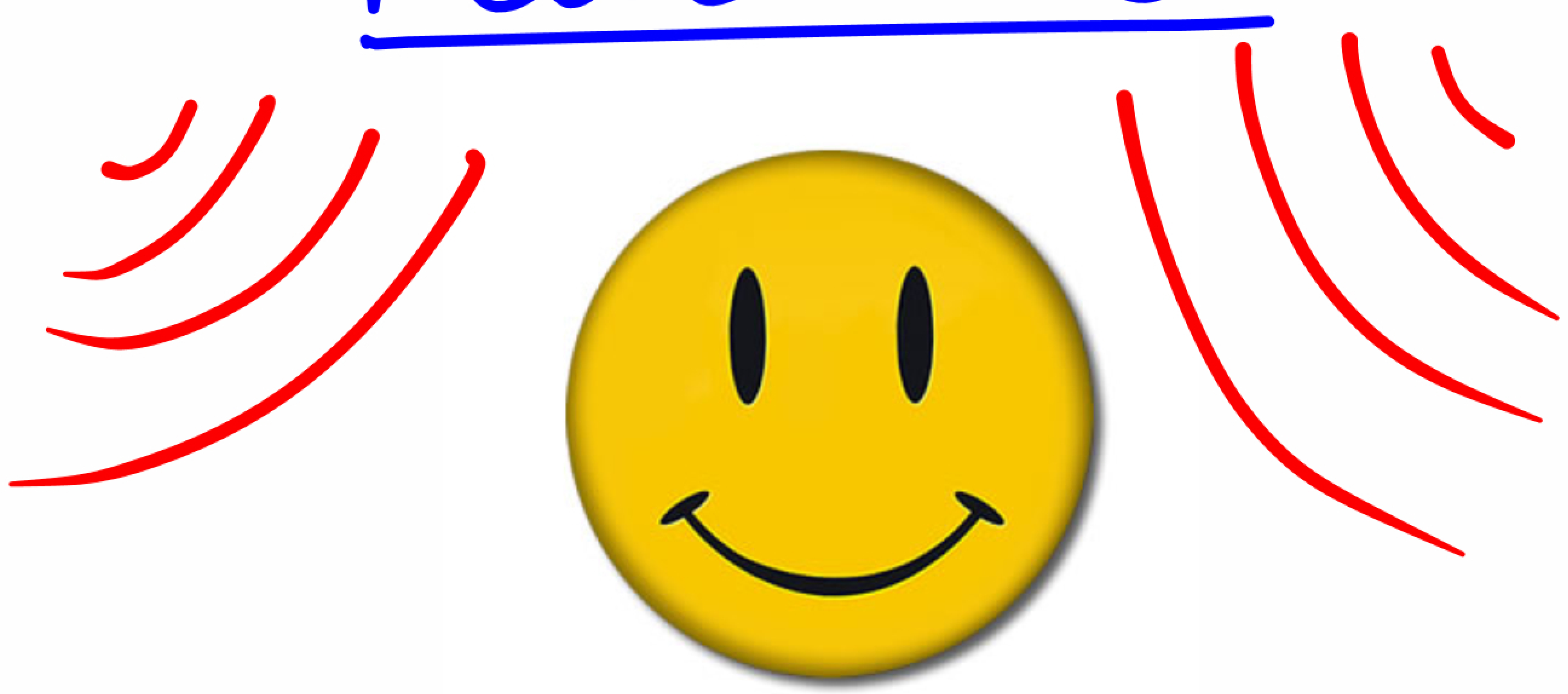
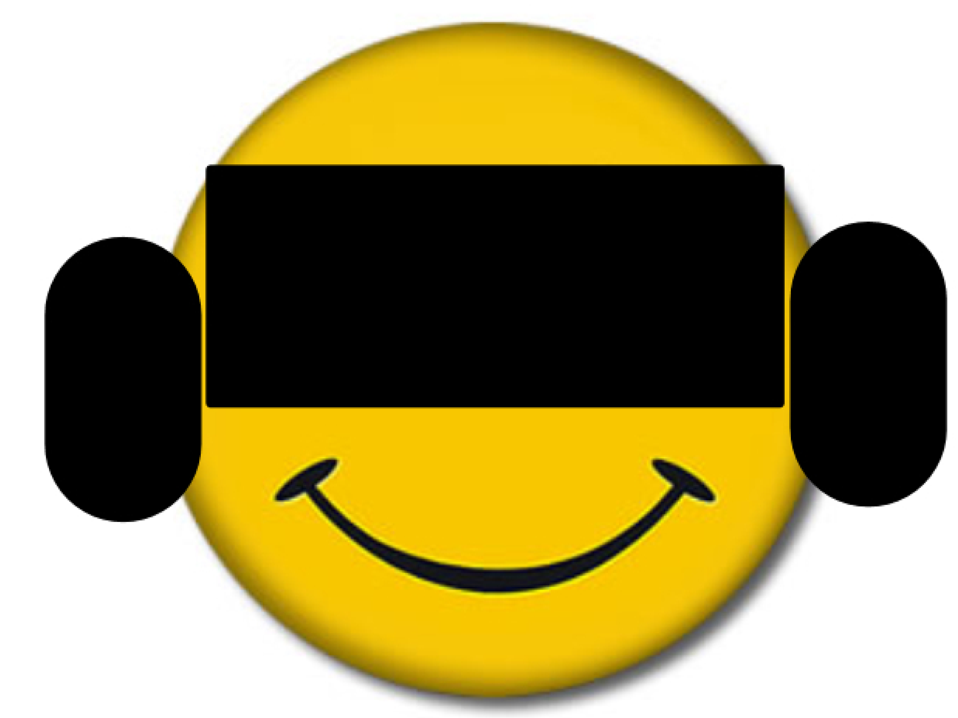
Announcements

- **Dec 9,** 7-9pm in DCL 1320
  Midterm 2, not accumulative

- **Dec 16,** 7-11pm in Siebel 4240.
  Final project presentations and Open House for CS department

Audio for VR





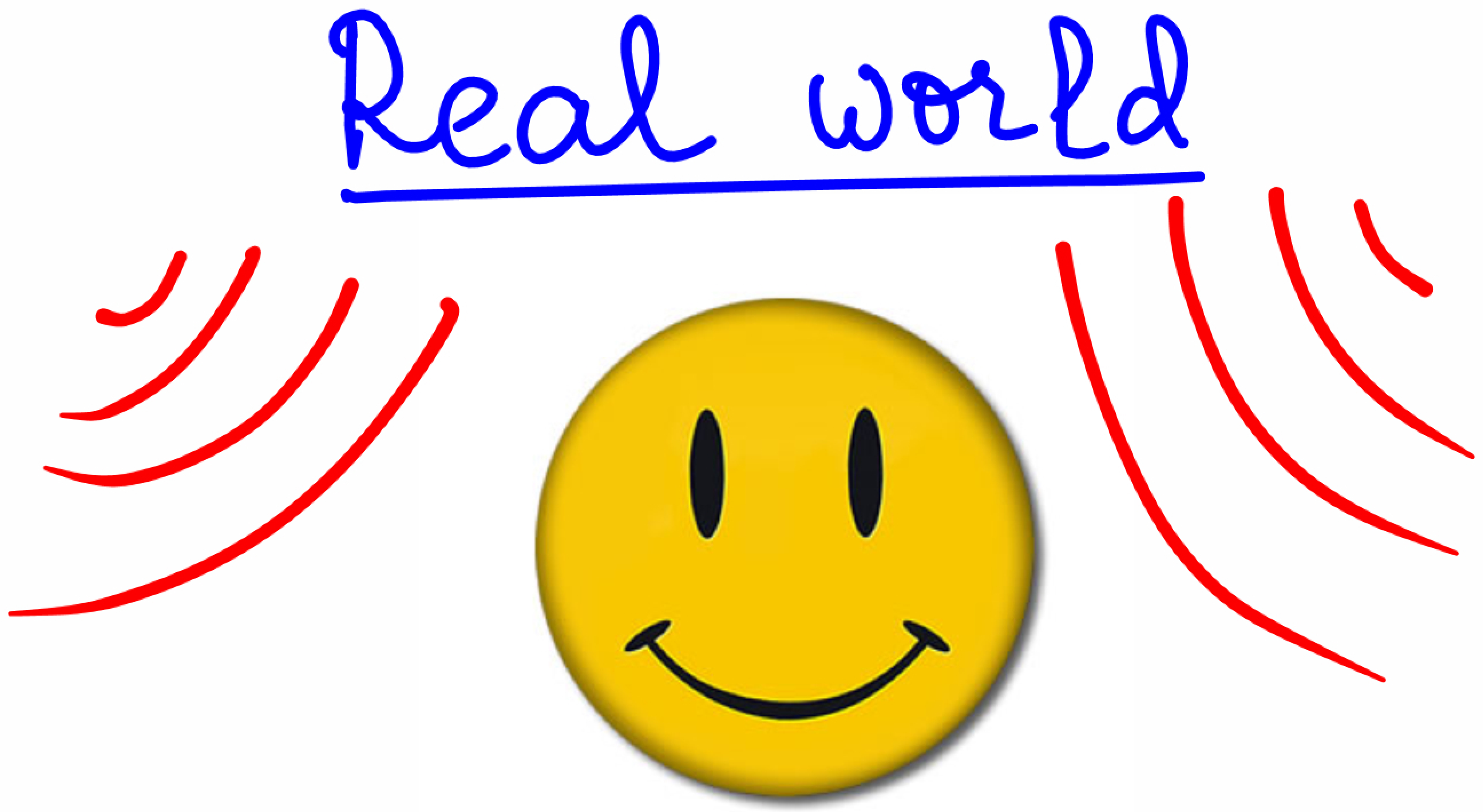
Sound waves are similar to light except:

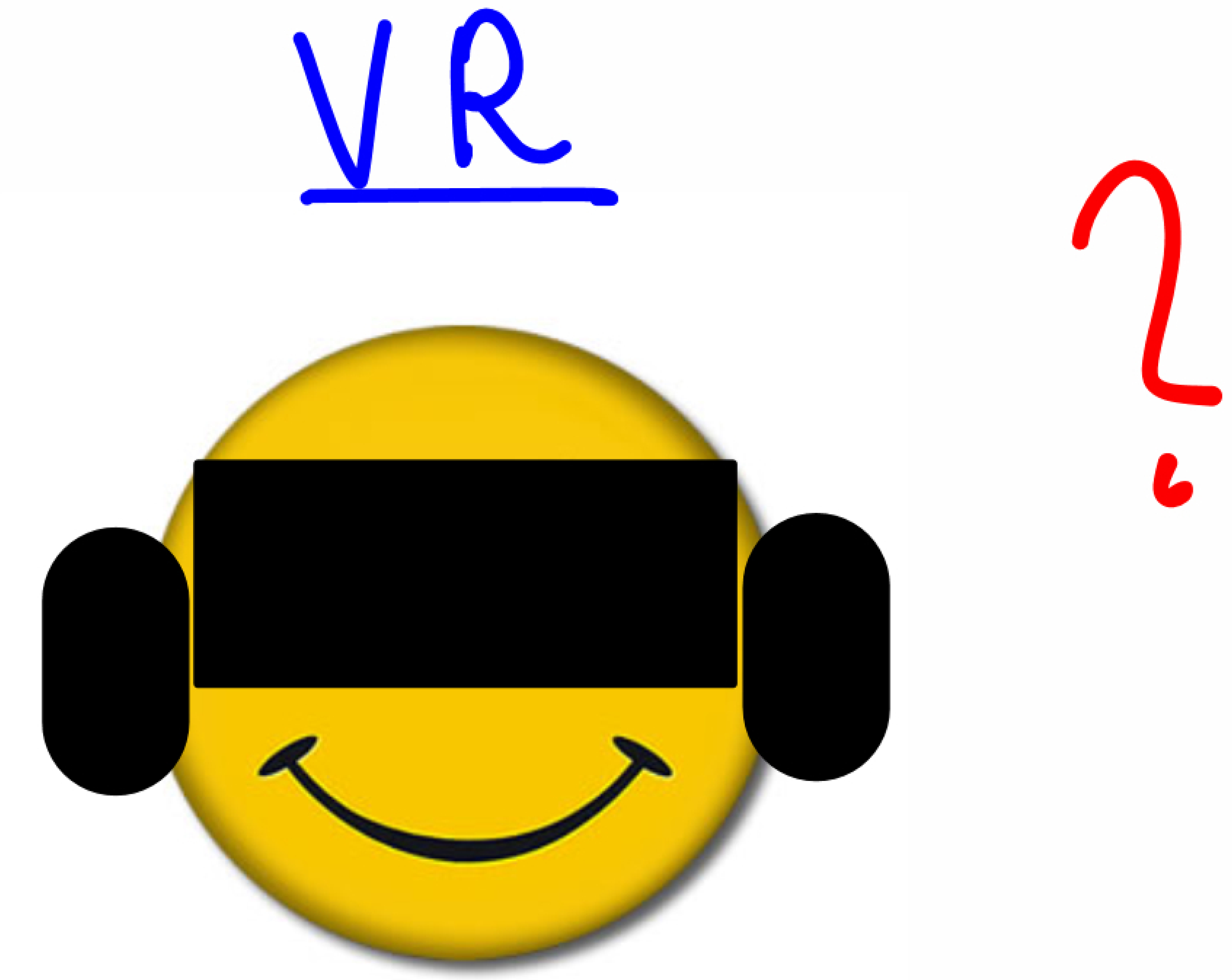
- Physics of sound → How the real world works
- Physiology of the human ear
- Perception of sound

→ How our senses perceive the real world

- Rendering of sound → How an engineered system can take the real world to human senses

Audio for VR: The Physics of Sound





Sound waves are similar to light except:

- Fluctuating air pressure (instead of EM/photons)
- Frequency is only 20Hz to 20000Hz (17 m to 17 mm, instead of 400-700nm wavelength)
- Speed is 343 m/s in air (instead of c = 3 x 10^8 m/s)

$$f = \frac{c}{\lambda}$$

Audio for VR: the Physics of Sound

Interaction with other media is similar to light:

Absorption | Refraction/transmission | Reflection | Diffraction

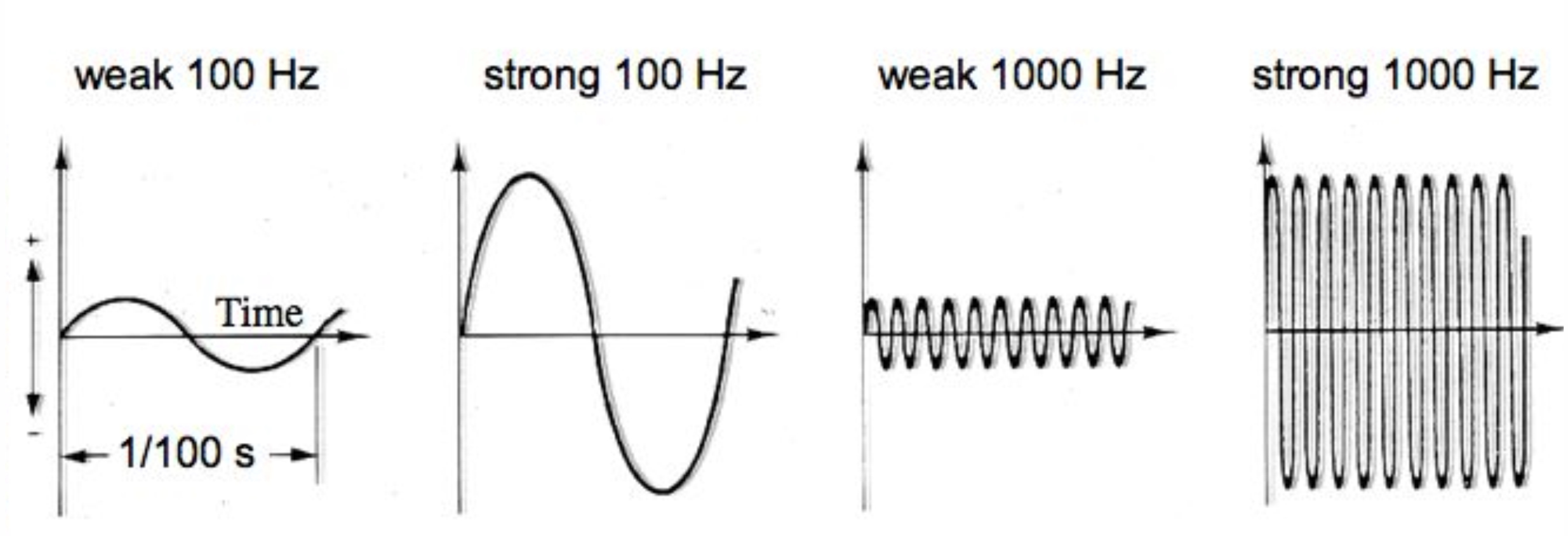
Audio for VR: the Physics of Sound

Frequency spectrum, just like light:

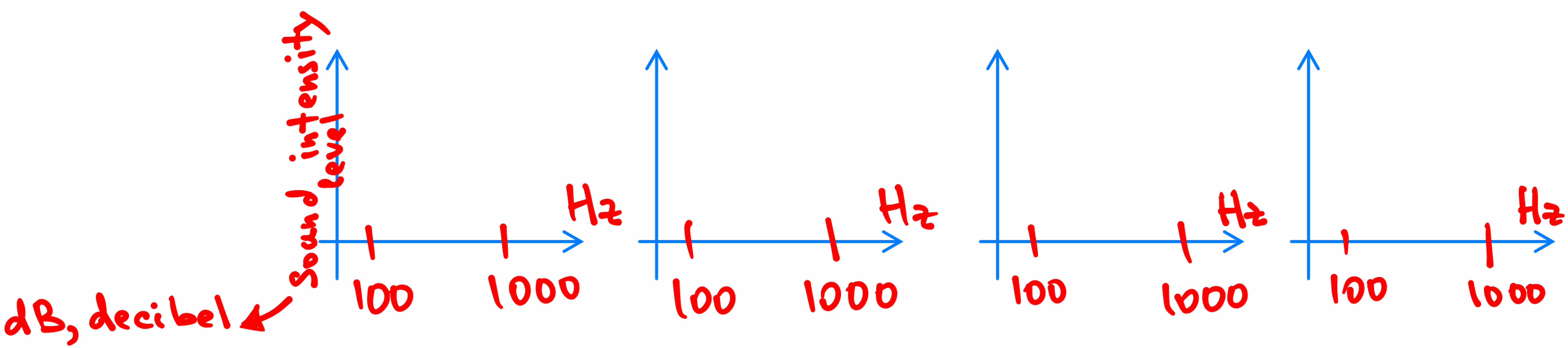
Pure tone , like R, G or B

http://www.psypress.co.uk/mather/resources/swf/Demo4_1.swf

Wavelength:



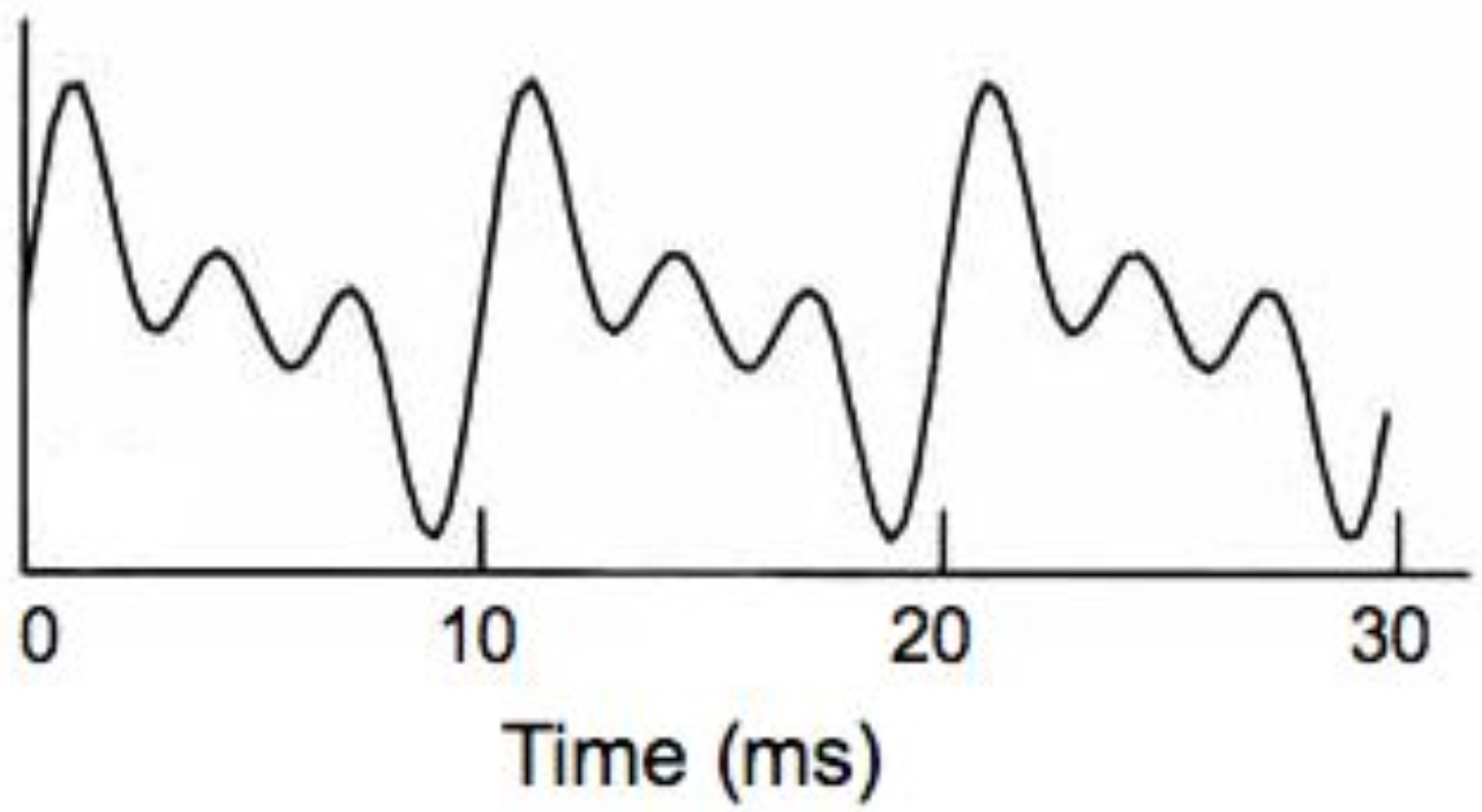
Frequency spectrum:

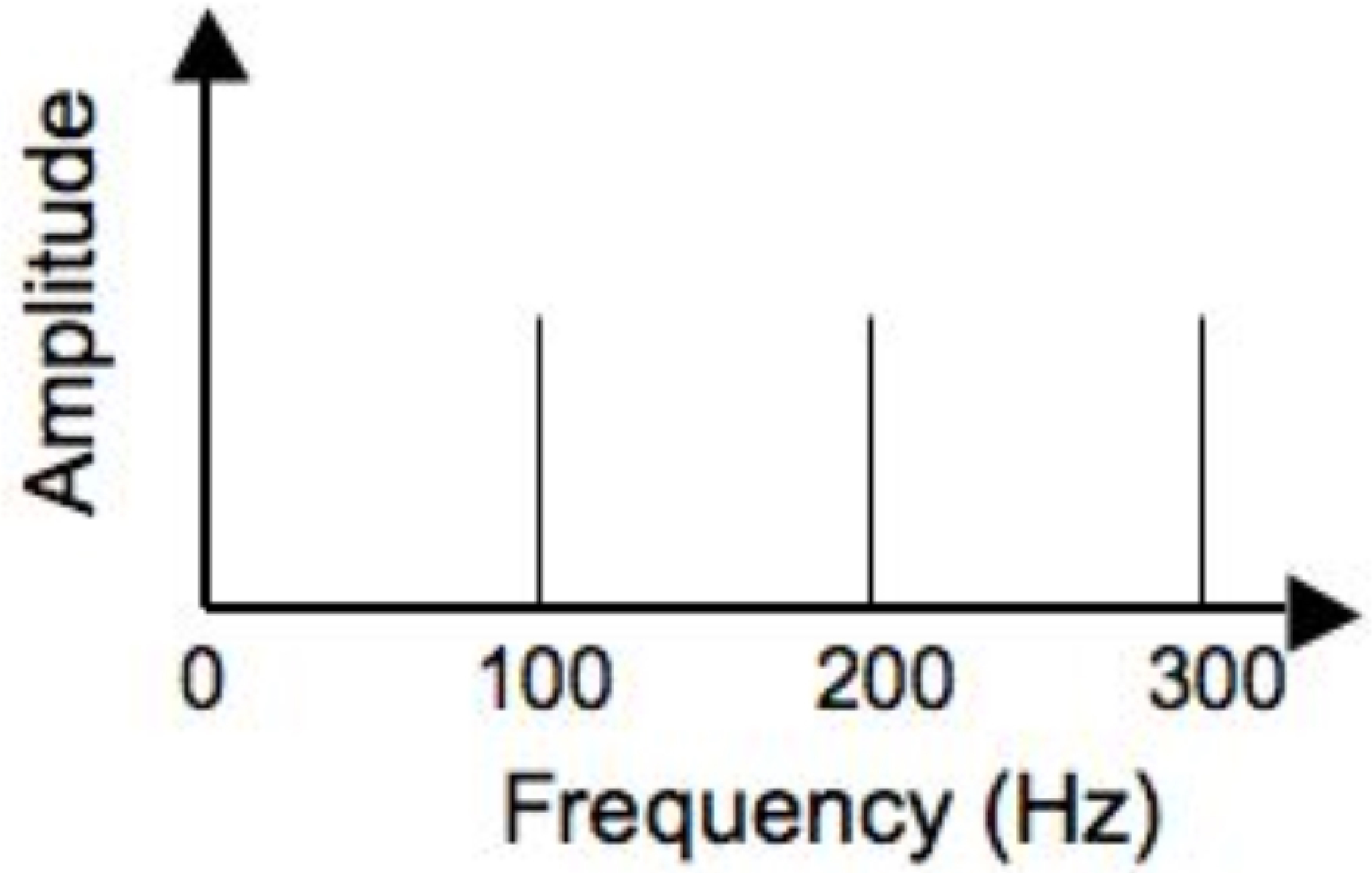


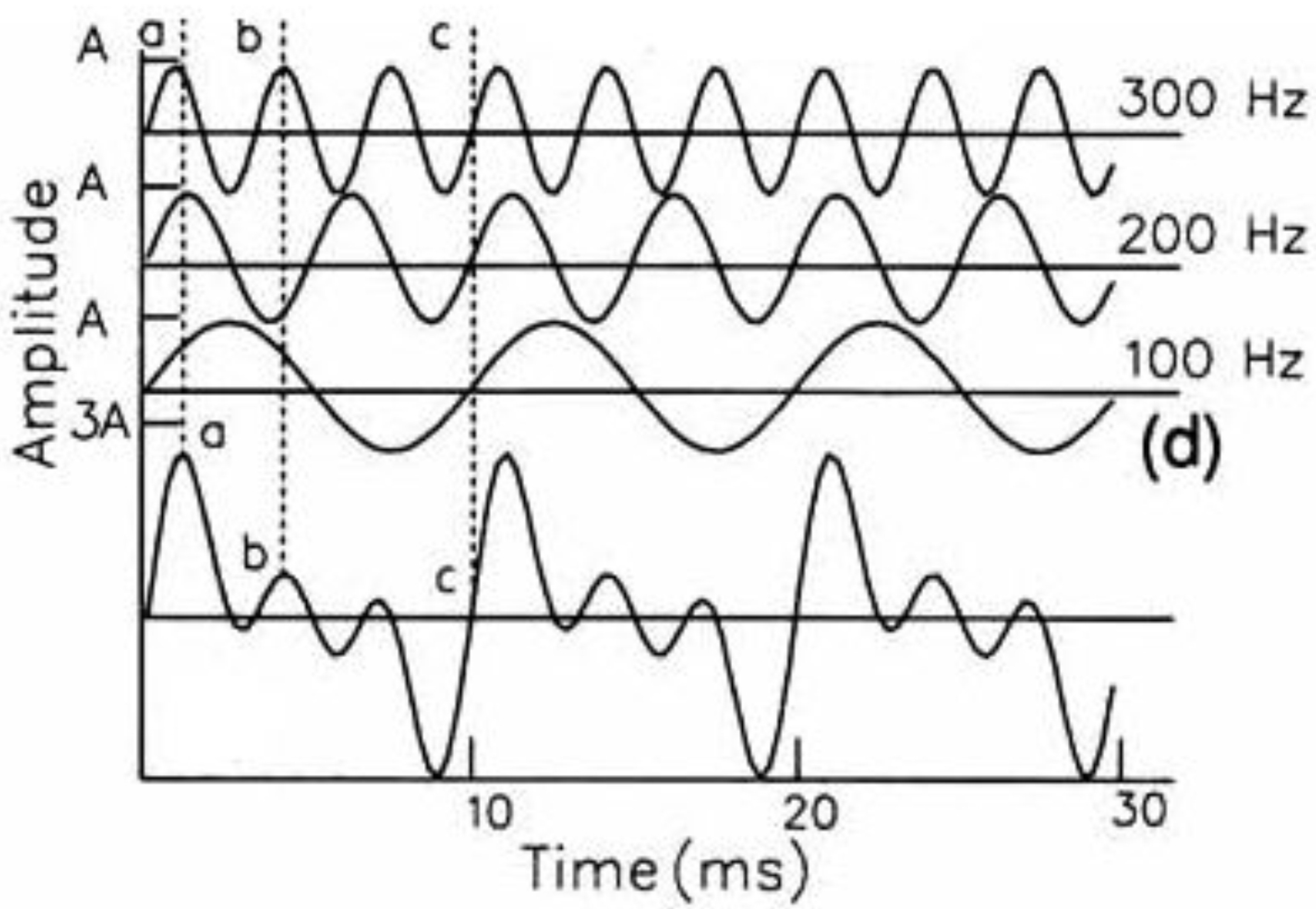
Audio for VR: the Physics of Sound

Complex wave: like mixed color (white)

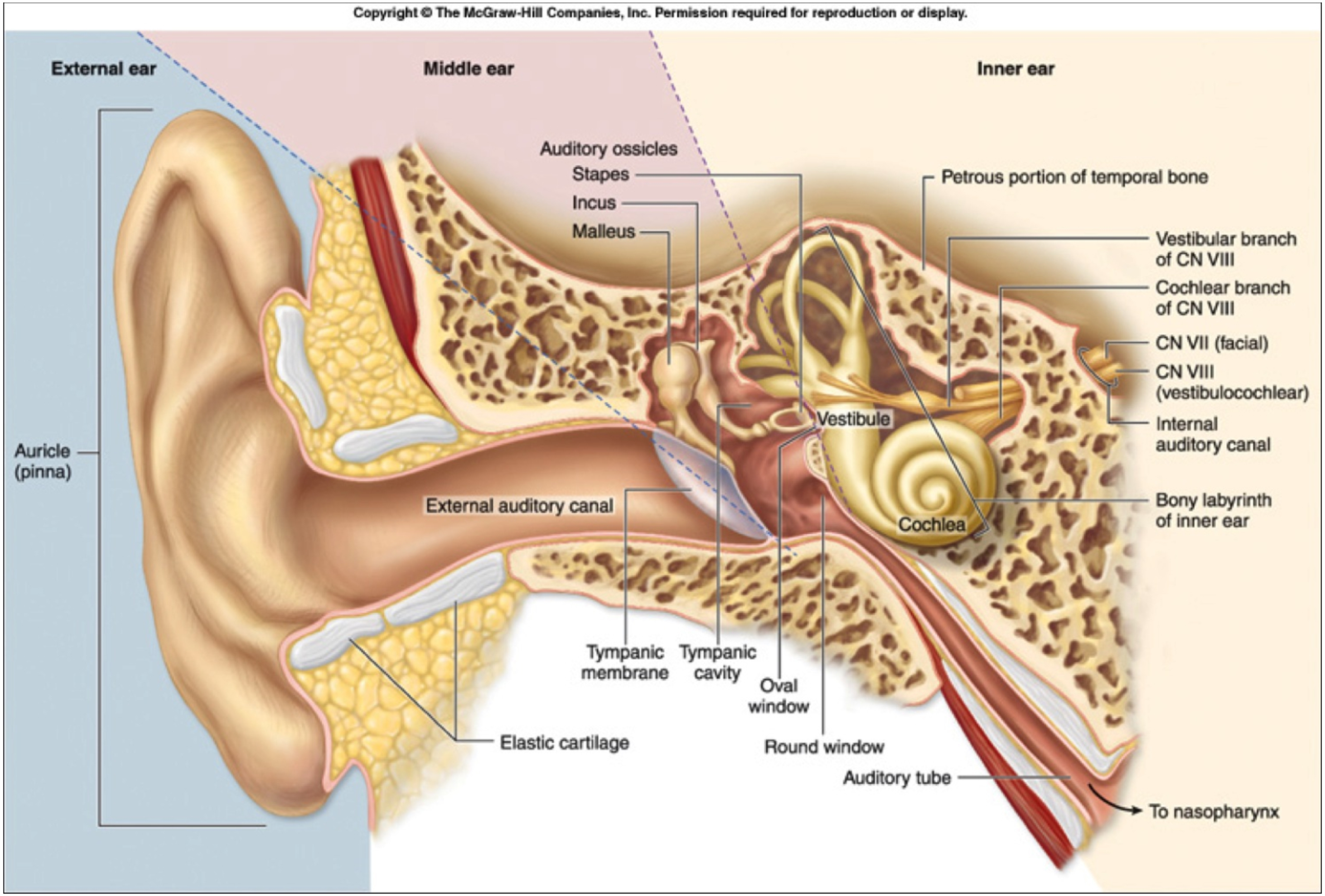
http://www.psypress.co.uk/mather/resources/swf/Demo4_2.swf







The Physiology of the Auditory System



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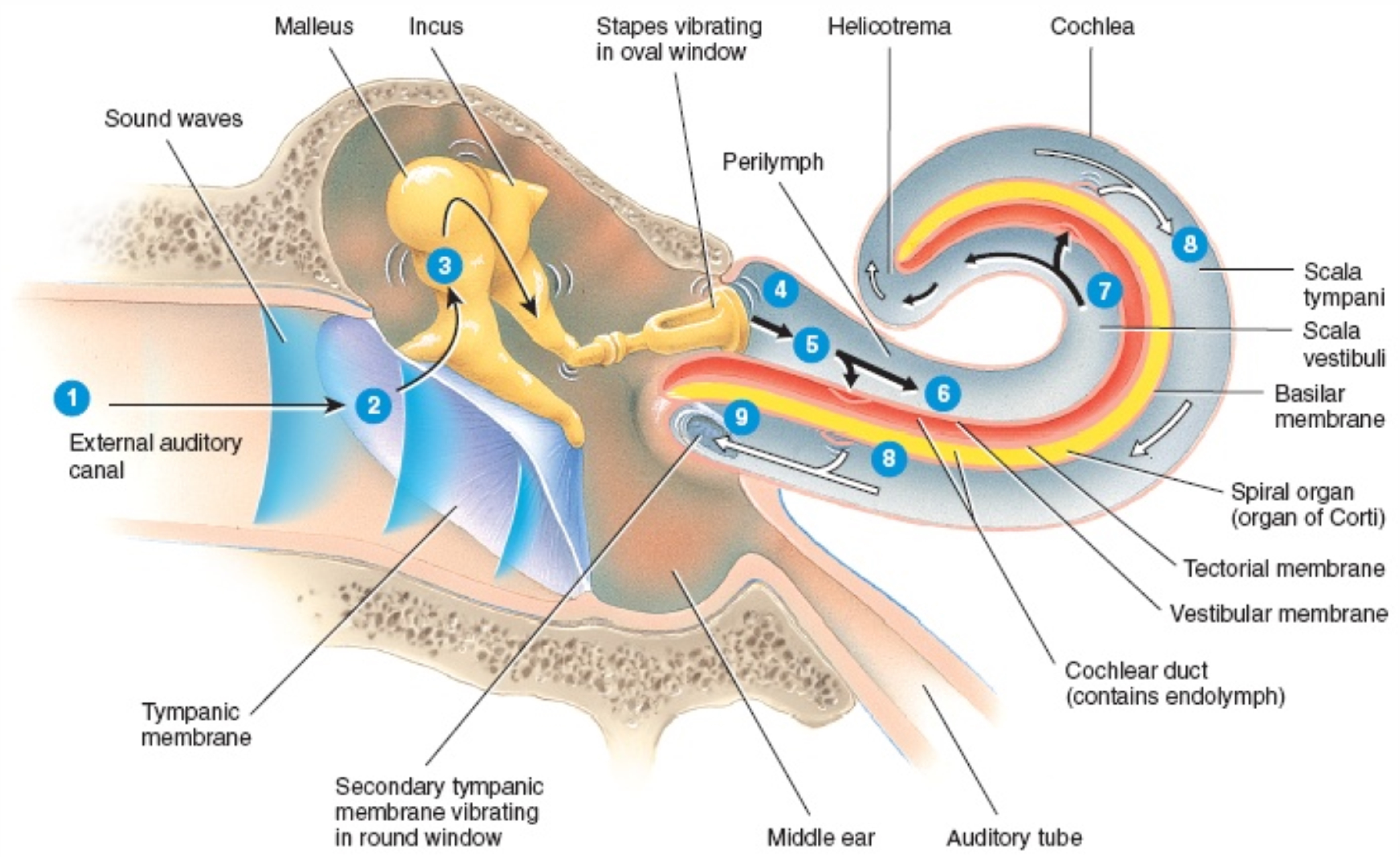

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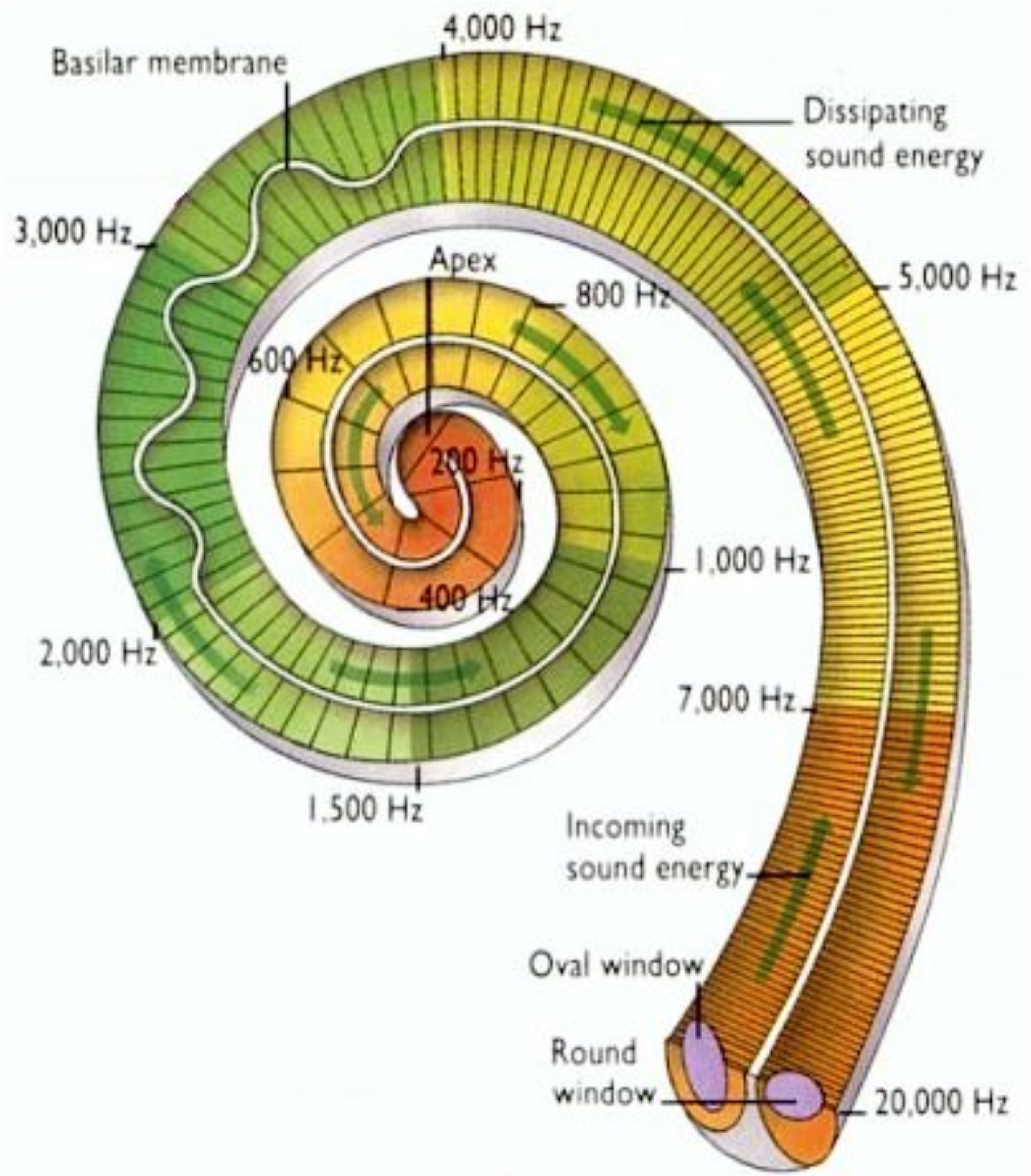

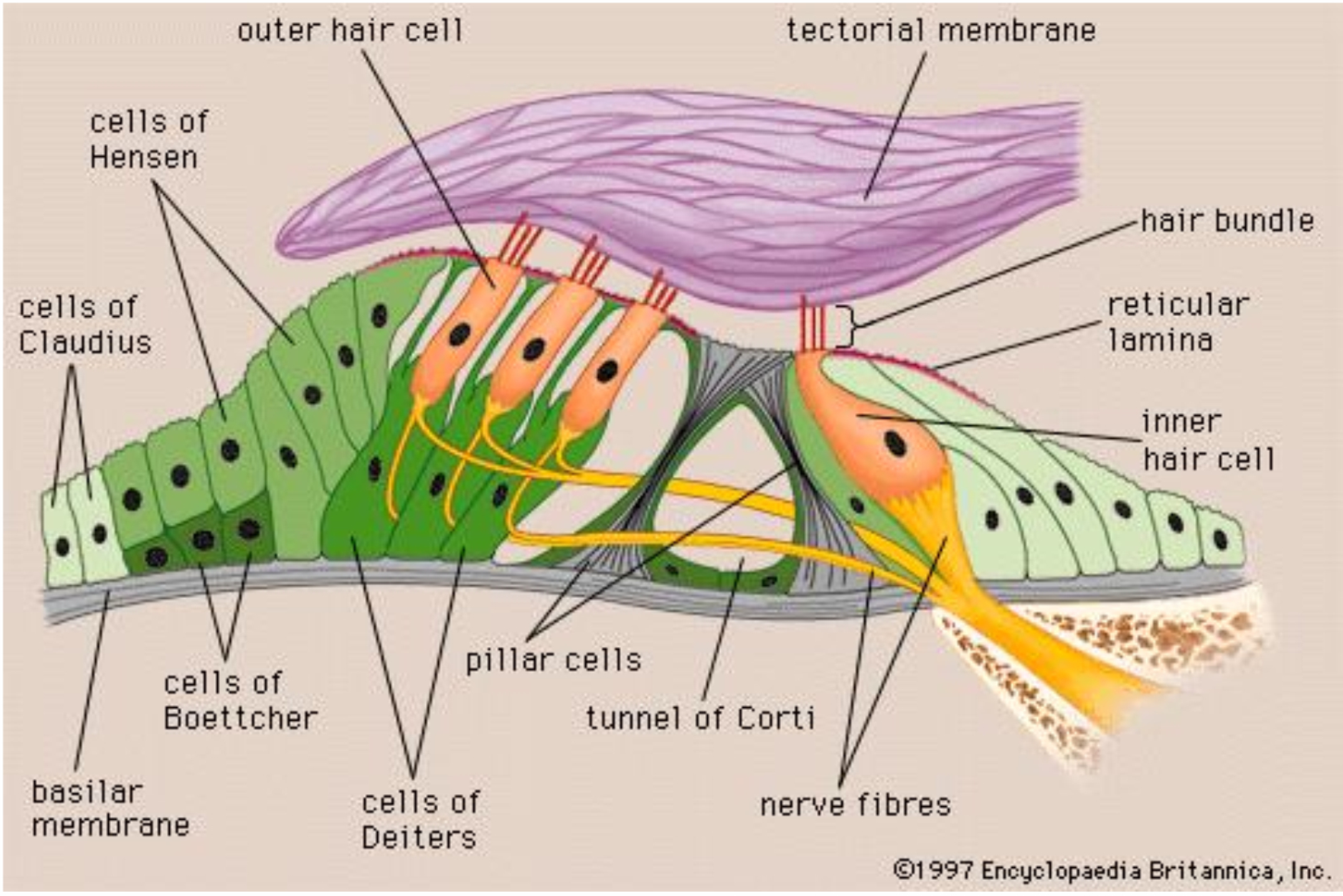

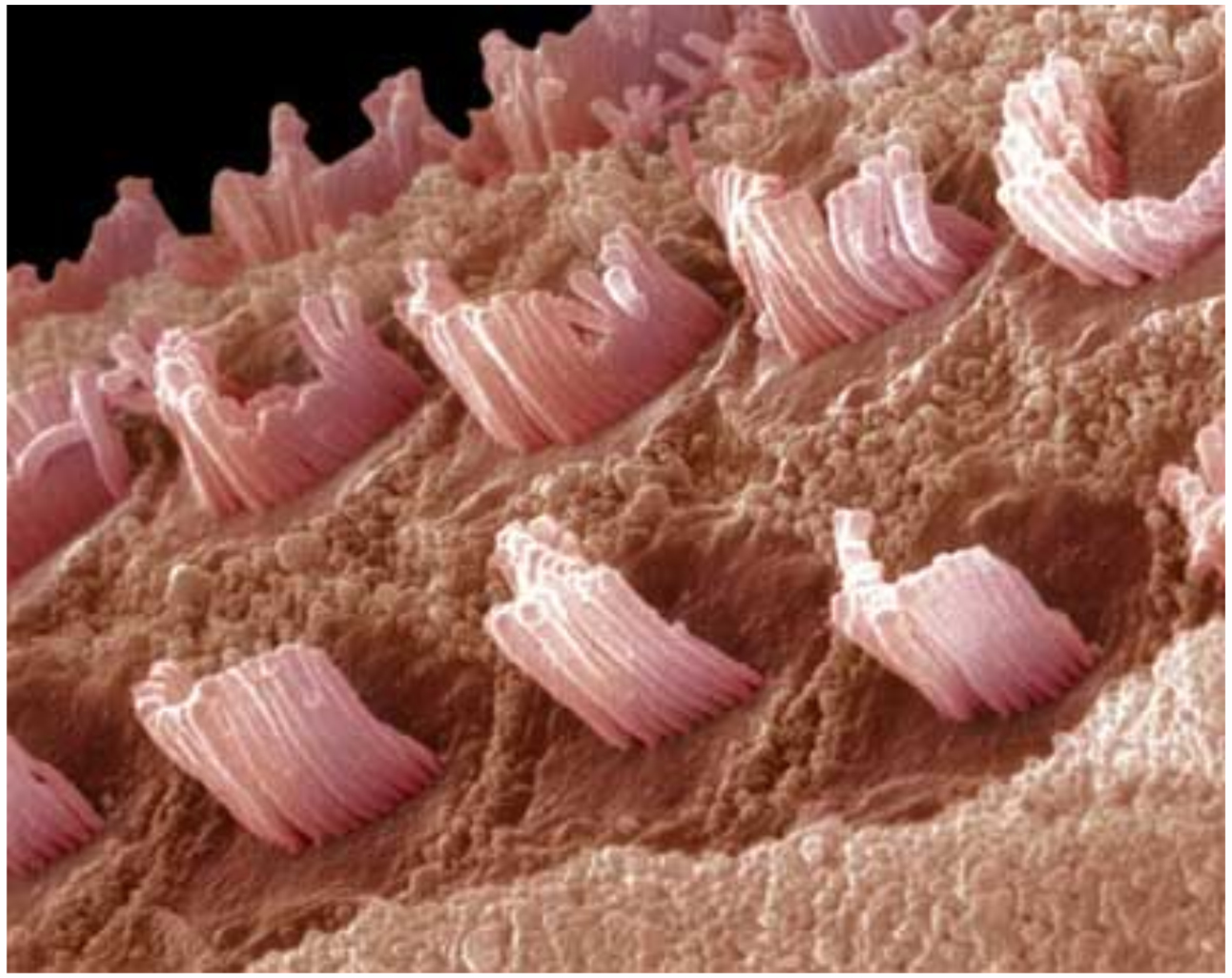

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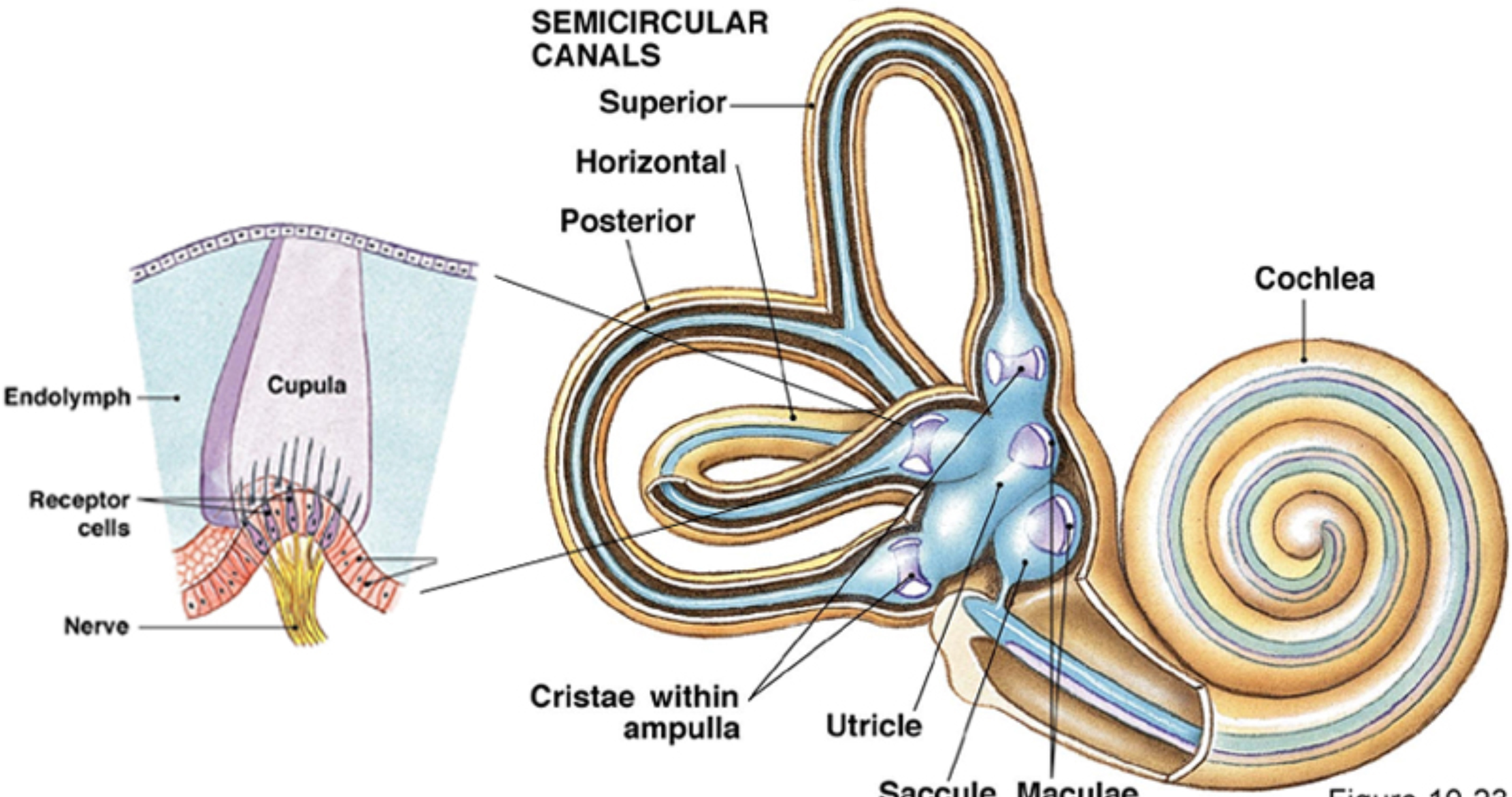


Figure 10-23

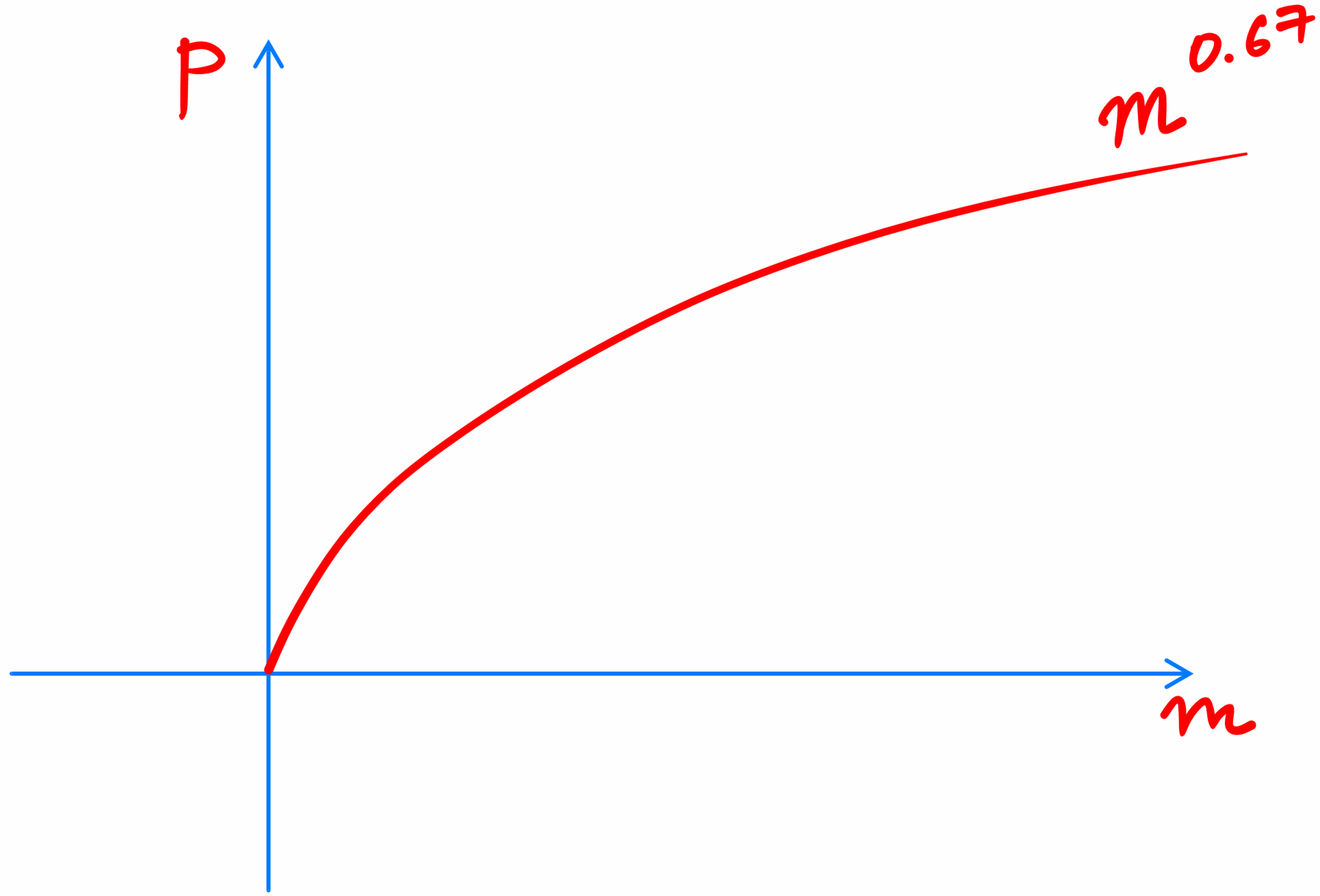
Perception of Sound

Steven's power law: $p = c \cdot m^x$

m - magnitude of stimulus

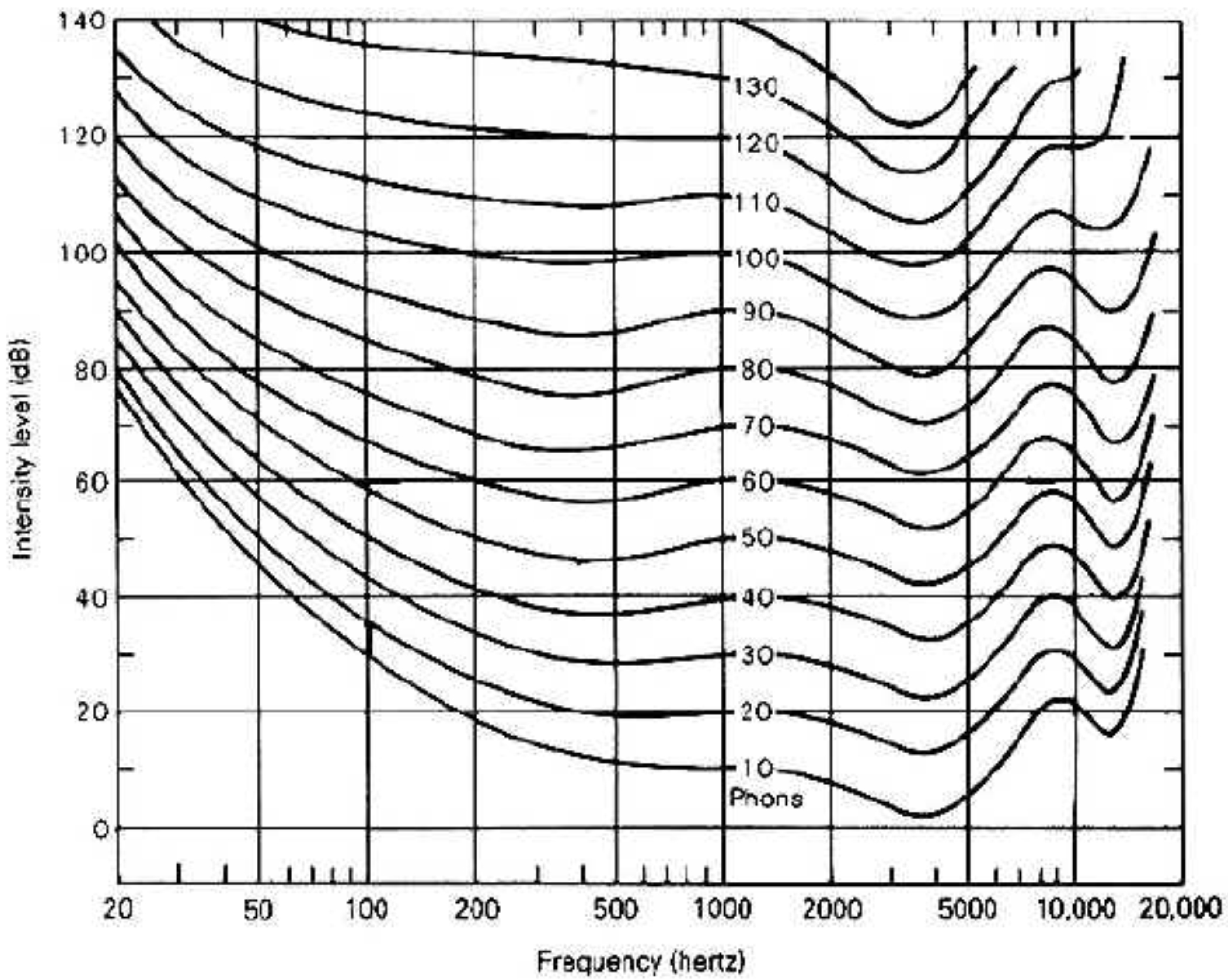
p - perceived magnitude

For loudness at 3000Hz: x = 0.67



Perception of Sound

- **Equal loudness perception** (Fletcher & Munson, 1933)**:**



- **Loudness adaptation over time.**
- **Pitch perception:** Frequency discrimination is remarkably good at low frequencies, but deteriorates at high frequencies.

Perception of Sound: Auditory Localization

Where is the sound coming from (similar to depth perception):

Minimum audible angle (MAA):

~ 1 degree 1000 Hz straight ahead
~ 5 degrees to the side
terrible around 1500-1800Hz on side

Monaural cues:

1) pinna and external ear canal shape
2) intensity decreasing by inverse square law
3) spectrum of sounds (low frequency travels further)
4) direct vs reverberation energy with reflecting surfaces

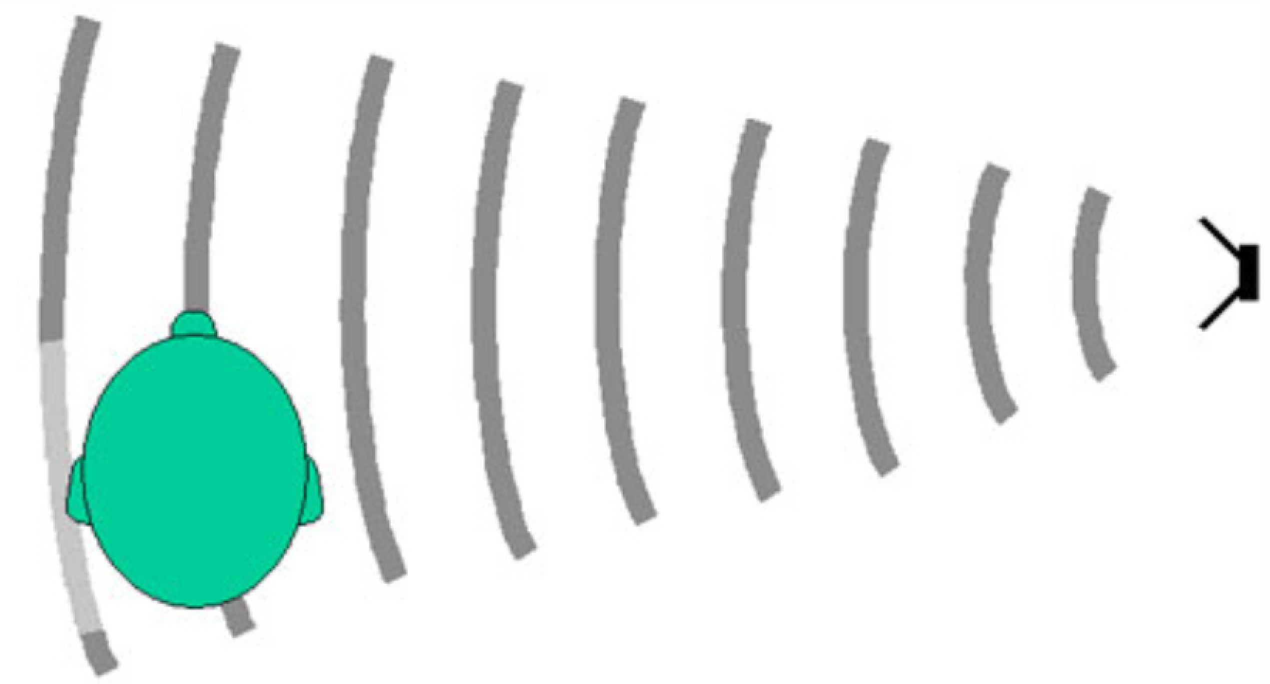
Audio illusion:

Preference of main/first wave; suppression of later waves.

Perception of Sound: Auditory Localization

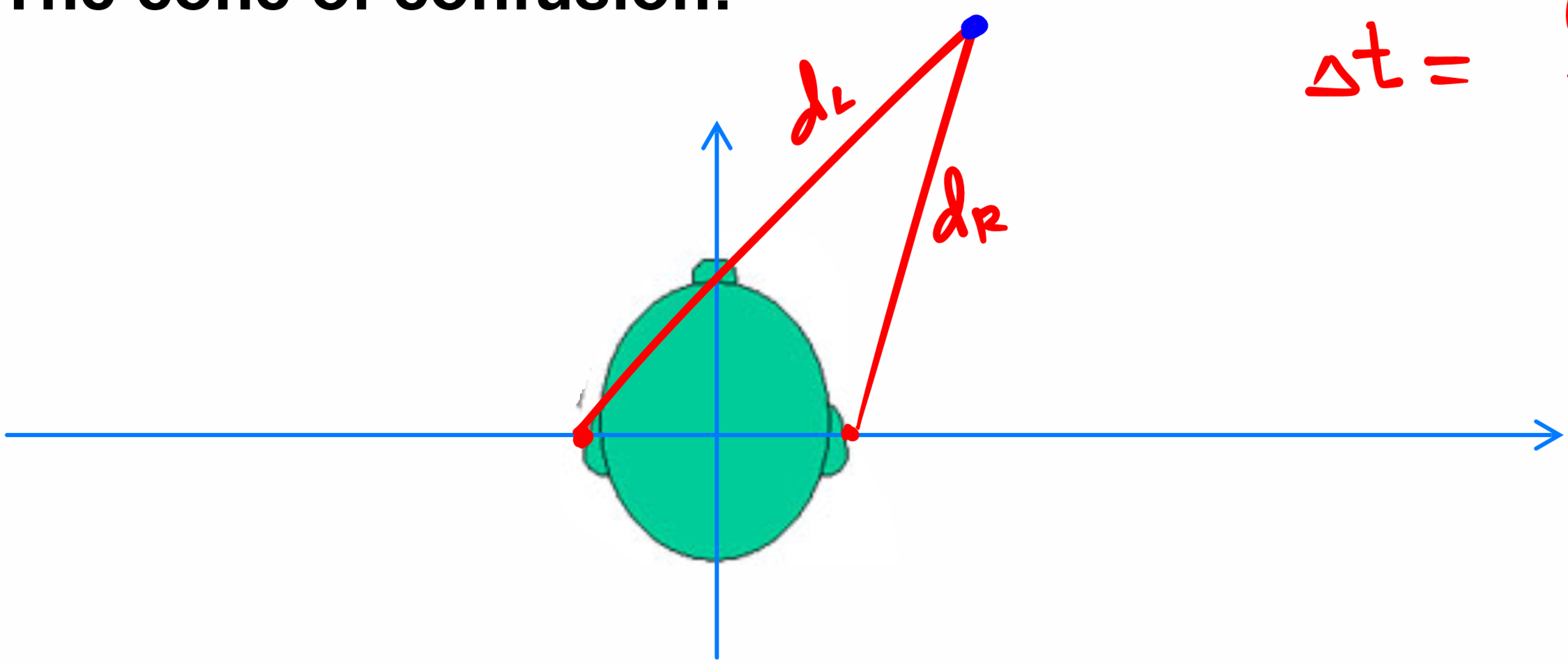
Where is the sound coming from (similar to depth perception):

Binaural cues:



1) ILD: Interaural Level Differences - acoustic shadow
2) ITD: Interaural Time Difference - arrival time, distance between ears ~14 cm

The cone of confusion:



$$\Delta t = \frac{(d_L - d_R)}{s} = .44\,ms$$

$$s \simeq 343\ m/s$$

Sound Rendering

Four steps:

1. Modeling
2. Propagation
3. Rendering
4. Display

Modeling:

- Geometric models - walls, obstacles
- Acoustic material properties - absorption, reflection, refraction
- Sound sources - point source, parallel wave source, loudness

Lower resolution than for graphics (only 1 pixel!)

Sound Rendering

Four steps:

1. Modeling
2. Propagation
3. Rendering
4. Display

Propagation:

- Reflection - specular, scattering
- Absorption, diffraction, refraction
- Doppler effect, https://www.youtube.com/watch?v=h4OnBYrbCjY

Computational approaches:

- Numerical, solve PDEs for wave equations, accurate but expensive
- Combinatorial, similar to graphics ray tracing, fast, approximate