Time-Frequency Analysis of Music

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In this project you will learn how to apply different tools such as wavelets, wavelet packets, and cosine packets to analyze and process music signals.

Level I.

Use the Fast Wavelet Transform to analyze two music signals. Compare at least four different wavelet systems, e.g. `HAAR, BIOR7/9, DAUB16, Coiflet3, or Coiflet4`.

Choose two different signals for your analysis. One signal should be from a single source with well structured frequency content, for example a recording of a xylophone. You are encouraged to find the sources on your own, but ask for assistance if you have trouble. Most music is recorded at 11kHz and higher, hence 1-2 seconds is sufficiently long. Note that Matlab reads WAV and AU formats directly.

The goal of the project is to experiment with the ability of wavelet systems to efficiently represent music signals. You will do this in two ways.

First, generate *time-frequency* plots of your signals based on the wavelet transform output. Your plots should provide a three-dimensional display of the wavelet representation based on time location, frequency location, and magnitude of the coefficients. The Analysis visualization in `The IDR FrameNet Portal` is a useful guide.

Second, reconstruct your signals using only the N largest coefficients in the representation, for some N of your choosing. Listen to the reconstructed version and compare with the original. Record your subjective (listening) analysis as well as the normalized ℓ_2 error of the reconstructed signal, i.e.,

$$err := \frac{||s - s_{rec}||_{\ell_2}}{||s||_{\ell_2}}$$

where s is the original signal and s_{rec} is the reconstructed signal based on N coefficients. Compare each system and signal for fixed N, and experiment with different values of N. You may also wish to try different criteria for choosing the N coefficients.

Your project should include a description of your input, an organized presentation of your experiments and results, and your conclusions. In particular, your conclusions should focus on what you learned about music and what you learned about the wavelet transform as a tool for signal processing.

Your discussion should also address the following: How well do the wavelet coefficients represent the key features of a music signal (e.g., attack, duration, frequency)? How do the different wavelet systems compare in this regard? In your answer to this question consider such properties of the mother wavelets as support, smoothness, approximation order, vanishing moments, degree of oversampling.

Turn in both an electronic copy (to yeon@cs.wisc.edu) and a hard copy of the report.

Level II.
`Do the assignment for Level I and the following.`

In this part of the project, you will learn another wavelet-based tool for signal analysis called *wavelet packets*. You will also learn some useful functions of WaveLab – a Matlab-based software implementing computational algorithms related to wavelet analysis, in particular, the ones related to the implementation of wavelet packets. Your mentor will help you get acquainted with the software.

Use WaveLab function `WPAnalysis` to analyze your signals using wavelet packets. Generate time-frequency plots and perform reconstruction experiments using the same values of N from Level I. How do your results compare to Level I?

A good reference for wavelet packets is the article "Signal Processing and Compression with Wavelet Packets" by Coifman, Meyer, Quake, and Wickerhauser, 1990. It is available from Wickerhauser's website.

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Level III.
`Do the assignment for Level I, II and the following.`

In this part of the project, you will use WaveLab to experiment with a third tool for signal analysis called *cosine packets*.

Use WaveLab function `CPAnalysis` to analyze your signals using cosine packets. Generate time-frequency plots and perform reconstruction experiments. How do your results compare with Level I and II? How does the structure of the cosine packet representation compare to wavelet packets.

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