VS 265 Lecture Notes

Auditory information processing

Frequency analysis

- Frequency analysis of sound begins in the cochlea and continues through many neural structures, including the cortex.

- Frequency analysis is the means by which the brain attempts to make sense of the auditory environment and break it down into its constituent components. It is perhaps the most fundamental aspect of auditory information processing.

- The *bandwidth* of frequency tuning refers to the range of frequencies to which a neuron is sensitive. A neuron with narrow bandwidth is excited only by frequencies very close to the preferred frequency. A neuron with wide bandwidth is not as picky and can be excited by a broader range of frequencies around the preferred frequency.

- The bandwidth of mechanisms within the auditory system may be measured psychophysically through *masking* experiments. This is typically done by adapting the system to narrow band noise (like a noisy whistle) and observing the range of frequencies around this band for which detection thresholds have been raised.

- *Critical bands* are measured by observing how thresholds for a single tone are affected by the bandwidth of the noise. Initially, thresholds for frequencies centered at the same place as the noise will rise as the bandwidth of the noise increases. But then at some point thresholds begin to asymptote, indicating that the increasing bandwidth of the noise no longer incrementally affects detection at the target frequency. The point at which this asymptote occurs is known as the critical band, and is also indicative of the bandwidth of internal (neural) auditory processing mechanisms.

Auditory pathways

- Auditory information follows a much more complicated and circuitous route to the cortex than does visual information. Whereas the retina is separated by only one synaptic relay from the cortex, the cochlea is separated by at least 4 subcortical processing stages from the cortex.

- Auditory information initially exits the cochlea via the *auditory nerve*, which contains about 30,000 nerve fibers (the axons of neurons that make contact with the hair cells). Note that in contrast to the retina, very little neural preprocessing takes place in the cochlea itself. Also, whereas in the retina there is a net convergence of photoreceptors to ganglion cells (ca. 100:1) there is a net divergence (ca. 1:10) from inner hair cells to auditory nerve fibers.

- The main path by which auditory information proceeds to the cortex is through the *cochlear nucleus*, *superior olive*, *inferior colliculus*, *medial geniculate nucleus* (MGN) of the thalamus, and then cortex. Most of these structures maintain a tonotopic representation of sound. The superior olive is the first stage at which information is combined from the two ears, and it is thought to subserve sound localization by computing interaural time differences (see below).

Sound localization

- Two of the main cues for localizing sound in space are interaural time differences (ITD) and interaural intensity differences (IID).

- Interaural time differences arise because of the time delay that is induced by the separation of the ears in space. Sounds coming from your left will first impinge upon the left ear, and then later on the right ear. By comparing the phase difference of frequency components at the left and right ear, the brain can infer the position of the sound source in space. This can be done unambiguously though only for relatively low frequencies (approximately below 1000 Hz).

- Interaural intensity differences arise because the head forms an *acoustic shadow,* and so sounds on your left will have higher intensity at the left ear and lower intensity at the right ear. By comparing the sound level at the two ears, the brain gets an additional cue to infer the direction a sound is coming from. The acoustic shadow is significant though only for frequencies above about 1000 Hz, and so this form of sound localization must be complimentary to that of ITD.

Pitch and timbre

- *Pitch* is the subjective percept that we typically attach to frequency. The sounds created by most natural instruments will have a fundamental mode of vibration in addition to a set of harmonics whose frequencies are at integer multiples of the fundamental. The brain seems to understand this aspect of the world, and so groups together the harmonics that are all consistent with a single fundamental frequency (i.e., they must all be integer multiples of a common number). The result of this grouping process is the percept of pitch.

- The *missing fundamental* demonstrates that pitch is largely an *inferred* quality. That is, you will identify a complex tone as having the same pitch as a 440 Hz tone even though the tone contains no frequencies at 440 Hz. (more on this next lecture)

- *Timbre* refers to the quality of sound that distinguishes a clarinet from a trombone, even though both may be playing the same pitch. The percept of timbre is created by the relative amplitudes of the harmonics created by an instrument.