Audio & Speech: Audio Reconstruction from MFCC

DSP Lab 2022 autumn Audio and Speech week 2

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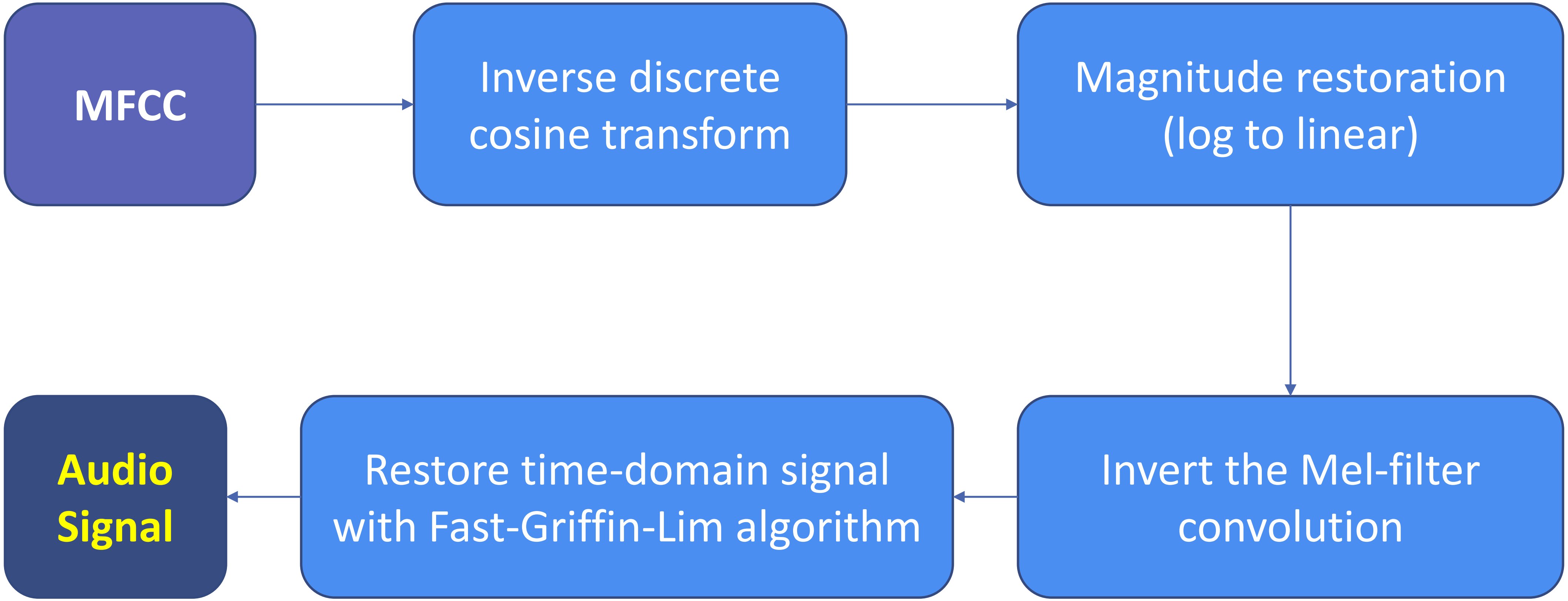
Outline:

- MFCC inversion overview.
- Elaboration on some components.
- Demo.
- Report requirements.

Audio reconstruction flow chart


MFCC
Inverse discrete cosine transform
Magnitude restoration (log to linear)
Invert the Mel-filter convolution
Restore time-domain signal with Fast-Griffin-Lim algorithm
Audio Signal

Component(1): Filter inv-convolution

- Recall that the convolution was:

$$\boldsymbol{Features} = \boldsymbol{STFT}\{\boldsymbol{signal}\} * \boldsymbol{Mel} - \boldsymbol{Filter}$$

- Notice that for a linear transformation $\boldsymbol{Y} = \boldsymbol{AX}$ with given $\boldsymbol{Y}$ and $\boldsymbol{A}$, the $\boldsymbol{X}$ that yields ordinary least square: $\left(\boldsymbol{Y} - \boldsymbol{A}\widehat{\boldsymbol{X}}\right)^T (\boldsymbol{Y} - \boldsymbol{A}\widehat{\boldsymbol{X}})$ can be found with equation:

$$\widehat{\boldsymbol{X}} = \boldsymbol{A}^T (\boldsymbol{A}\boldsymbol{A}^T)^{\dagger} \boldsymbol{Y}$$

- Where $\boldsymbol{Y}$ is ***Features***, the ***Mel-Filter*** is $\boldsymbol{A}$, and we want ***STFT{signal}*** as $\boldsymbol{X}$.
- $\boldsymbol{A} \in \mathbb{R}^{\mathrm{L}\times\mathrm{M}}, \boldsymbol{Y} \in \mathbb{R}^{\mathrm{L}}, \boldsymbol{X} \in \mathbb{R}^{\boldsymbol{M}}$

L: # of energy bands

M: length of spectrum

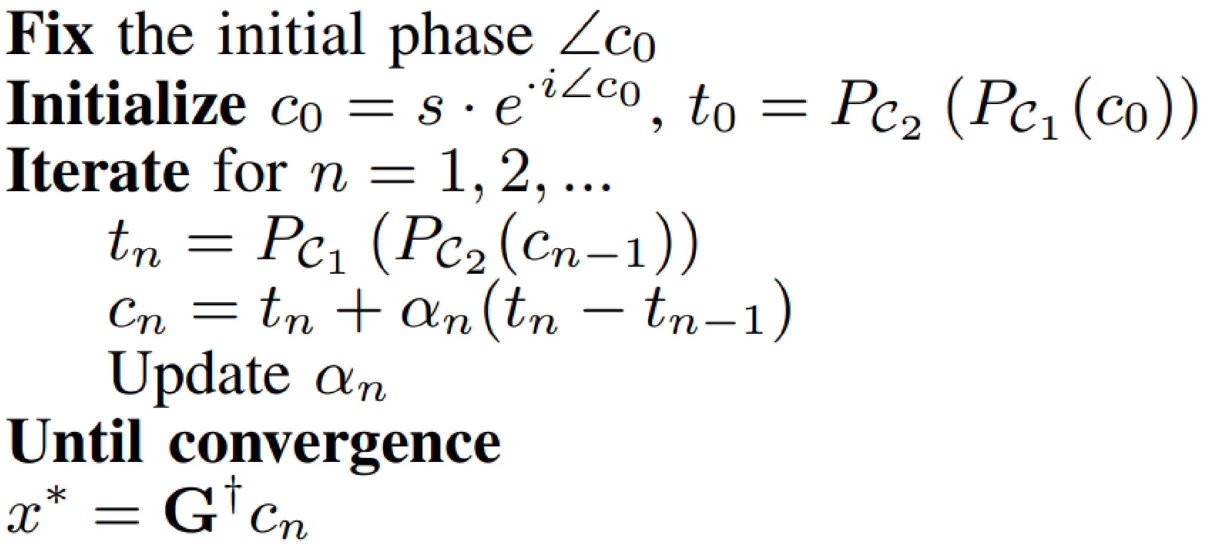
Component(2): Fast Griffin-Lim

$$P_{C_1}(c) = STFT\{\, invSTFT\{\, c \,\}\,\}$$

$$P_{C_2}(c) = s \cdot e^{i\angle c}$$

$$\alpha_n : step\ size$$

$$G^{\dagger} : invSTFT\{\}$$



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Fix the initial phase $\angle c_0$
Initialize $c_0 = s \cdot e^{\cdot i\angle c_0}$, $t_0 = P_{\mathcal{C}_2}\left(P_{\mathcal{C}_1}(c_0)\right)$
Iterate for $n = 1, 2, \ldots$
    $t_n = P_{\mathcal{C}_1}\left(P_{\mathcal{C}_2}(c_{n-1})\right)$
    $c_n = t_n + \alpha_n(t_n - t_{n-1})$
    Update $\alpha_n$
Until convergence
$x^* = \mathbf{G}^{\dagger} c_n$
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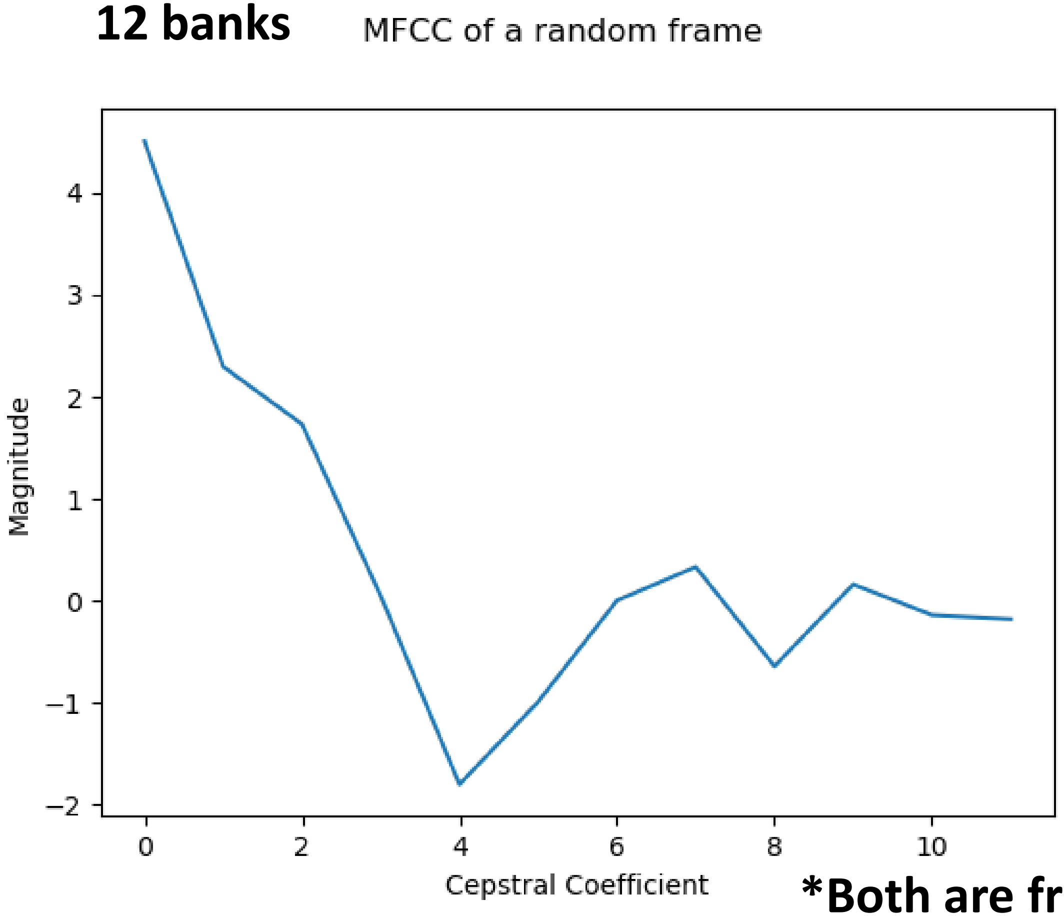
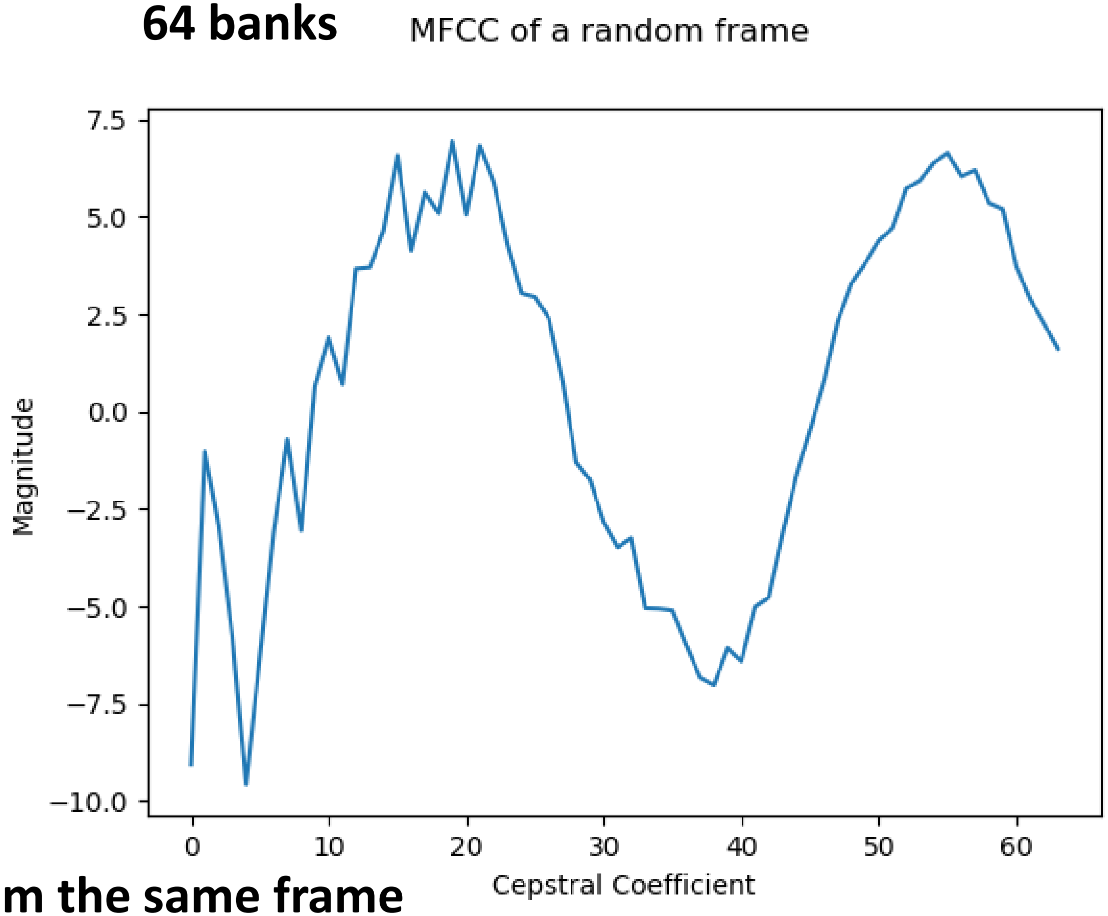
Source: Perraudin, Nathanaël & Balazs, Peter & Søndergaard, Peter. (2013). 'A Fast Griffin–Lim Algorithm.' IEEE Workshop on Applications of Signal Processing to Audio and Acoustics. 1-4. 10.1109/WASPAA.2013.6701851.

Demo(1): Effect of num Mel-Filter banks

12 banks



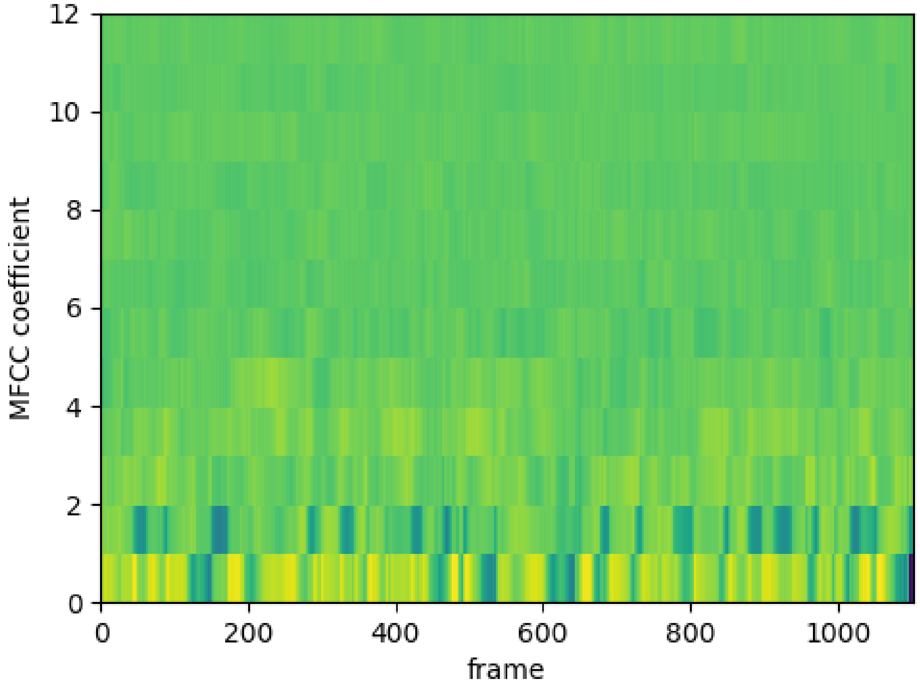
64 banks



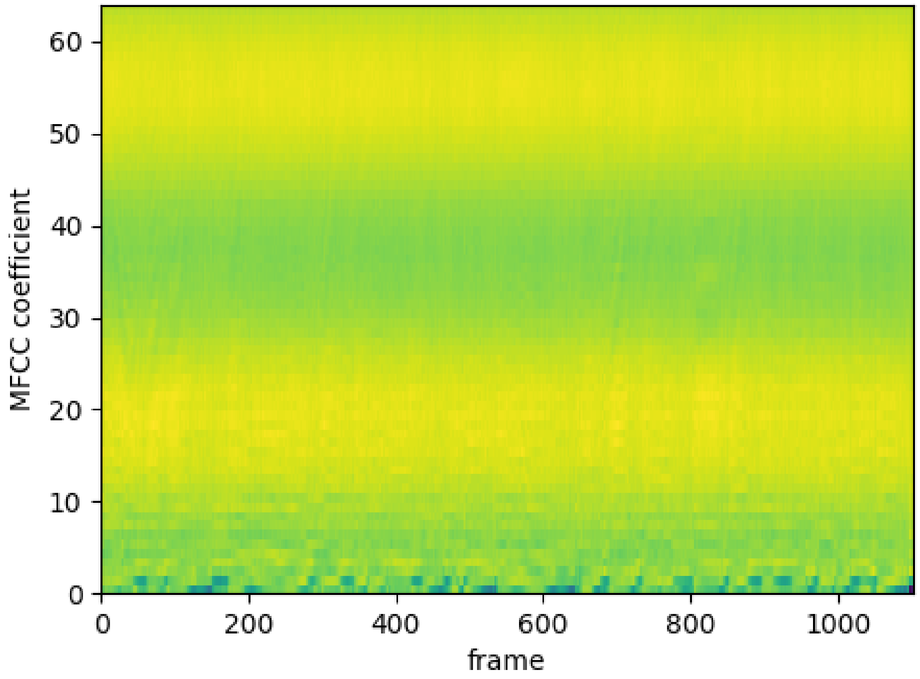
***Both are from the same frame**

Demo(2): Effect of num Mel-Filter banks

12 banks MFCC

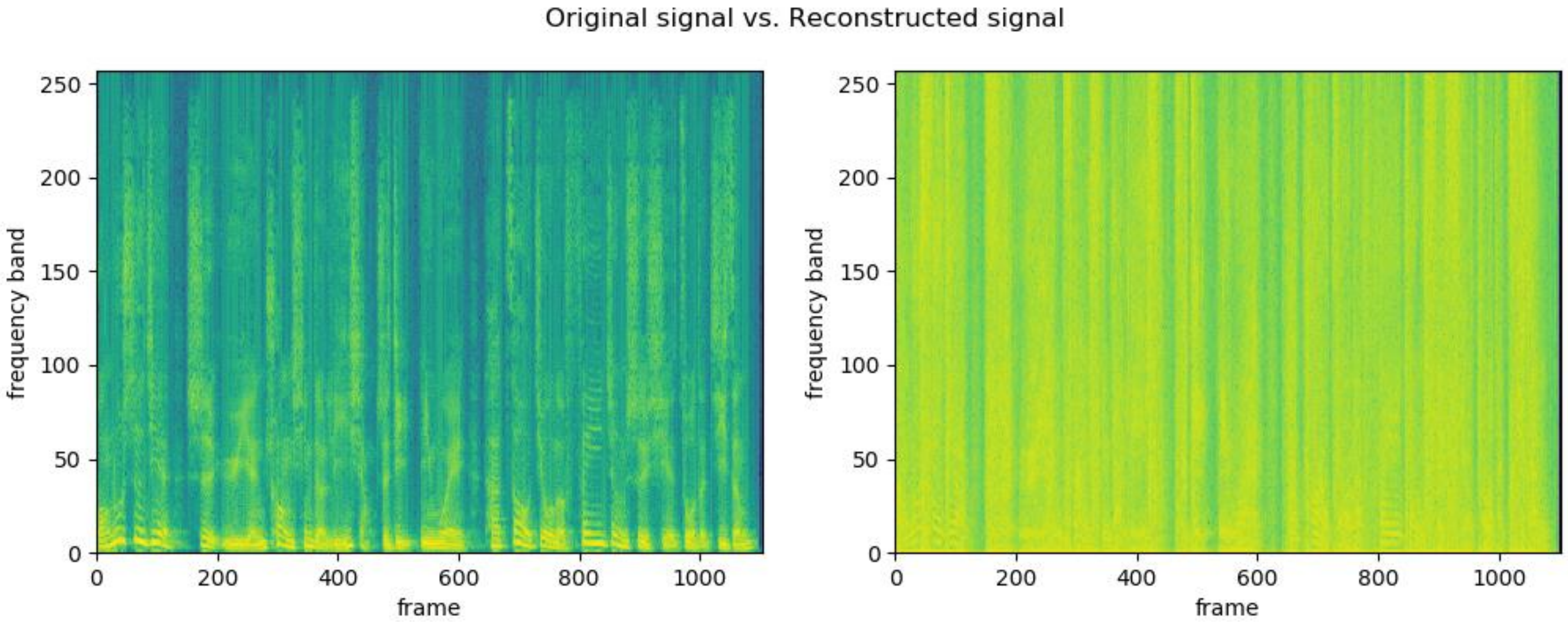


64 banks MFCC



Demo(3): Ori vs Reconstructed

64 banks, magnitude is log-scaled



Demo(4): Reconstructed Audio

- 64 banks pre-emphasized:

- 64 banks NOT pre-emphasized:

- 12 banks pre-emphasized:

- 12 banks NOT pre-emphasized:

- Original:

Report questions:

1. **Question 1:** What are the artifacts and distortions in the reconstructed audio? Suggest what the causes of these degradations are. (i.e. which sections of the MFCC extraction process are not invertible?)

2. **Question 2:** Experiment with different frame length, step length, and number of fbanks; discuss what effects each of them has in the reconstruction process.

3. **(Bonus 1)** Aside from setting optimal parameters, what can be added in the reconstruction algorithm to improve the end quality? Implement your proposal and present some experiments of it.

4. **(Bonus 2)** We did not perform dimension reduction/reconstruction in the DCT/inv-DCT sections. Modify those parts such that we have a complete algorithm that performs compression/decompression. Discuss how this influences the reconstruction quality.