COMP47700
Speech and Audio

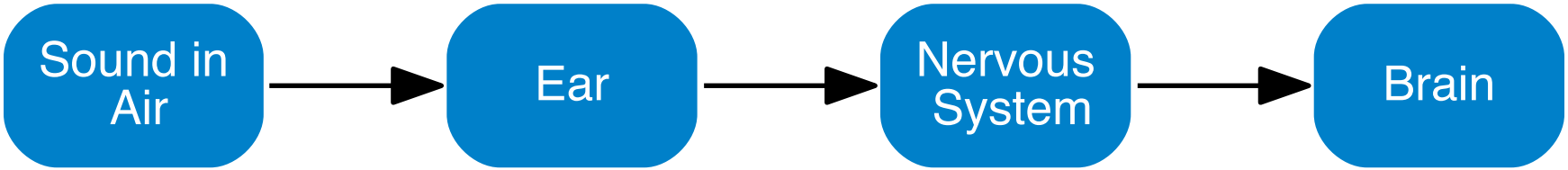
Dr Alessandro Ragano

Office: 3rd Floor, Science East, Insight Centre
School of Computer Science
University College Dublin

alessandro.ragano@ucd.ie

4.1
How We Hear: The Sound Pathway and Auditory Periphery

Human Auditory System: How do we hear?



Process of Hearing

- Ear mechanics (outer, middle, inner)
- sound pressure wave to understanding in the brain
- wider brain function (other senses interacting)

Physical Processes

- Several steps contribute to unequal distribution of features
- Cause a mismatch between perception by subject and physical signal ($\therefore$ use log (dB) scaling intensity)
- We perceive amplitude logarithmically: A-law compression better than linear for 8-bit quantisation

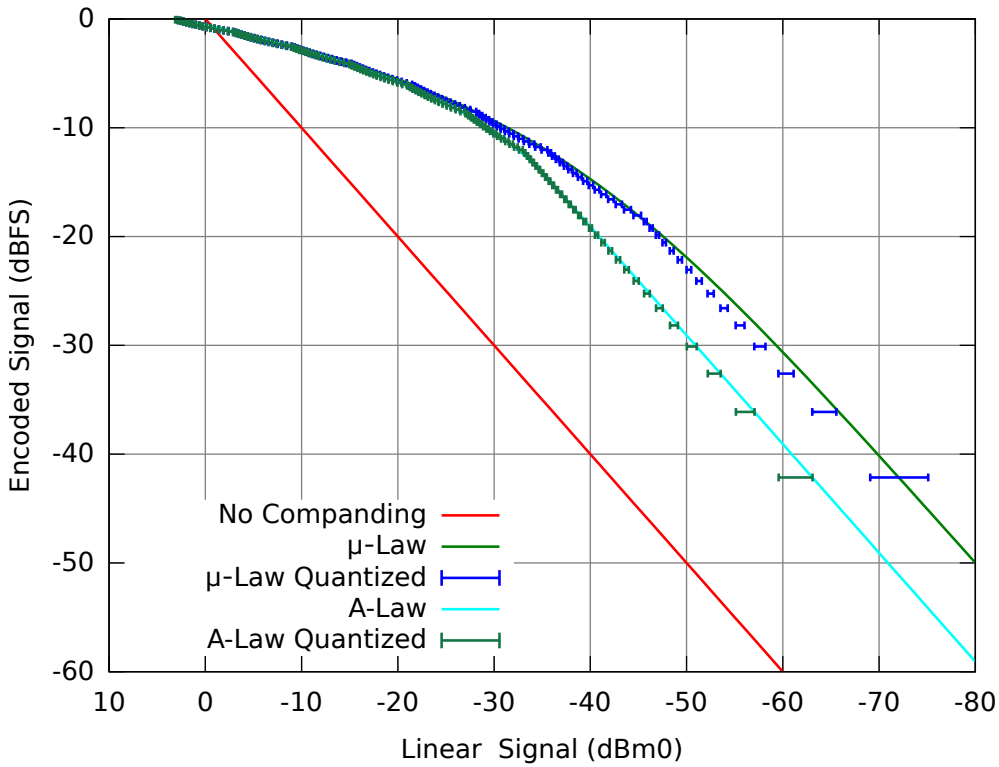
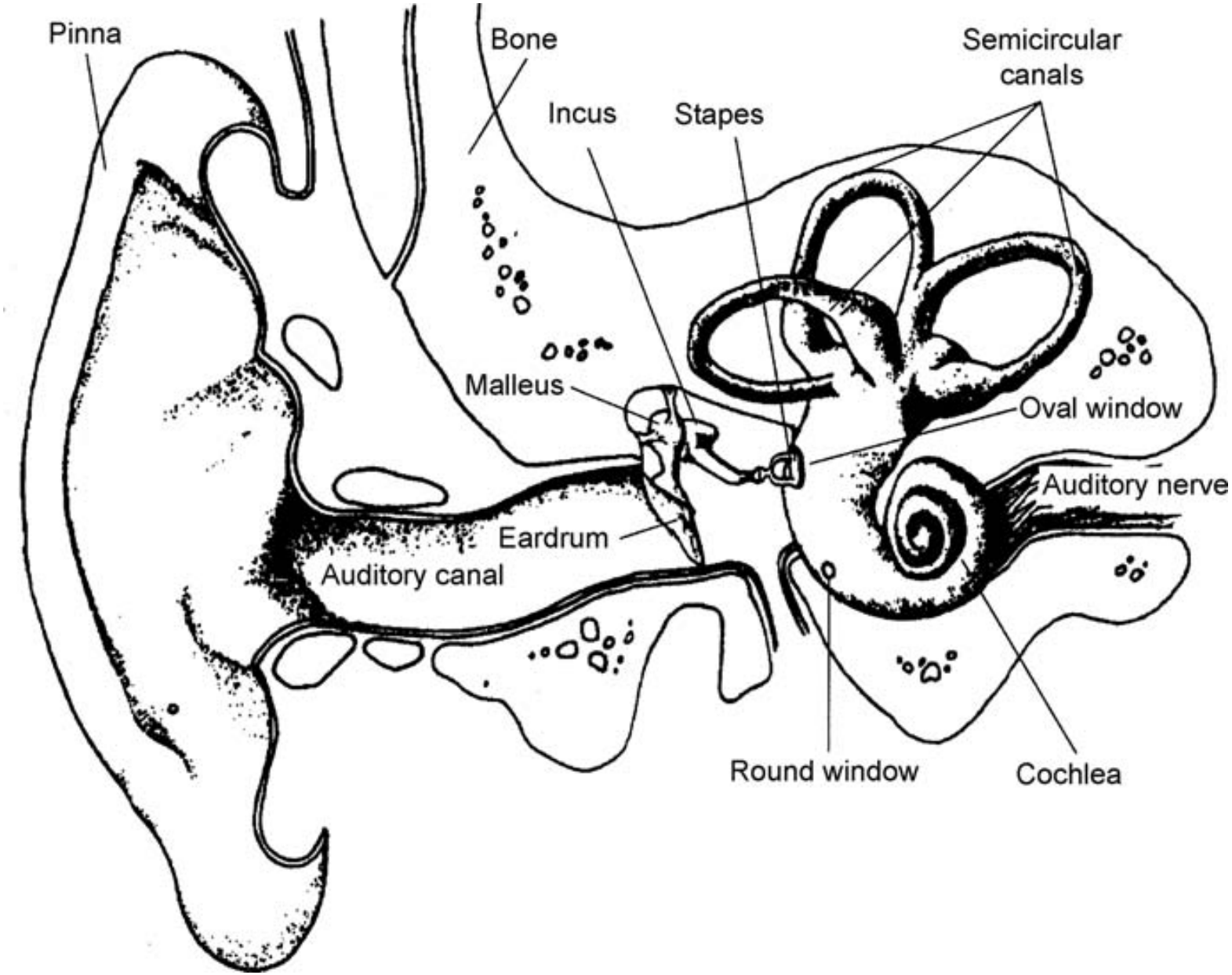
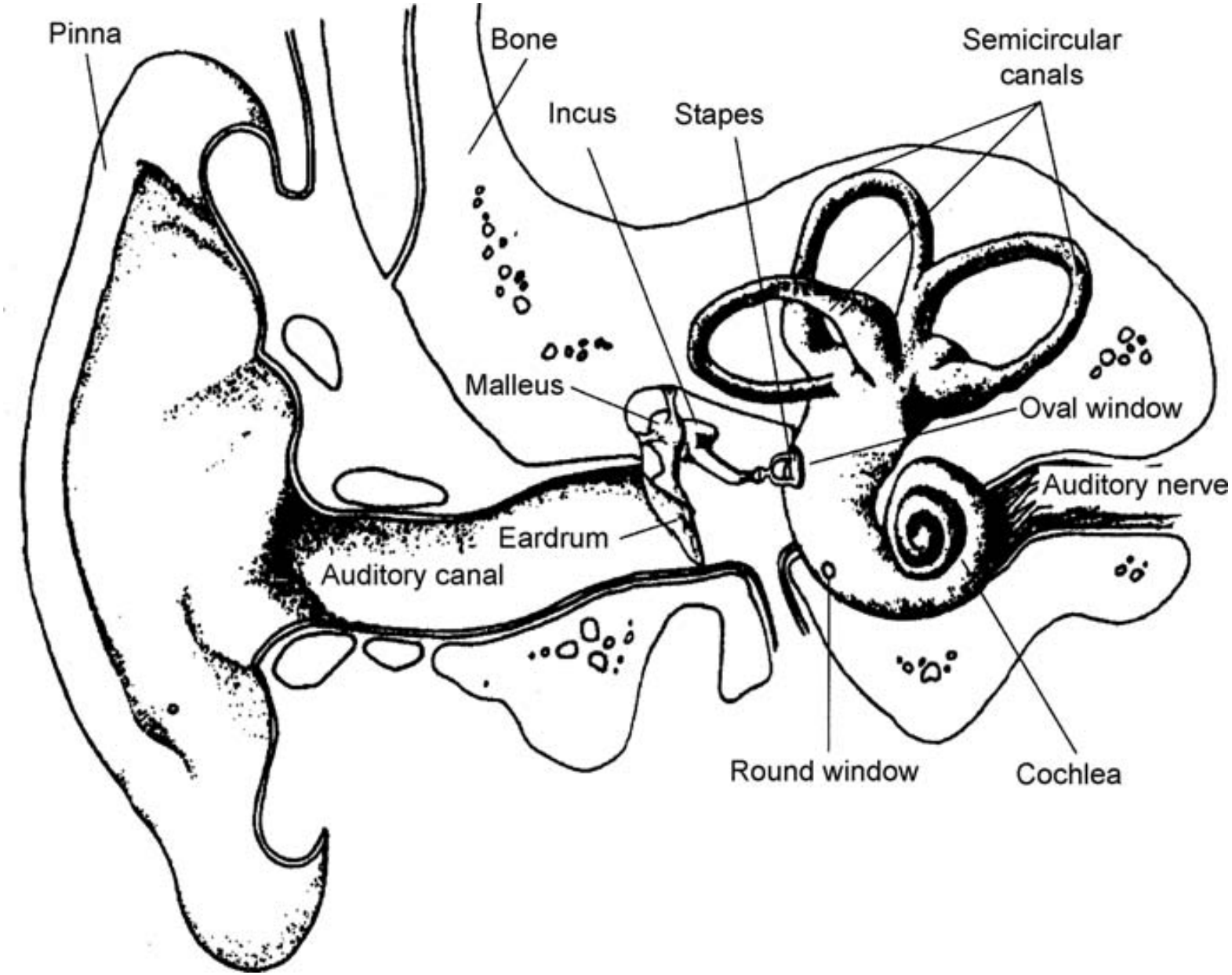


Image Adapted from: https://commons.wikimedia.org/wiki/File:Ulaw_alaw_db.svg

The Ear


Pinna
Bone
Semicircular canals
Incus
Stapes
Malleus
Oval window
Auditory nerve
Eardrum
Auditory canal
Round window
Cochlea

The Ear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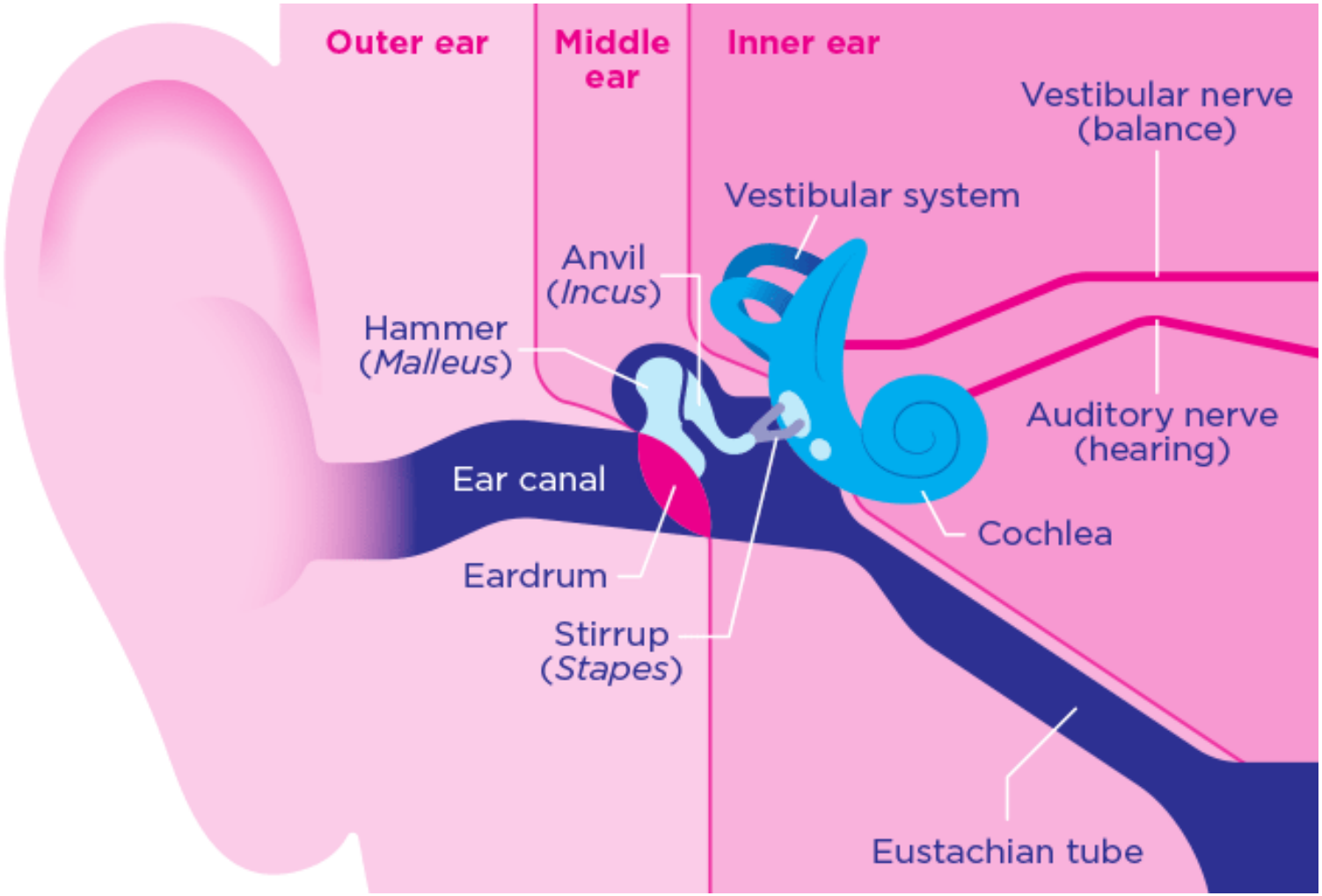
The Ear (Again)



Source: https://www.actiononhearingloss.org.uk/hearing-health/how-the-ear-works/

The Ear

Outer

Pinna: focuses sound into the auditory canal
All are different *shapes* (modelled with HRTFs for spatial audio)
Pinna and auditory canal impose filtering characteristics based on unique shapes
Ear Drum: Barrier to middle ear

Head Related Transfer Function (HRTF)

A response that characterises how an ear receives a sound from a point in space; a pair of HRTFs for two ears can be used to synthesise a binaural sound that seems to come from a particular point in space.

The Ear

Middle

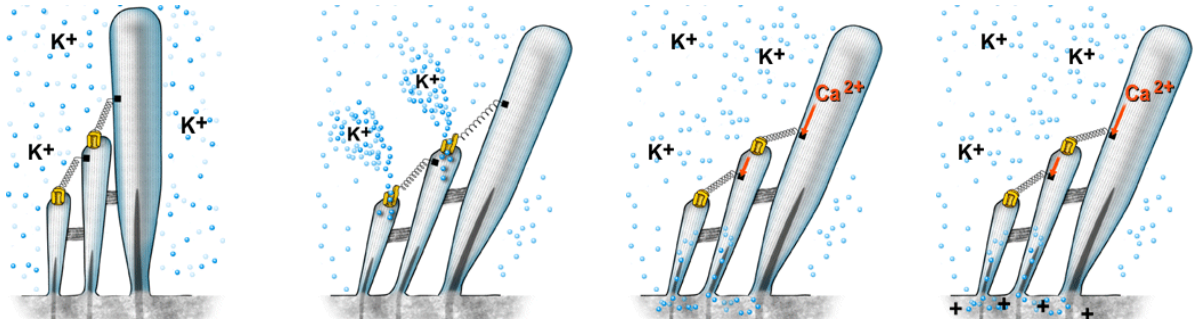
Ossicles (bones): Malleus, Incus, Stapes
Act as a mechanical transformer, converting pressure on the **eardrum** to pressure on the **oval window** with a step-up factor of up to 30
Most of the step-up factor is due to area differences (eardrum vs. oval window) $\Rightarrow$ about 20 times
Lever action of the ossicles accounts for another 1.5 factor
Oval Window
Middle ear hearing related problems generally due to trauma

The Ear: Inner Ear

Inner Ear: Cochlea, Basilar membrane, Organs of Corti

- **Cochlea**: transforms pressure variations to neural impulses
- **Semicircular canals**: control balance (and kept safe in ear!)
- **Hair cells**: Along basilar membrane (about 37 mm long)
- **Bone conduction**: to inner ear is also significant.
- **Auditory nerve fibres** are "tuned" to different centre frequencies

The Ear: Inner Ear



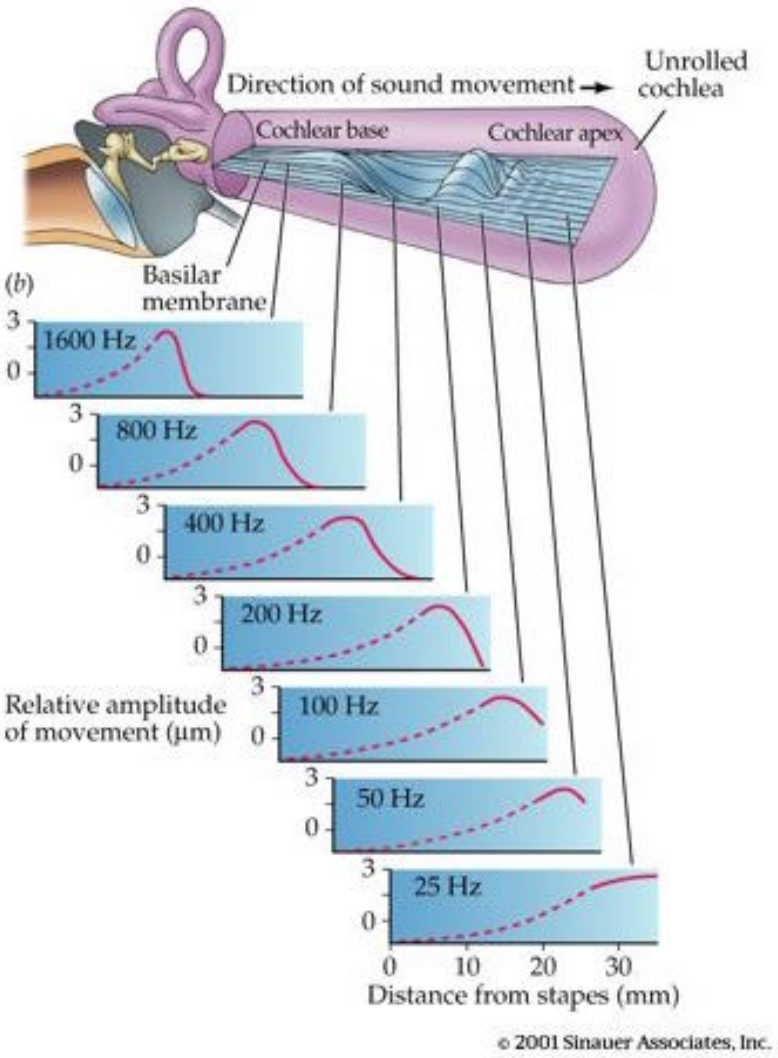
Hair cells

- Have many **cilia** or hairs which bend with the vibrations of the basilar membrane.
- **Outer hair cells** ($\sim 3k$): acoustical pre-amplifiers
- **Inner hair cells** ($\sim 20k$): Sound to neural signal transduction
- **High-frequency detection**: Occurs along rigid section of the basilar membrane closest to the oval window
- **Low-frequency detection**: greatest low-frequency amplitude ripples occurs near far end of the basilar membrane.

Figure from animation on: `http://www.cochlea.eu/en/hair-cells`

Frequency Selectivity

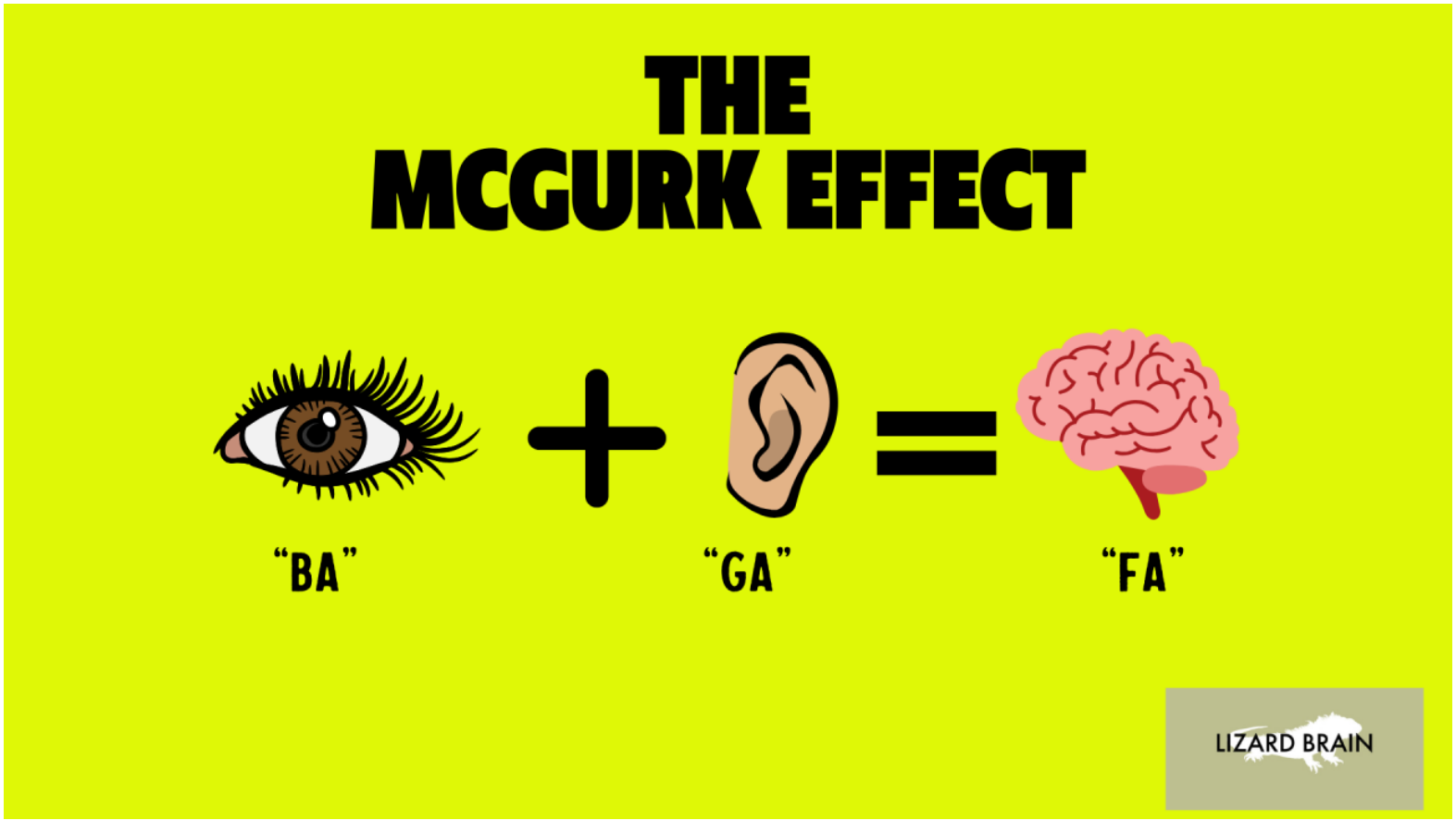
Hair cells in the cochlear perform sound filtering



Brain Interpretation

- Electrical impulses to the brain
- Highly non-linear
- Correlations between ears (binaural):
  - localisation
  - source separation
- Correlations between senses:
  - McGurk effect (audio-visual systems)
  - smell, taste

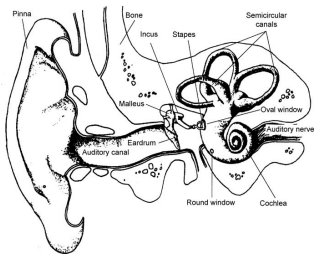
Brain Interpretation - McGurk Effect



Summary

Physical Systems

- Process of Hearing
- The ear
- Frequency selectivity
- Brain interpretation



Perception

- Psychoacoustics
- Equal Loudness
- Combination tones
- Phase Locking
- Signal Processing
- Temporal Integration
- Masking
- Precedence