9.35 Spring 2024
Problem Set 2

The goals of this problem set are to:
a) gain experience generating sounds, for use in the upcoming Illusion Lab
b) think about beating and its relationship to phase, and to the filtering of the cochlea
c) think about the difference between harmonic and inharmonic sounds
d) think about amplitude modulation
e) review principles of sound localization, and learn about their refinement
f) review the (healthy) cochlea's compressive response, and think about its relation to loudness

Please show your work for all problems.

If you use Python to complete this problem set, make sure to import these libraries:

```
import matplotlib.pyplot as plt
import plotly.express as px
import numpy as np
import math
from scipy import signal
from IPython.display import Audio
```

1. Generate a set of complex tones with harmonics 1-5, 6-10, 11-15, and 15-20 of 200 Hz. Make two versions of each tone, one where all harmonics start with a phase of zero, and one where the starting phase of each harmonic is a random number between 0 and 2*pi. Give all harmonics equal amplitude, and set the rms level of the complex tone to be .05. Make a figure with plots of the eight waveforms, setting the axis limits to show 20ms or so of each waveform. What effect does the phase randomization have on the waveform shape? Now listen to each pair of tones using soundsc in MATLAB and Audio in Python (use headphones rather than your laptop speakers). Is the phase randomization more salient for some sets of harmonics than others? Explain why this might be, in terms of what we discussed in class about the perception of beating.

2. Generate a complex tone with harmonics 1-10 of 200 Hz, all with a starting phase of zero. Give all harmonics equal amplitude, and set the rms level of the complex tone to be .05. Now make a second version in which each of the 10 harmonics has its frequency increased by a random amount uniformly distributed between 0 and 50 Hz. This second tone is *inharmonic*. Make a figure with plots of the waveforms of the two tones, setting the axis limits to show 20ms or so of each waveform. What effect does the inharmonicity have on the waveform shape?

Listen to each of the two complex tones using soundsc in MATLAB and Audio in Python. Describe any differences you hear between the two tones.

3. Download the barbershop sound demo. Listen to it over headphones while sitting in a chair. Now listen to it over headphones while lying down on your bed. Does the quality of the spatialization change across the two listening conditions? What does this suggest about sound localization? What is the barber's name?

4. Please read the paper "Detectability of interaural delay in high-frequency complex waveforms" (by Bruce Henning, from 1974).

a) What is one explanation for the good performance shown in Figure 2 despite the poor performance in Figure 1?

b) Draw a diagram of the spectra of the stimuli in the 3900-4200 condition of Experiment 3 (by hand or using Matlab, as you wish).

c) Would the Jeffress circuit proposed to account for ITD detection need to be modified to account for the results in this paper? If so, how?

d) How does the "duplex" theory of sound localization need to be modified in light of these results?

5. A standard model of loudness is that loudness is proportional to the total number of auditory nerve action potentials evoked by a sound within a short window of time (e.g. 100 ms). Under this model, what should be the qualitative relationship between the loudness of a one-octave band of noise and a one-third-octave band of noise if both noises are centered at the same frequency and are normalized to have the same total RMS amplitude?

Assume:

a) the rate of action potentials in an auditory nerve fiber is proportional to a compressive function of the instantaneous power falling within its corresponding cochlear filter (e.g. $r = P^{0.3}$),

b) auditory nerve fibers (and cochlear filters) are evenly spread across a log-frequency scale, such that three times as many fibers respond to the one-octave band as to the third-octave band,

c) that the noise power is the same in each third-octave band and that the audiogram is flat over the region of the spectrum occupied by both noises, and

d) the ERBs of the auditory filters that they stimulate are a third of an octave.

A qualitative answer is sufficient, but please explain the logic behind your answer.

Extra Credit (Matlab only). Please follow the instructions at:
http://auditoryneuroscience.com/spatial-hearing/ITD-ILD-practical

to estimate your ITD and ILD thresholds at 500 and 1800 Hz. Paste your results graphs into your homework document and provide answers to the 10 questions that are posted on the web pages linked from the above URL. You will need to use headphones or earphones – let us know if you do not have easy access to a pair and we will figure something out.