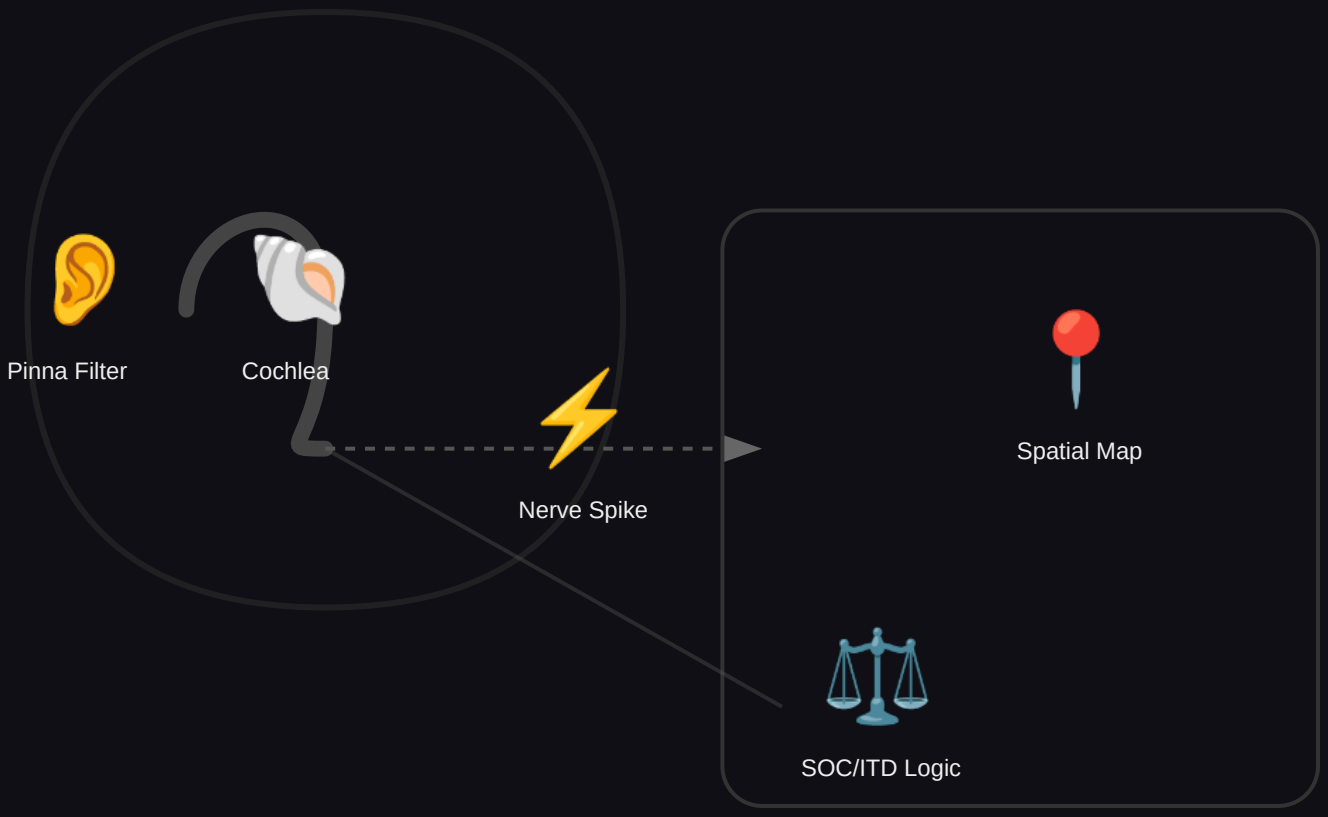

Vectree

Neurobiology of the cochlea and binaural localization algorithms

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👂 Pinna & HRTF

The Pinna acts as a biological acoustic filter. Its unique shape creates reflections that interfere with direct sound waves, producing spectral ‘notches’ and ‘peaks’ at specific frequencies. These spectral cues are processed by the brain to determine the elevation and front-back position of a sound source, a process mathematically described by the Head-Related Transfer Function (HRTF).

🐚 Cochlear Tonotopy

The cochlea is a fluid-filled spiral that performs a mechanical Fourier Transform. Along the Basilar Membrane, resonance occurs at specific locations depending on frequency: high frequencies resonate at the stiff base, while low frequencies reach the flexible apex. This ‘tonotopic’ map is the fundamental organizational principle of the entire auditory system.

⚡ Neural Temporal Coding

Information is transmitted from the cochlea via the auditory nerve. For frequencies below ~4-5 kHz, neurons utilize ‘phase-locking,’ firing action potentials at specific phases of the sound wave. This temporal precision is critical for binaural algorithms to calculate the exact microsecond arrival differences between the two ears.

⚖️ Superior Olivary Complex

The Superior Olivary Complex (SOC) is the first site in the brain to receive input from both ears. It houses two primary circuits: the Medial Superior Olive (MSO), which uses delay lines to calculate Interaural Time Differences (ITD), and the Lateral Superior Olive (LSO), which compares sound intensity to calculate Interaural Level Differences (ILD). Together, these form the basis of the Duplex Theory of sound localization.

📍 Inferior Colliculus Integration

The Inferior Colliculus (IC) serves as a major integration hub where timing, intensity, and spectral cues converge. It contains neurons that are ‘tuned’ to specific points in 3D space, creating a topographical map of the auditory environment. This allows the animal to orient its head and eyes toward a sound source near-instantaneously.