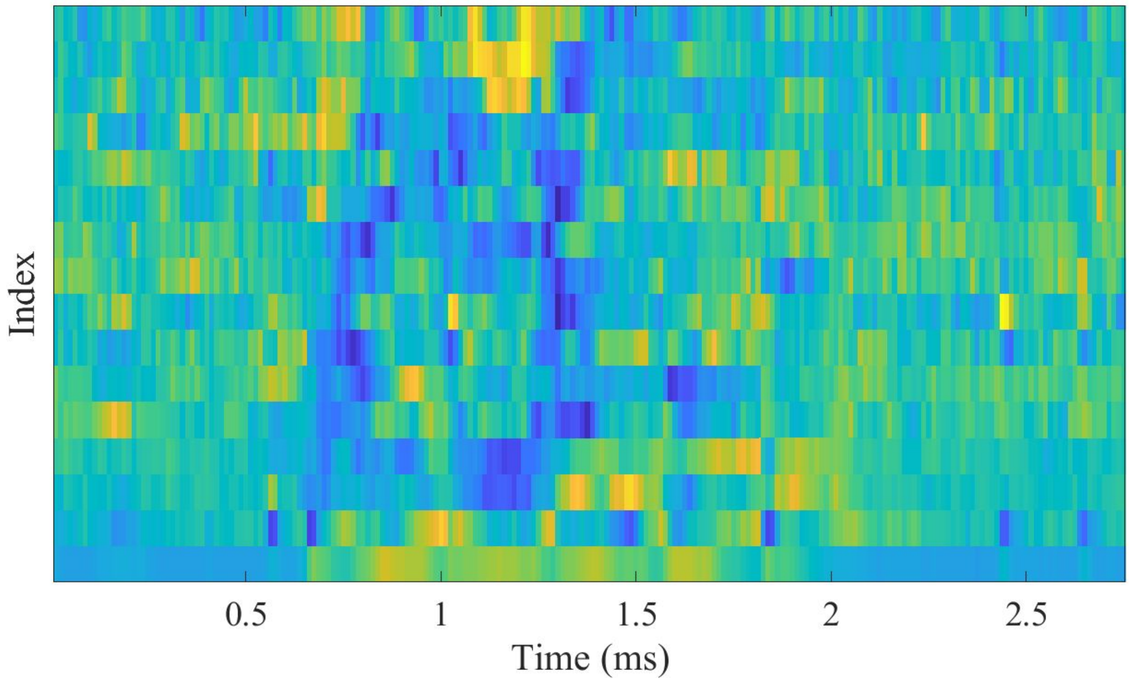
Why Discrete Cosine Transform?

- Simplified version of Fourier Transform
- Get real-valued coefficient
- Decorrelate energy in different mel bands
- Reduce # dimensions to represent spectrum

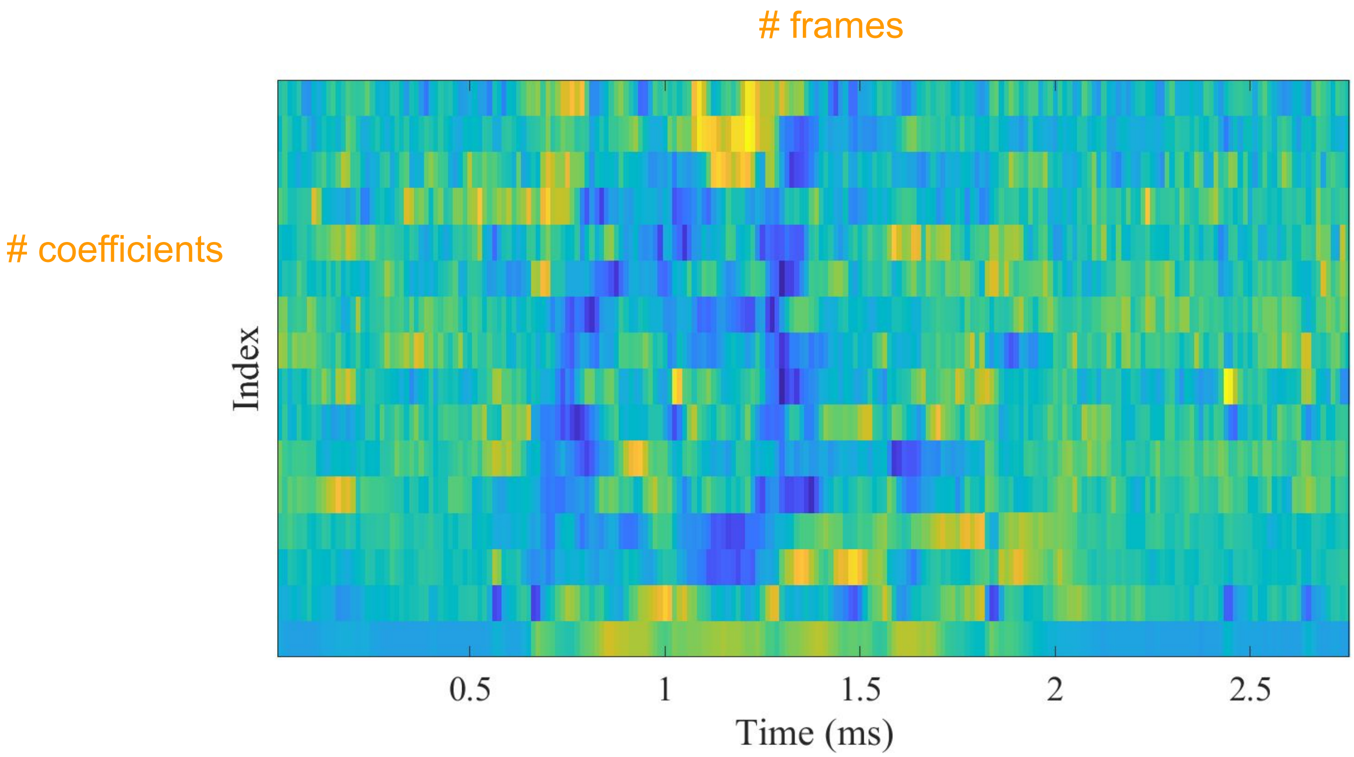
How many coefficients?

- Traditionally: first 12 - 13 coefficients
- First coefficients keep most information (e.g., formants, spectral envelope)
- Use Δ and $\Delta\Delta$ MFCCs
- Total 39 coefficients per frame

Visualising MFCCs



Visualising MFCCs



MFCCs advantages

- Describe the “large” structures of the spectrum
- Ignore fine spectral structures
- Work well in speech and music processing

MFCCs disadvantages

- Not robust to noise
- Extensive knowledge engineering
- Not efficient for synthesis

MFCCs applications

- Speech processing
  - Speech recognition
  - Speaker recognition
  - ...
- Music processing
  - Music genre classification
  - Mood classification
  - Automatic tagging
  - ...

What’s up next?

- Extract MFCCs with Python and Librosa
- Visualise MFCCs