Auditory system: the way we transduce sound waves into neural impulses

- Amplitude:
  - The local maxima (peaks) of a sound wave; determines *how loud* a sound is
    - The larger the peak, the louder the sound
- Frequency:
  - In physics, frequency is defined as the *number of wavelengths per second*; determines the *pitch* of the sound
    - The higher the frequency, the more compressed the waves are and the higher pitched the sound
  - Pitch: *perceived* frequency; what we hear
- Auditory Transduction Pathway:
  - Sound waves enter the ear and travel down the inner ear canal until they meet the **tympanic membrane** (ear drum)
    - Sound waves are really just waves of compressed and rarefied air, so when they encounter the tympanic membrane, **vibration** of the membrane occurs
      - Resting on the other side of the tympanic membrane are the **ossciles:** 3 bones that vibrate with the tympanic membrane corresponding to the characteristics of the sound wave
        - The three bones in the ossciles are the ***malleus*** (rests against tympanic membrane and is the first bone in the series), the ***incus***, and the ***stapes*** (aka the stirrup)
      - Because of the pivotal motion of the ossciles, the stapes moves like a piston through the ***oval window*** of the *bony labyrinth* (the crazy-looking structure that includes the cochlea)
        - The bony labyrinth is a completely rigid structure that is *filled with fluid;* the ***piston-like movement of the stapes allows fluid to be displaced through the entire rigid structure.***
          - A small *membranous* section of the rigid bony labyrinth is located right below the oval window, called the ***round window***
            - This ultimately allows the fluid to be displaced by the piston motion of the stapes
    - **The cochlea** is the part of the bony labyrinth that looks like a snail shell
      - The **basilar membrane** spans the entire length of the cochlea, dividing the cochlea into 2 large and 1 smaller fluid-filled sections: the *scala vestibuli* on top, the *scala*

tympani on the bottom, and the *cochlear duct* in the middle, respectively

- **Organ of Corti:** the sensory organ in auditory transduction, embedded in the basilar membrane with cilia poking out into the cochlear duct and one long cilium resting against the **tectorial membrane** (jetting out from one side of the cochlear duct)
    - As vibrations within the fluid travel up the cochlea through the scala vestibuli, vibrations travel down across the basilar membrane into the scala tympani
        - When these vibrations travel down the basilar membrane, it vibrates, which **pushes the hair cells up against the tectorial membrane** in an oscillatory fashion that corresponds to the original sound wave
            - Pushing against the tectorial membrane ***depolarizes the hair cells***, which then release glutamate onto cochlear nerves embedded in the basilar membrane

- The cilia of the hair cells are physically tethered together and have mechanically gated ion channels
    - When the longest cilium is pushed against the tectorial membrane, the other cilia are pulled in the same direction
        - When they are pulled to one side, it **pulls their channels open,** allowing ***POTASSIUM*** ions to flow into the cell and depolarize it
            - The reason potassium flows into the cell is because inside the cochlear duct, the fluid that fills the cavity is *much higher in potassium than extracellular fluid*
                - Thus, potassium flows down its concentration gradient into the cell. Since it has a positive charge, it will depolarize the cell and allow calcium channels to open and trigger neurotransmitter release (glutamate)

- The **cochlear nerves** (bipolar neurons; cell bodies found in spiral ganglion) that are also embedded in the basilar membrane *make synapses onto these hair cells*

    - When a hair cell is mechanically activated by the vibration of the basilar membrane, it is depolarized and it releases glutamate onto these cochlear nerves which excites them until they can send an action potential
        - *Hair cells DO NOT send action potentials; they simply release glutamate in response to calcium influx. Cochlear nerves, however, DO send APs in response to depolarization by glutamate binding*
- Cochlear nerves then send an action potential and synapse on **cochlear nuclei in the medulla**
    - Neurons in the cochlear neurons then project to either the ***medial*** **superior olives** or the ***lateral*** **superior olives**
        - Medial – detect differences in *time*
            - i.e. the difference in time it takes for sound to enter one ear compared to the other
        - Lateral – detect differences in *amplitude*
    - These neurons then project to the ***inferior and superior colliculi in the tectum (midbrain)***
        - This projection is *not* tonotopic; it instead reflects a visual map of auditory space
            - The superior colliculi are more heavily involved in *visual* transduction; their participation in auditory transduction assists sound localization
            - These neurons then project to the medial geniculate nucleus of the thalamus, and then to the primary visual cortex
                - The primary visual cortex is tonotopically organized
                    - Columnar arrangement of neurons respond to similar frequency sounds
                - The secondary visual cortex is not well characterized; we just know that it involves more complex sounds
    - Association areas:
        - Posterior parietal pathway – "Where" the sound is coming from
        - Anterior pathway (towards prefrontal cortex) – "what" the sound is