Speech Denoising via Nonnegative Matrix Factorization

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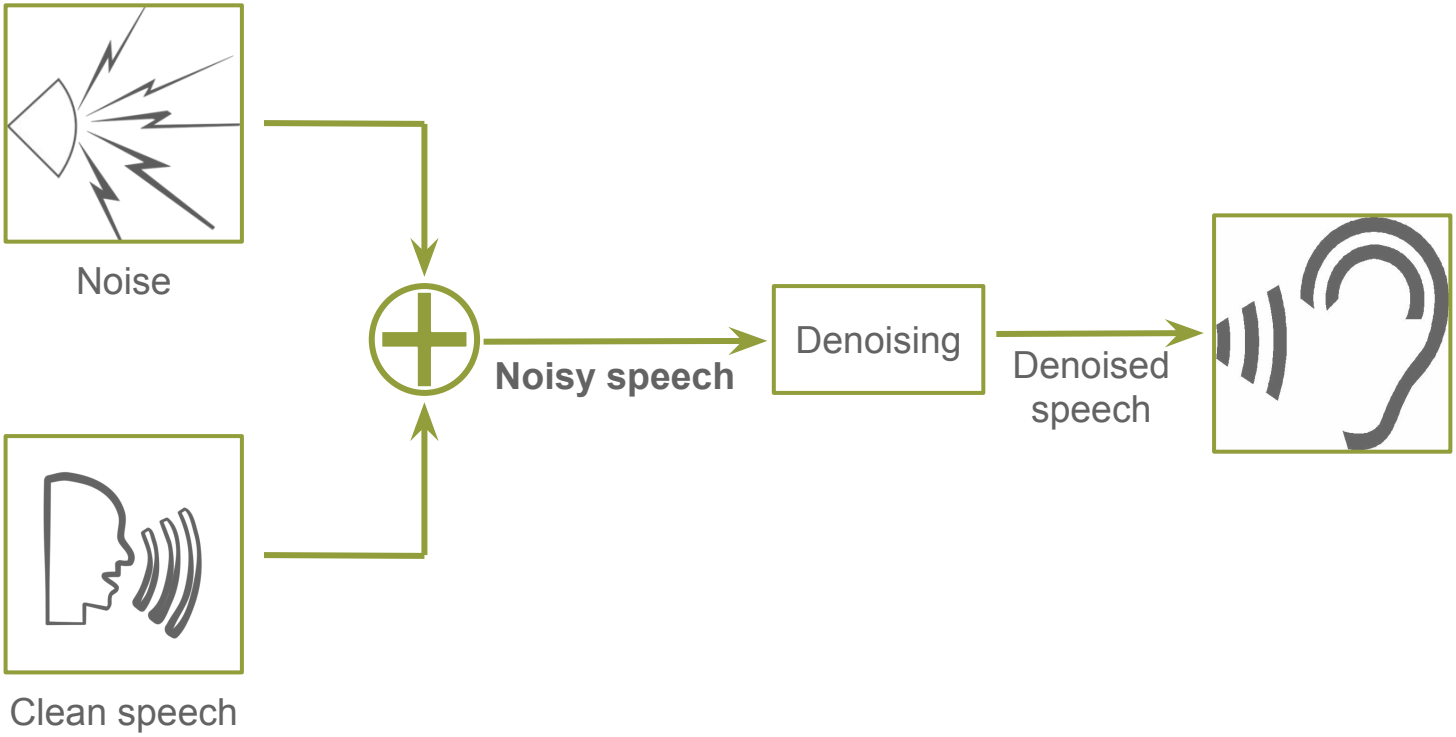
Problem


Noise
Clean speech
Noisy speech
Denoising
Denoised speech

Applications

Automatic Speech Recognition

Telephone conversations

Hearing aids

Data

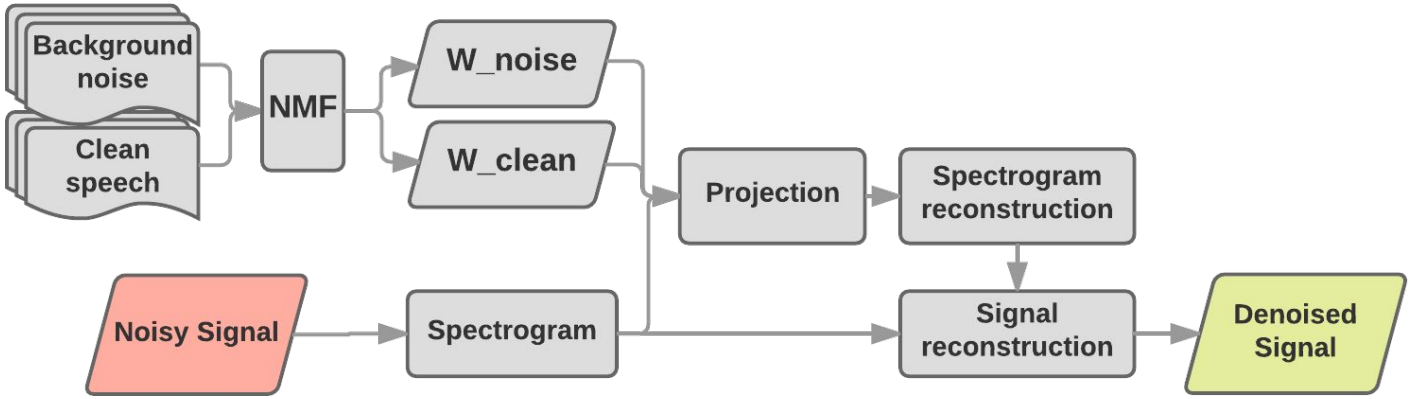
- CHiME Speech Separation and Recognition Challenge
  http://spandh.dcs.shef.ac.uk/chime_challenge/chime_download.html
  Recordings of WSJ utterances + 8 hours of noise

- Berlin Database of Emotional Speech
  http://www.emodb.bilderbar.info/download/
  Clean utterances

- Aurora noising
  http://aurora.hsnr.de/download.html

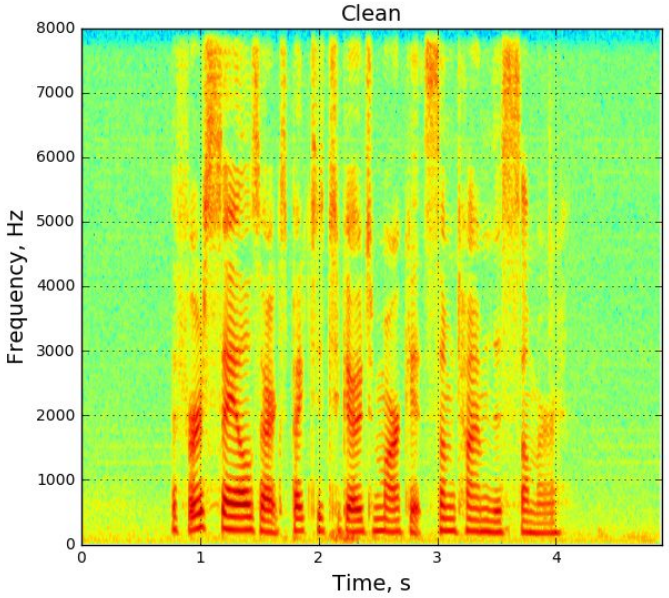
Solution

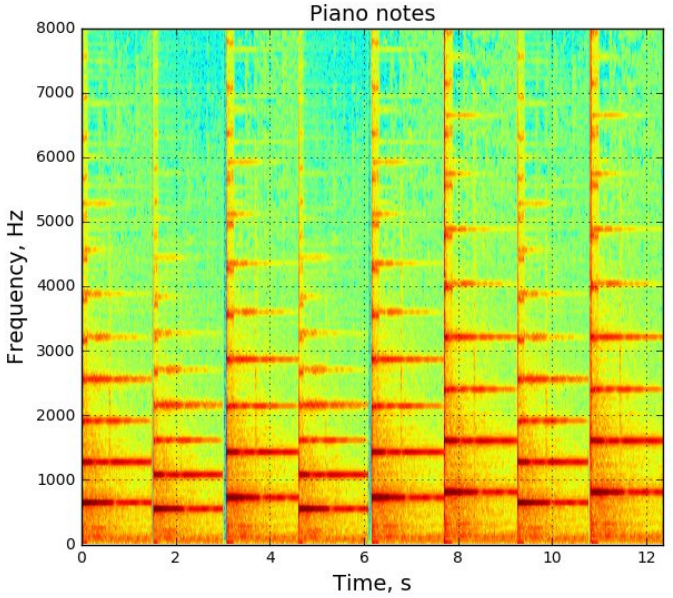
- Learn frequency patterns from speech and noise via NMF
- Decompose new signal by joint “dictionary” of patterns
- Take only projection corresponding to “clean speech”



Spectrogram

- Represent signal in Time-Frequency domain
- Built by means of Short-Term Fourier Transform - FFT in sliding window
- STFT - Complex spectrogram S ⇒ Amplitudes V





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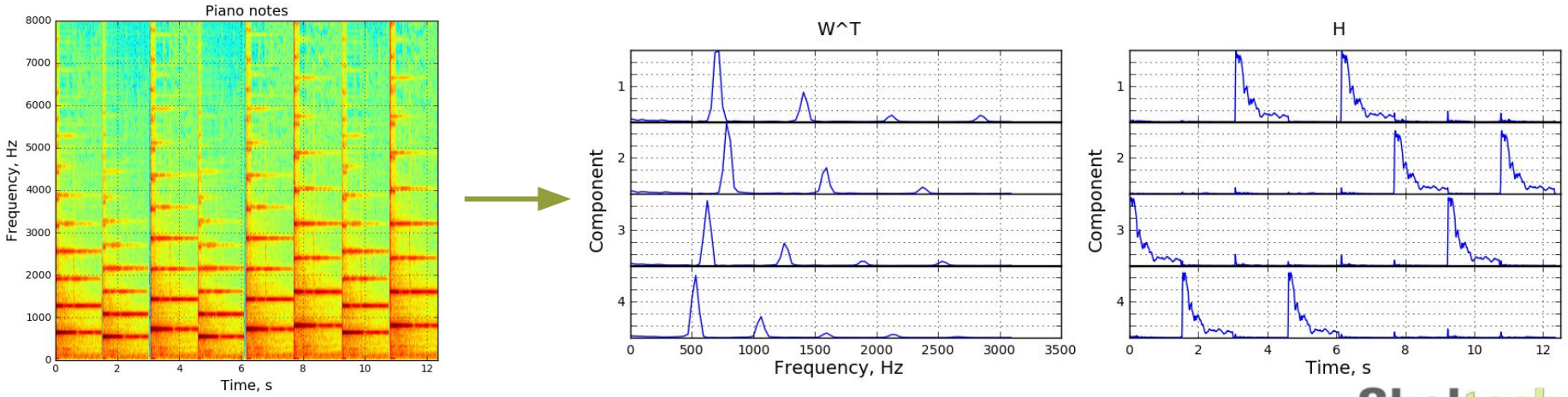
NMF

- Factorization V ≈ W * H, where V, W, H - real nonnegative
- Interpretation: W - frequency patterns, H - time-activation matrix
- Hidden dimension ≈ number of phonemes ≈ 40
- Learn speech and noise “building blocks”



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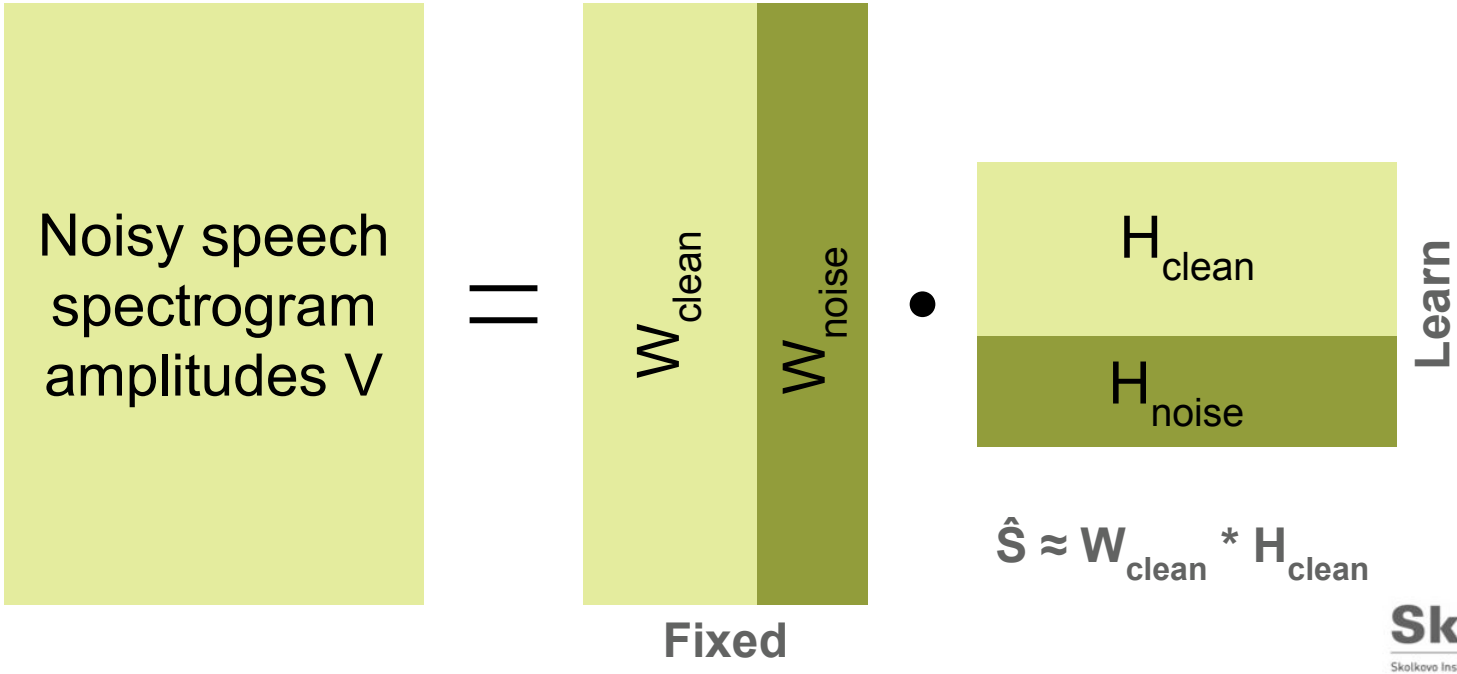
Projection

- Join “dictionaries” - concatenate matrices W_{noise} and W_{clean}
- Project signal onto them



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NMF: how to compute

Optimization problem:

$$(W^*, H^*) = \operatorname{argmin}_{W \geq 0, H \geq 0} D\left(V, WH\right)$$

$$D\left(P, Q\right) = \sum_{i=1}^{m} \sum_{j=1}^{n} d(p_{ij}, q_{ij})$$

The most popular metrics:

$$d(p, q) = (p - q)^2 \quad \text{Frobenius norm}$$

$$d(p, q) = p \ln(\frac{p}{q}) - p + q \quad \text{KL divergence}$$

Multiplicative Update Method:

$$[\nabla_H]_{kj} = \frac{\partial D\left(V, WH\right)}{\partial h_{kj}} = [\nabla_H^+]_{kj} - [\nabla_H^-]_{kj}$$

$$h_{kj} \leftarrow h_{kj} - \frac{h_{kj}}{[\nabla_H^+]_{kj}} \left([\nabla_H^+]_{kj} - [\nabla_H^-]_{kj}\right)$$

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NMF: how to compute

Alternating Nonnegative Least Squares:

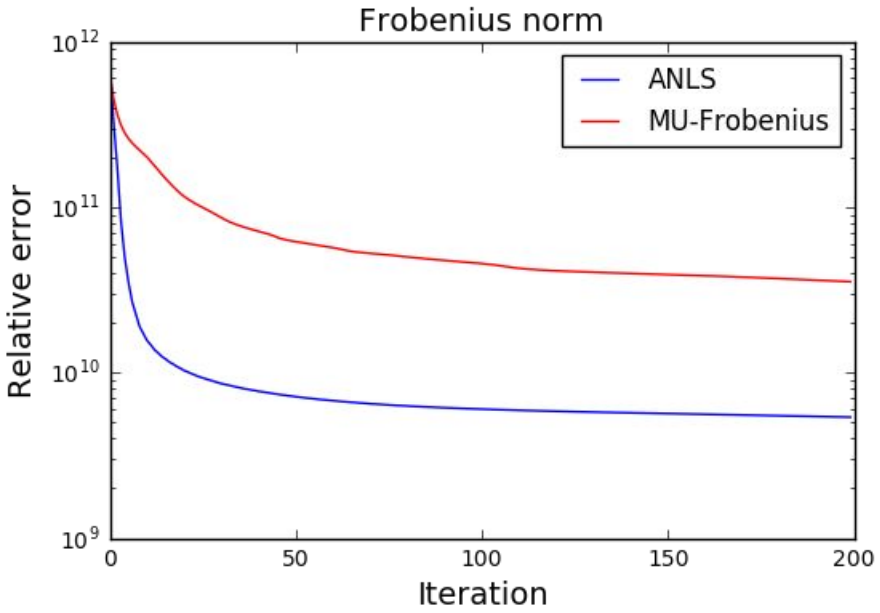
1) Initialize $W_{ia}^1 \geq 0, H_{bj}^1 \geq 0, \forall a, i, b, j.$

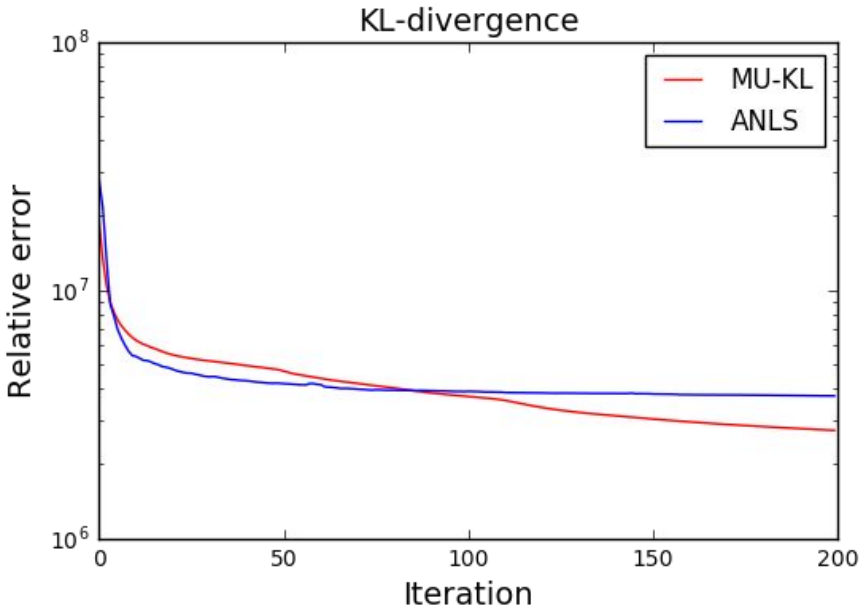
2) For k=1,2,...

$$W^{k+1} = \text{argmin}_{W \geq 0} D\left(V, WH^k\right),$$

$$H^{k+1} = \text{argmin}_{H \geq 0} D\left(V, W^{k+1}H\right).$$

Methods Convergence





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Signal reconstruction

- Naive method with zero phase:

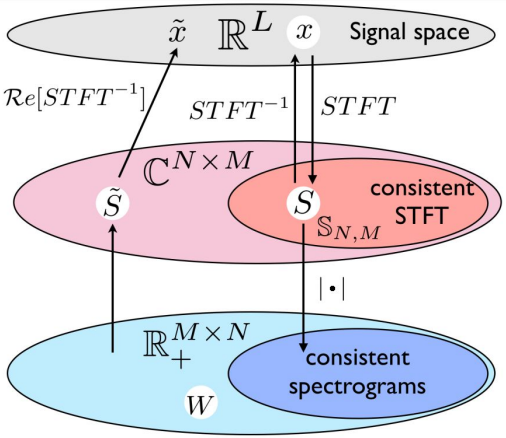
$$\hat{X} = STFT^{-1}(\hat{S})$$

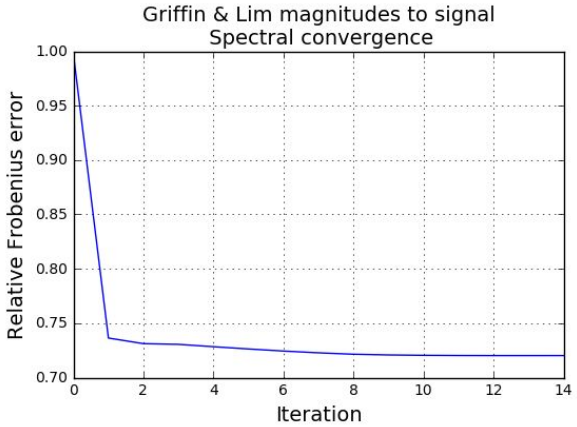
- Noisy signal phases:

$$\hat{X} = STFT^{-1}(\hat{S} \times \exp(i \angle STFT(X_{noisy})))$$

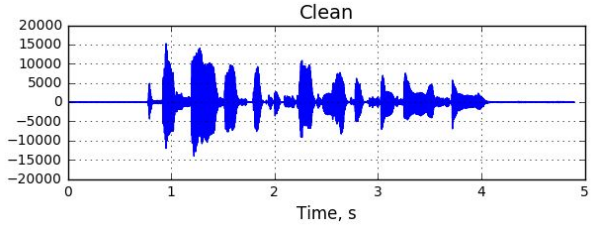
- Griffin & Lim iterative method:

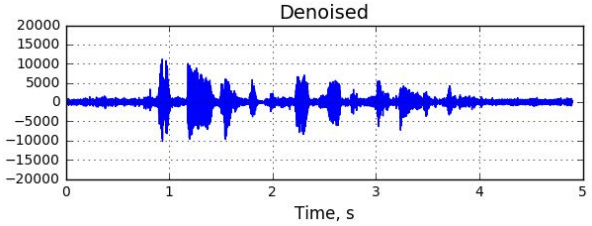
$$\hat{X}_n = STFT^{-1}(\hat{S} \times \exp(i \angle STFT(\hat{X}_{n-1})))$$

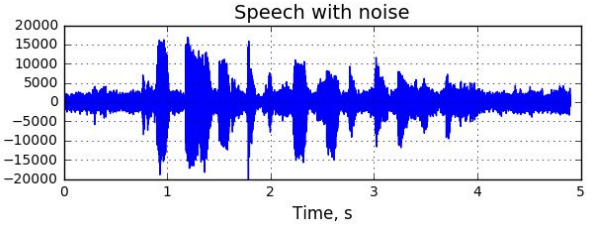


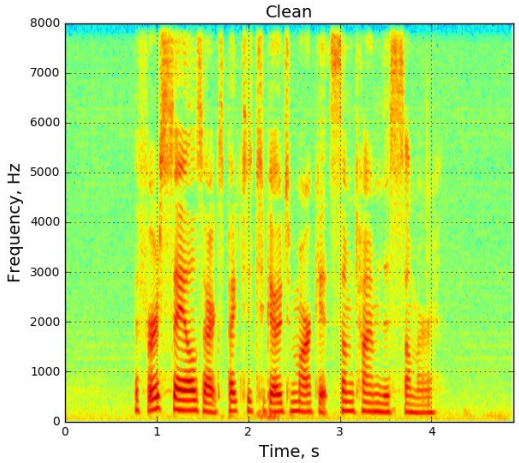


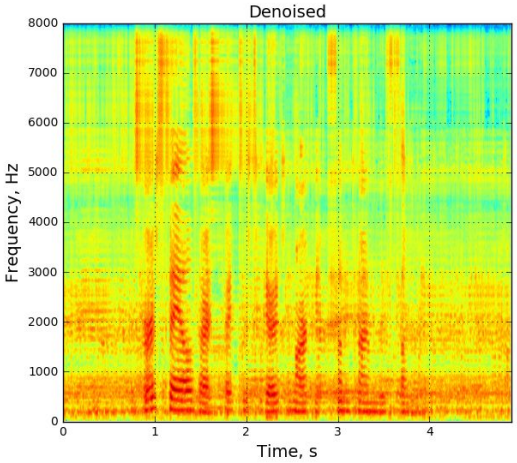
Demo

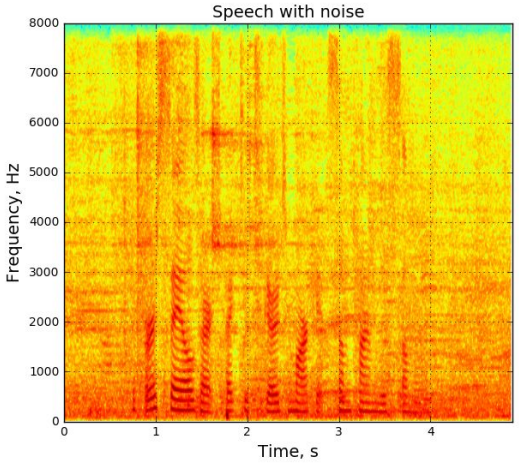












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