Current Topics in Biophysics (BPHS 2090)

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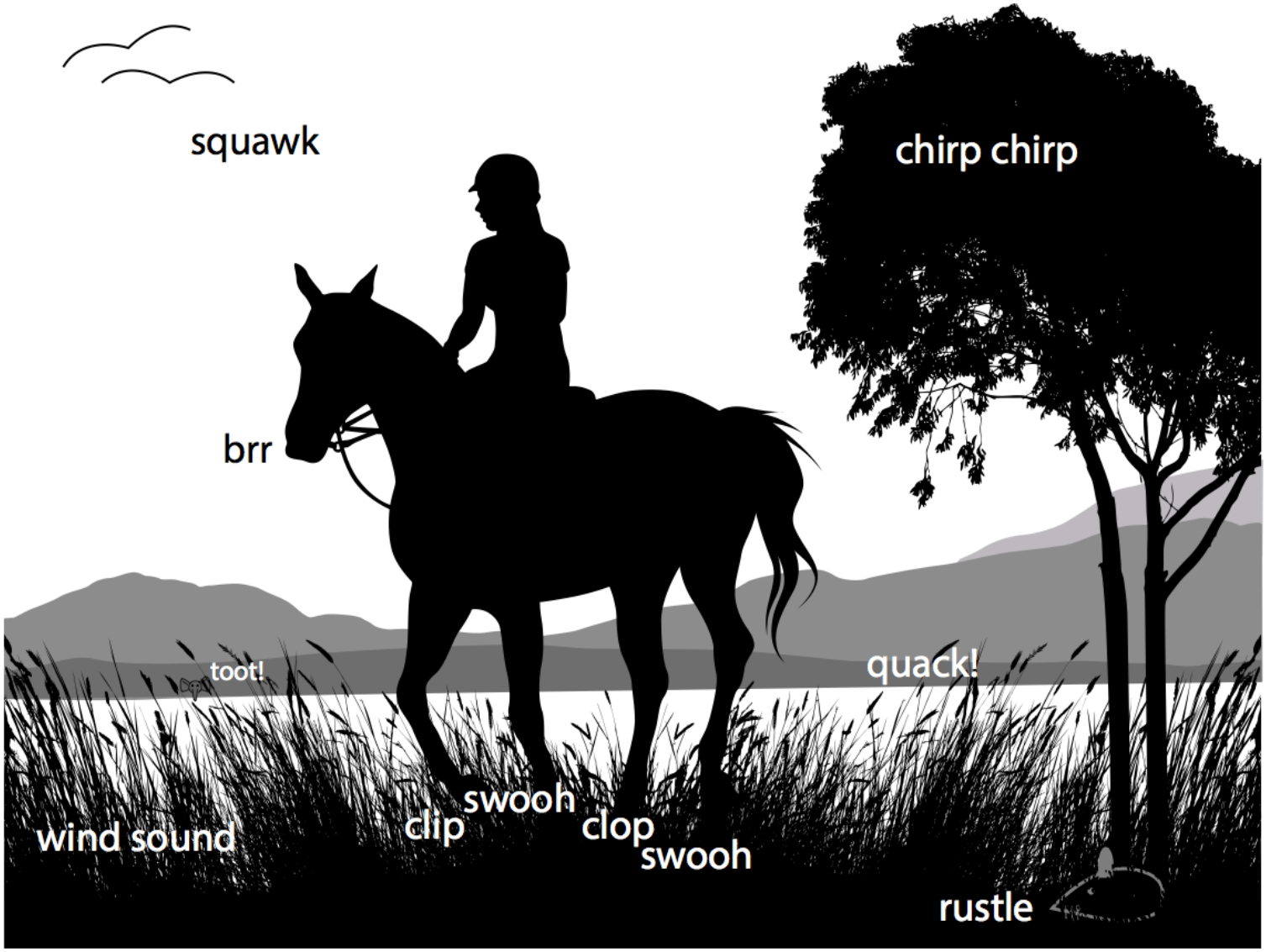
Website: http://www.yorku.ca/cberge/2090F2015.html

York University
Fall 2015 (11/26/15)

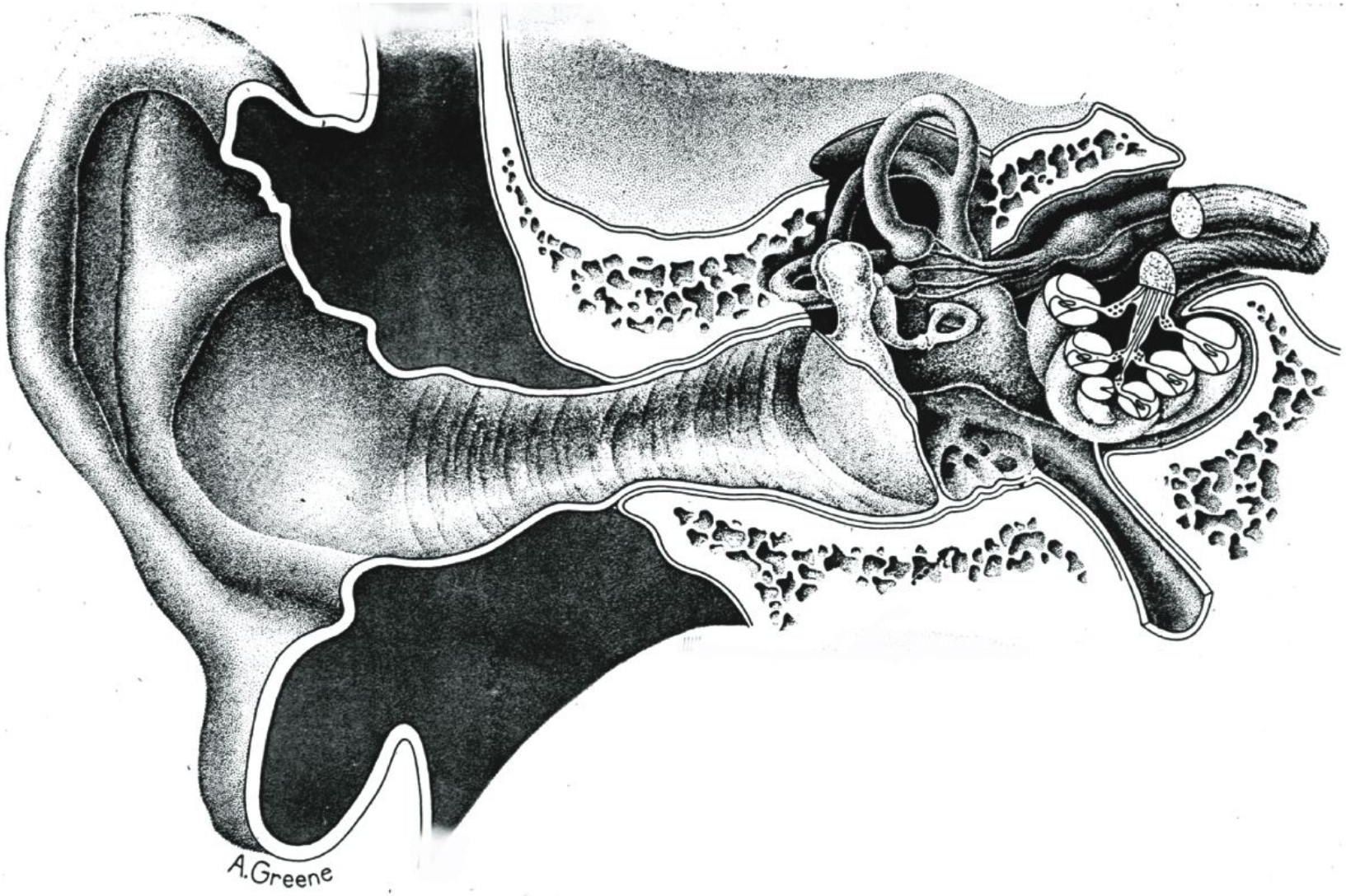
References/Acknowledgement:
→ see webpage

Moving on: Sensory systems

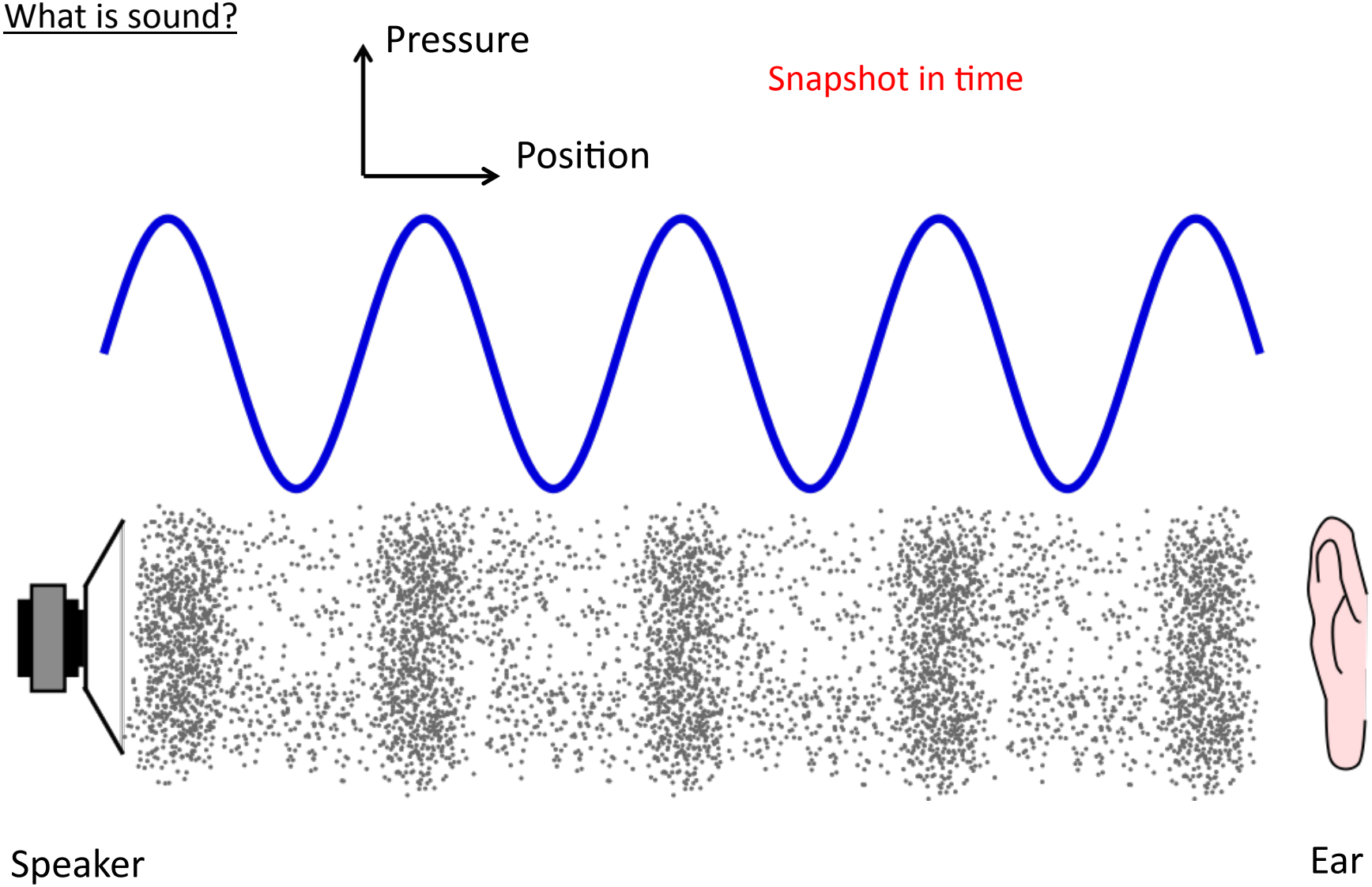


Pulkki & Karjalainen (2015)

Auditory periphery



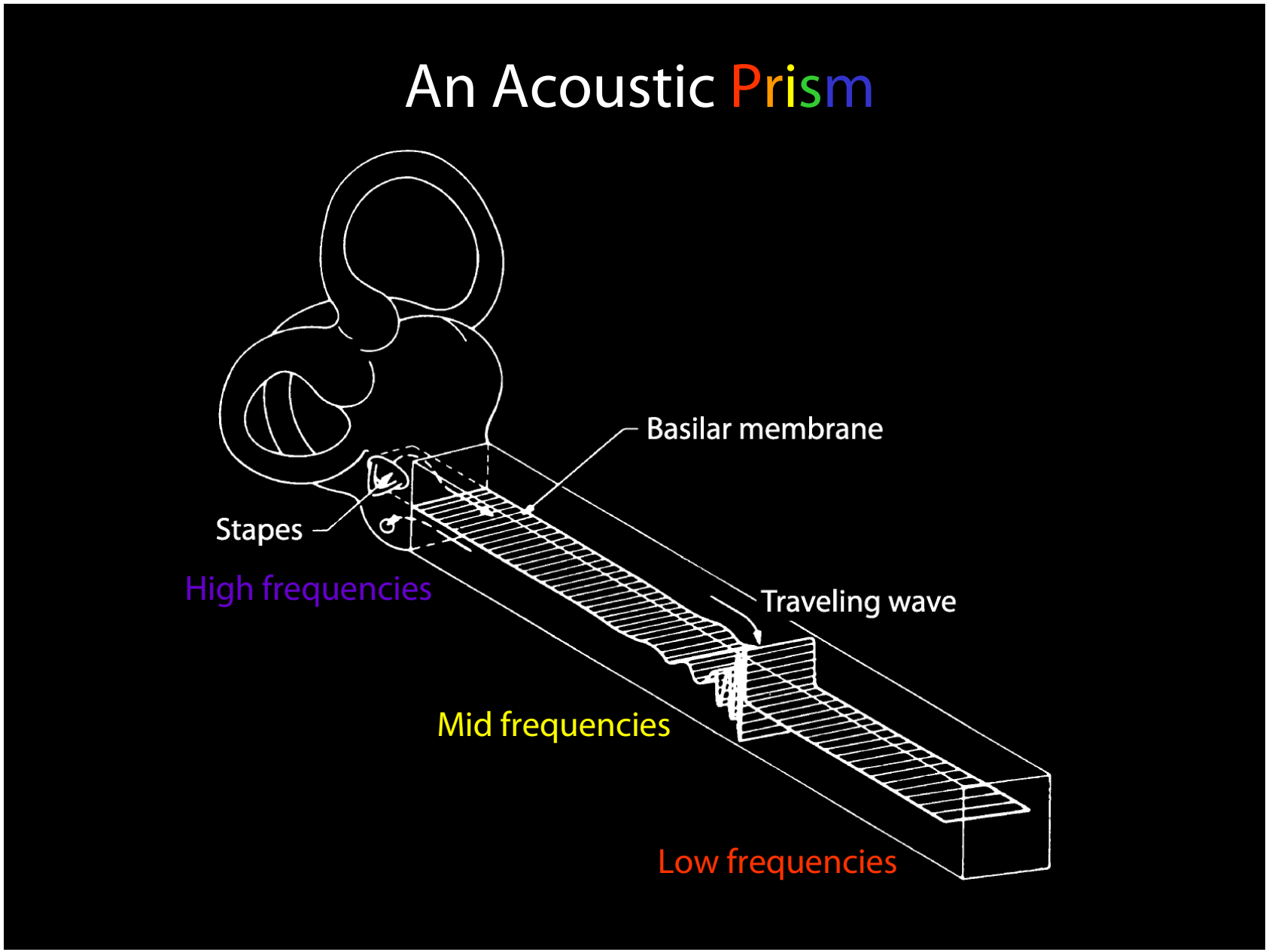
What is sound?



→ Note the periodic nature present....

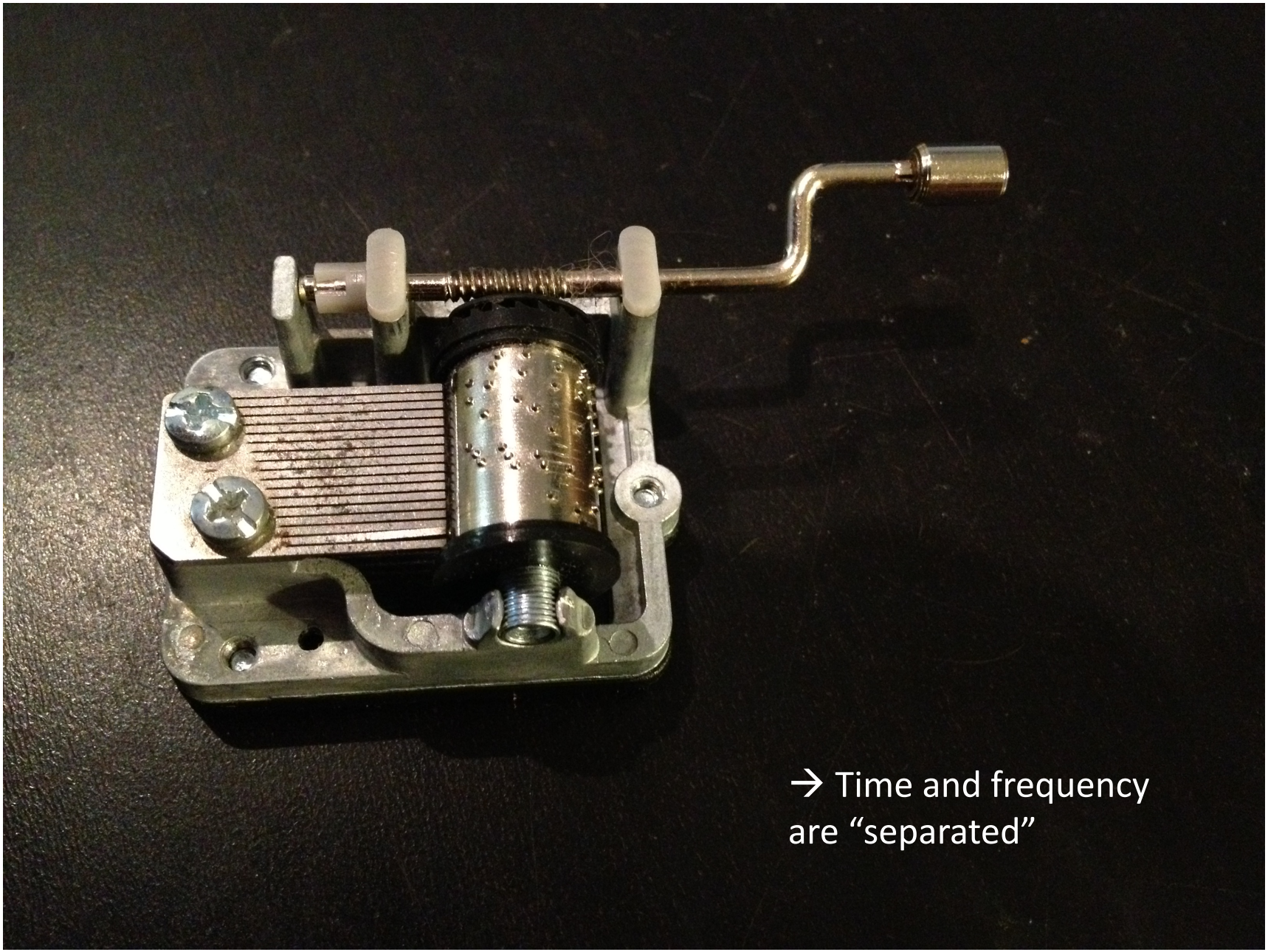
Pulkki & Karjalainen (2015)

Tonotopicity



Zweig et al. (1976)

Aside: Fourier analysis



Fourier series

- Intuitive connection back to Taylor series:

$$y(x_1 + \Delta x) \approx y(x_1) + \sum_{n=1}^{N} \frac{1}{n!} \left. \frac{d^n y}{dx^n} \right|_{x_1} (\Delta x)^n. \qquad \text{(D.2)}$$

$$f(x) = f(x_o) + f'(x_o)(x - x_o) + \frac{f''(x_o)}{2!}(x - x_o)^2 + \cdots + \frac{f^{(n)}(x_o)}{n!}(x - x_o)^n + \cdots$$

$$= \sum_{n=0}^{\infty} \frac{f^{(n)}(x_o)}{n!}(x - x_o)^n$$

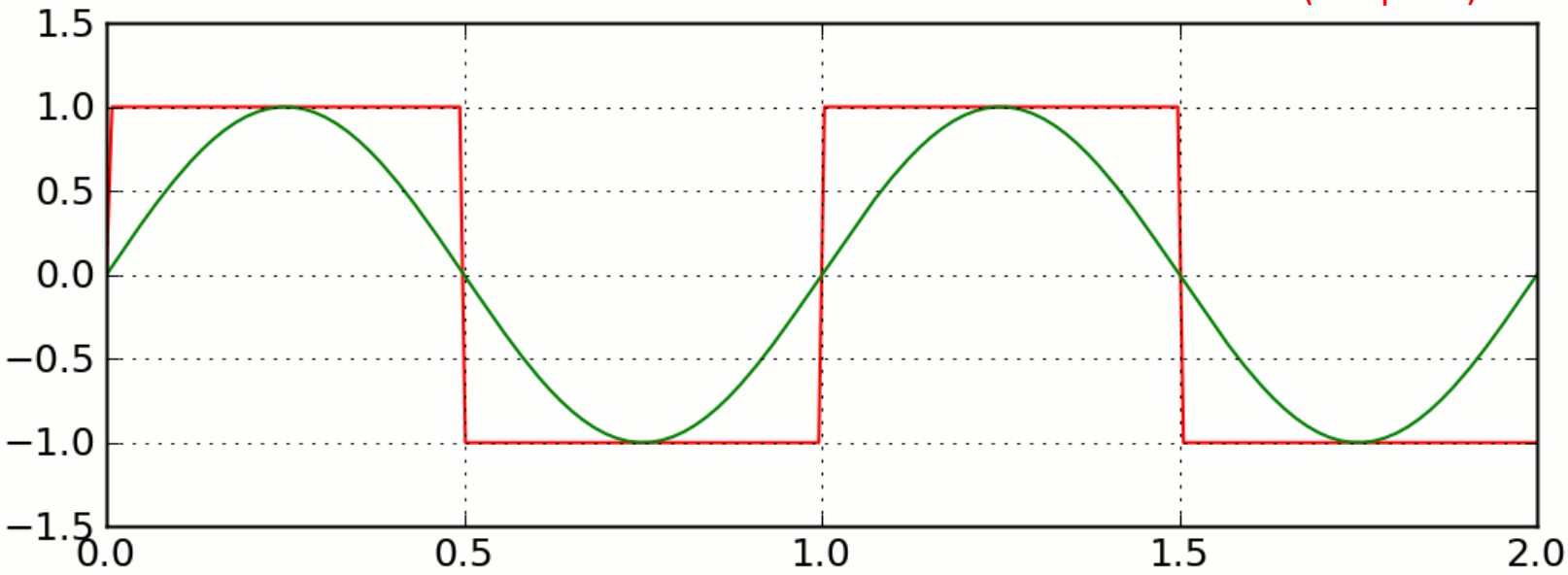
Taylor series → Expand a function as a (infinite) sum of polynomials

Different Idea: *Fourier series* → Expand function as a (infinite) sum of sinusoids

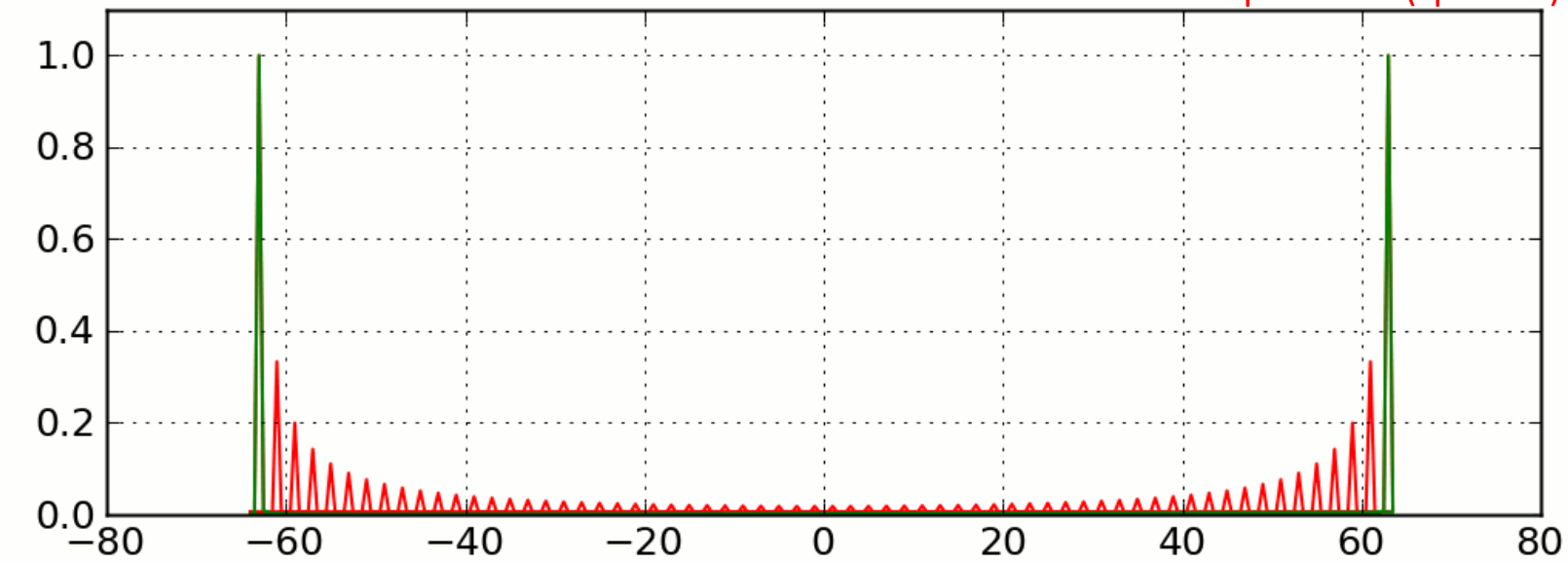
Hobbie & Roth (2007)

Fourier series

‘Waveform’ (temporal)

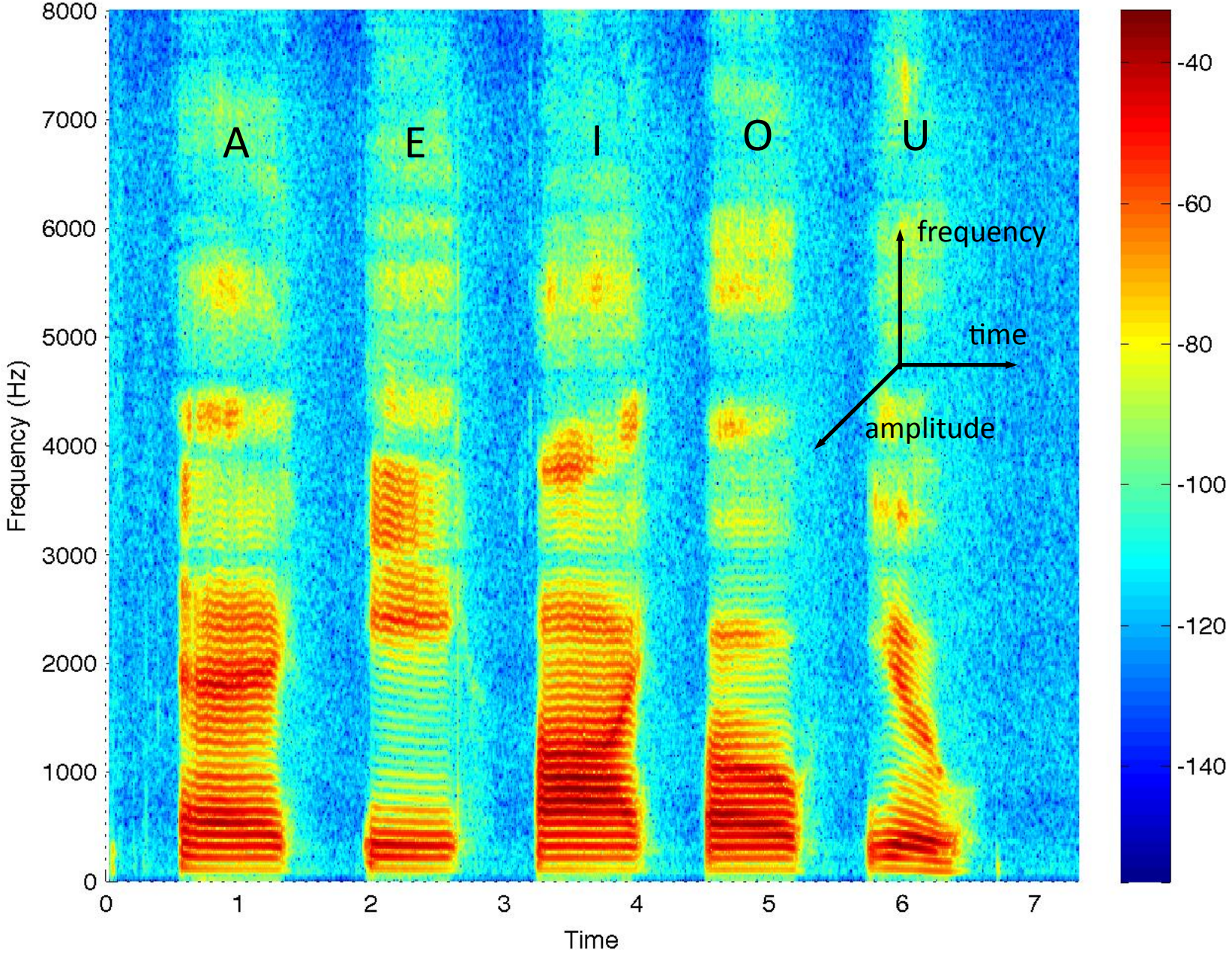


‘Power spectrum’ (spectral)



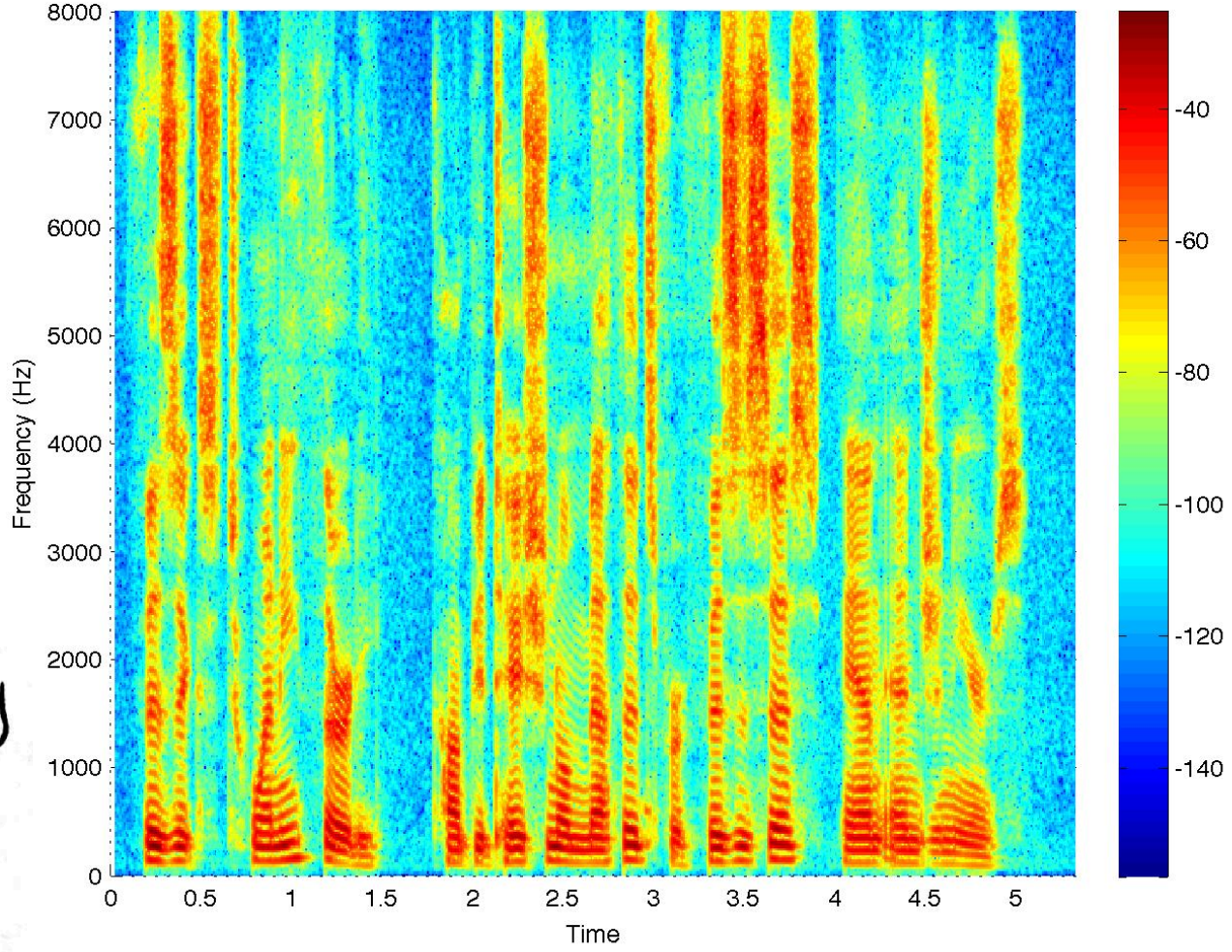
wikipedia (square wave)

Aside: Fourier analysis

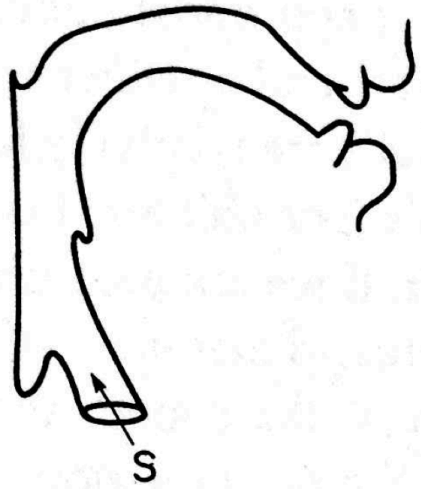


Aside: Fourier analysis

EXspectrogram.m



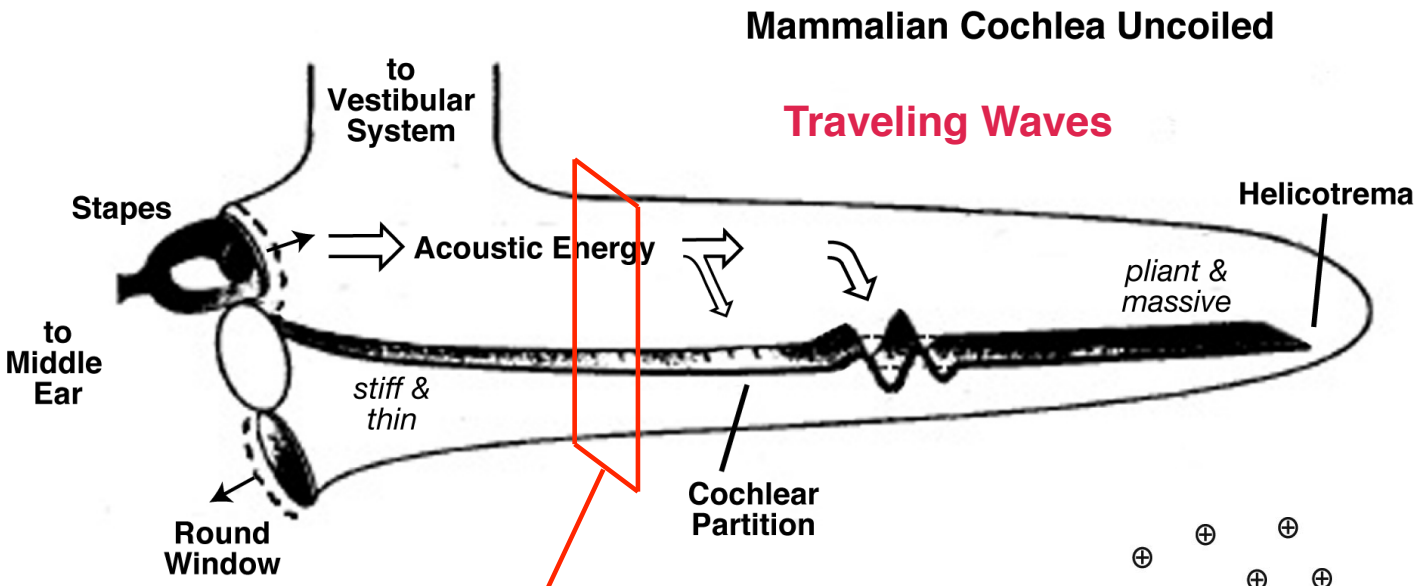
Human vocal tract cross-section

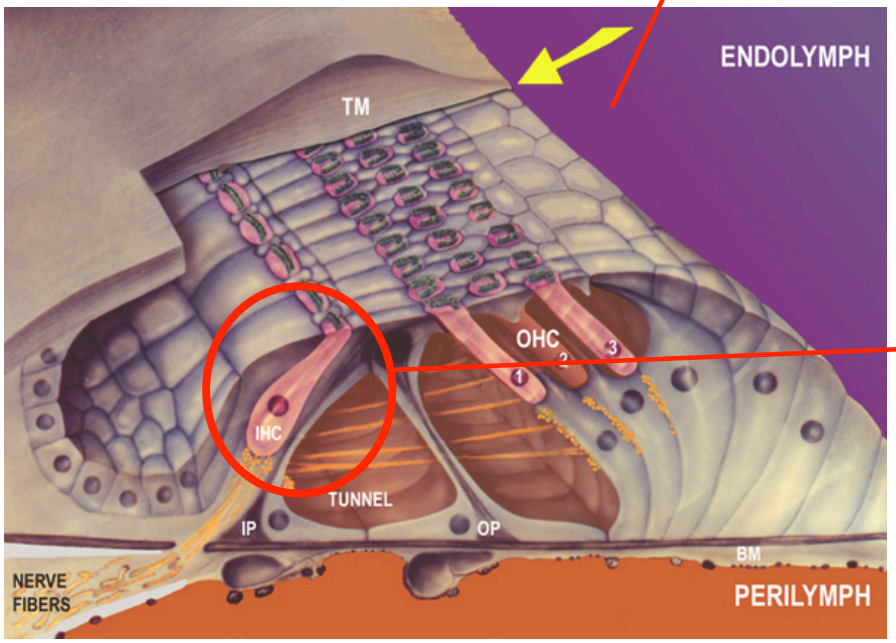


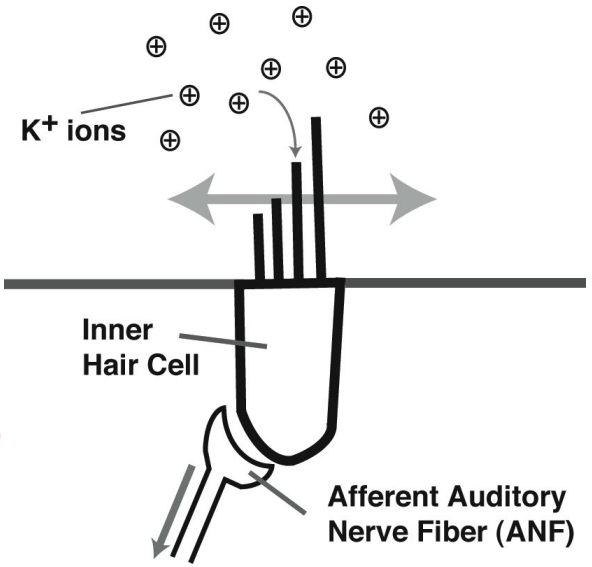
"Physics 2030 Computational methods for physicists and engineers"

→ Try making a spectrogram of your own speech!

Hair cell = ‘Mechano-electro’ transducer







Geisler; Bohnke

Putting it all together....

Biological Basis of Hearing-Aid Design

MURRAY B. SACHS,[1] IAN C. BRUCE,[1] ROGER L. MILLER,[2] and ERIC D. YOUNG[1]

nals of Biomedical Engineering, Vol. 30, pp. 157–168, 2002

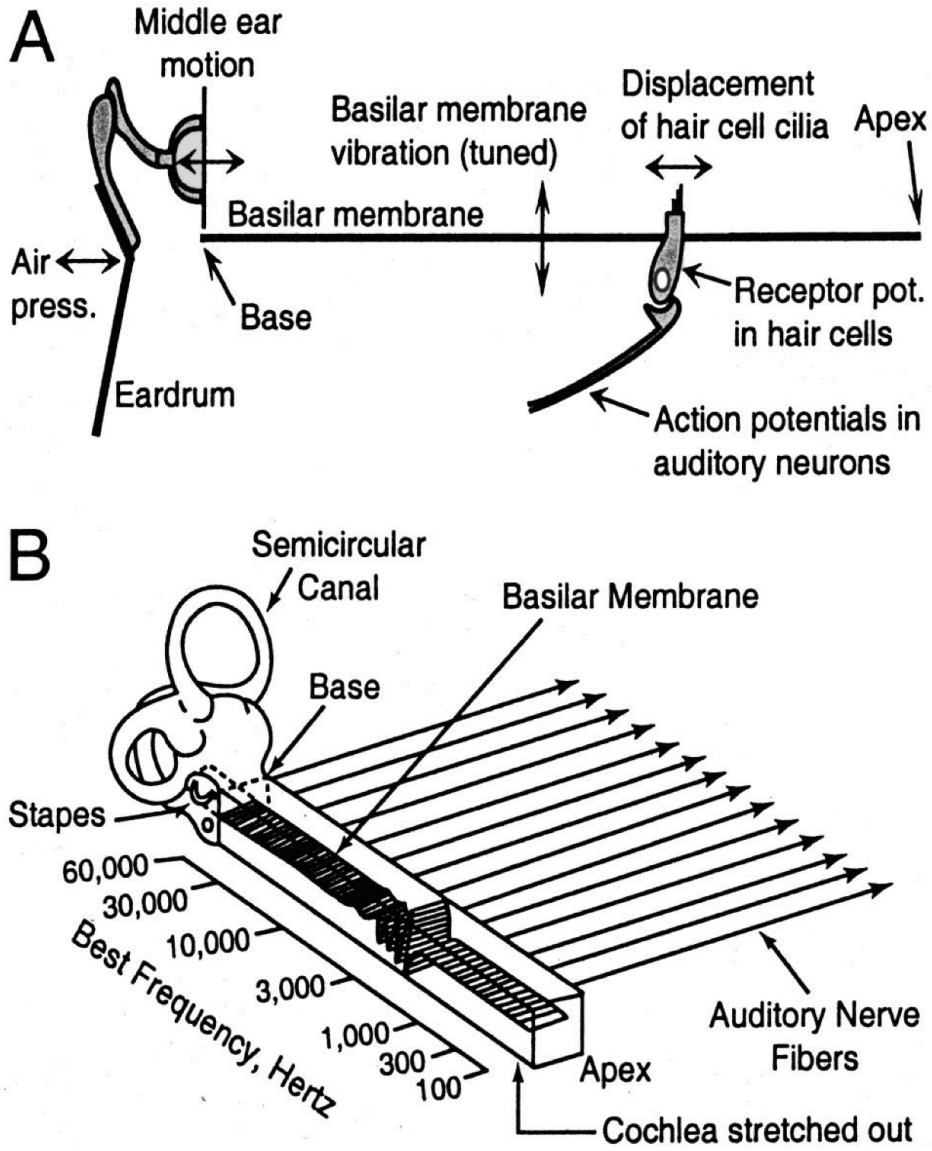


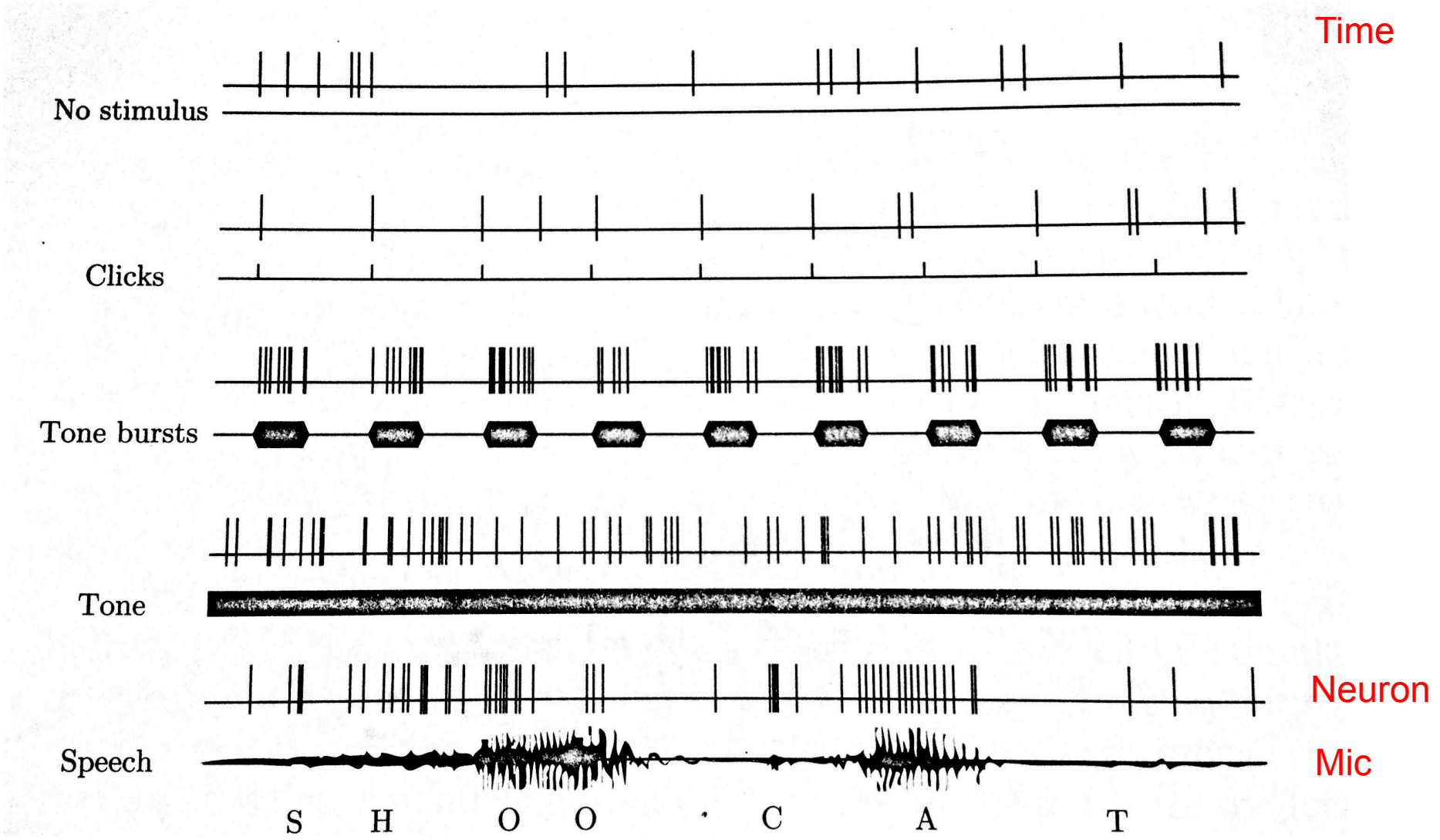
FIGURE 1. (A) Summary of the transduction process in the mammalian cochlea. Sound (air-pressure fluctuations) cause mechanical vibrations of the eardrum and middle ear bones; these couple the vibrations to the inner ear, where they produce vibration of the basilar membrane (BM). BM vibrations, in turn, displace the cilia of hair cells which transduce the vibration into electrical potentials that excite action potentials in auditory-nerve fibers. (B) Illustration of the tonotopic organization of the cochlea. The BM vibrations are tuned, so that energy at a given frequency causes a vibration which peaks at one point along the membrane. The scale at left shows the mapping of frequencies of maximum displacement (or best frequencies) into place along the BM for the cat cochlea. Auditory-nerve fibers innervate one hair cell, and so are sensitive to the BM vibration at that point [(B) redrawn from Zweig *et al.* (Ref. 44)].

Neural coding of sound

Voltage

Time

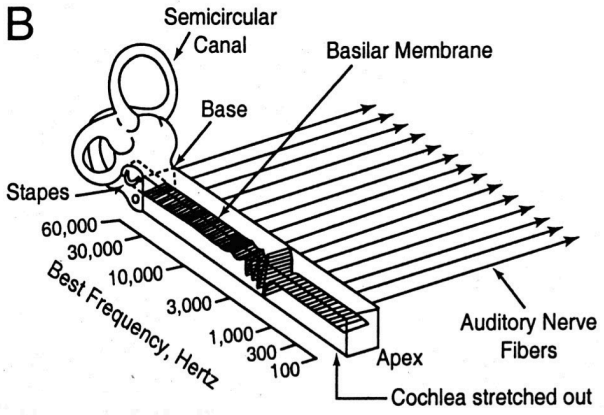
Note: Responses shown here are from a single auditory nerve fiber

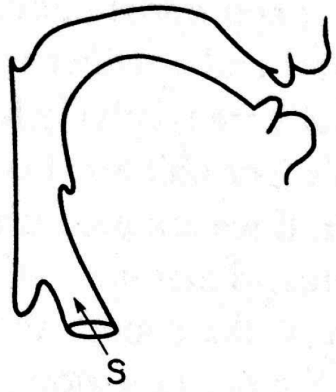


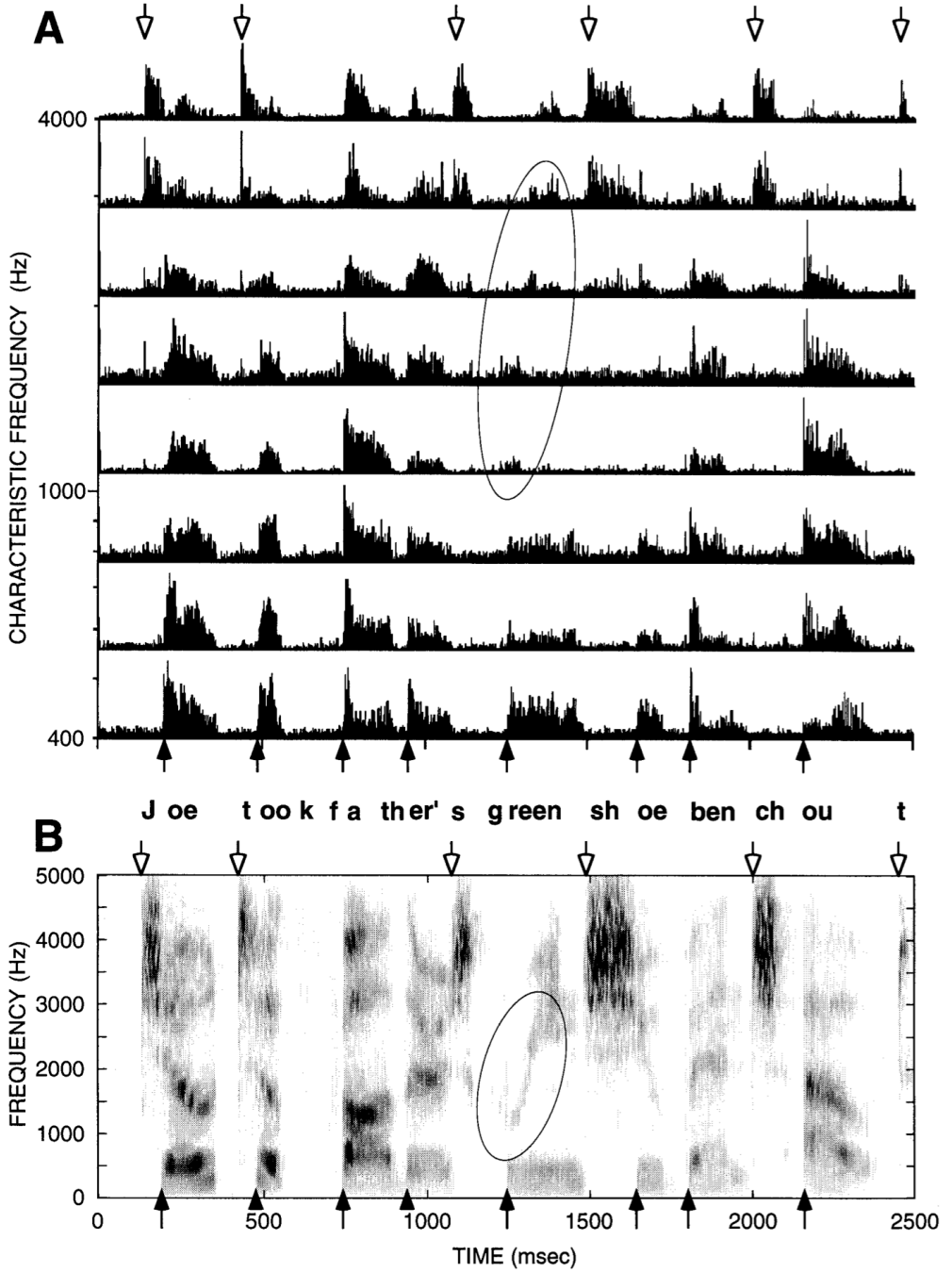
Kiang

Neural coding of speech

Fig. 1. Neurogram and spectrogram for a speech utterance produced by a female speaker. A. Neurogram display of the activity of the cat auditory nerve in response to the utterance. Each trace represents the average post-stimulus-time histogram for 2-7 auditory-nerve fibers whose CFs are located in a 1/2 octave band centered at the vertical ordinate. All histograms were computed with a bin width of 1 msec, and have been normalized to the same maximum in order to emphasize temporal patterns. The stimulus level was such that the most intense vowels were at 50 dB SPL. B. Broadband spectrogram of the utterance. Filled arrows point to rapid increases in amplitude in the low frequencies (and their neural correlates on top), while open arrows point to rapid increases in amplitude in the high frequencies. The ovals show the second-formant movement in "green" and its neural correlate.

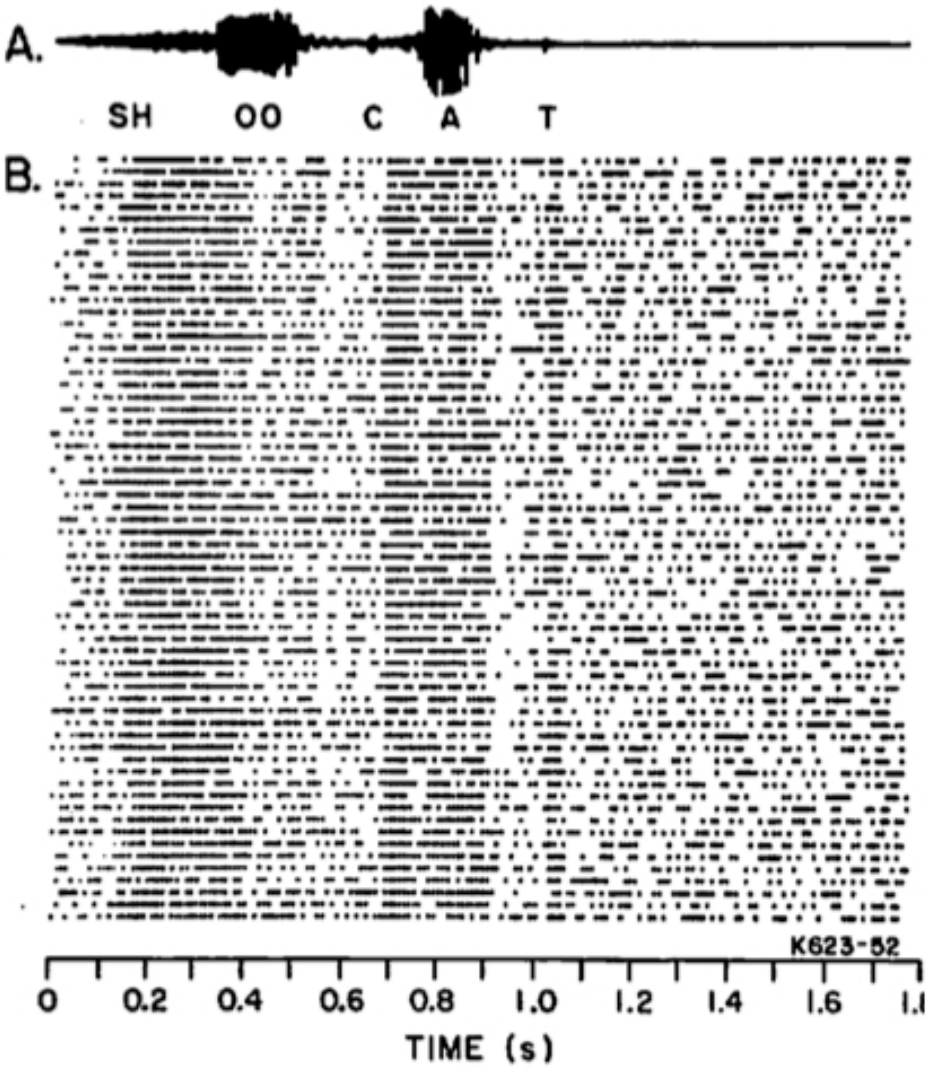






Delgutte (1997)

Neural coding of speech

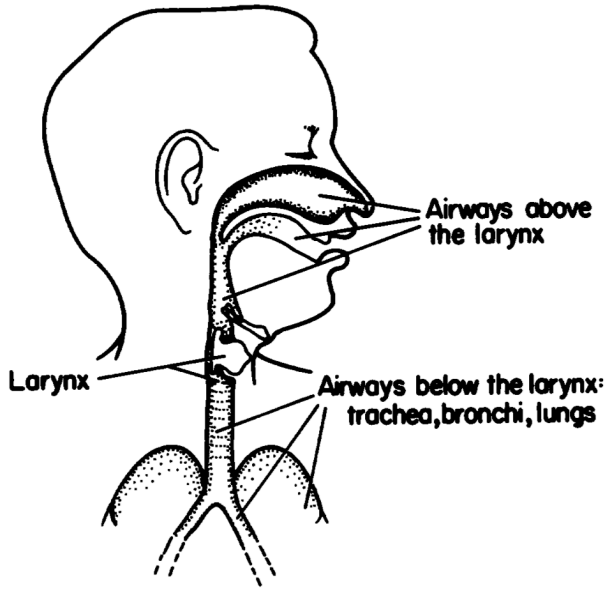


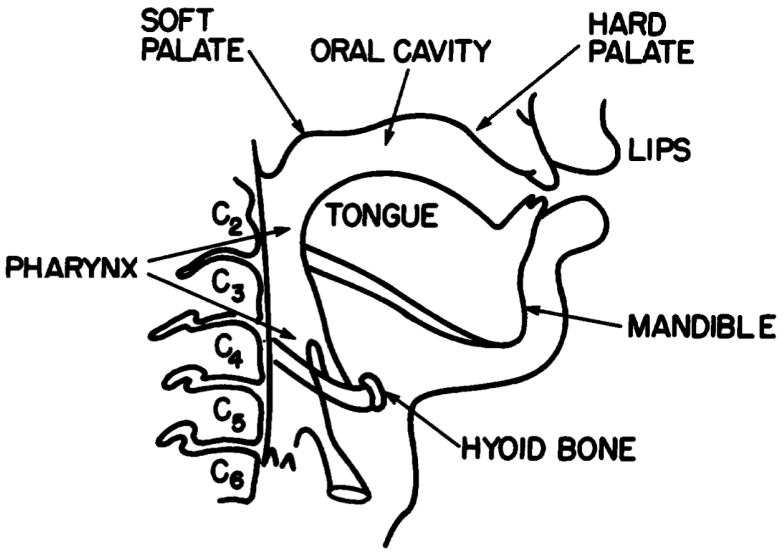
→ Temporal variation within a single nerve fiber across different repetitions (noisy?)

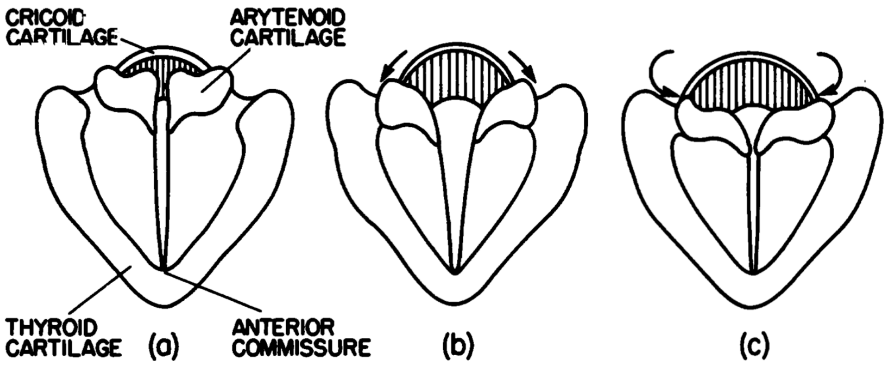
FIG. 1. Responses of a single auditory-nerve fiber to a speech stimulus. At the top is shown the waveform for the utterance "SHOO CAT." Below is a display in which each dot means that there was at least one spike discharge in a 10-ms interval (bin) represented by the width of the dot. Each row of 180 bins covers a time interval of 1.8 s during which the taped "SHOO CAT" stimulus is presented beginning at the first bin. The stimulus is presented 64 times, and the resulting discharge patterns are displayed in the 64 consecutive rows of dots. The stimulus level was approximately 80 dB p–p *re* 0.0002 dyn/cm^2 during the "OO". A post-stimulus-time histogram showing the average response pattern was computed from these data and is displayed in Fig. 4.

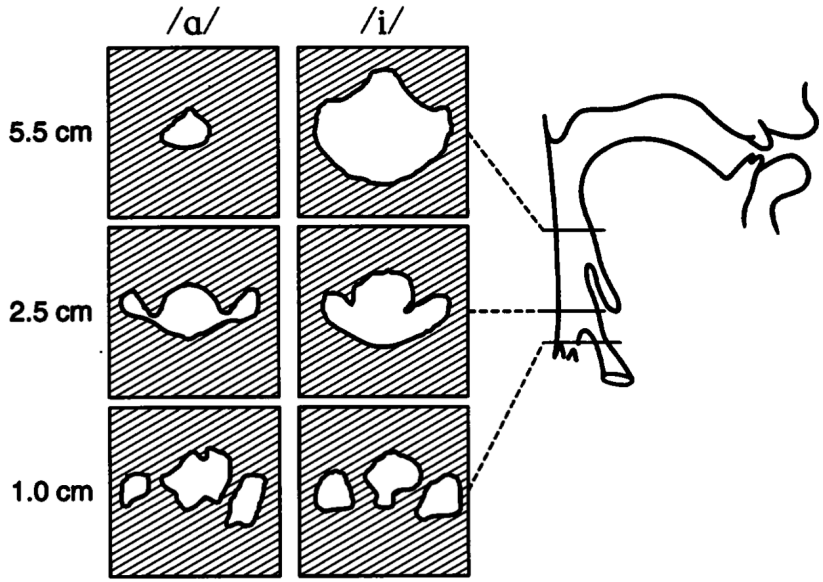
Kiang (JASA, 1980)

Biomechanics of speech





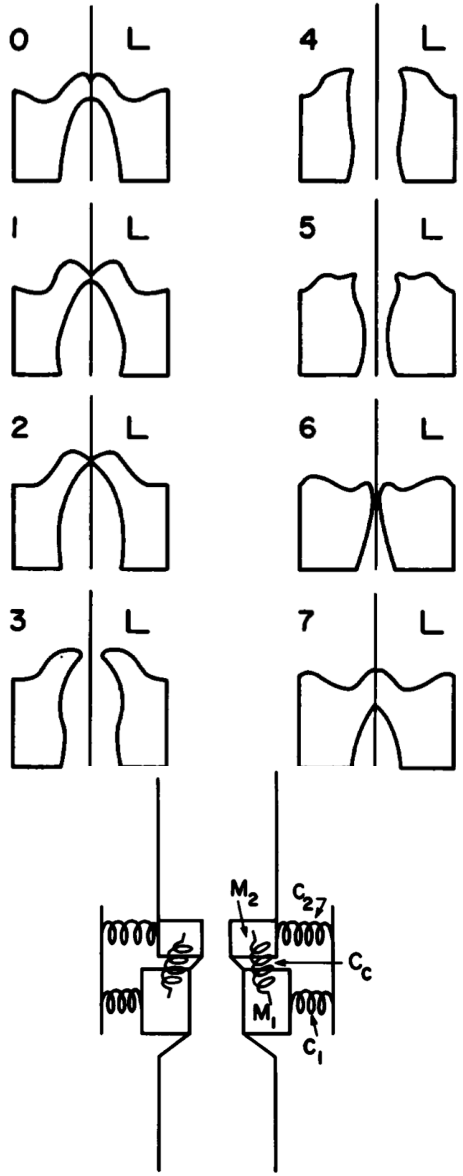


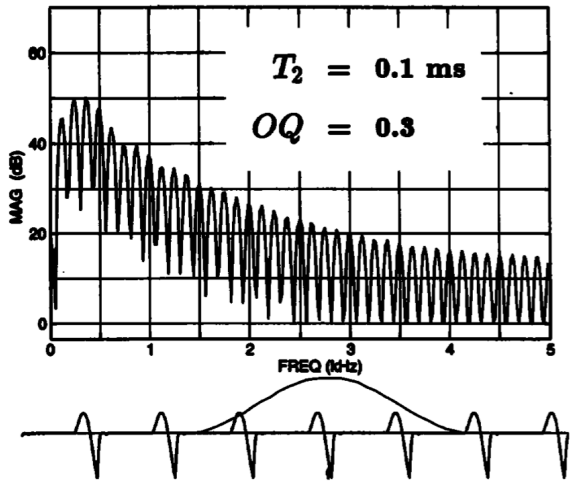


Stevens (2000)

Biomechanics of speech

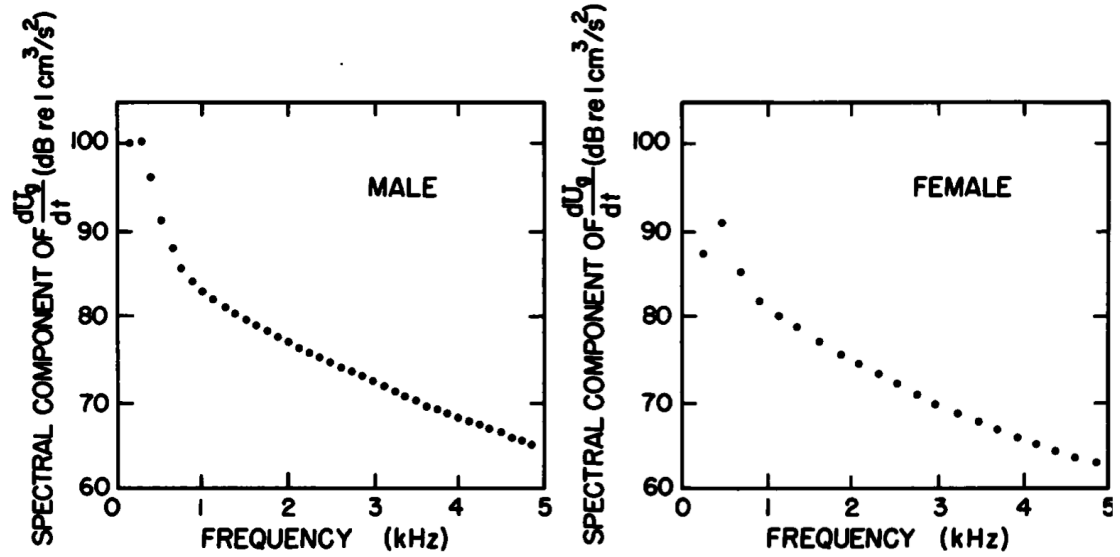
Vocal folds





Key idea:
Spectrum
→ x-axis is
frequency [Hz]
(i.e., Fourier transform)

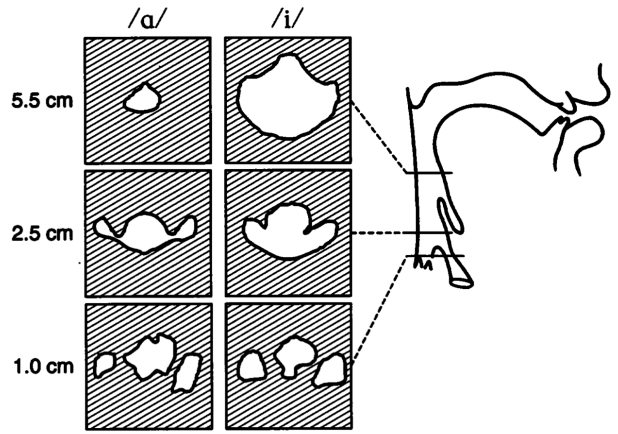
→ Vibrating vocal folds give off 'buzzy' sound due to harmonics



→ Males have lower 'fundamental' (due to more massive vocal folds)

Stevens (2000)

Biomechanics of speech

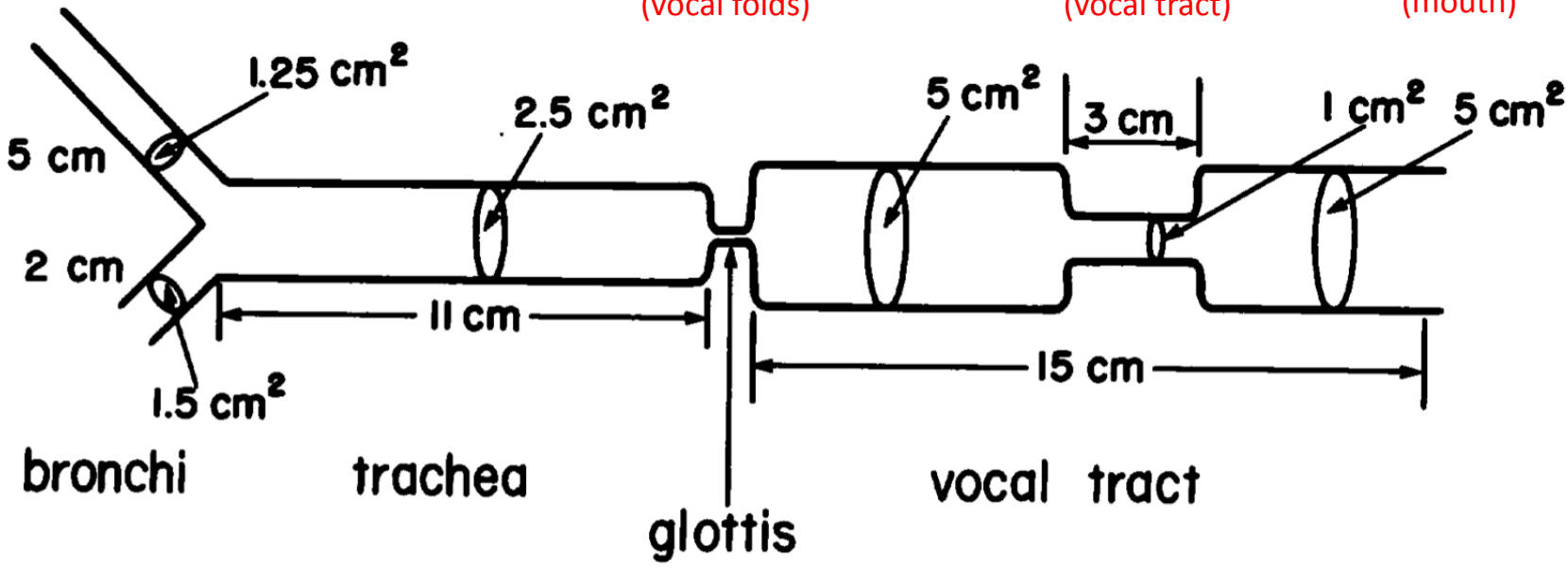


Pressure source (lungs)

Vibration source (vocal folds)

Filter (vocal tract)

Output (mouth)



→ Complex acoustic process is boiled down to a relatively simple/tractable framework of 'sources' and tubes!

Stevens (2000)

Biomechanics of speech

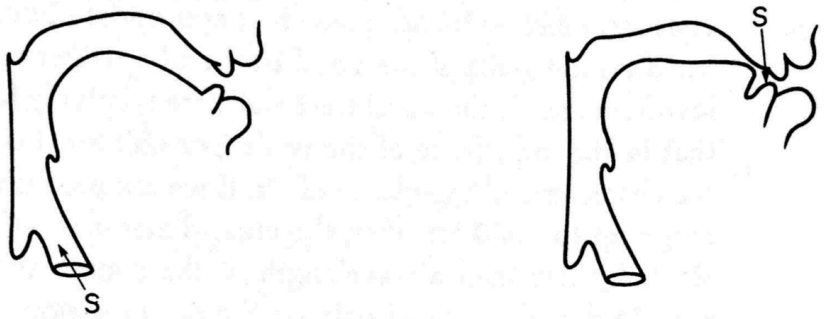
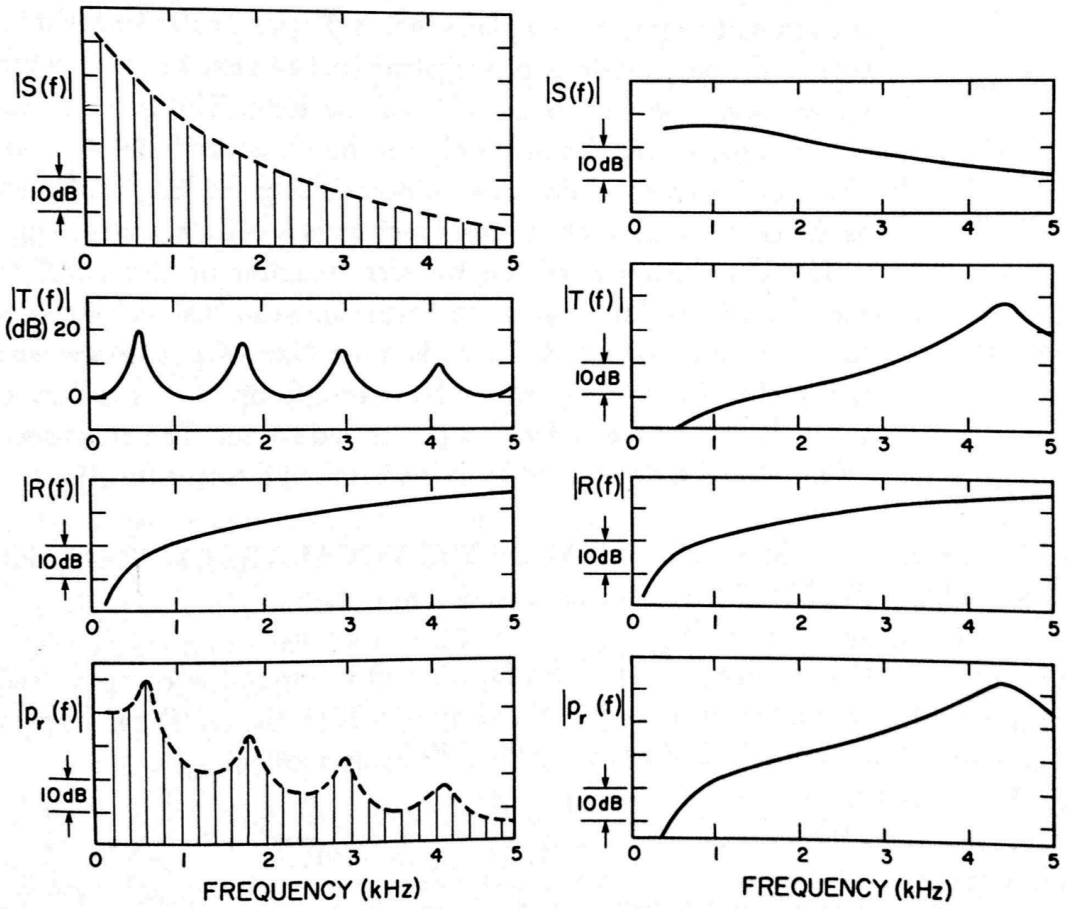
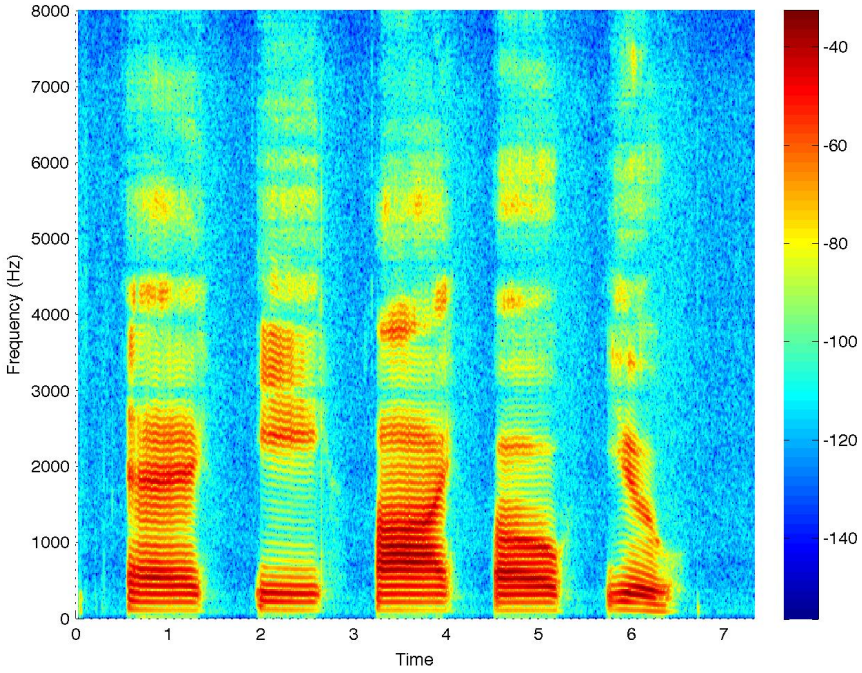


Figure 3.1 Sketches indicating components of the output spectrum $|p_r(f)|$ for a vowel and a fricative consonant. The output spectrum is the product of a source spectrum $S(f)$, a transfer function $T(f)$, and a radiation characteristic $R(f)$. The source spectra are similar to those derived in figures 2.10 and 2.33 in chapter 2. For the periodic source, $S(f)$ represents the amplitudes of spectral components; for the noise source, $S(f)$ is amplitude in a specified bandwidth. See text.

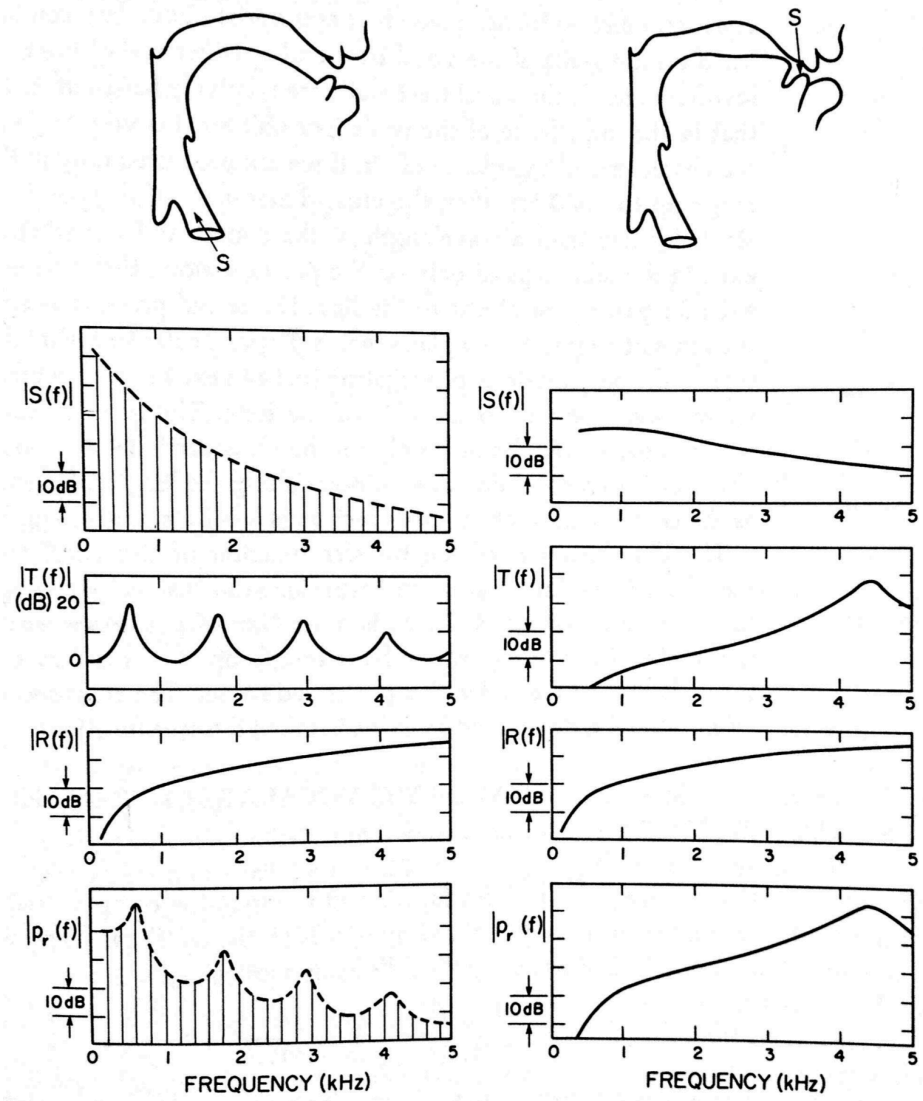
- Most easily described in spectral domain (i.e., via Fourier transforms)
- Vocal folds (S) act as a (noisy) source, sometimes vibrating
- Vocal tract shapes that sound (T), creating “formants” for vowel sounds

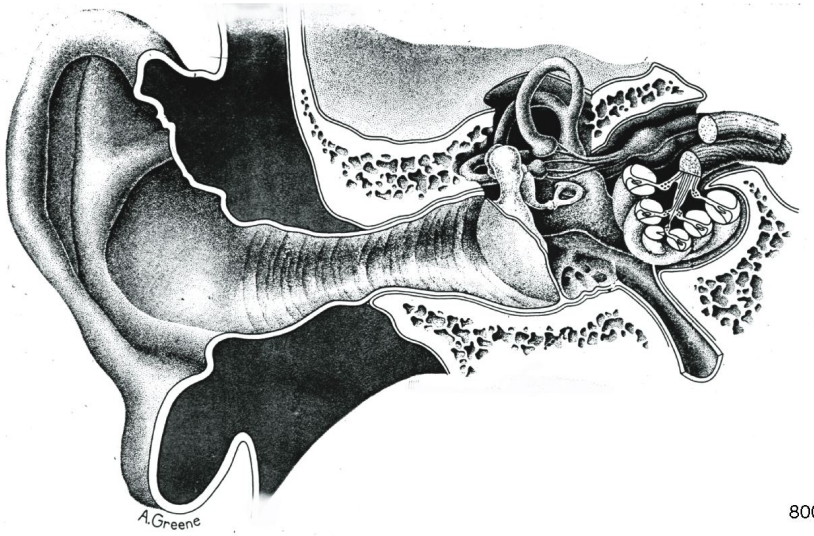


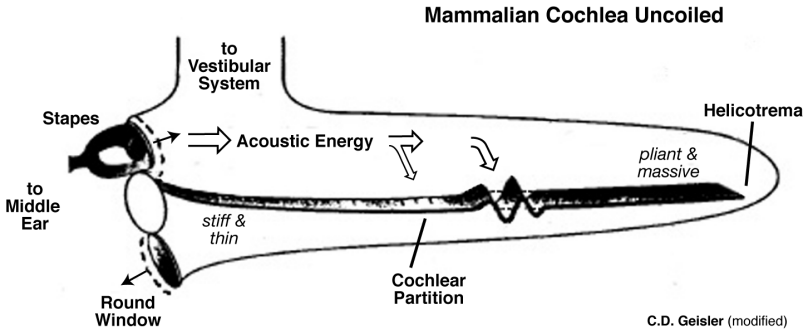
Stevens (1998)

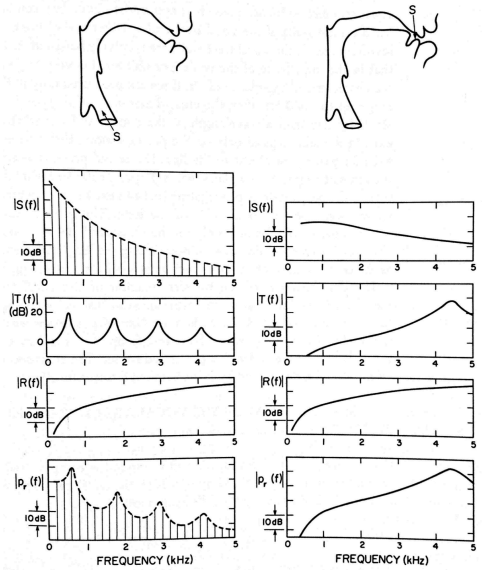


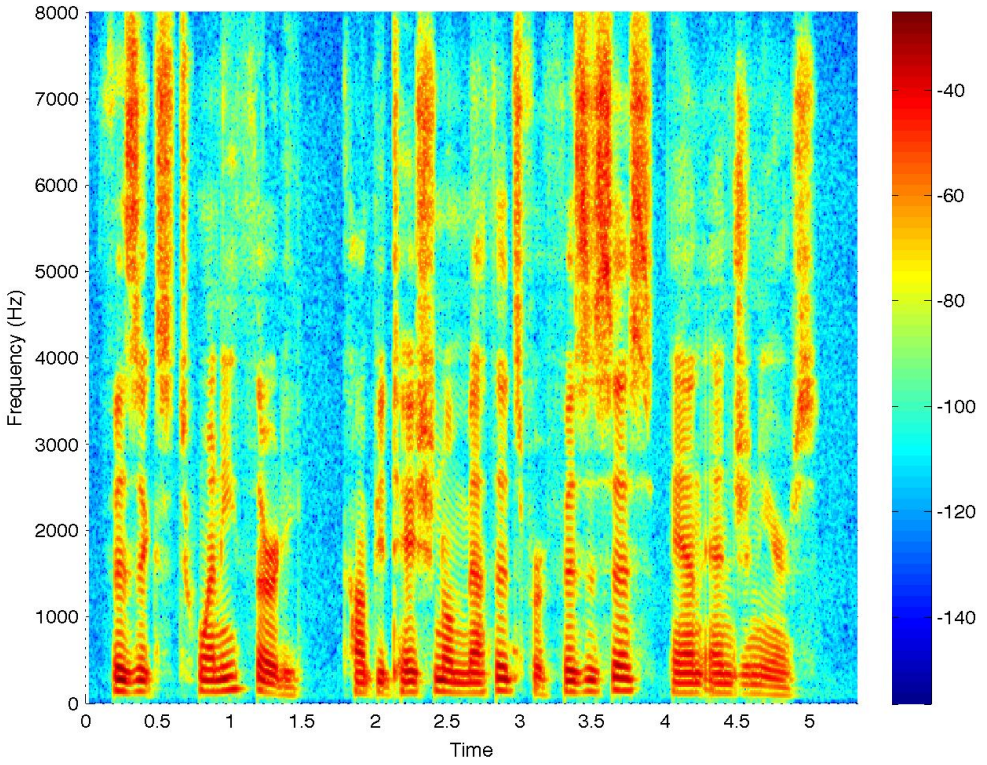
→ You can see both aspects (S and T) in the spectrogram!





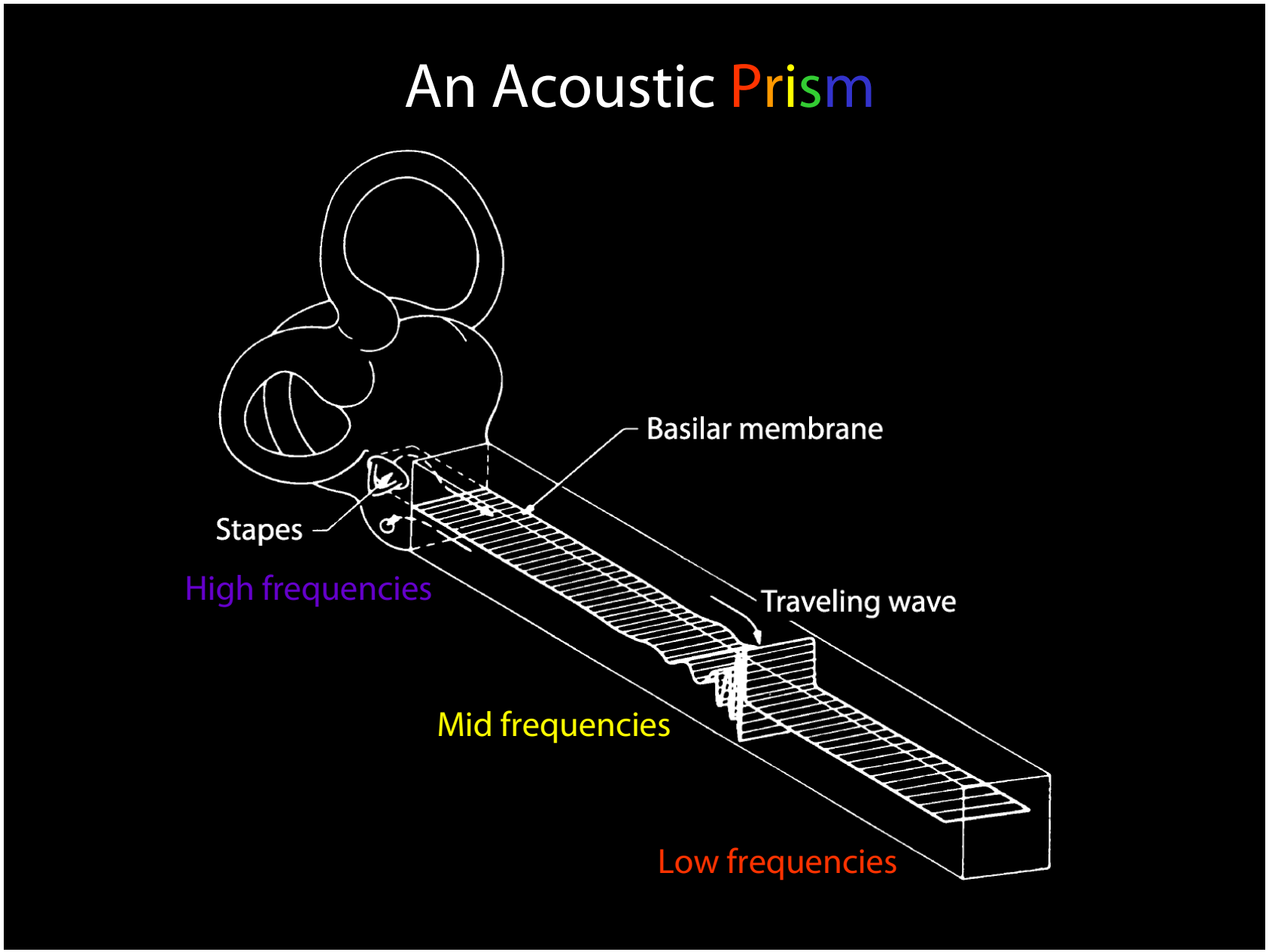






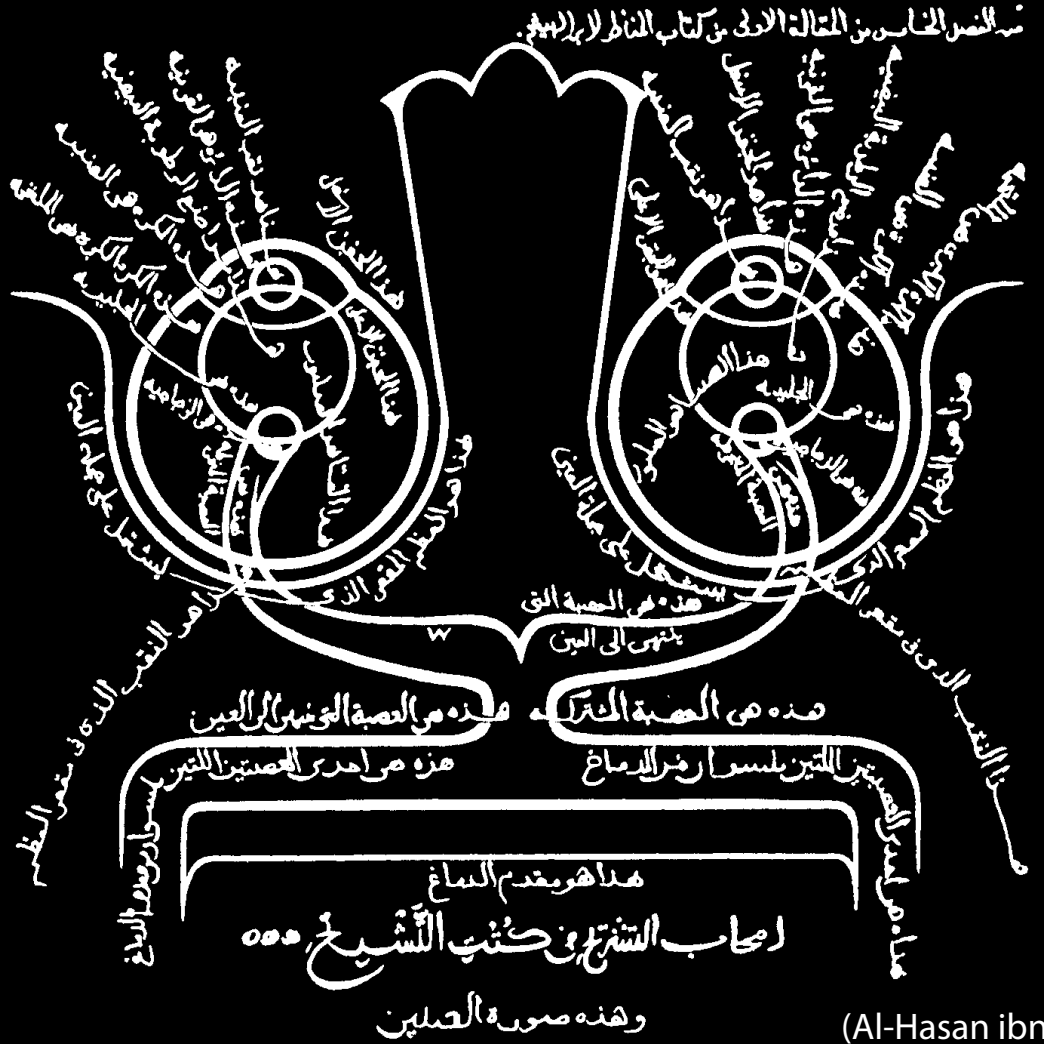
→ The ear's main job to to do this sort of spectral decomposition!

Tonotopicity



Zweig et al. (1976)

The Eye



(Al-Hasan ibn al-Haitham 1083)

Vision

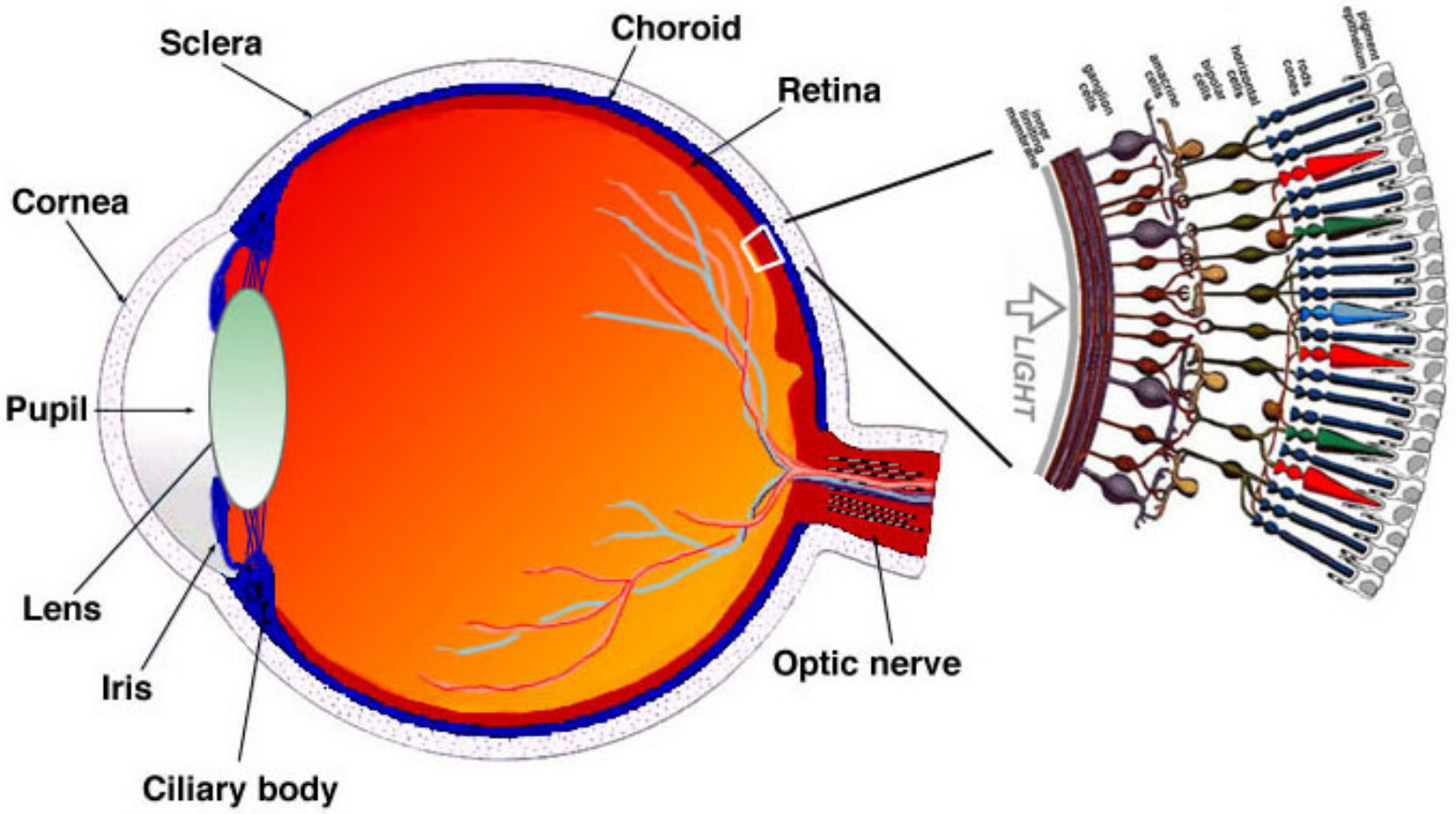
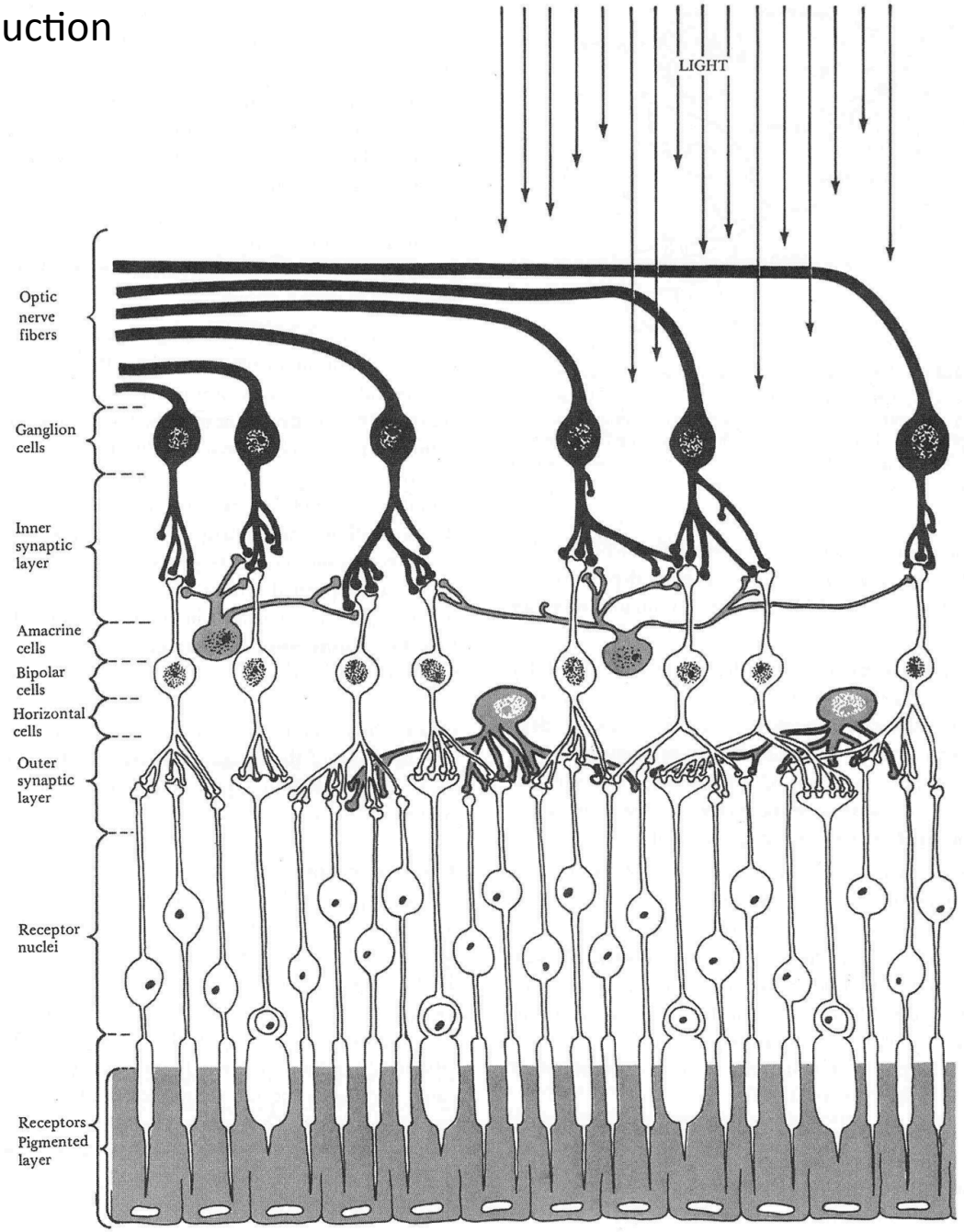


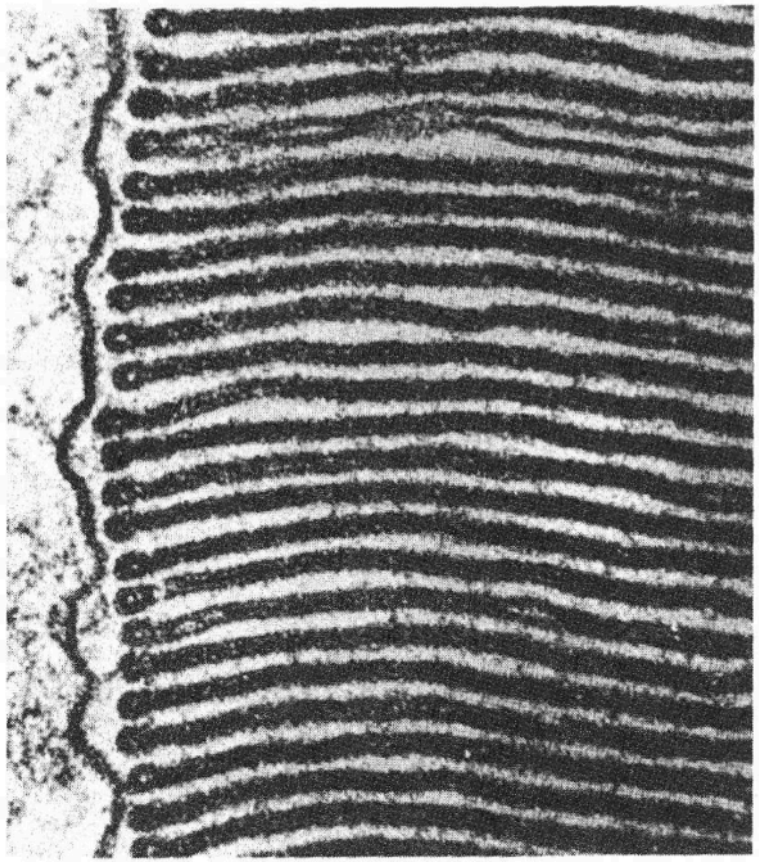
Fig. 1.1. A drawing of a section through the human eye with a schematic enlargement of the retina.

Vision: Phototransduction

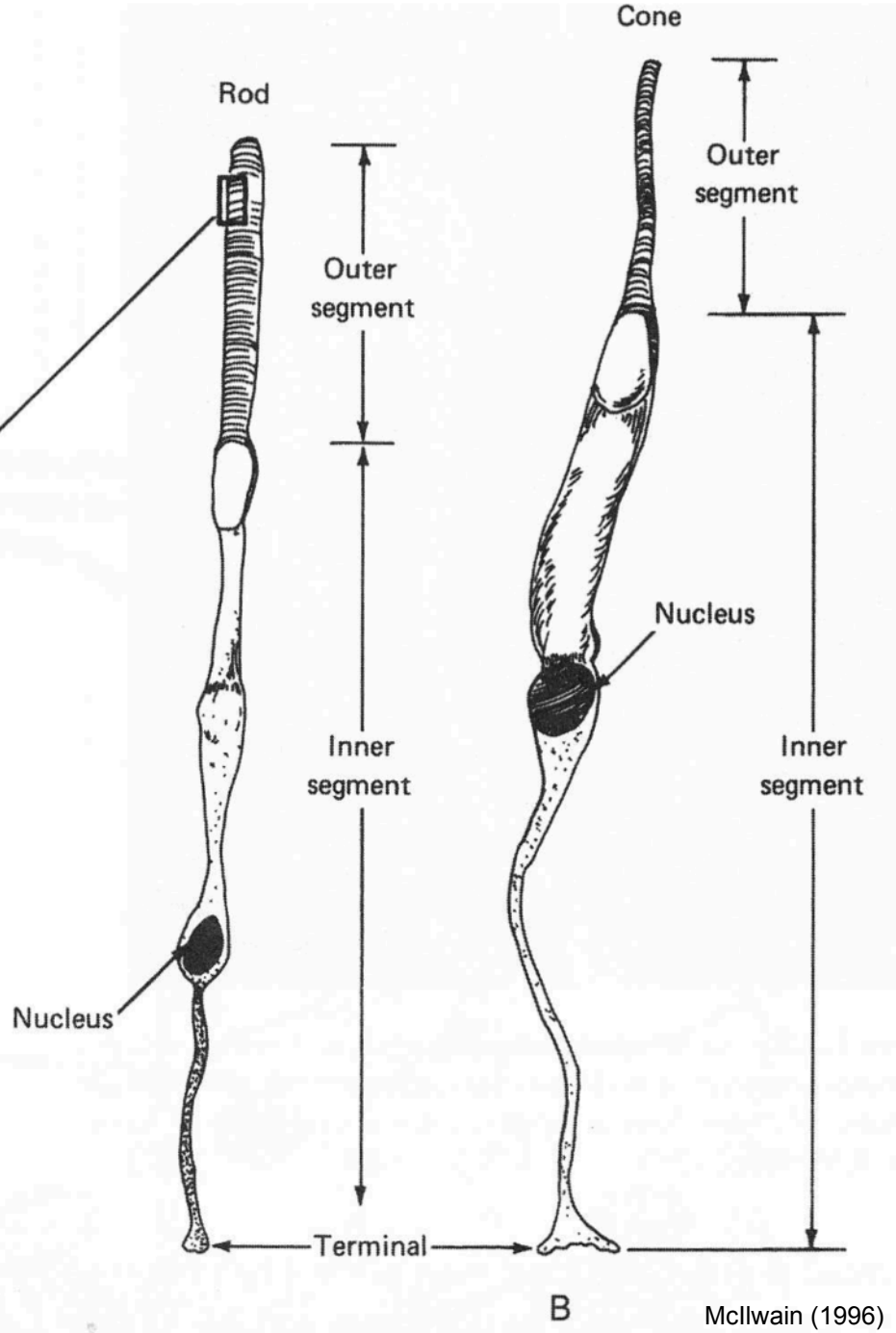


Palmer (1999)

Vision: Phototransduction



A



McIlwain (1996)

Vision: Phototransduction

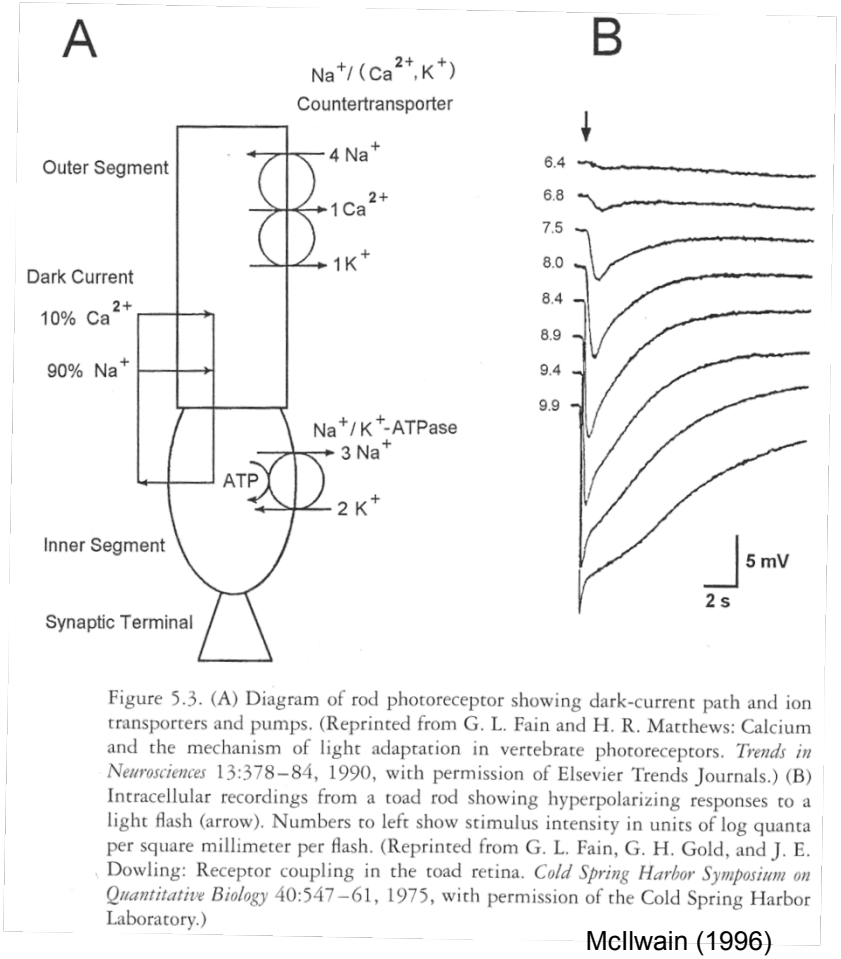


Figure 5.3. (A) Diagram of rod photoreceptor showing dark-current path and ion transporters and pumps. (Reprinted from G. L. Fain and H. R. Matthews: Calcium and the mechanism of light adaptation in vertebrate photoreceptors. *Trends in Neurosciences* 13:378–84, 1990, with permission of Elsevier Trends Journals.) (B) Intracellular recordings from a toad rod showing hyperpolarizing responses to a light flash (arrow). Numbers to left show stimulus intensity in units of log quanta per square millimeter per flash. (Reprinted from G. L. Fain, G. H. Gold, and J. E. Dowling: Receptor coupling in the toad retina. *Cold Spring Harbor Symposium on Quantitative Biology* 40:547–61, 1975, with permission of the Cold Spring Harbor Laboratory.)

McIlwain (1996)

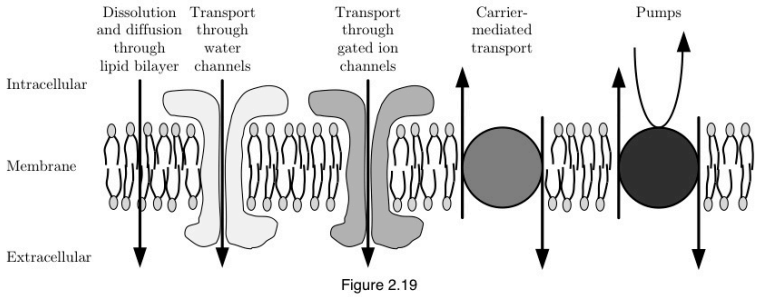
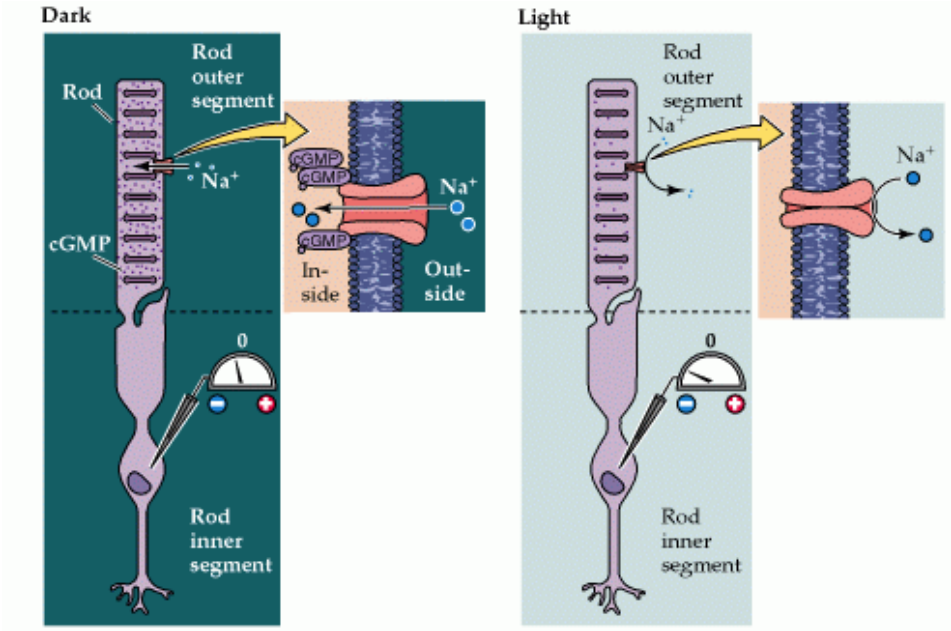


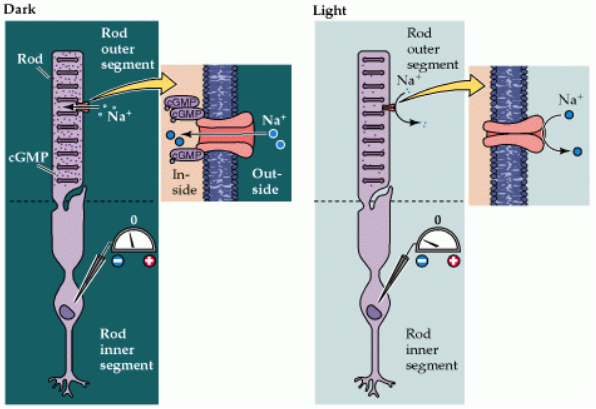
Figure 2.19



http://openwetware.org/wiki/BIO254:Phototransduction

In a nutshell: Light causes channels in cell membrane to close, thereby triggering an electrical response

Vision: Phototransduction



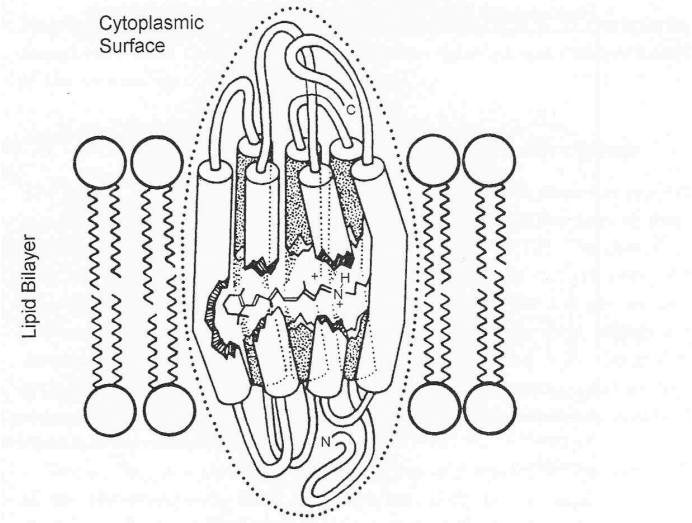
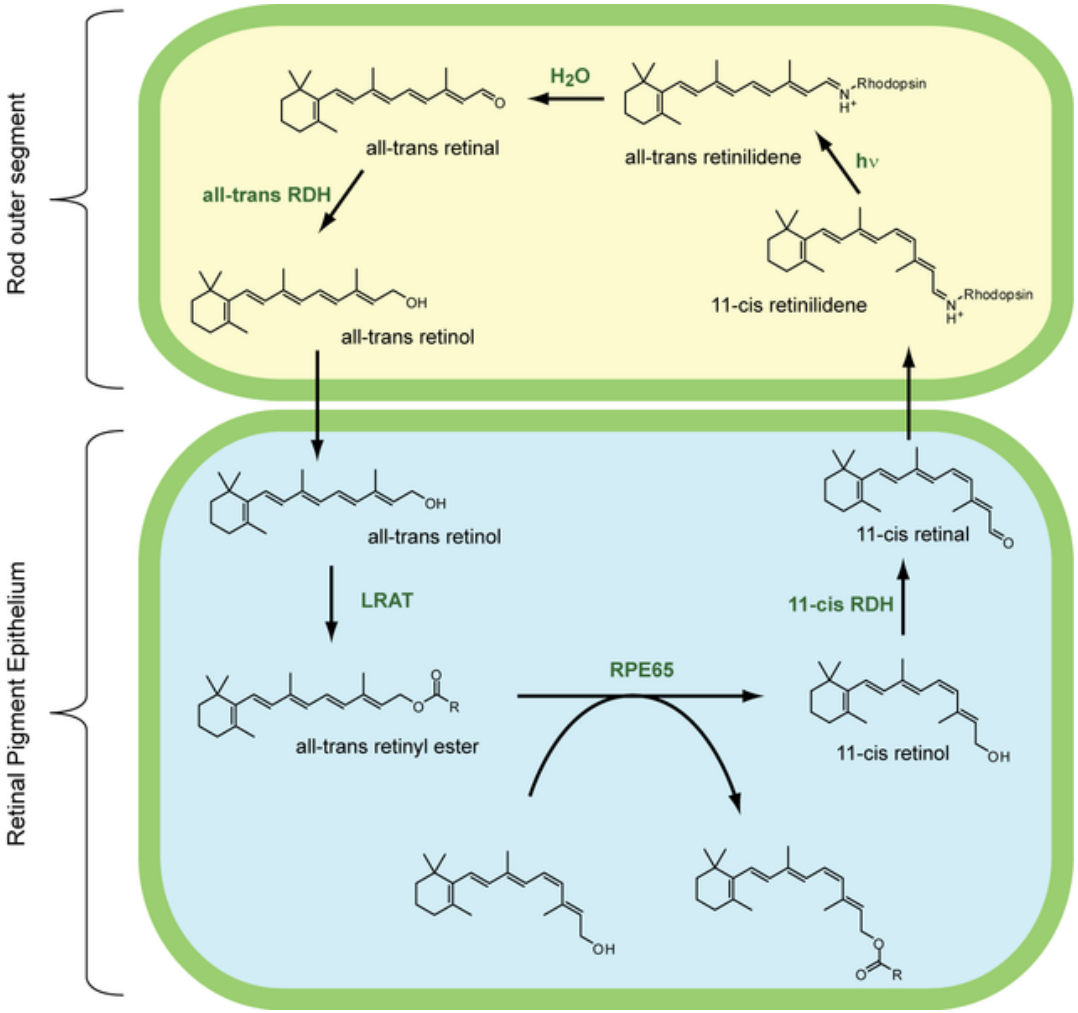


Figure 5.5. Diagram of a photopigment complex composed of a molecule of retinaldehyde nestled within the seven membrane-spanning elements of the opsin. The photopigment is an integral part of the cell membrane and is surrounded by the lipid bilayer. (Adapted from E. A. Dratz and P. A. Hargrave: The structure of rhodopsin and the rod outer segment disk membrane. *Trends in Biochemical Sciences* 8:128–31, 1983, with permission of Elsevier Trends Journals.)

McIlwain (1996)

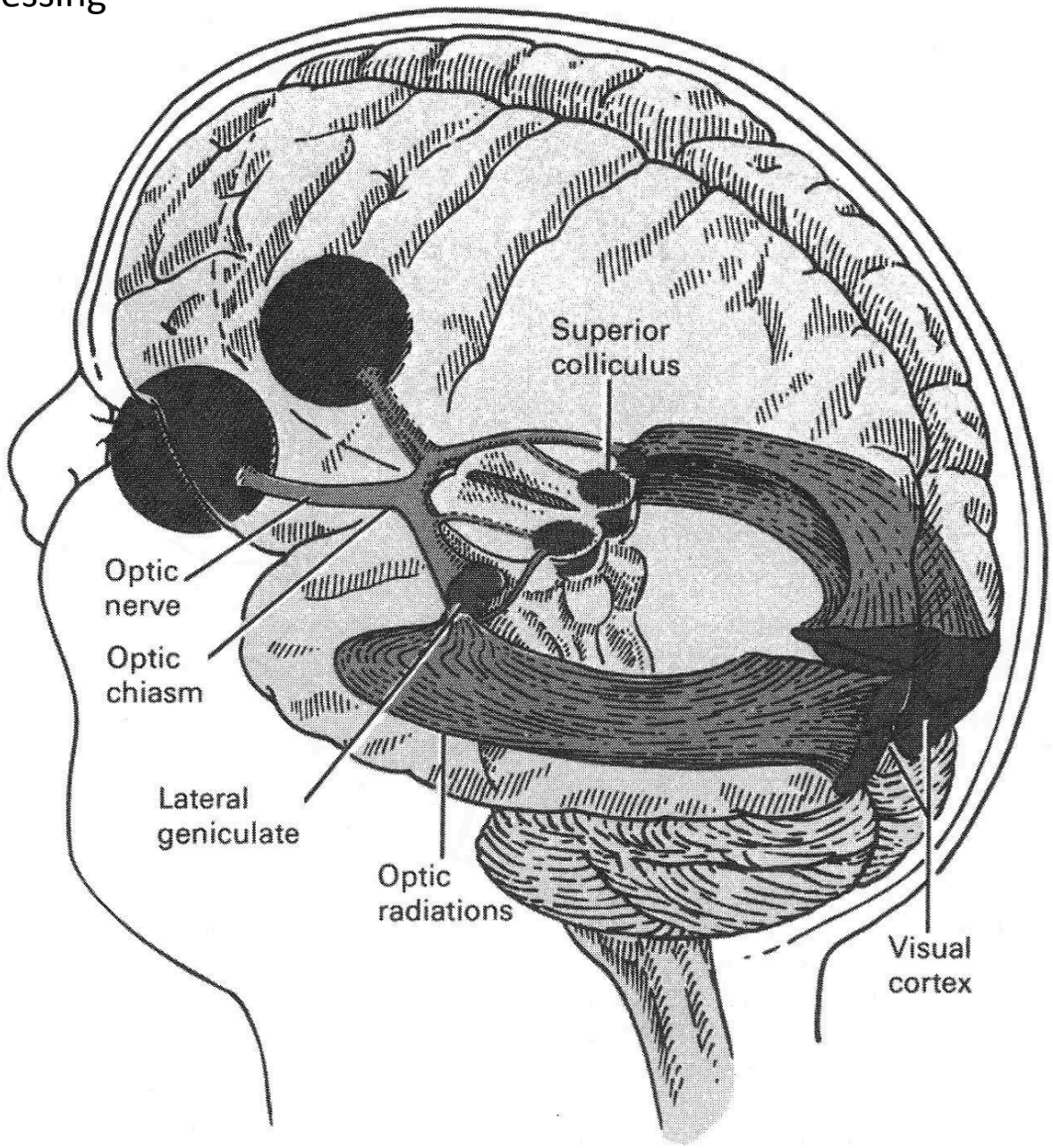
→ Biochemical/molecular viewpoint...



e.g., G-coupled proteins

Wikipedia

Vision: Neural processing



Palmer (1999)

Vision: Neural processing

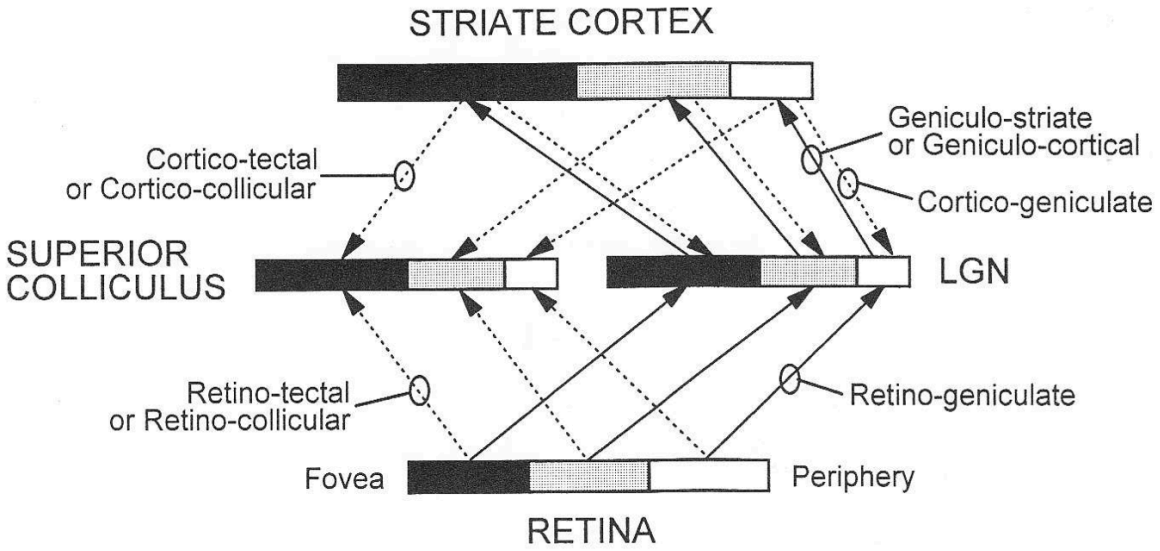
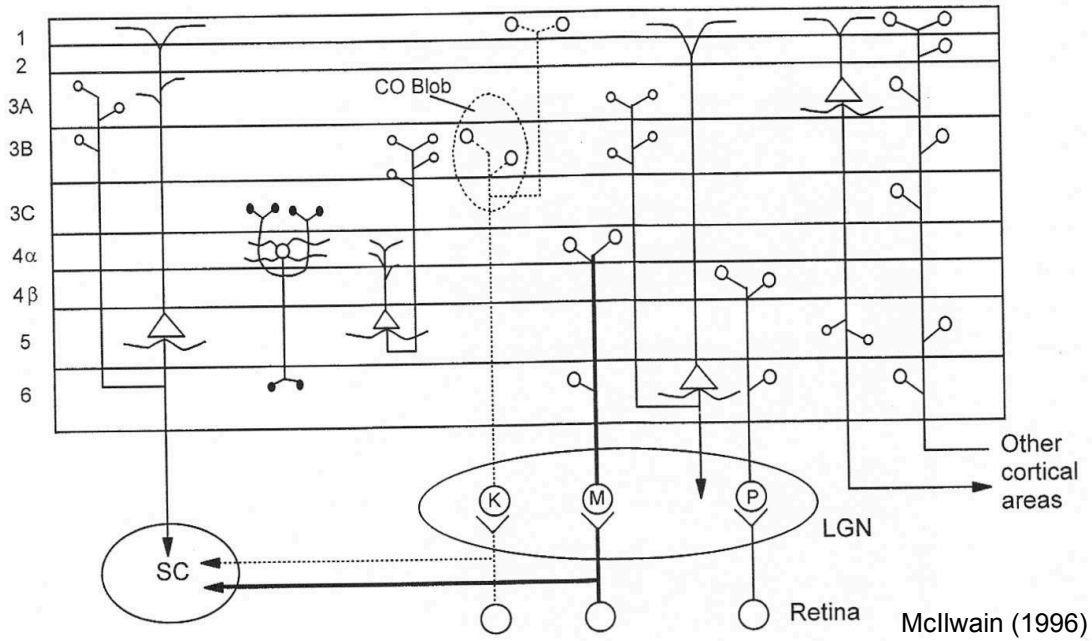


Figure 4.9. Schematic representation of the retino-geniculo-striate and retino-tectal projections and the return projections from the visual cortex.

Note: These are just the "basic" vision bits

Note: Neurons are the basic building blocks that make up these "circuits"



McIlwain (1996)

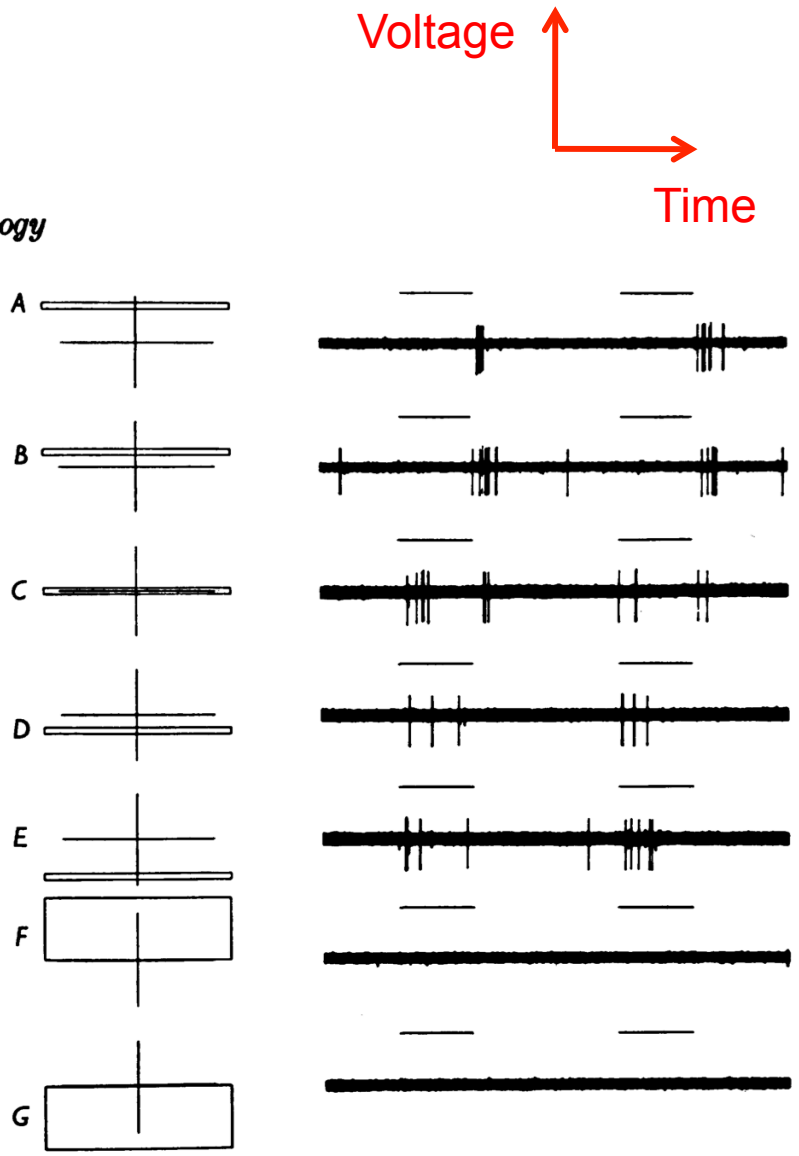
J. Physiol. (1962), **160**, *pp.* 106–154
With 2 plates and 20 text-figures
Printed in Great Britain

RECEPTIVE FIELDS, BINOCULAR INTERACTION AND FUNCTIONAL ARCHITECTURE IN THE CAT'S VISUAL CORTEX

BY D. H. HUBEL AND T. N. WIESEL

From the Neurophysiology Laboratory, Department of Pharmacology Harvard Medical School, Boston, Massachusetts, U.S.A.

Note: This work on the neural basis of "receptive fields" led to Hubel & Wiesel winning the 1981 Nobel Prize



Vision: Receptive fields

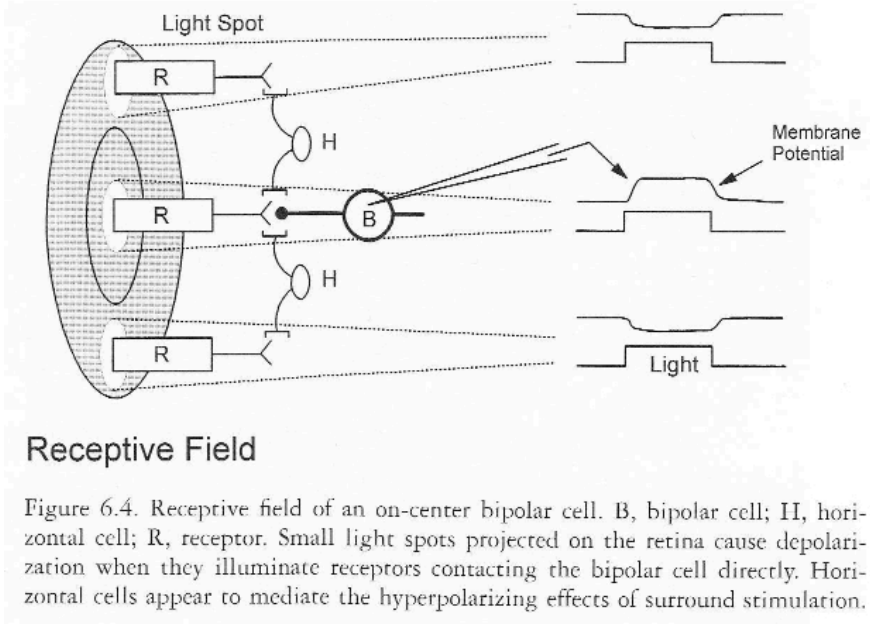


Figure 6.4. Receptive field of an on-center bipolar cell. B, bipolar cell; H, horizontal cell; R, receptor. Small light spots projected on the retina cause depolarization when they illuminate receptors contacting the bipolar cell directly. Horizontal cells appear to mediate the hyperpolarizing effects of surround stimulation.

McIlwain (1996)

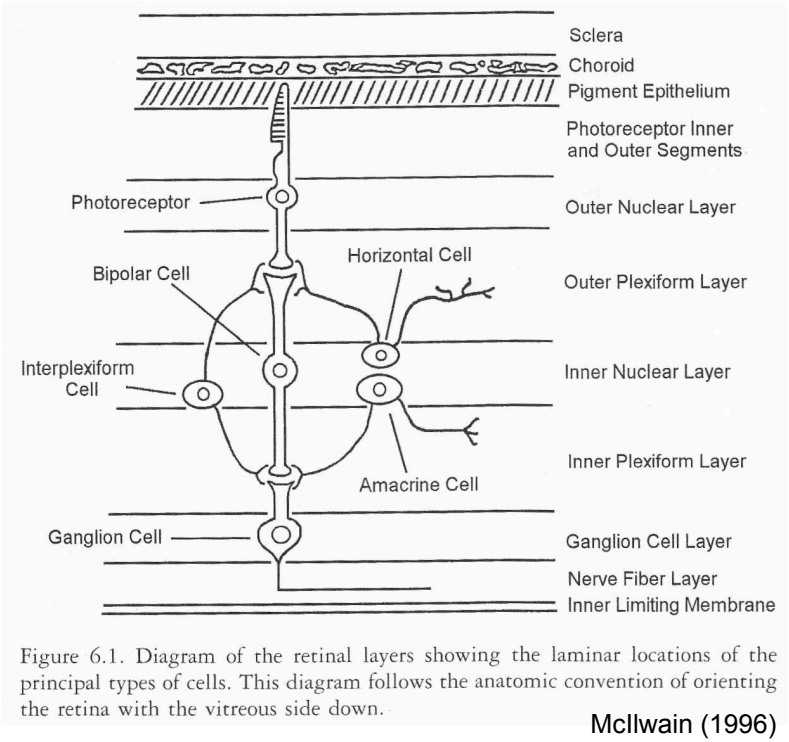
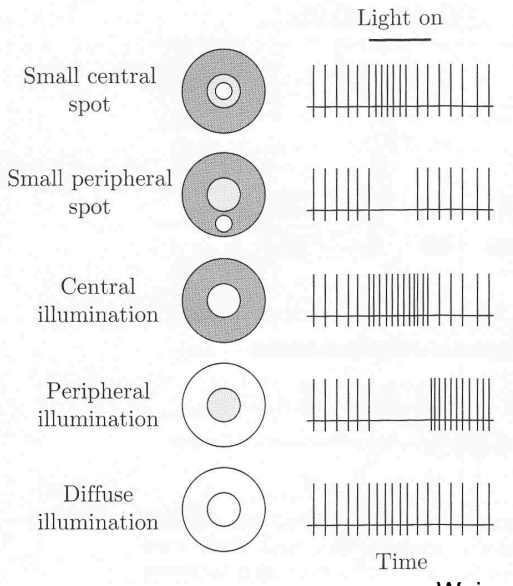


Figure 6.1. Diagram of the retinal layers showing the laminar locations of the principal types of cells. This diagram follows the anatomic convention of orienting the retina with the vitreous side down.

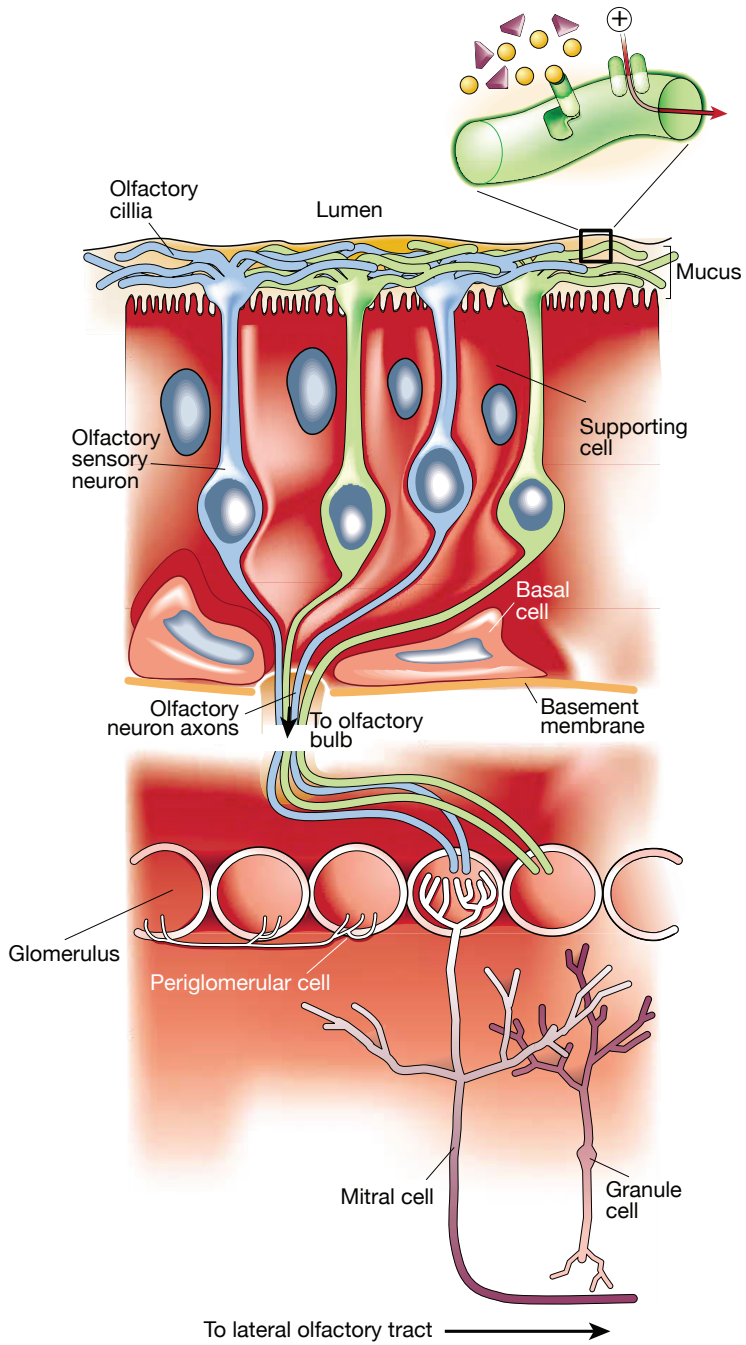
McIlwain (1996)



Weiss (1996)

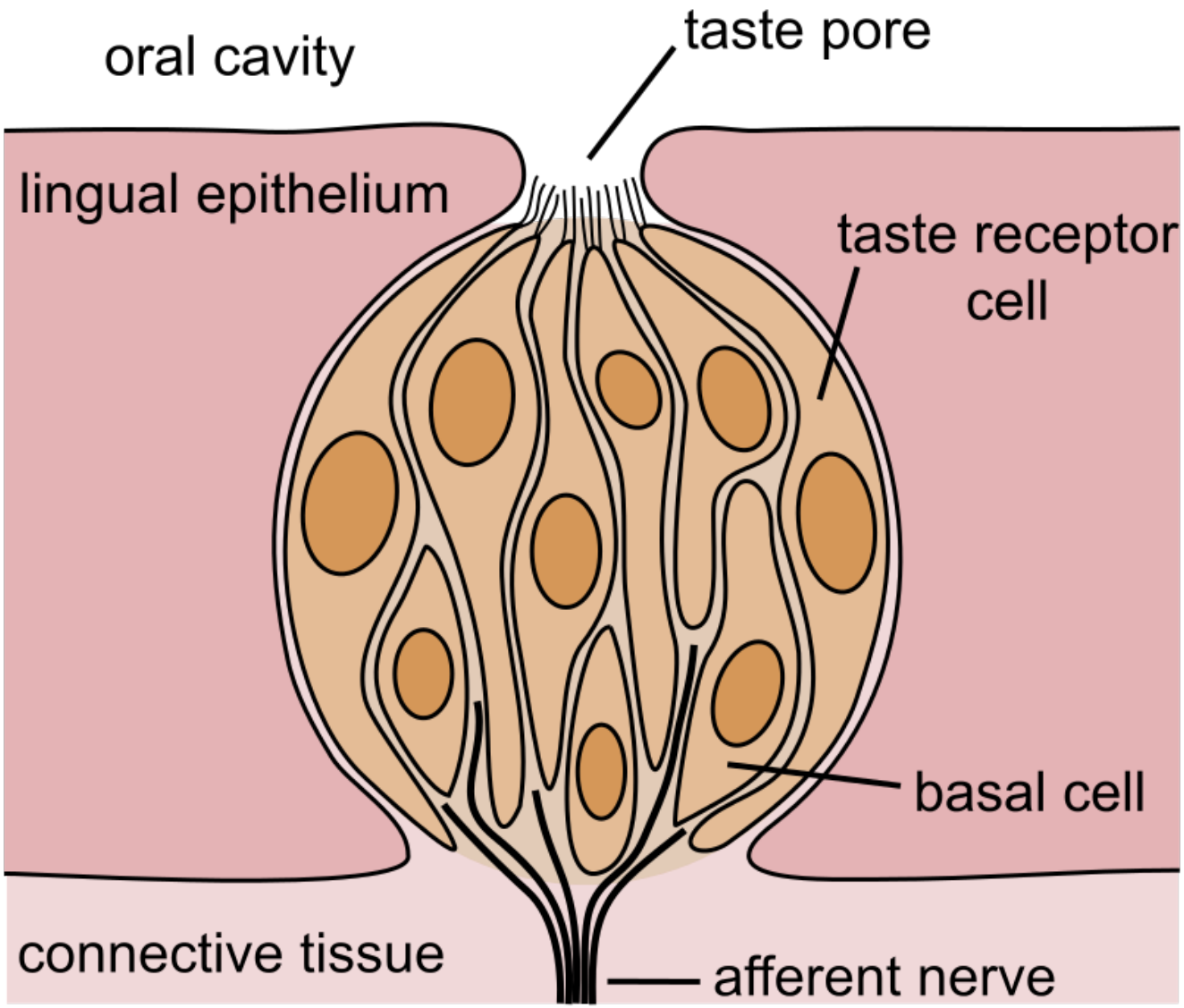
→ Cell-based electrodynamic circuits creates the underlying “logic”

Olfaction (i.e., smell)



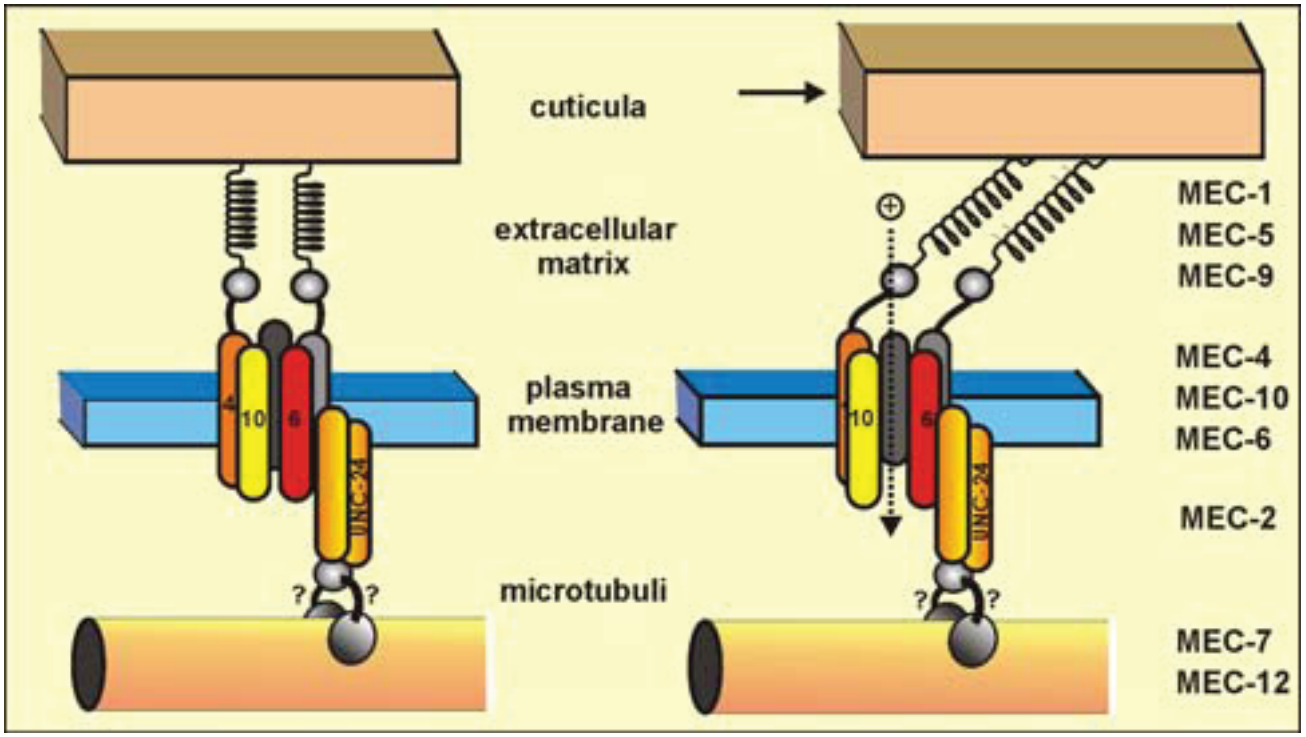
Firestein (2001)

Gustaoception (i.e., taste)



Wikipedia (taste)

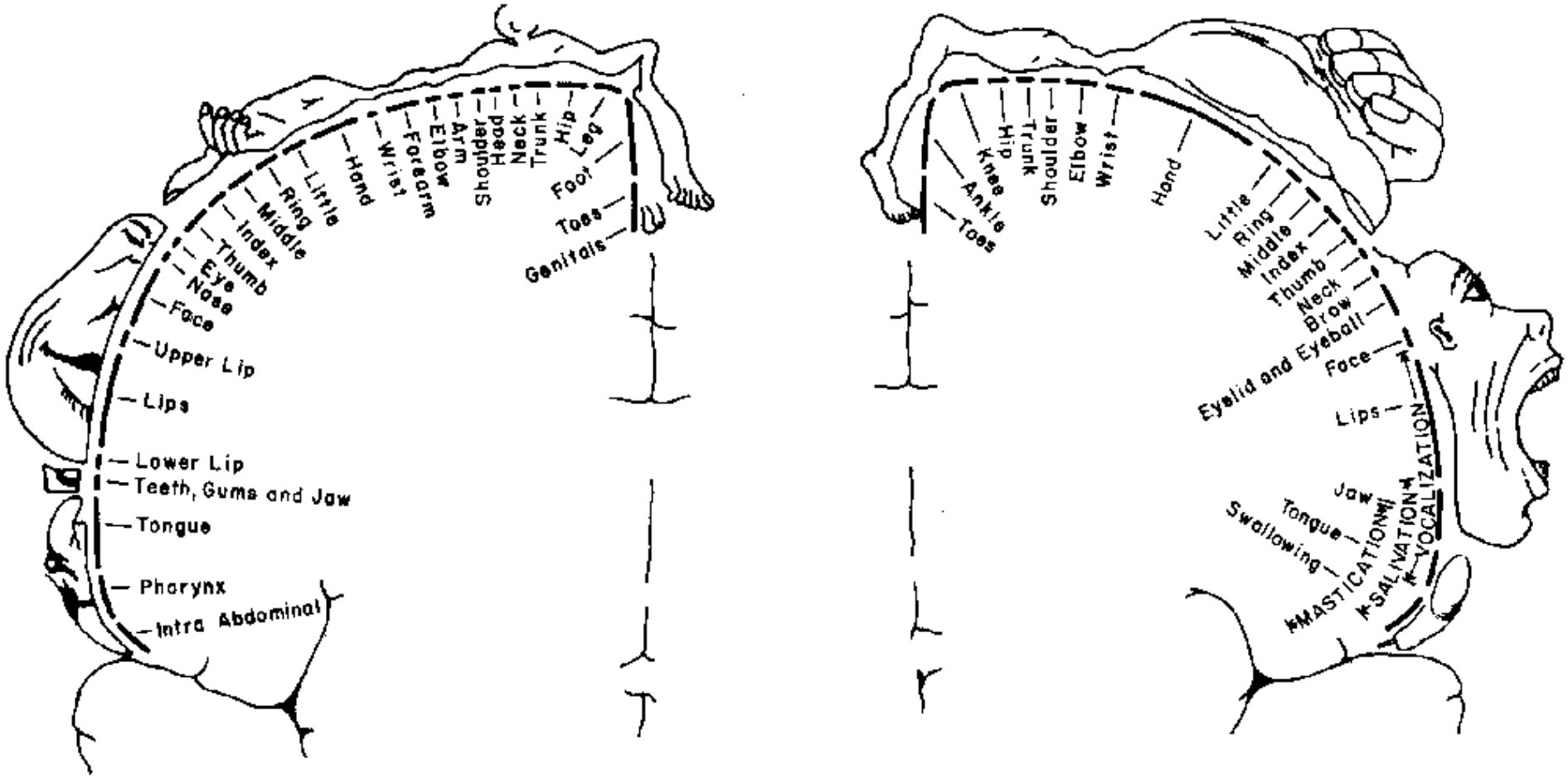
Tactioception (i.e., touch)



The mechanosensitive protein complex of *C. elegans*. *Left:* nine diVerent MEC proteins co-assemble to form an ion channel in the plasma membrane of a mechanosensory neuron. The channel is formed by MEC-4, MEC-6, and MEC-10. Other MEC proteins tether the channel to the cuticula and to the cytoskeleton. *Right:* when the cuticula is shifted by gentle touch, the channel is pulled open, and cation inXux generates a receptor potential

Frings (2009)

Cortical Homunculus



Wilder Penfield

Summary

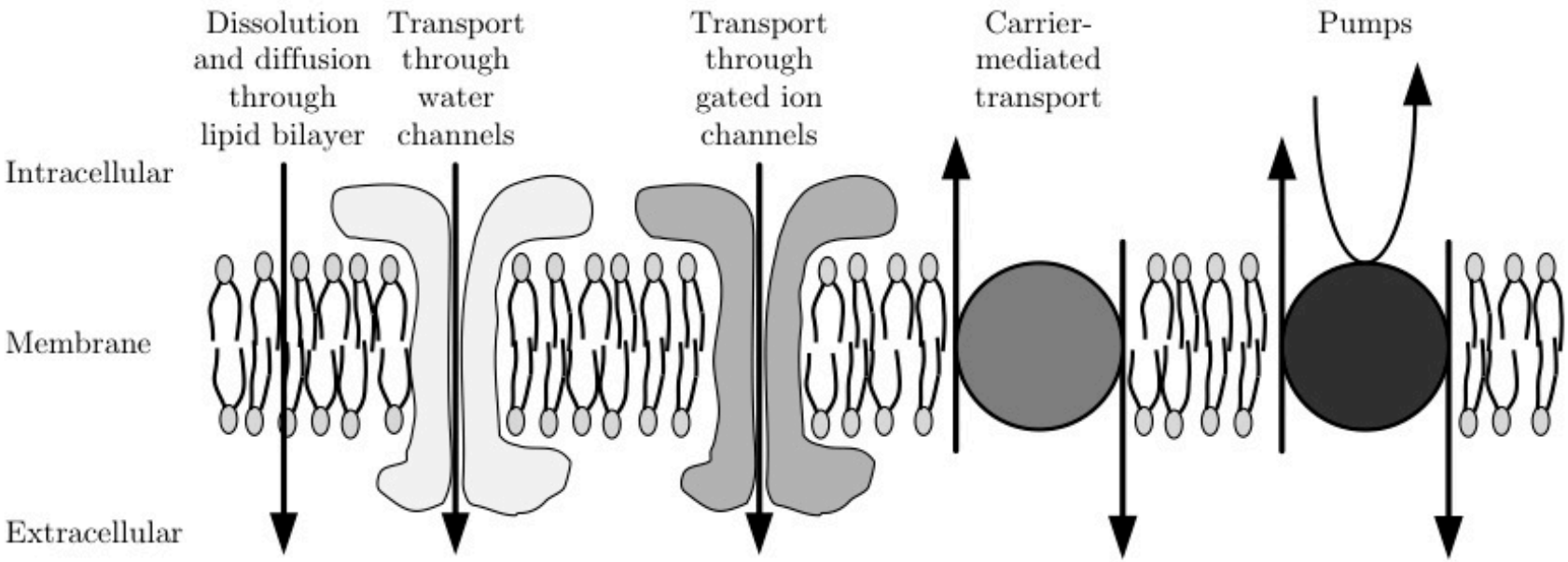


Figure 2.19

→ All these aspects relates directly back to our picture of what is/moves across the cell membrane and how such affects electrodynamics

Summary

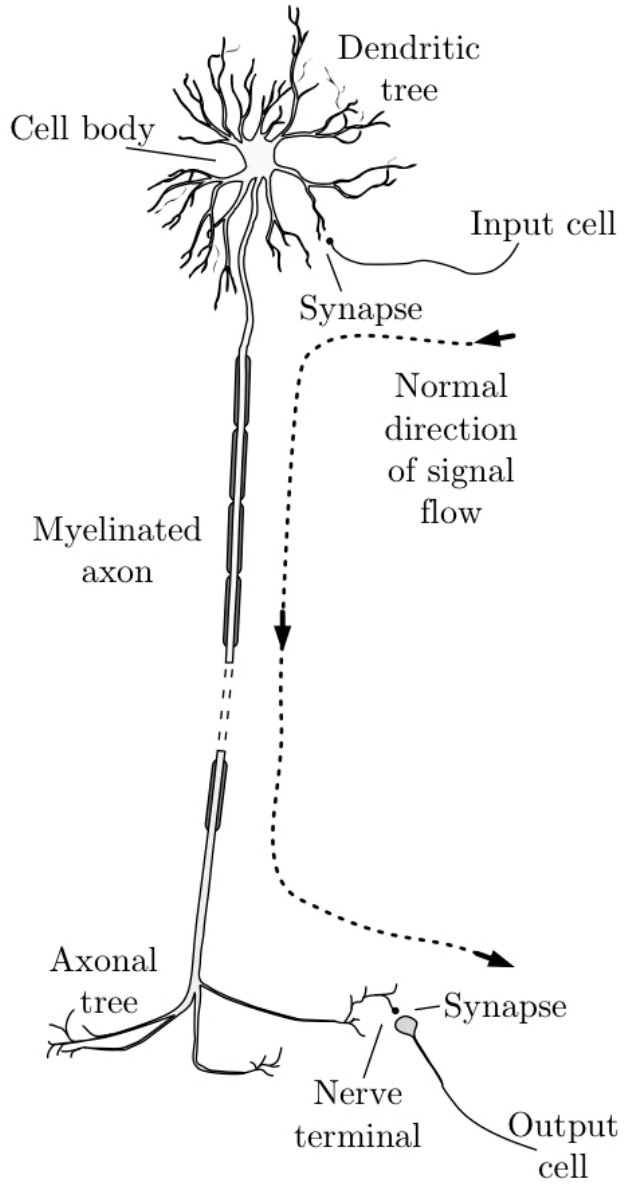


Figure 1.22

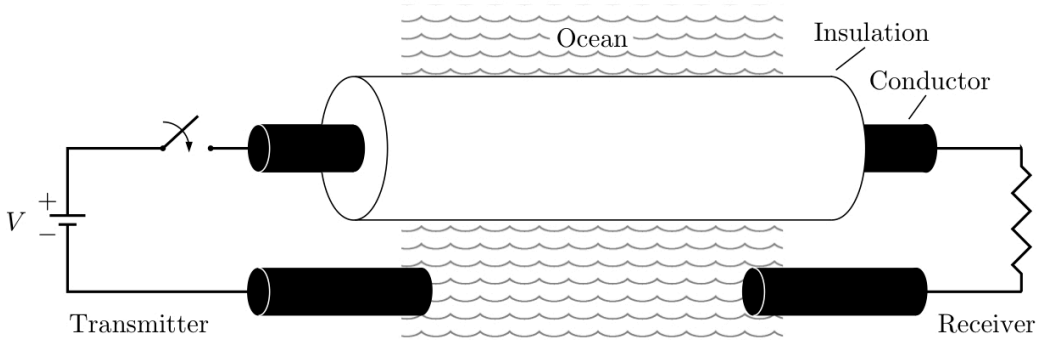


Figure 3.8

→ This "story" is continued in (much more detail) in BPHS 4080....

Fini