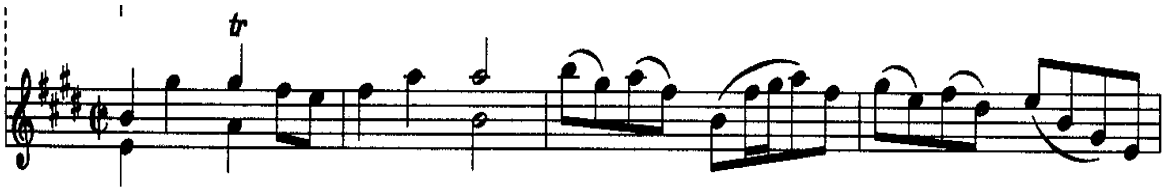
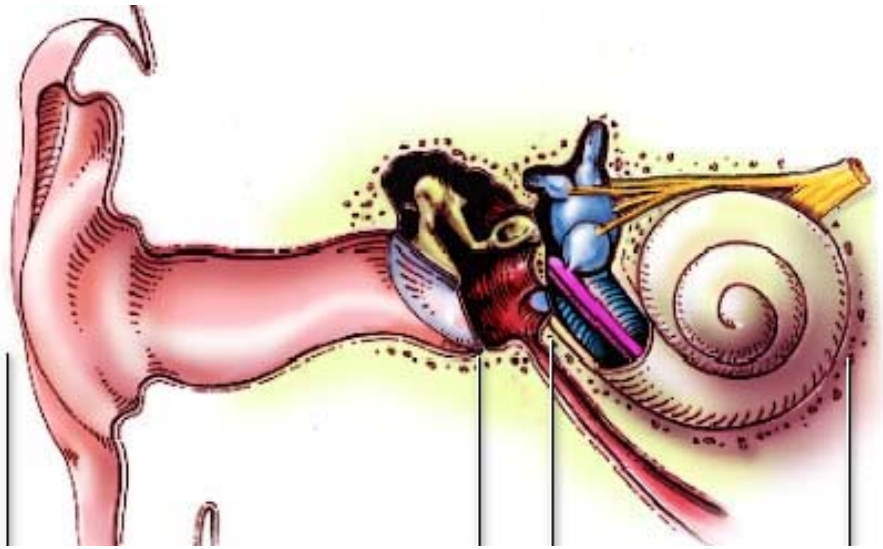
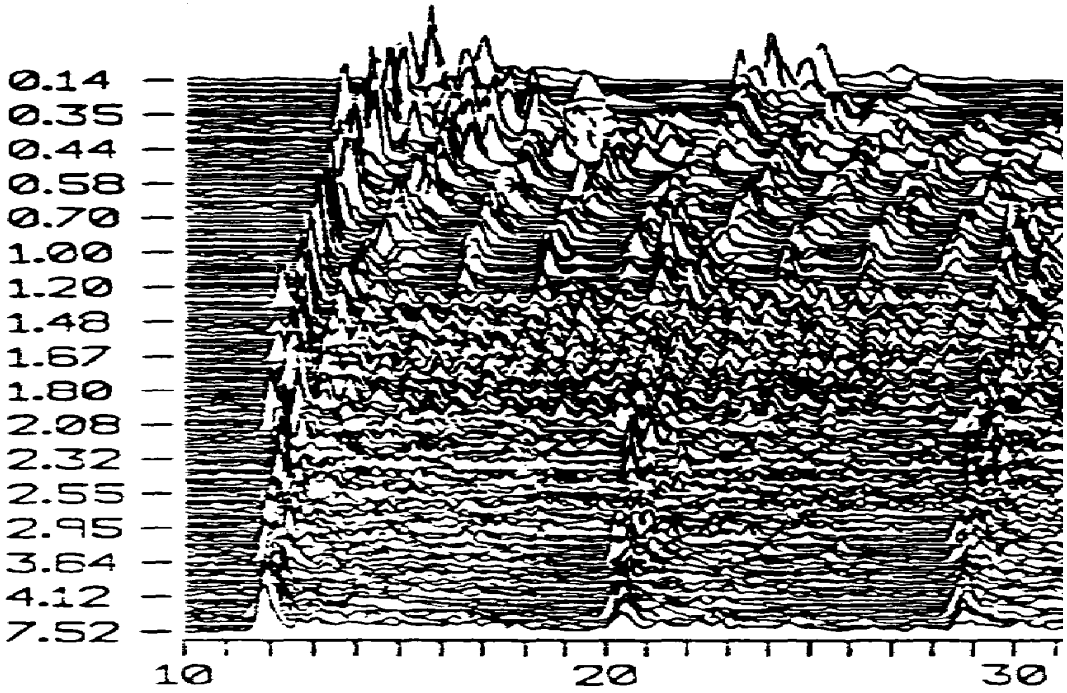
Harvard-MIT Division of Health Sciences and Technology
HST.725: Music Perception and Cognition
Prof. Peter Cariani
Prof. Andy Oxenham
Prof. Mark Tramo



The Auditory System:

Where it happens (first)





From cochlea to cortex

10,000k — **Primary auditory cortex (Auditory forebrain)**

Auditory thalamus

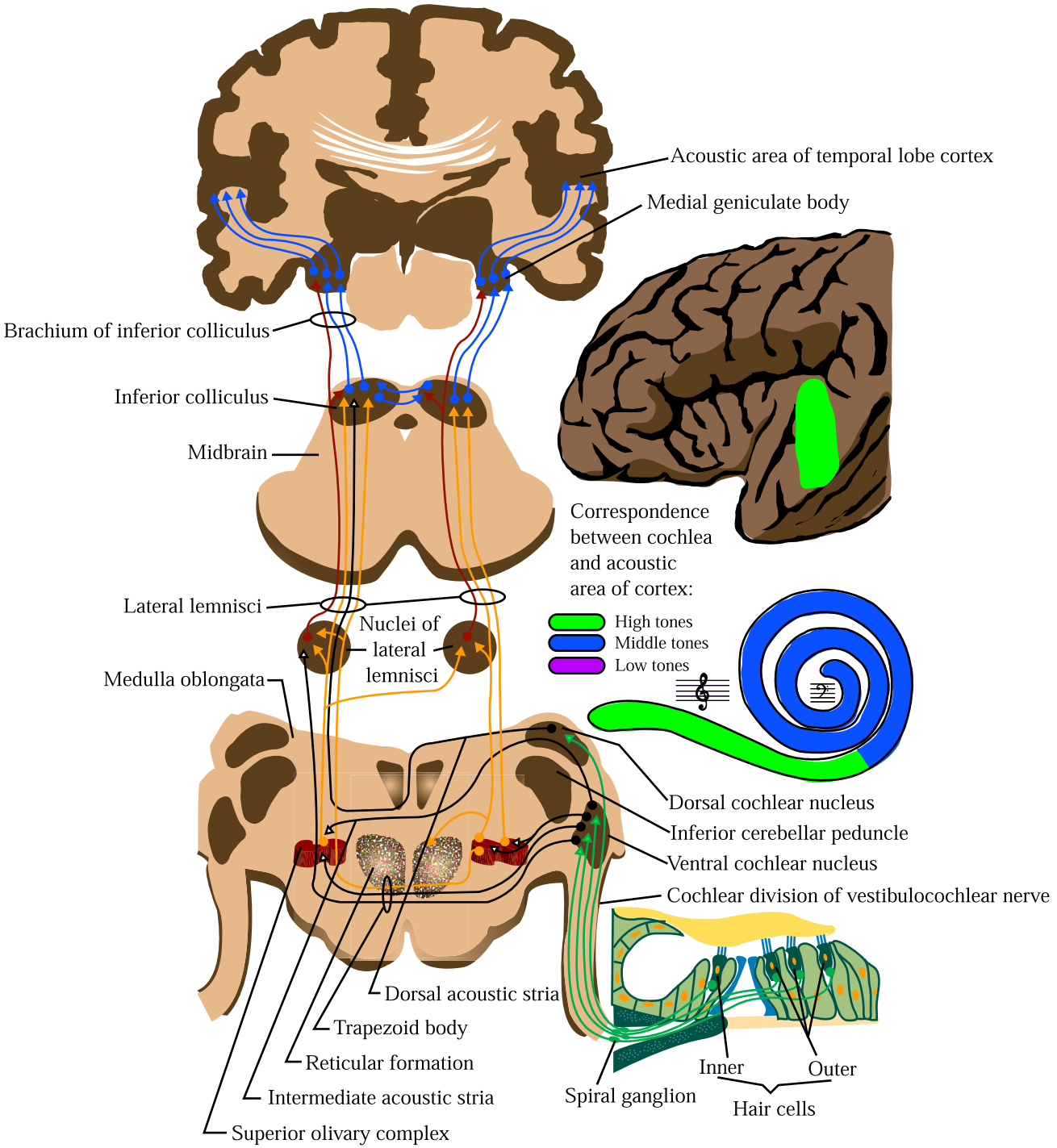
500k — **Inferior colliculus (Auditory midbrain)**

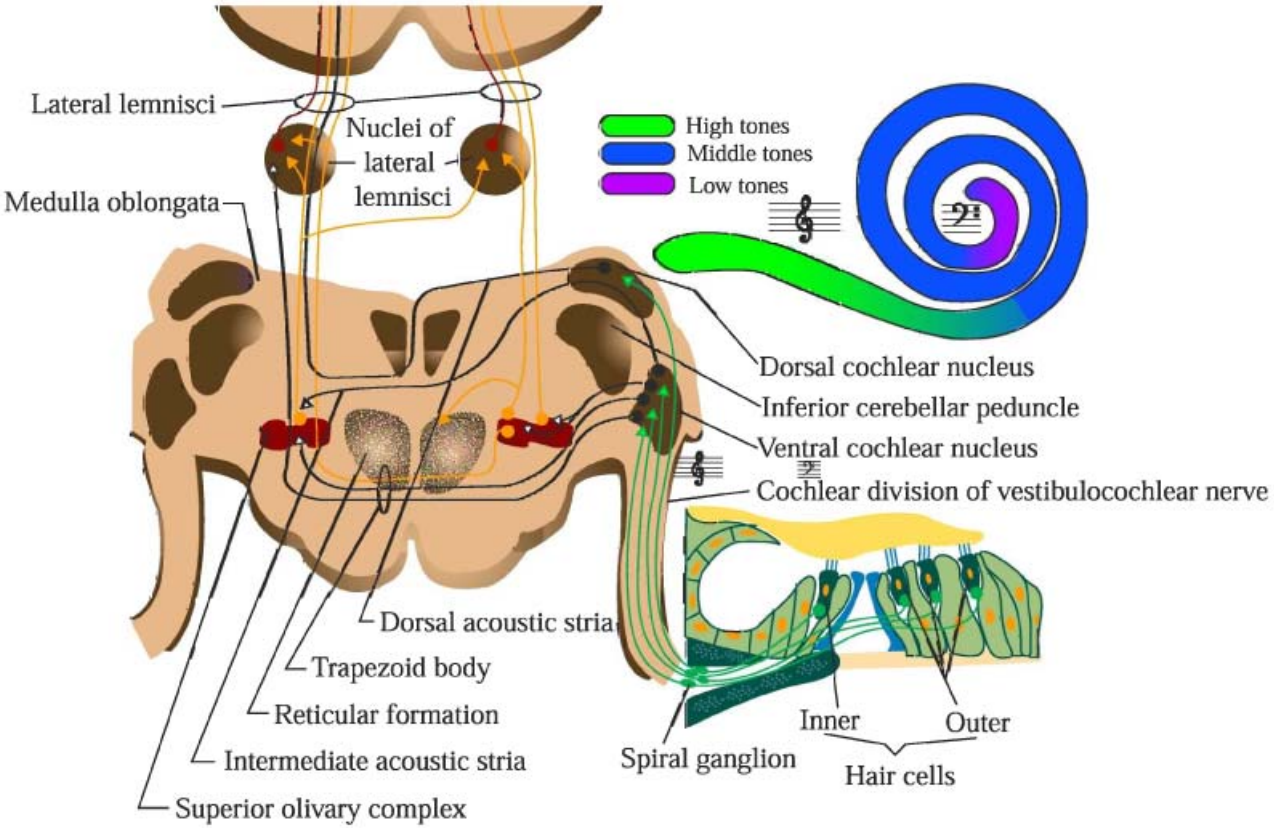
Lateral lemniscus

Auditory brainstem

30k — **Auditory nerve (VIII)**

3k — **Cochlea**



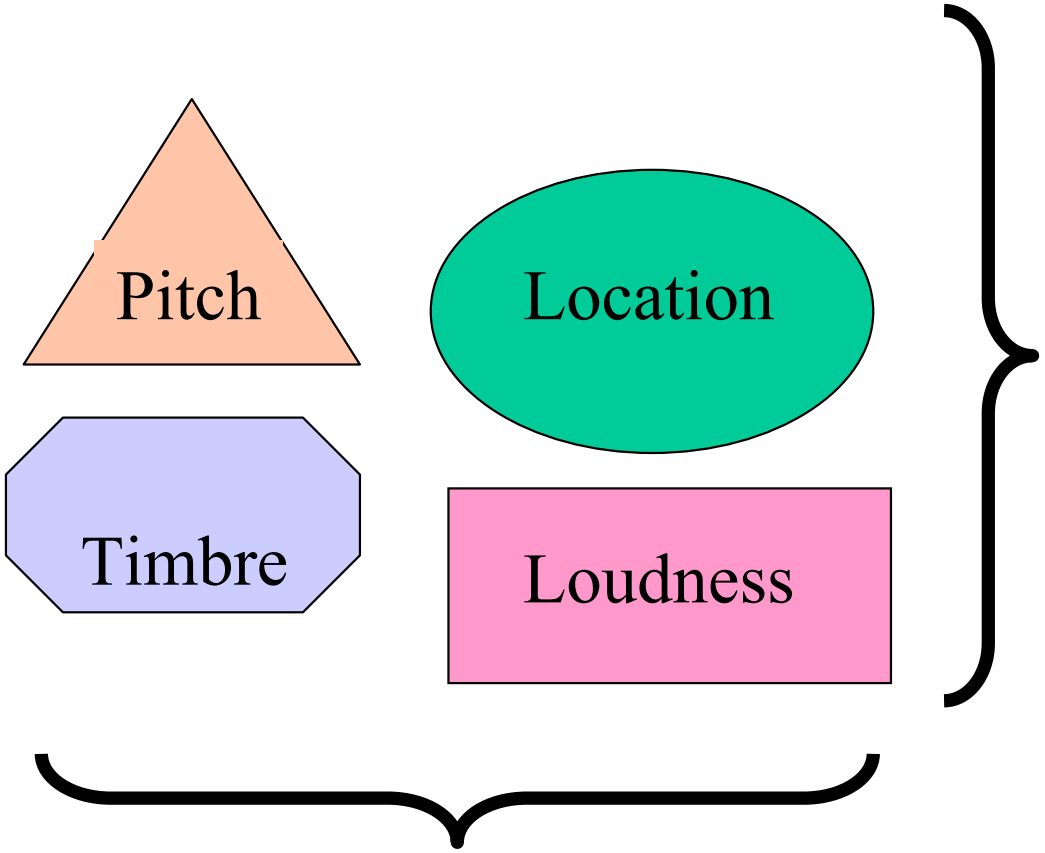

Lateral lemnisci
Nuclei of lateral lemnisci
Medulla oblongata
High tones
Middle tones
Low tones
Dorsal cochlear nucleus
Inferior cerebellar peduncle
Ventral cochlear nucleus
Cochlear division of vestibulocochlear nerve
Dorsal acoustic stria
Trapezoid body
Reticular formation
Intermediate acoustic stria
Superior olivary complex
Spiral ganglion
Inner
Outer
Hair cells

The auditory system: where it happens (first)

- A crash course in neuroscience
  - Nervous systems -- general functions
    - perception, steering and coordination of action
  - Reverse-engineering: what do you need to know to understand how it works?
  - Neurons -- cells specialized for signaling
  - Neural coding: how neurons convey information
  - Neural representations and computations
  - General plan of nervous systems - periphery & central (CNS)

- The auditory pathway -- anatomy, response properties, functions
  - Cochlea
  - Auditory nerve
  - Brainstem
  - Midbrain (a.k.a. inferior colliculus, IC)
  - Thalamus (a.k.a. medial geniculate body, MGB)
  - Auditory cortex
  - Other cortical territories

Basic auditory qualities
Dimensions of auditory perception



TEMPORAL EVENT STRUCTURE
Meter, sequence

FUSION
Grouping into separate objects
Temporal co-occurrence
harmonic structure

John Lurie
Car Cleveland
Music from Stranger than Paradise

The problem of reverse-engineering

Given a vastly complicated device engineered
by an advanced alien civilization (or wartime enemy)
whose technology you don't understand, figure out:

1. What the device is for (what's its function)
2. How it works (what are the functional principles underlying its operation?)
3. How other devices can be built using the same functional principles.

How does the brain work?
What are the signals?
How are they processed?

What is it for and how does it work?

What do you need to know to understand how this device works?

Neural coding: What is the nature of the signals in the wires?

Knowledge that helps:

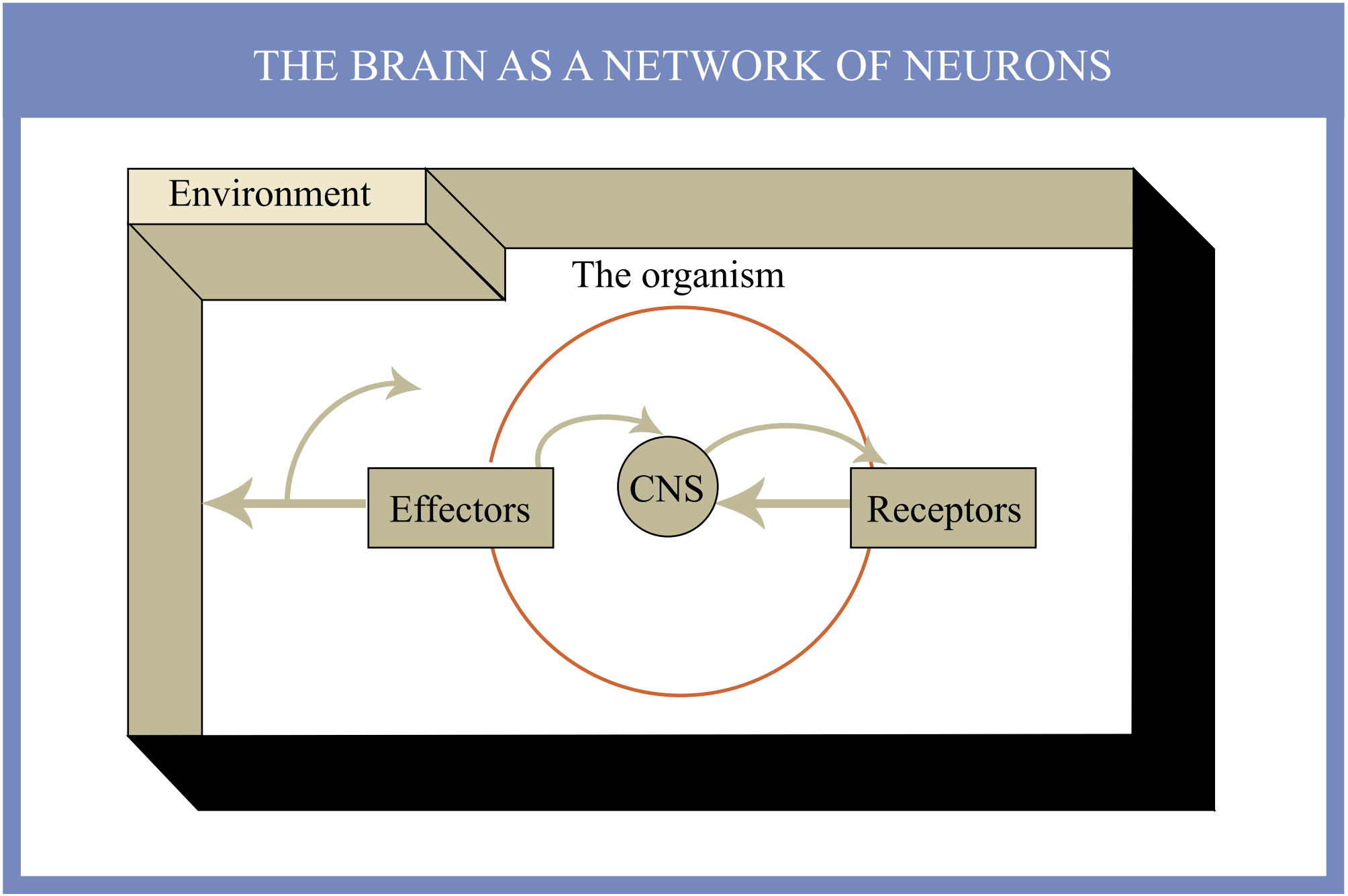
Purpose(s), function(s)

Parts-lists; What parts are essential?

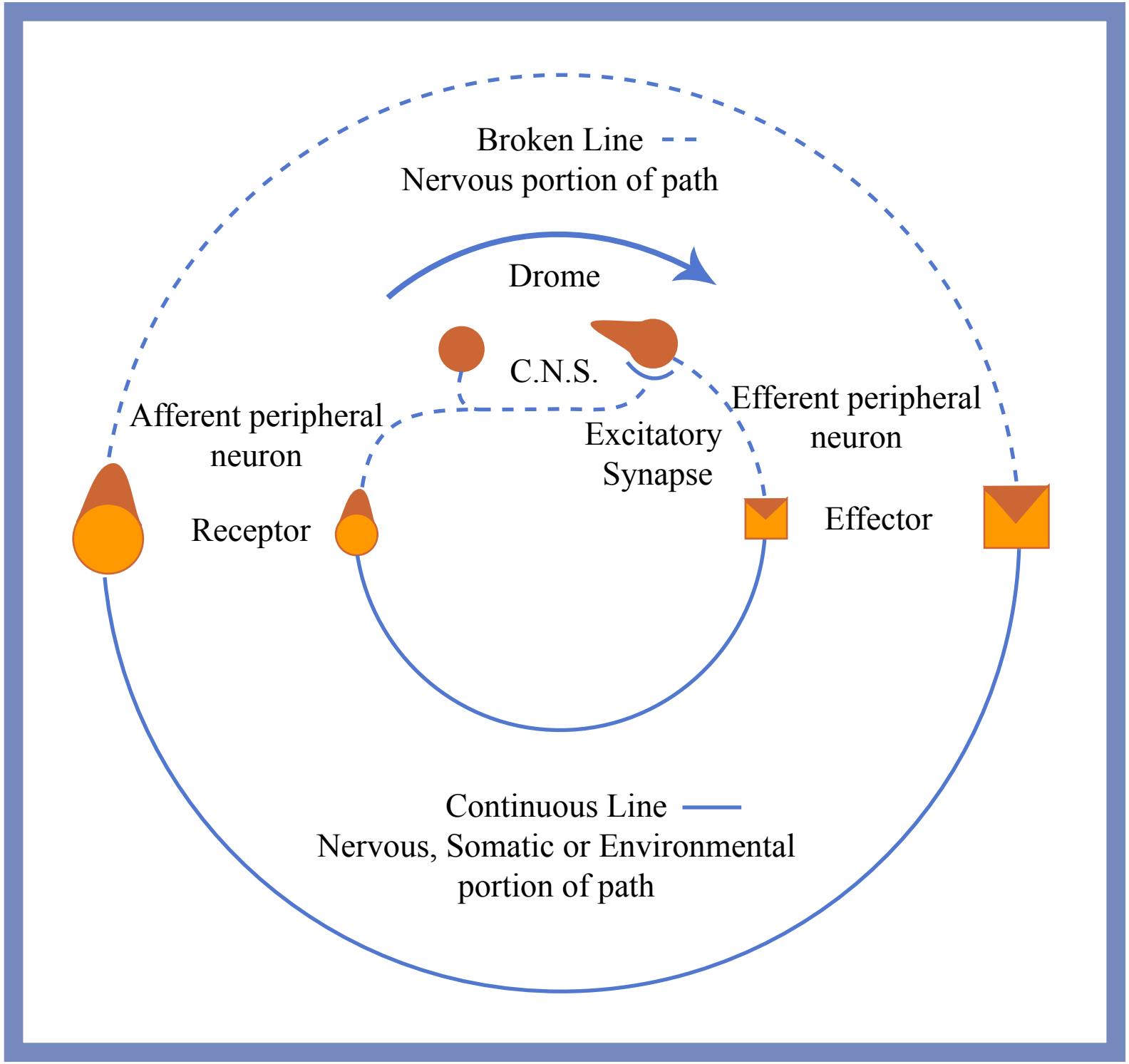
Wiring diagrams: interconnections

How do the individual elements operate?

Perception & action: receptors, interneurons & effectors



McCulloch's internal and external loops

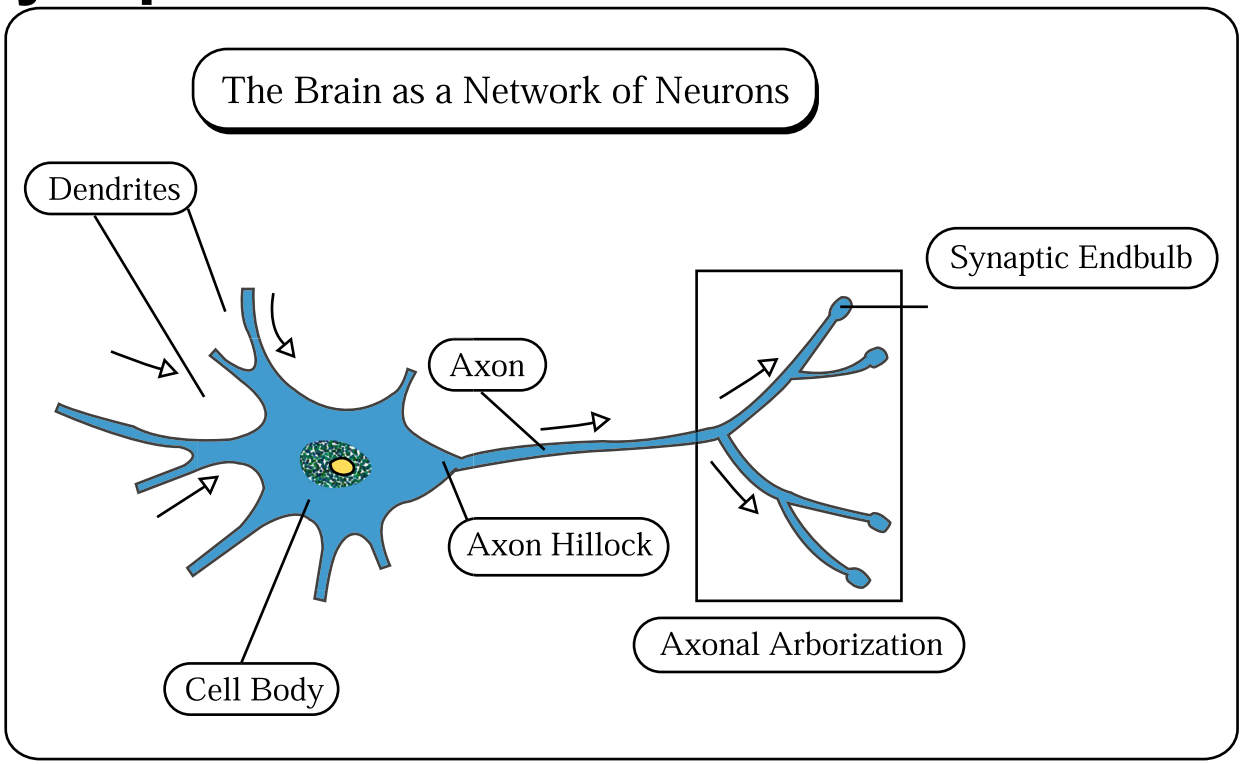


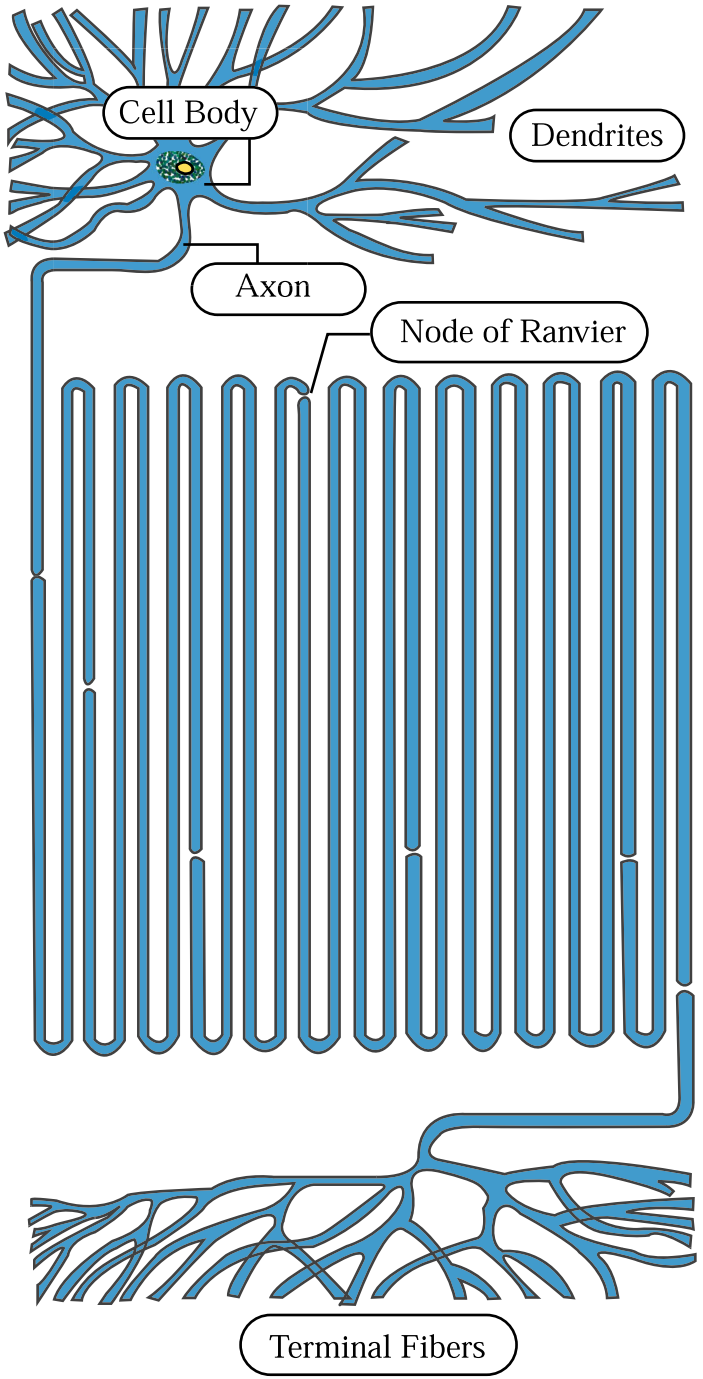
Neurons

Please see information about Santiago Ramón y Cajal and his neuroanatomical slides (http://www.psu.edu/nasa/cajal2.htm)

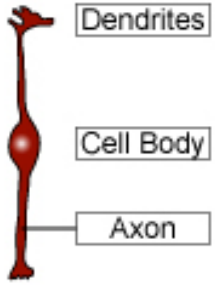
Neurons as signaling elements

Dendrites
Soma (cell body)
Axon
Synapses

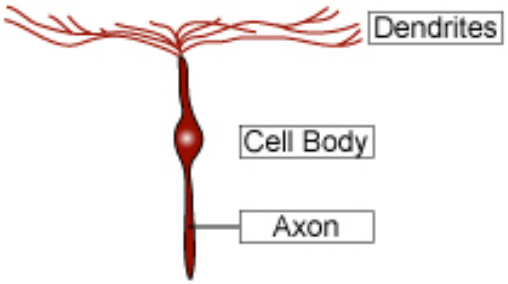




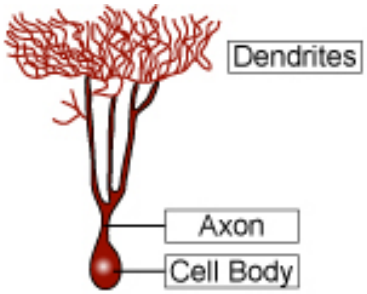
Neuron types



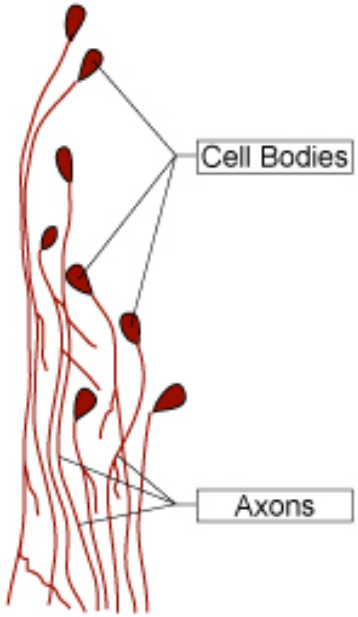
Retinal bipolar cell



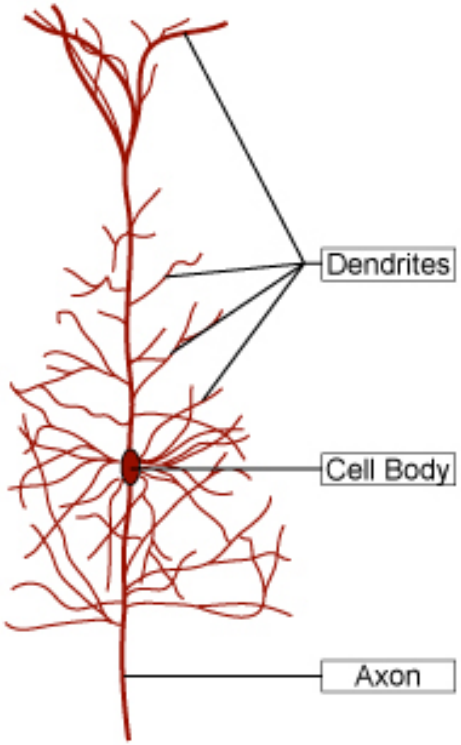
Retinal ganglion cell



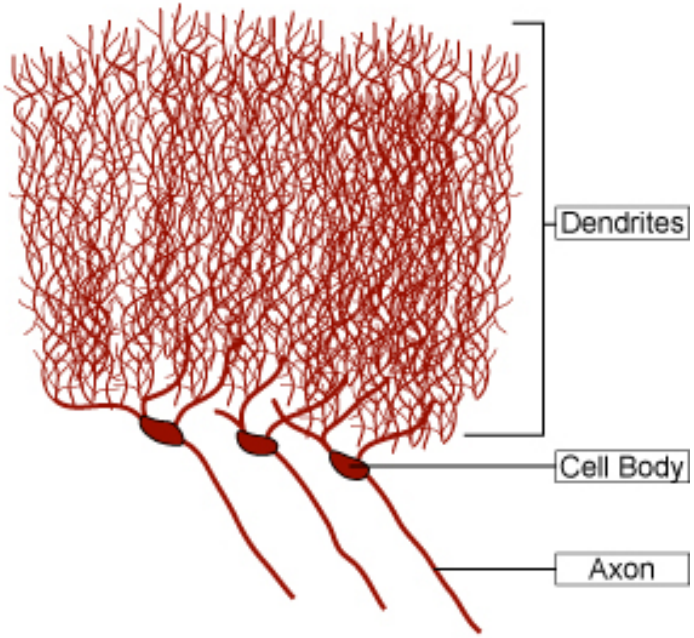
Retinal amacrine cell



Neurons in mesencephalic nucleus of cranial nerve V

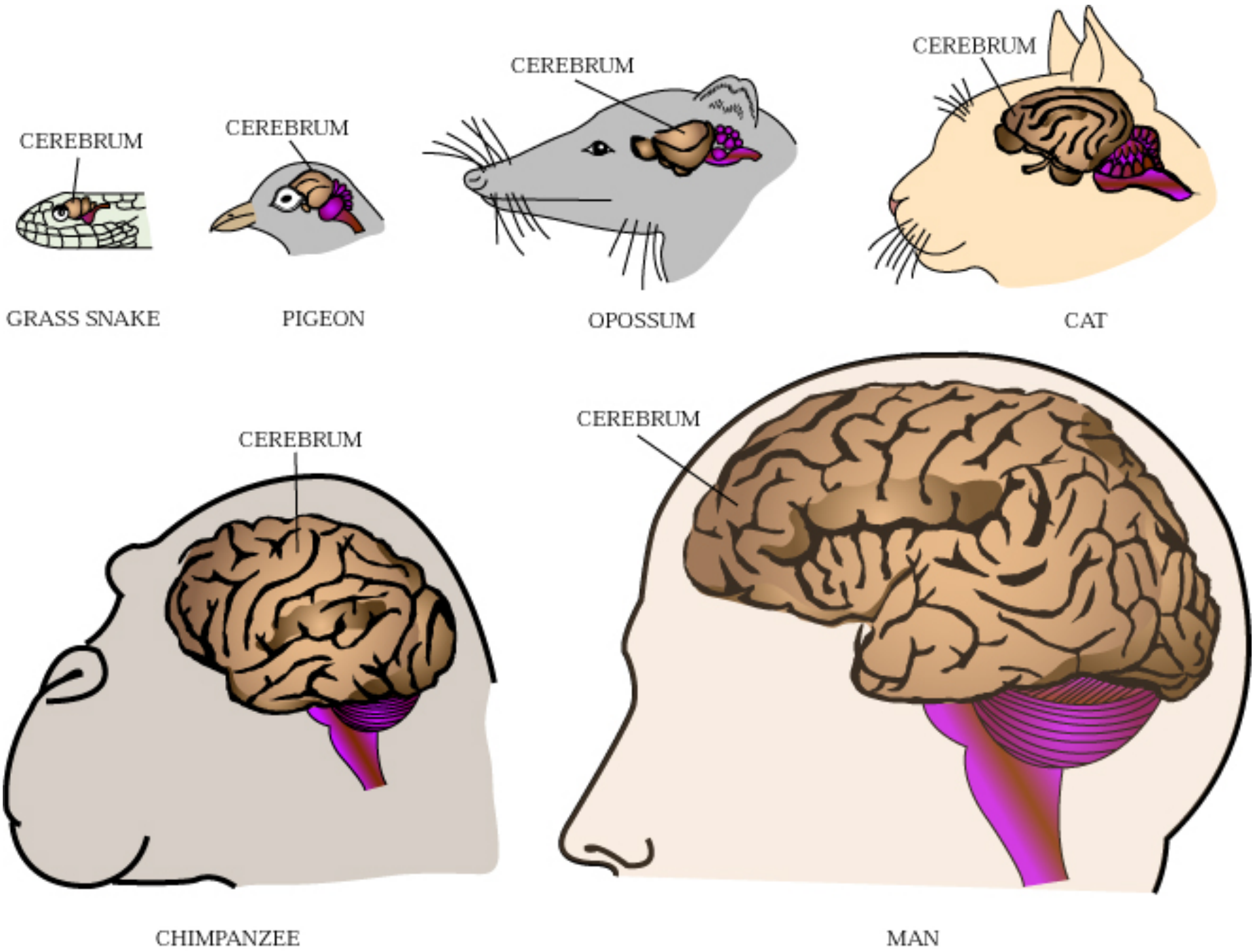


Cortical pyramidal cell

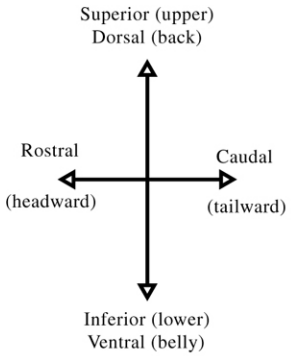


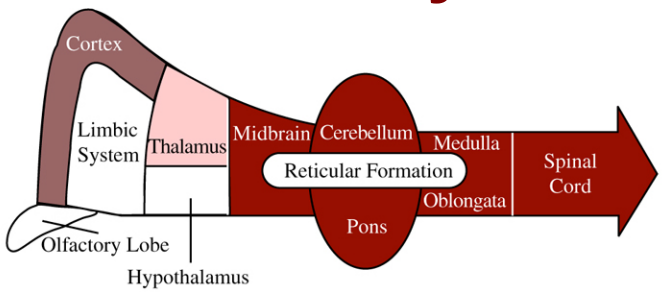
Cerebellar Purkinje cell

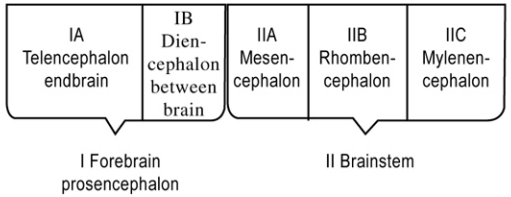
Comparative neuroanatomy

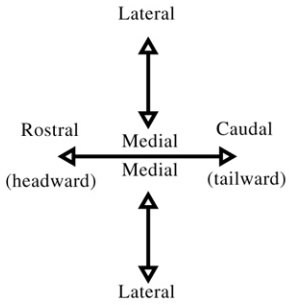


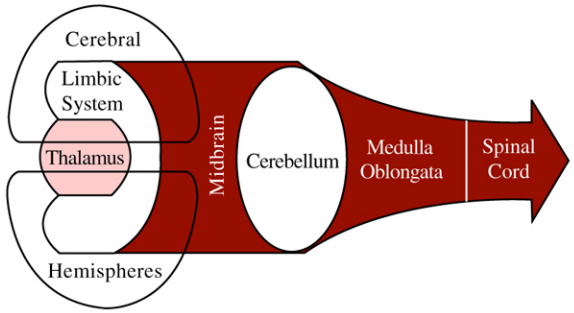
General plan of the vertebrate nervous system

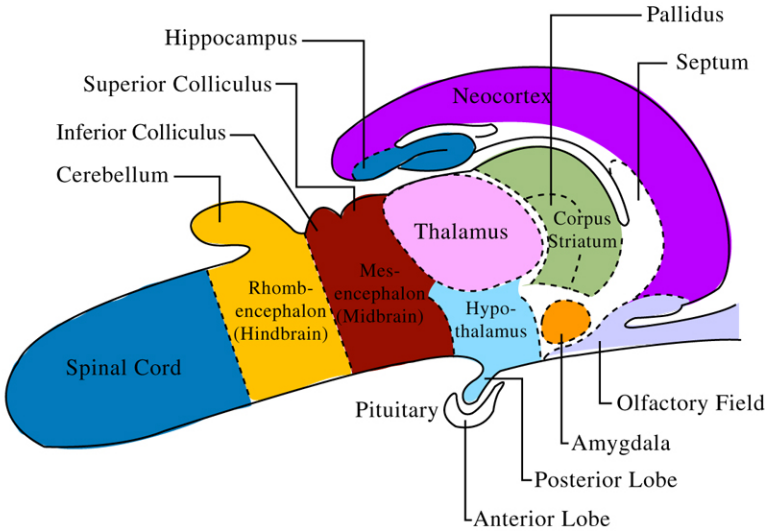












C Neural pulse codes

Rate-channel codes

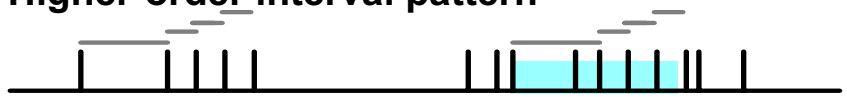
Average discharge rate

Temporal pattern codes

Interspike interval code

Multiplexed intervals

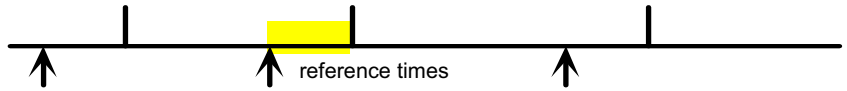
Higher-order interval pattern



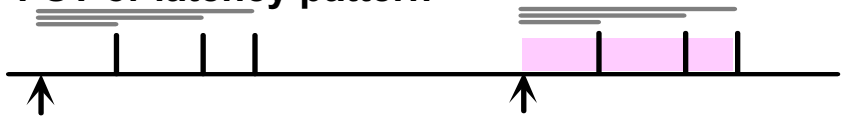
Burst length, interburst interval

Time-of-arrival codes

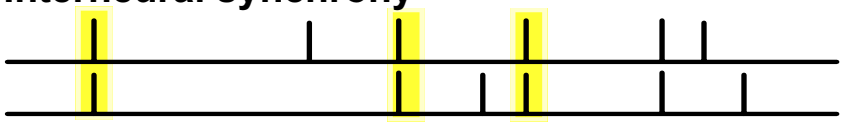
Spike latency



PST or latency pattern



Interneural synchrony



Codes are defined in terms of their functional roles

What spike train messages have the same meanings?
(functional equivalence classes)

What constitutes a difference that makes a difference?

Temporal codes are neural codes in which timings of spikes relative to each other are essential to their interpretation.

Temporal pattern codes

Temporal pattern codes

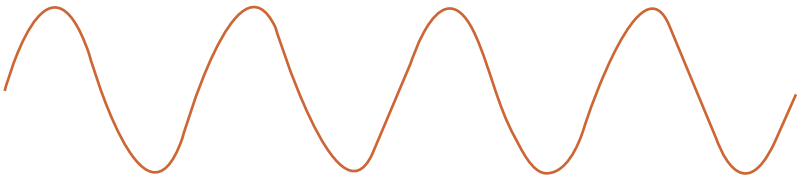
Interspike interval code

Multiple intervals in same spike train

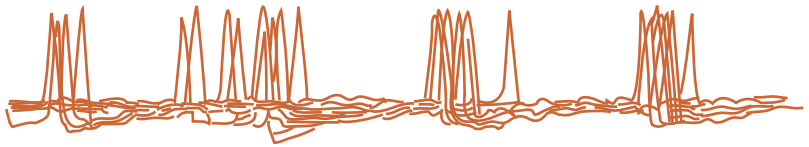
Higher-order interval pattern

Phase-locking in auditoryl neurons
Cat auditory nerve fibers, 250 Hz tone

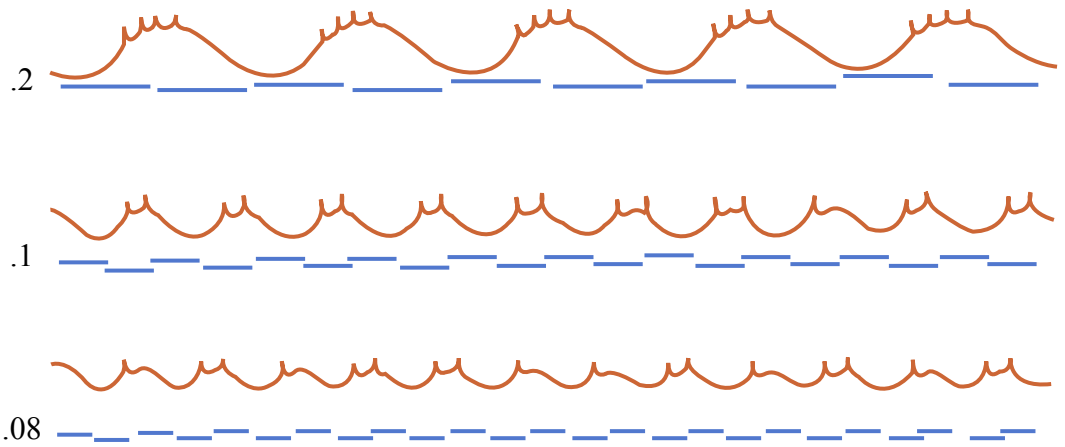
Tone



Spikes

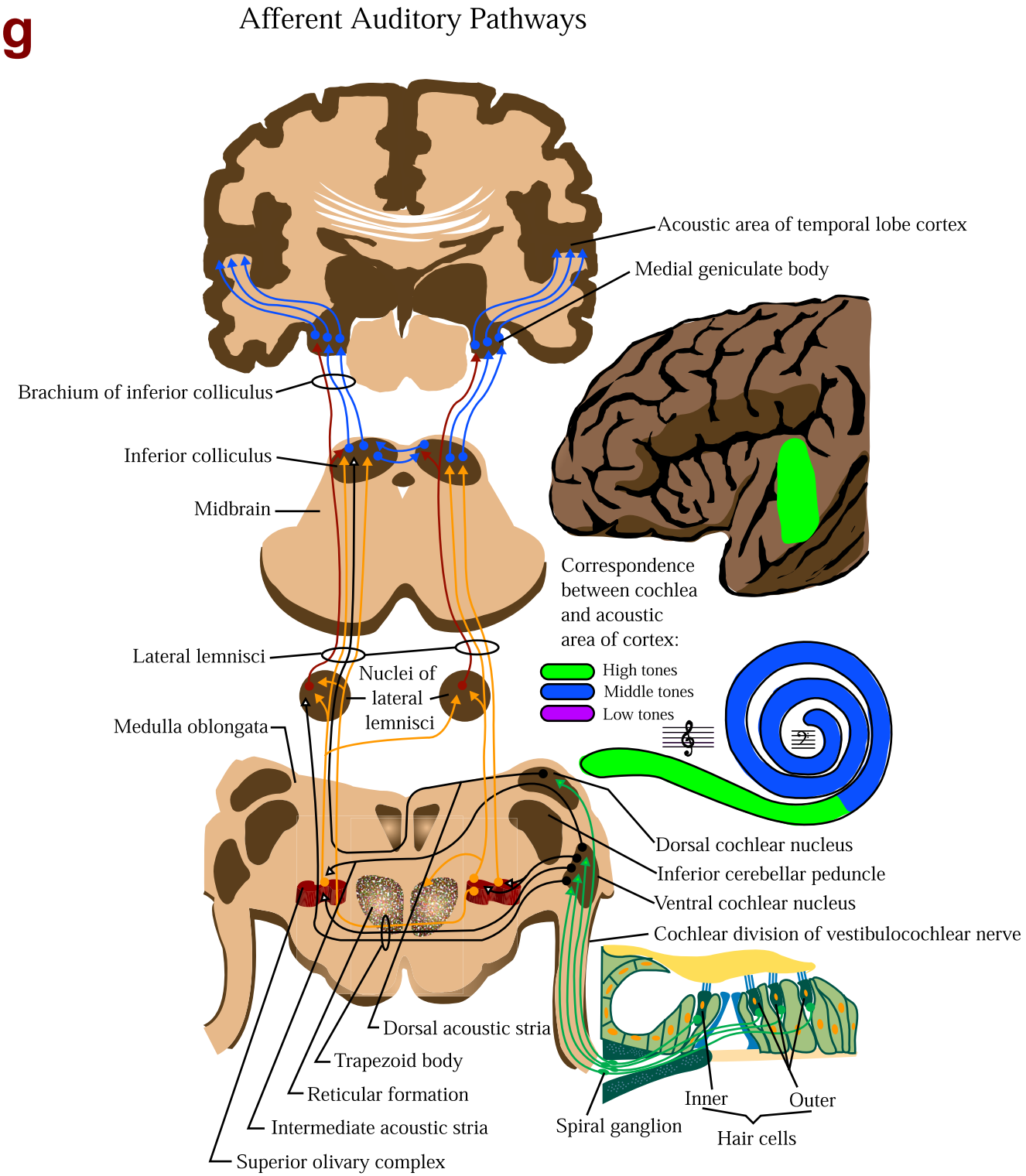


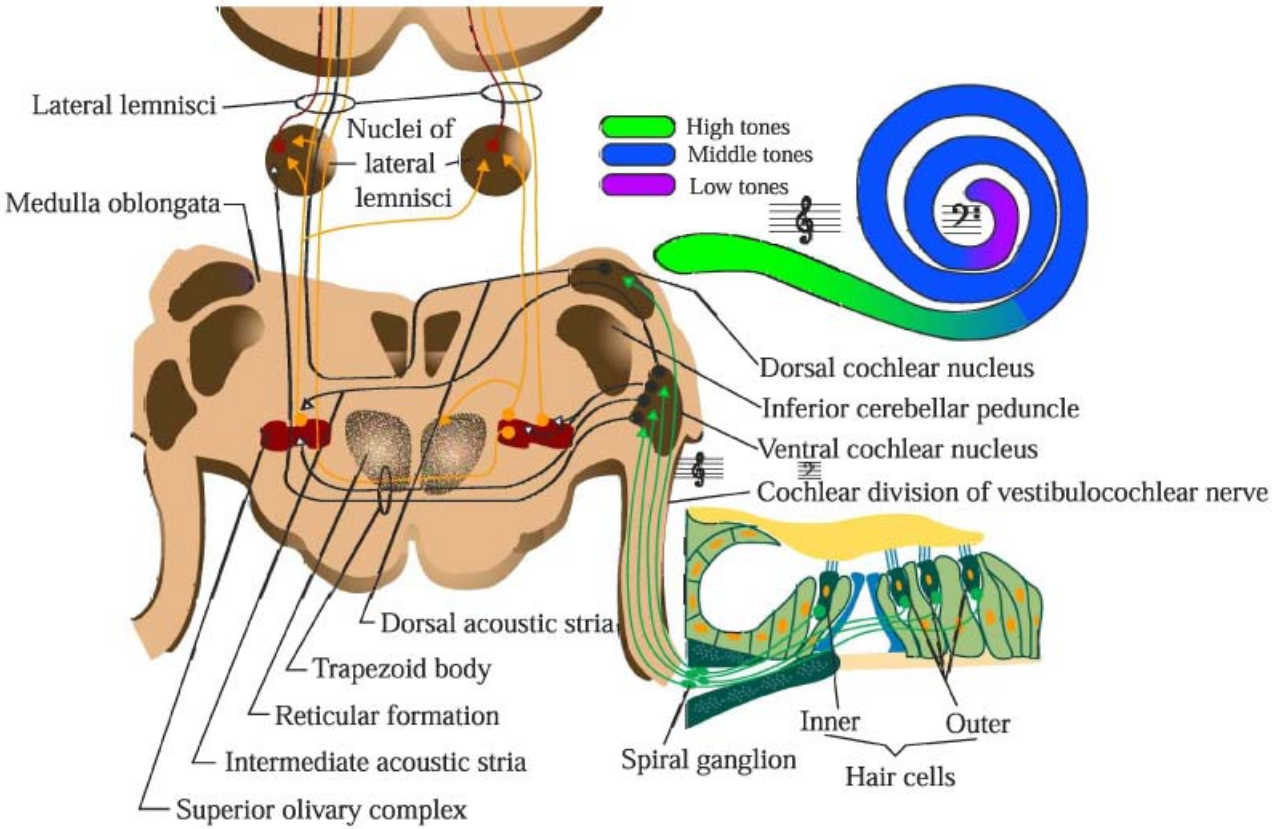
Phase-locking in visual neurons
(Horseshoe crab ommatidium, 5-15 Hz flashes)



Adapted from:
Miller, Ratliff, and Hartline. "How Cells Receive Stimuli."
Scientific American 215, no.3 (1961): 222-238.

Ascending auditory pathway




Lateral lemnisci
Nuclei of lateral lemnisci
Medulla oblongata
High tones
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Dorsal cochlear nucleus
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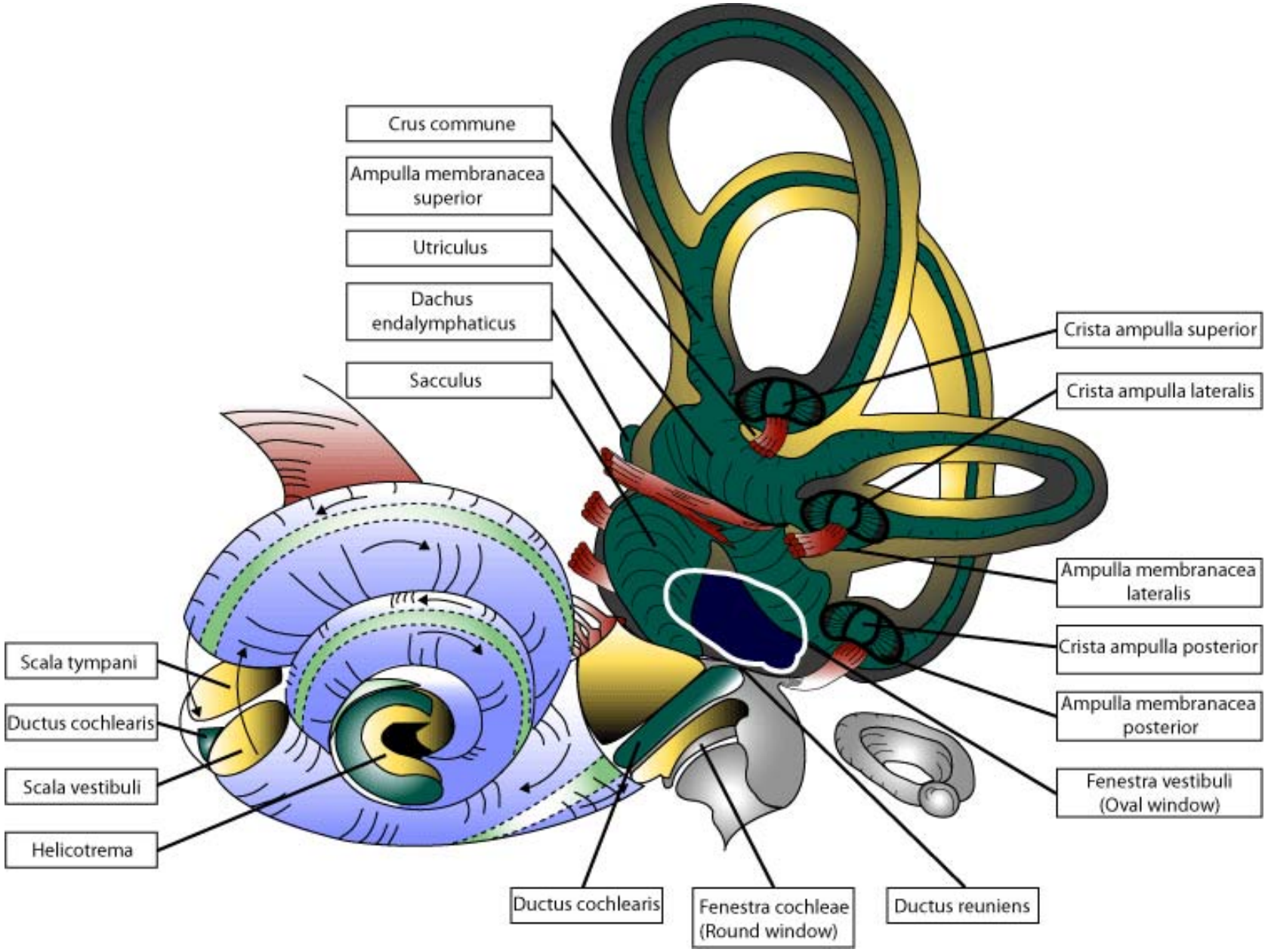
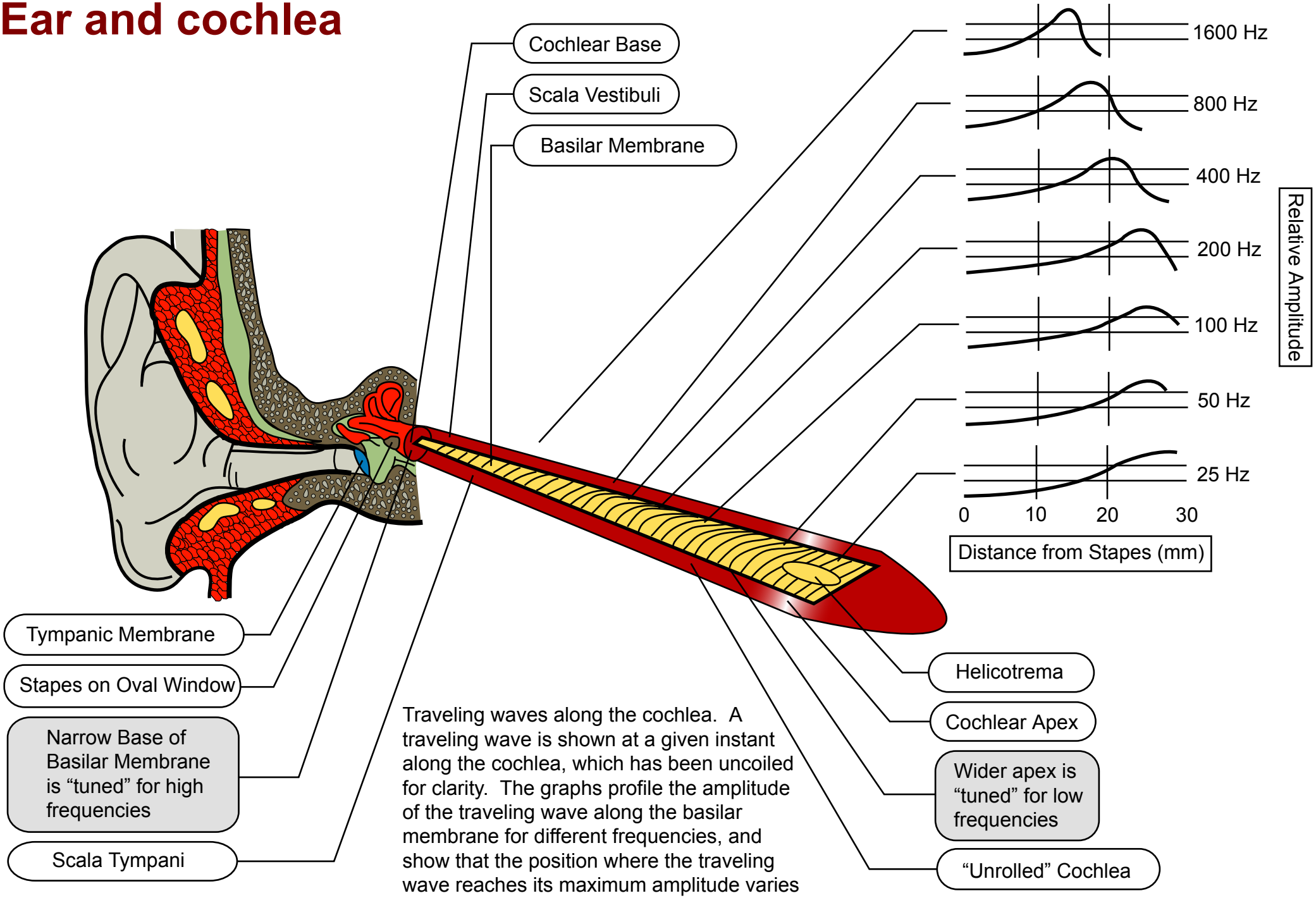
Cochlear division of vestibulocochlear nerve
Dorsal acoustic stria
Trapezoid body
Reticular formation
Intermediate acoustic stria
Superior olivary complex
Spiral ganglion
Inner
Outer
Hair cells

Ear

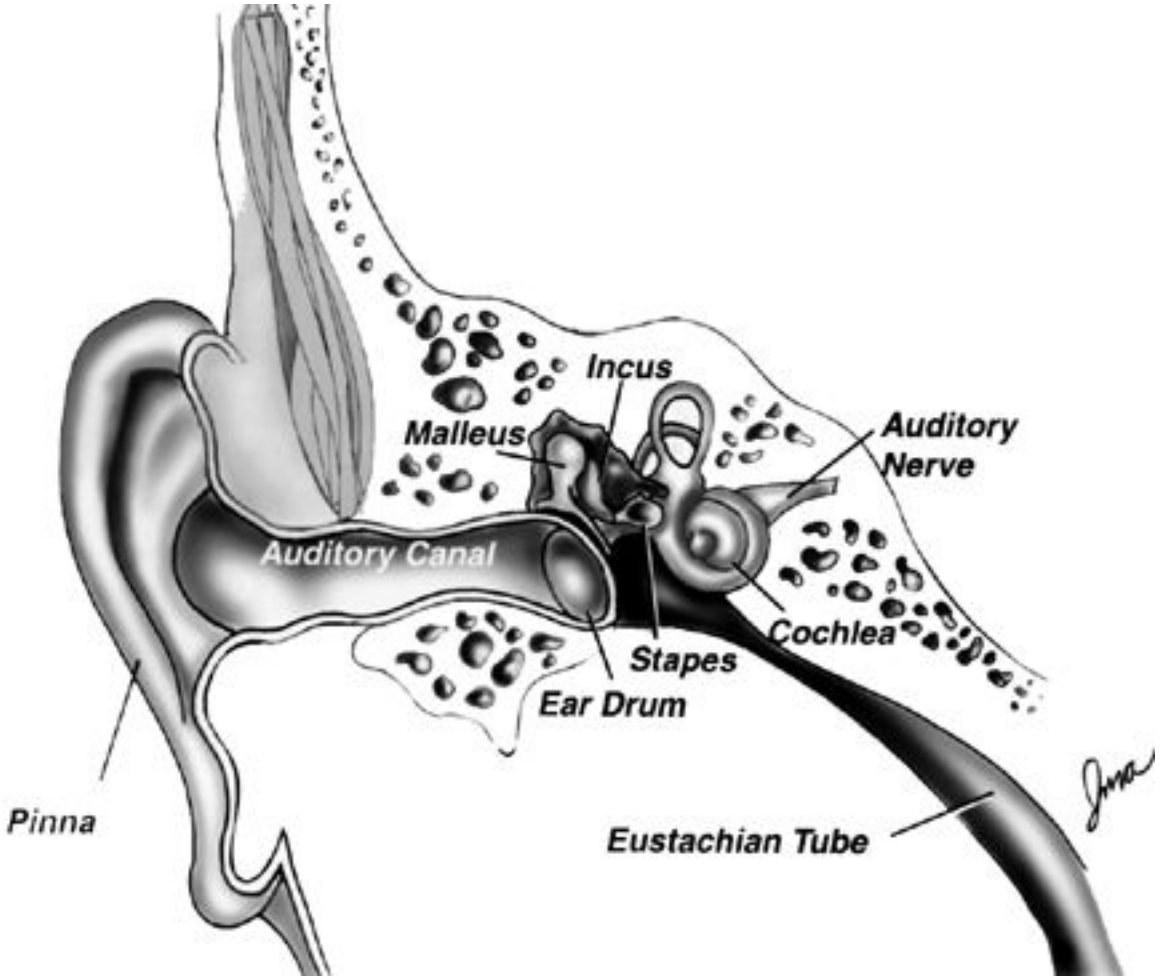

Crus commune
Ampulla membranacea superior
Utriculus
Dachus endalymphaticus
Sacculus
Crista ampulla superior
Crista ampulla lateralis
Ampulla membranacea lateralis
Crista ampulla posterior
Ampulla membranacea posterior
Fenestra vestibuli (Oval window)
Scala tympani
Ductus cochlearis
Scala vestibuli
Helicotrema
Ductus cochlearis
Fenestra cochleae (Round window)
Ductus reuniens

Ear and cochlea



Traveling waves along the cochlea. A traveling wave is shown at a given instant along the cochlea, which has been uncoiled for clarity. The graphs profile the amplitude of the traveling wave along the basilar membrane for different frequencies, and show that the position where the traveling wave reaches its maximum amplitude varies directly with the frequency of stimulation. (Figures adapted from Dallos, 1992 and von Bekesy, 1960)

Ear & Cochlea

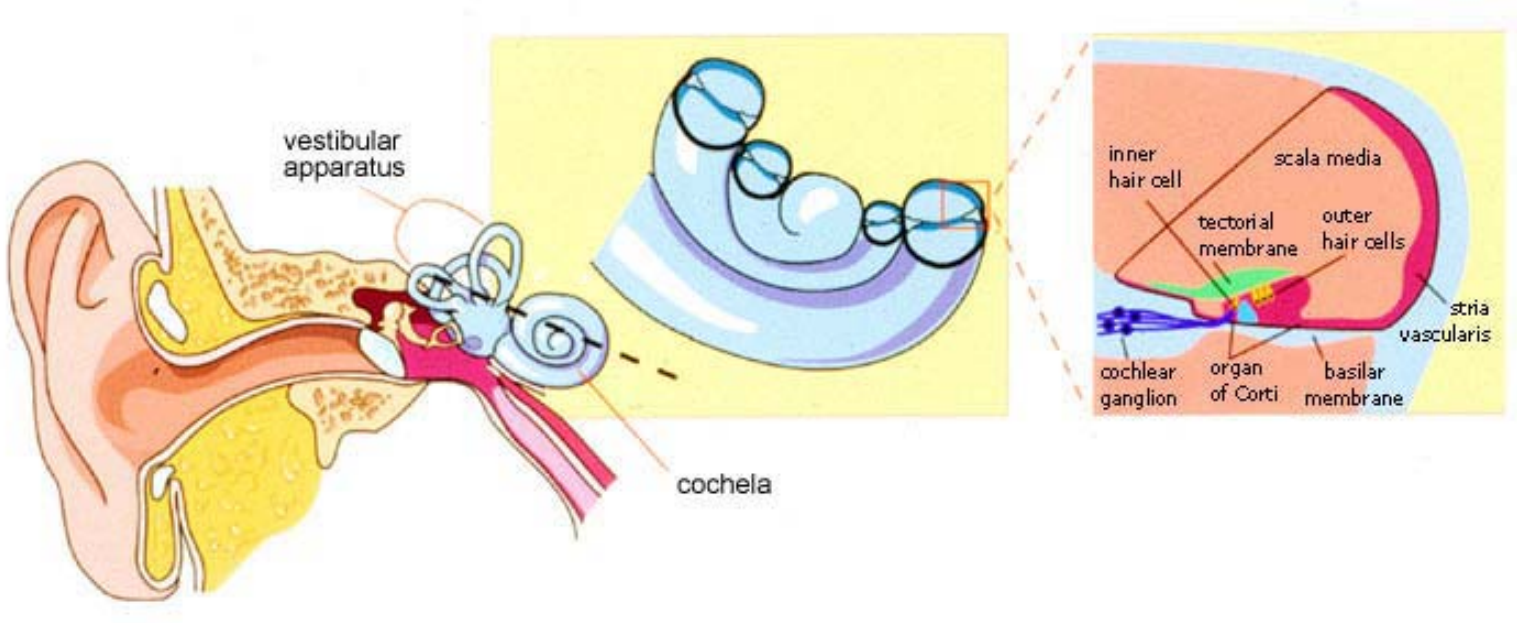

Incus
Malleus
Auditory Nerve
Auditory Canal
Cochlea
Stapes
Ear Drum
Pinna
Eustachian Tube

Cochlear anatomy

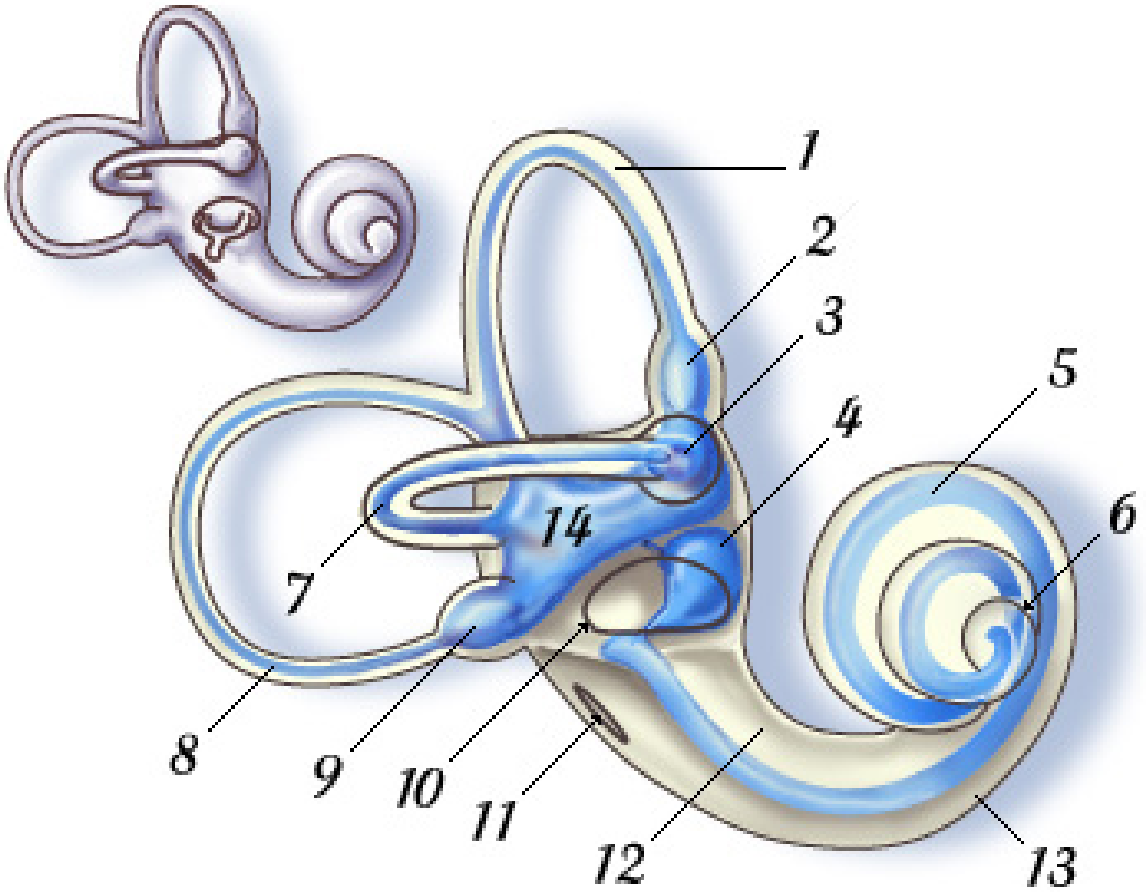
Fluid-filled spiral structure embedded in bone Basilar (basement) membrane Tectorial (roof) membrane

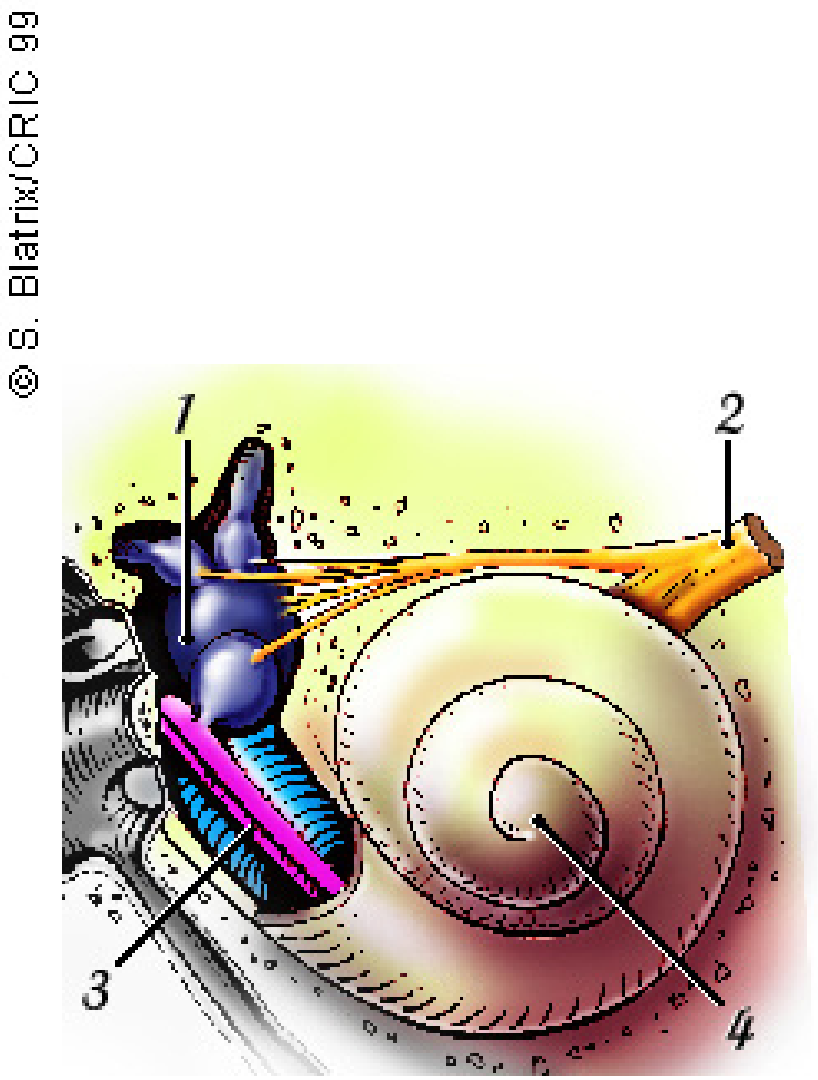
Travelling wave Place principle Transmission of vibrations to hair cells

Mechanical filtering Active amplifiers (OHCs) Transduction of vibrations into electrical currents (ion flows) Initiation of spikes in auditory nerve fibers (cochlear nerve) Afferents and efferents



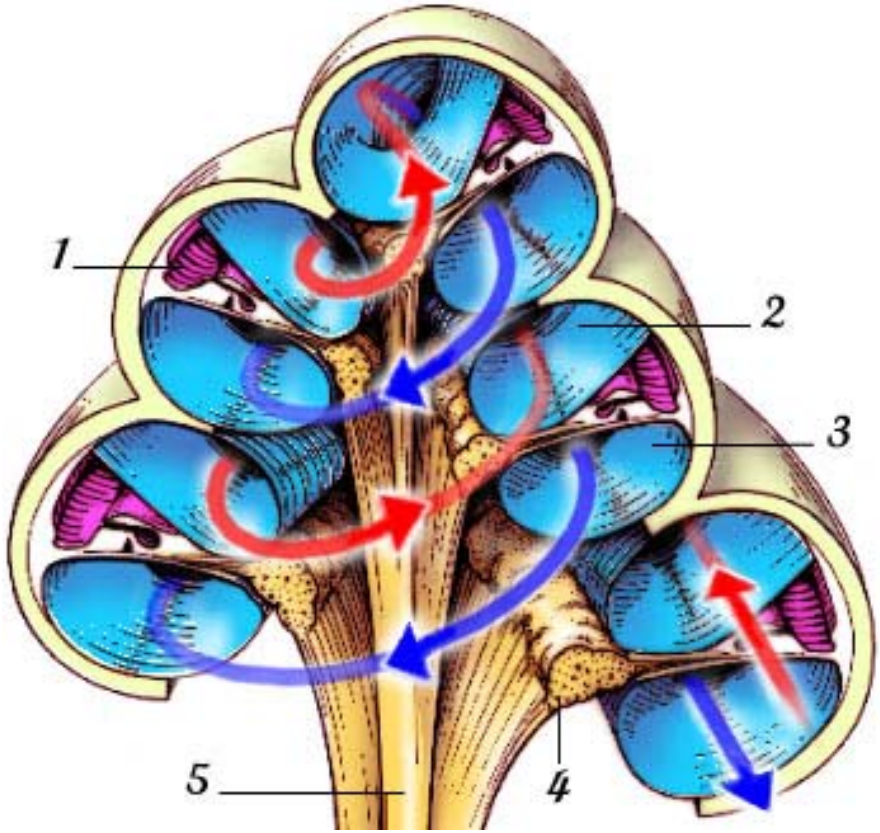
Cochlea





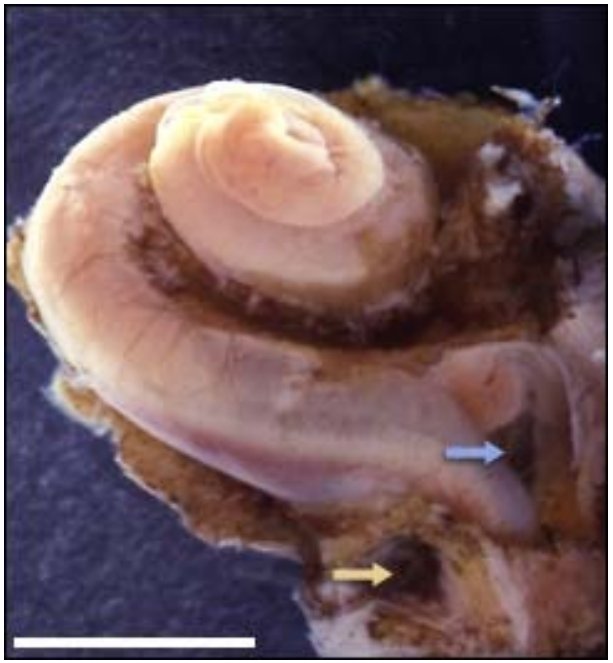
"Promenade 'round the Cochlea"
These slides, animations, and tutorials on sound & hearing
http://www.iurc.montp.inserm.fr/cric/audition/english/ear/fear.htm

Cochlea



M. Lavigne-Rebillard

Cochlea from a human fetus (5 months of gestation)



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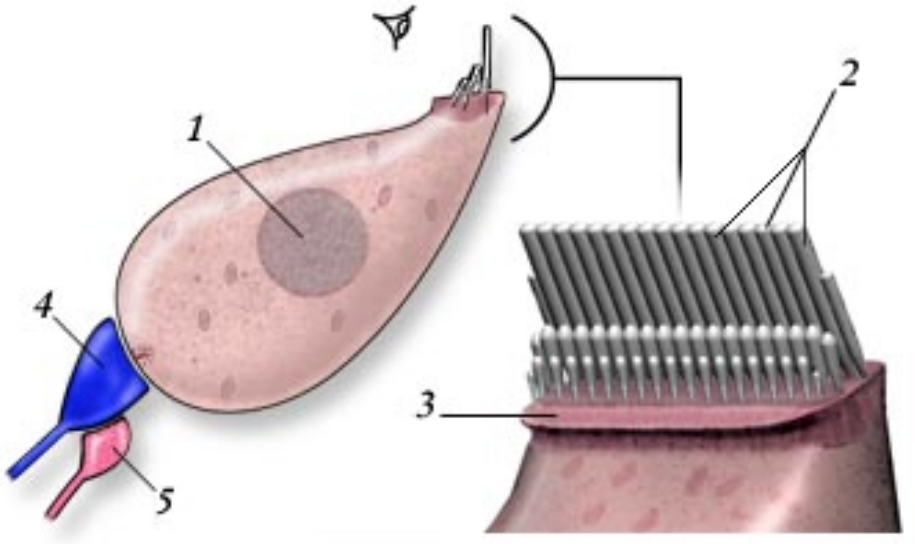
Cochlear hair cells

Inner hair cells
IHCs



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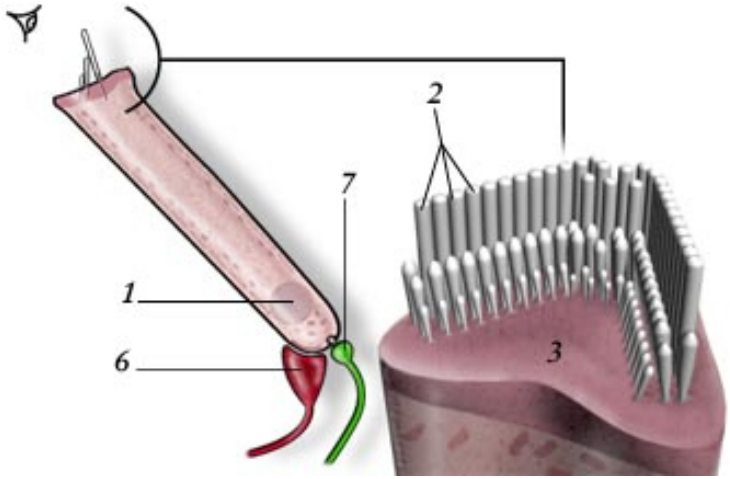
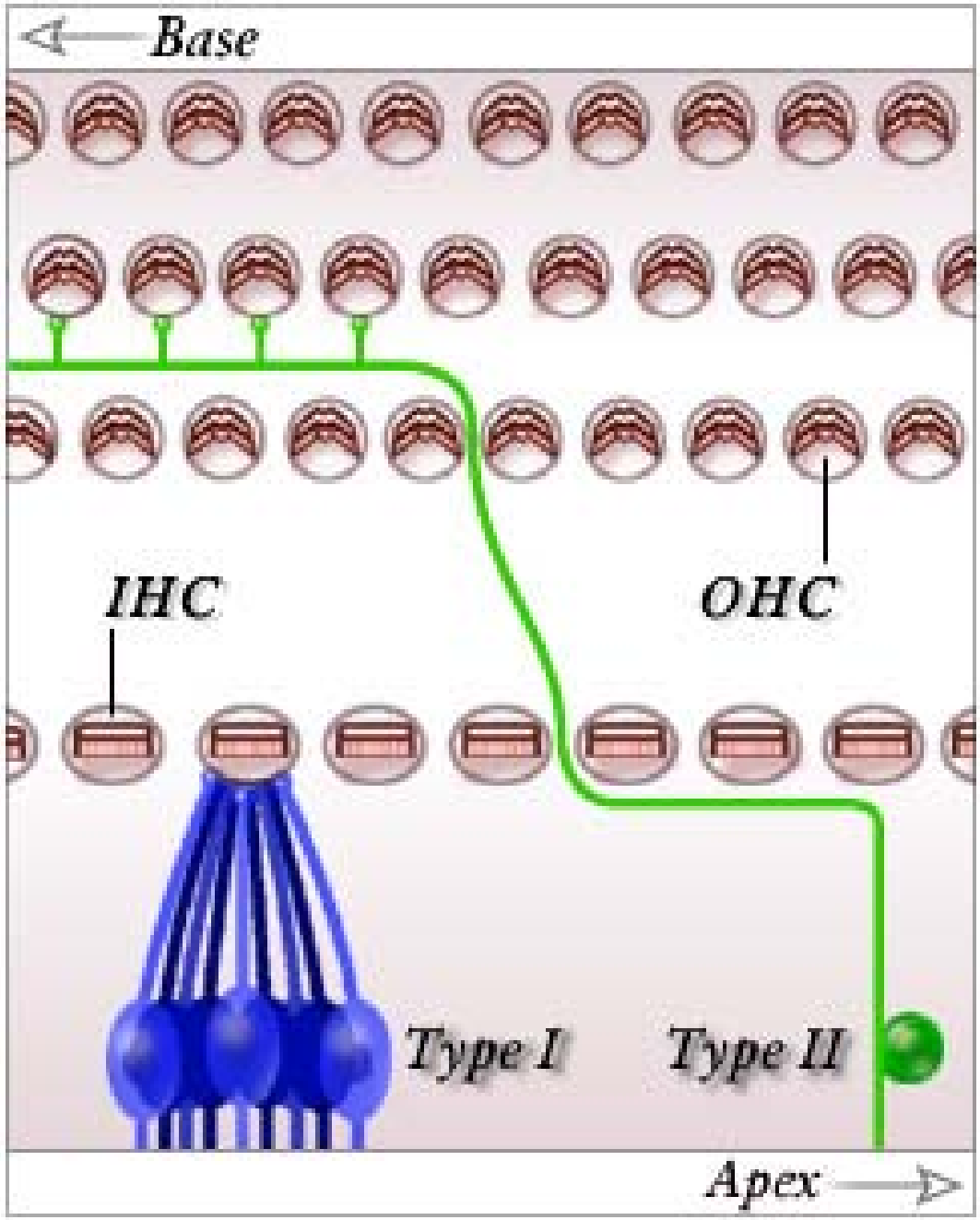


Outer hair cells
OHCs

IHCs & ANFs

Type I ANFs
myelinated (fast)
innervate inner hair cells
afferents: convey info.
to the CNS

Type II ANFs
unmyelinated (slow)
innervate outer hair cells
efferents: convey info.
from CNS to cochlea



Humans
~30k Type I ANFs
~3k IHCs

Diagram of the Human Basilar Membrane

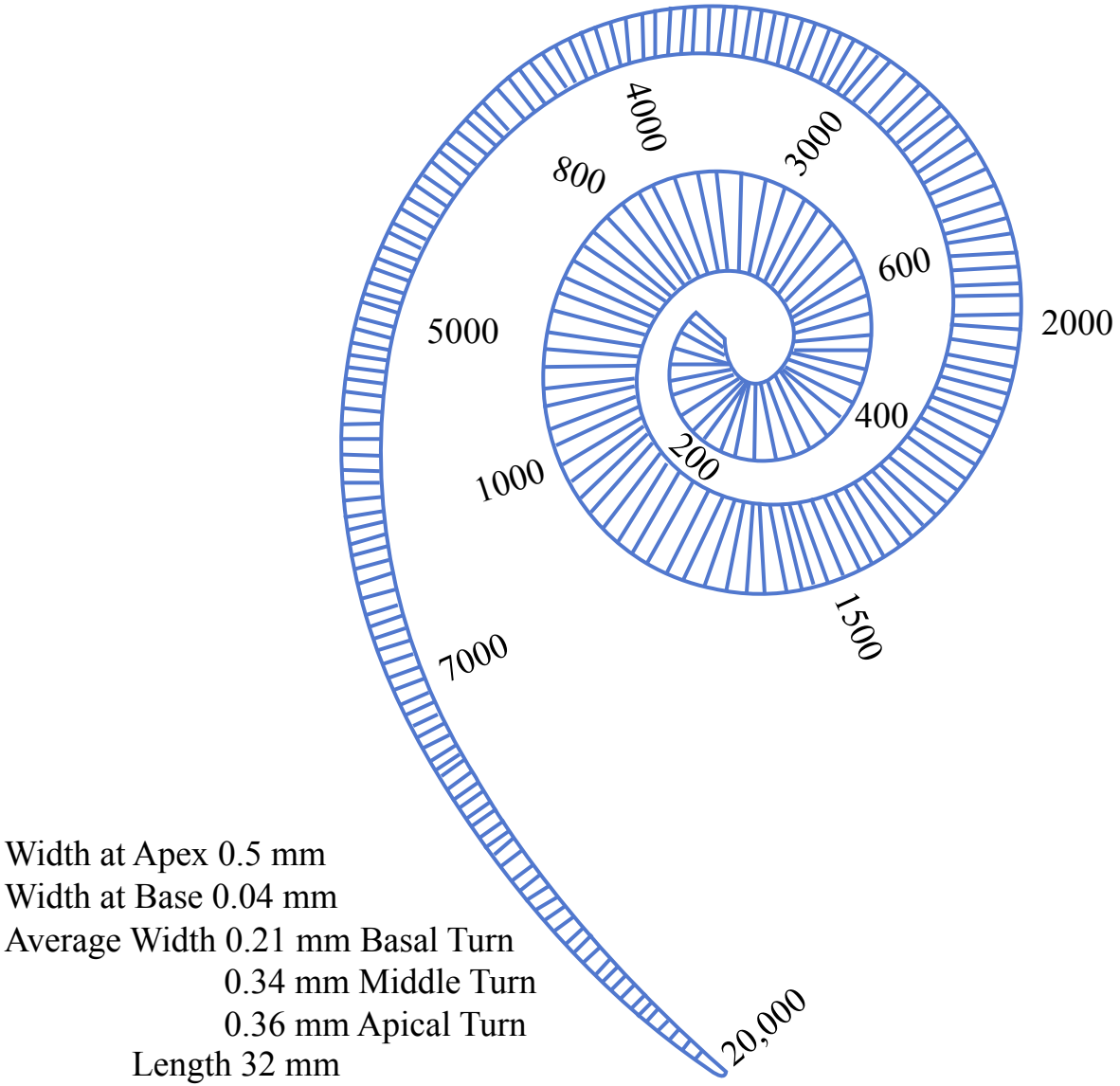


Diagram of the human basilar membrane showing the approximate positions of maximal displacement to tones of different frequencies and changes in width going from the base (near the stapes and oval window) to the apex (near the helicotrema). The ratio of width to length is exaggerated to show more clearly the variation in width.
Adapted from Stuhlman, 1943.

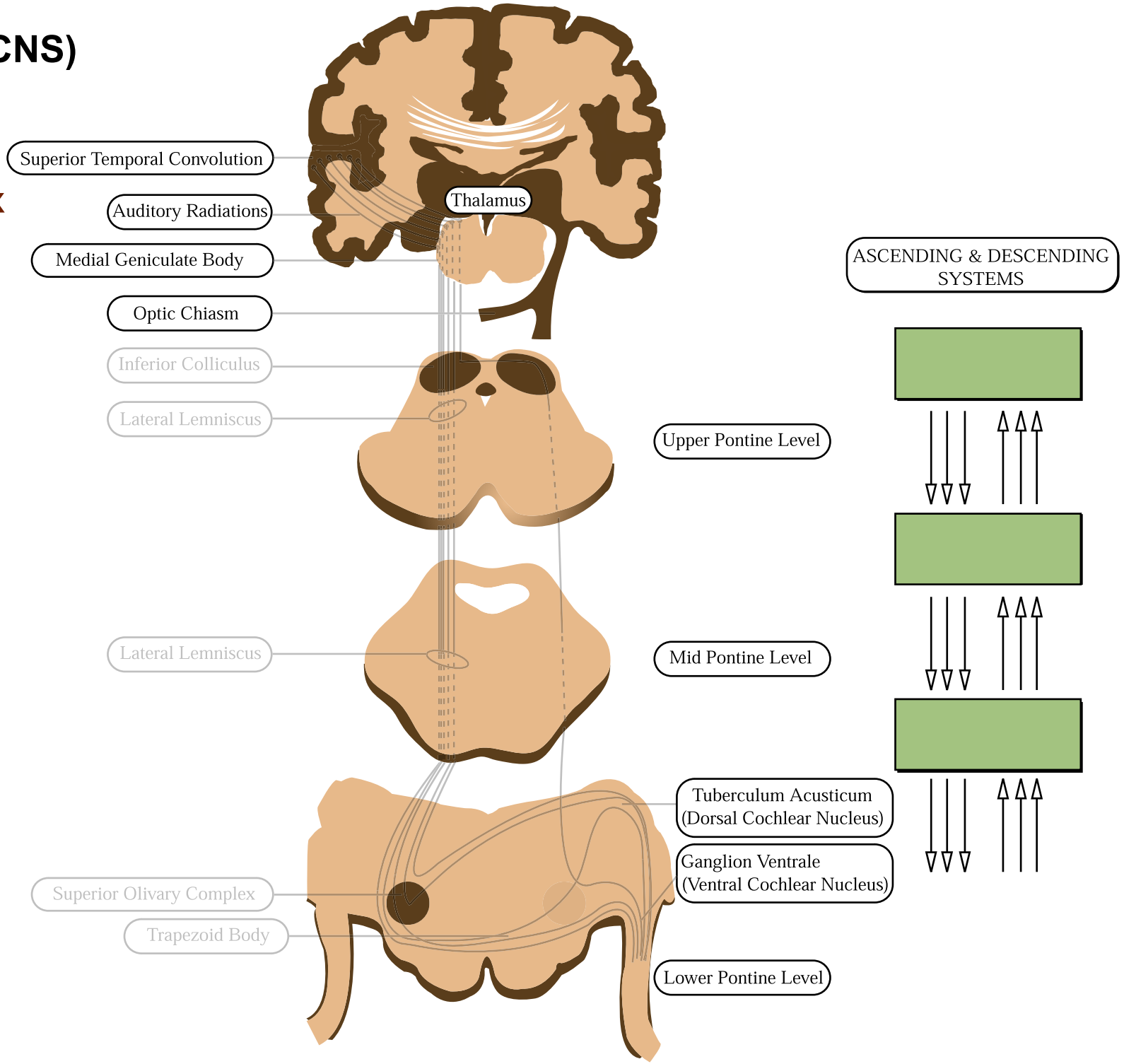
The auditory pathway (CNS)

Primary auditory cortex (forebrain)

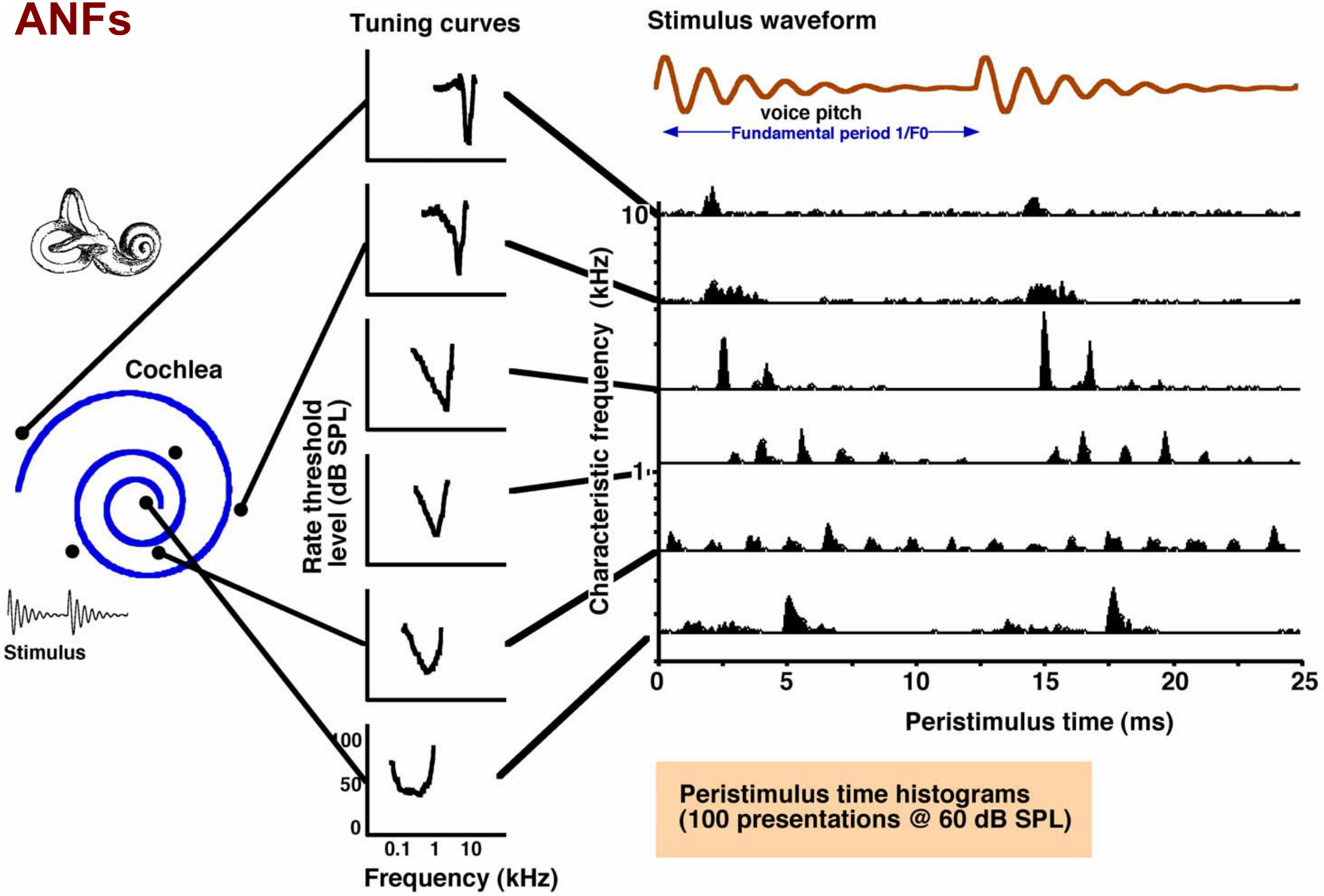
Auditory thalamus

Inferior colliculus (midbrain)

Auditory brainstem



ANFs


Tuning curves
Stimulus waveform
voice pitch
Fundamental period 1/F0
Cochlea
Stimulus
Rate threshold level (dB SPL)
100
50
0
0.1
1
10
Frequency (kHz)
Characteristic frequency (kHz)
10
1
0
5
10
15
20
25
Peristimulus time (ms)
Peristimulus time histograms
(100 presentations @ 60 dB SPL)

Auditory nerve