University of Pennsylvania
Department of Electrical and System Engineering
Digital Signal Processing

HW5: Multi-rate Processing and Frequency Response Sunday, February 25th

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Due: Sunday, March 10th, 11:59PM

- **Homework Problems:** All problems must be turned in and are not optional for full credit

  1. Homework problems from the book: 4.37, 4.46, 4.59
  2. Matlab problem: Decimation
     In this problem, we will explore how the application of an anti-aliasing filter before downsampling can affect a downsampled signal. To accomplish this, we will utilize the MATLAB routines `decimate` and `downsample`. The function `decimate` passes the input signal through an anti-aliasing filter before downsampling, while the function `downsample` does not include an anti-aliasing filter.

     (a) Downsampling by 2 without an anti-aliasing filter. Use the following code to generate a time-domain signal, $x[n]$, that produces a rectangularly-shaped DTFT:

     ```
     % We have provided you with a time-domain function
     % x whose DTFT is a rectangle:
     F = [0 0.249 0.25 0.5 0.75 1];
     M = [1 1 0 0 0 0];
     Order = 1000;
     x = fir2(Order, F, M);
     ```

     Using this function, complete the following:
     - Compute the DTFT of the function $x[n]$ provided using `freqz`. Plot the magnitude of the DTFT. Make sure to create the frequency axis and label your axes.
     - Now, downsample the time-domain function by a factor of 2 using the downsample routine. Plot the magnitude of the DTFT of the downsampled signal. Use the `hold on` command to overlay the two plots on the same graph
     - Submit your overlain plots and write a few sentences describing any changes you notice between the two DTFTs. Is there any aliasing in this case?

     (b) Downsampling by 5 without an anti-aliasing filter. Using the original time-domain function $x[n]$ that we provided, complete the following:

- Repeat steps 1 and 2 from part (a), this time downsampling by a factor of 5. Again, use the downsample routine.
- Submit your overlain plots and write a few sentences describing any changes you notice between the two DTFTs. Is there any aliasing in this case?

(c) Downsampling with an anti-aliasing filter. Again using the original time-domain function that we provided you, complete the following:

- Repeat steps 1 and 2 from part (a), this time downsampling by a factor of 5. This time, use the `decimate` routine instead of `downsample`.
- Submit your overlain plots and write a few sentences describing any changes you notice between the two DTFTs. How does the DTFT of this anti-aliased downsampled signal compare to the DTFT of the downsampled signal from part (b)?

3. Matlab problem: Decimation and Interpolation
The MATLAB routines `decimate`, `interp`, and `resample` are used to accomplish decimation, interpolation, and general change of sampling rate, respectively. In MATLAB, enter the command `load mtlb`, to load a pre-recorded segment of a genuine Mathworks employee uttering the word MATLAB. The signal is sampled at 7000 Hz.

(a) Let the sequence $x[n]$ represent samples `1000` through `1127` of the waveform `mtlb`. Plot $x[n]$ and its DTFT.

(b) Upsample the sequence $x[n]$ by a factor of 3. Plot the new sequence and its DTFT. Compare to your plots in (a). What is the new sampling frequency?

(c) Downsample the original sequence $x[n]$ by a factor of 2. Plot the new sequence and its DTFT. Compare to your plots in (a) and (b). What is the new sampling frequency?

(d) Create the sequence that is derived from the original sequence $x[n]$ by increasing its sampling rate by a factor of 1.5. Again plot the new sequence and its DTFT. Compare to your plots in (a). What is the new sampling frequency?

- **Recommended Problems for Practice:** From the book: 4.50 (There is a typo in the filter bank diagram and it should say $G_1(z) = -H_1(z)$),