2019 CVRSS

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Dept. of Physics & Astronomy

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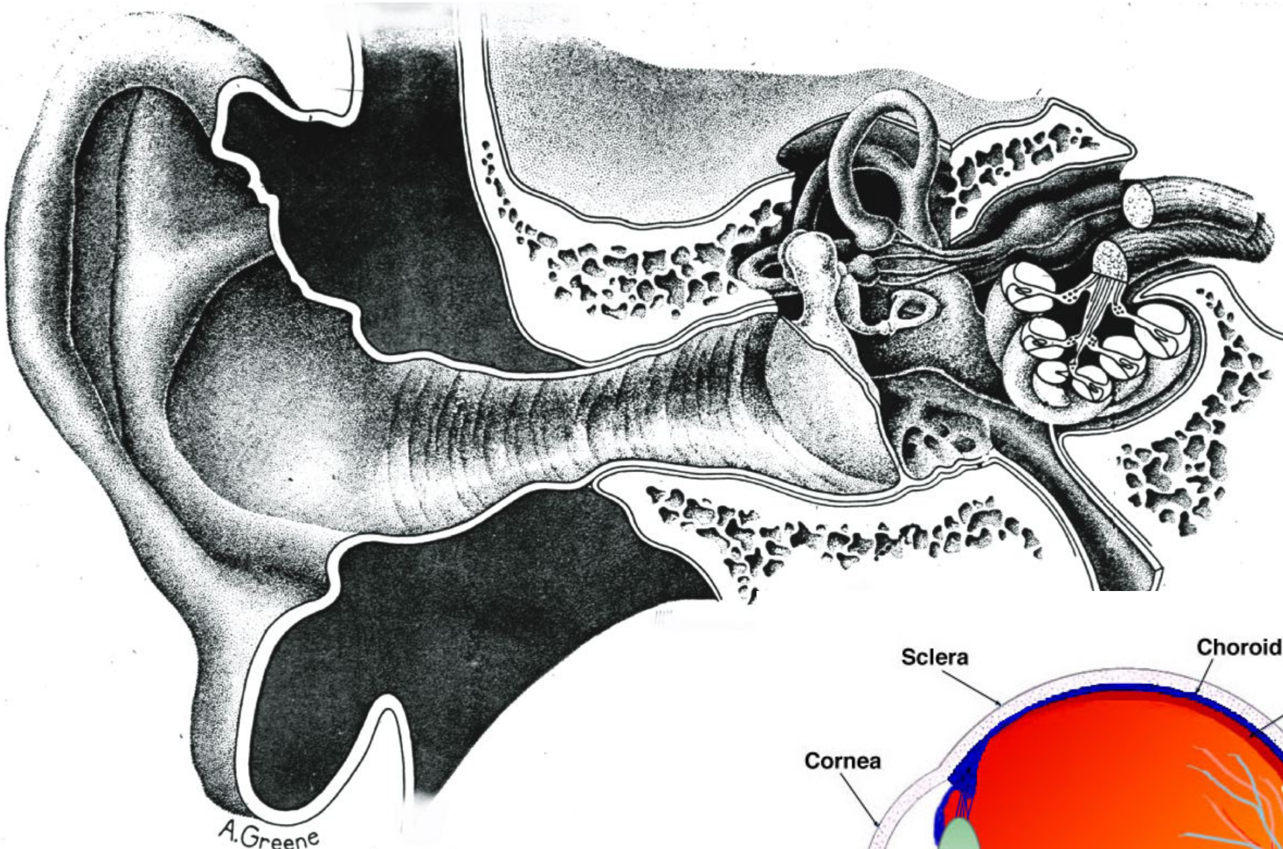
Peripheral sensory systems



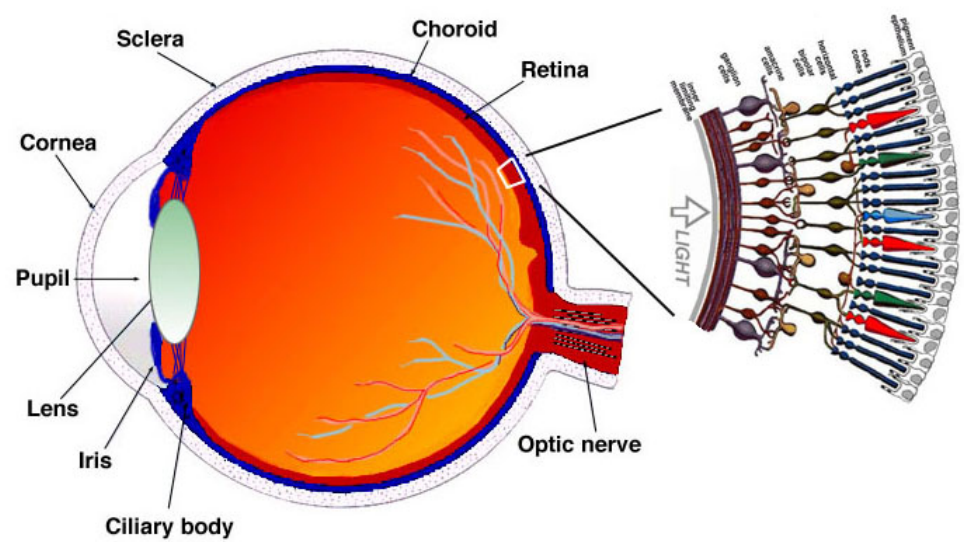


Fig. 1.1. A drawing of a section through the human eye with a schematic enlargement of the retina.

Pop Quiz #1

How many neurons are there in the human brain? Synapses?

Pop Quiz #1

How many neurons are there in the human brain? Synapses?

Human brain contains ~10^{11} (100 billion) neurons!
(with 100 trillion+ connections inbetween)

Pop Quiz #2

$$\frac{1}{2\pi a(r_o + r_i)} \frac{\partial^2 V_m}{\partial z^2} = C_m \frac{\partial V_m}{\partial t} + G_K(V_m, t)\,(V_m - V_K) + G_{Na}(V_m, t)\,(V_m - V_{Na}) + G_L(V_m - V_L)$$

$$G_K(V_m, t) = \overline{G}_K n^4(V_m, t)$$

$$G_{Na}(V_m, t) = \overline{G}_{Na} m^3(V_m, t) h(V_m, t)$$

$$n(V_m, t) + \tau_n(V_m)\frac{dn(V_m, t)}{dt} = n_\infty(V_m)$$

$$m(V_m, t) + \tau_m(V_m)\frac{dm(V_m, t)}{dt} = m_\infty(V_m)$$

$$h(V_m, t) + \tau_h(V_m)\frac{dh(V_m, t)}{dt} = h_\infty(V_m)$$

$$\tau_x \frac{dx}{dt} + x = x_\infty \qquad \frac{dx}{dt} = \alpha_x(1 - x) - \beta_x x$$

$$x_\infty = \alpha_x / (\alpha_x + \beta_x) \text{ and } \tau_x = 1/(\alpha_x + \beta_x)$$

$$\alpha_m = \frac{-0.1(V_m + 35)}{e^{-0.1(V_m+35)} - 1},$$

$$\beta_m = 4e^{-(V_m+60)/18},$$

$$\alpha_h = 0.07e^{-0.05(V_m+60)},$$

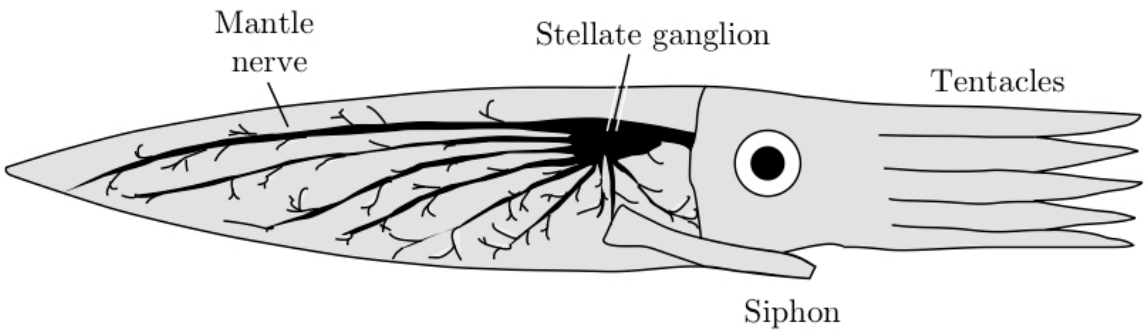
$$\beta_h = \frac{1}{1 + e^{-0.1(V_m+30)}},$$

$$\alpha_n = \frac{-0.01(V_m + 50)}{e^{-0.1(V_m+50)} - 1},$$

$$\beta_n = 0.125e^{-0.0125(V_m+60)},$$

What do these equations represent?

Pop Quiz #2



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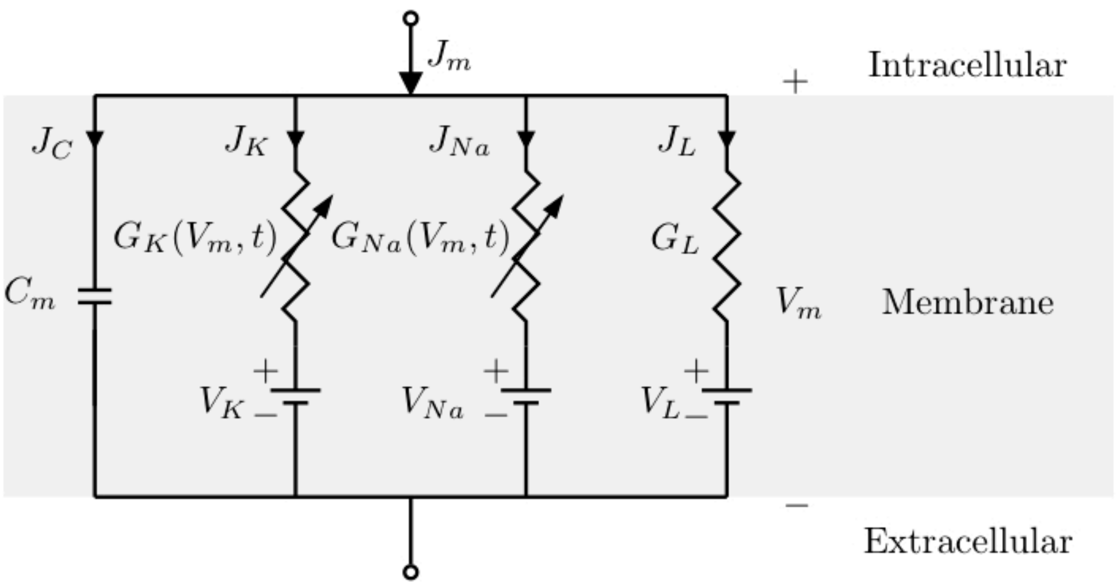
Hodgkin Huxley model

Variable Na+ and K+ conductances



Weiss (1996)

Neurons

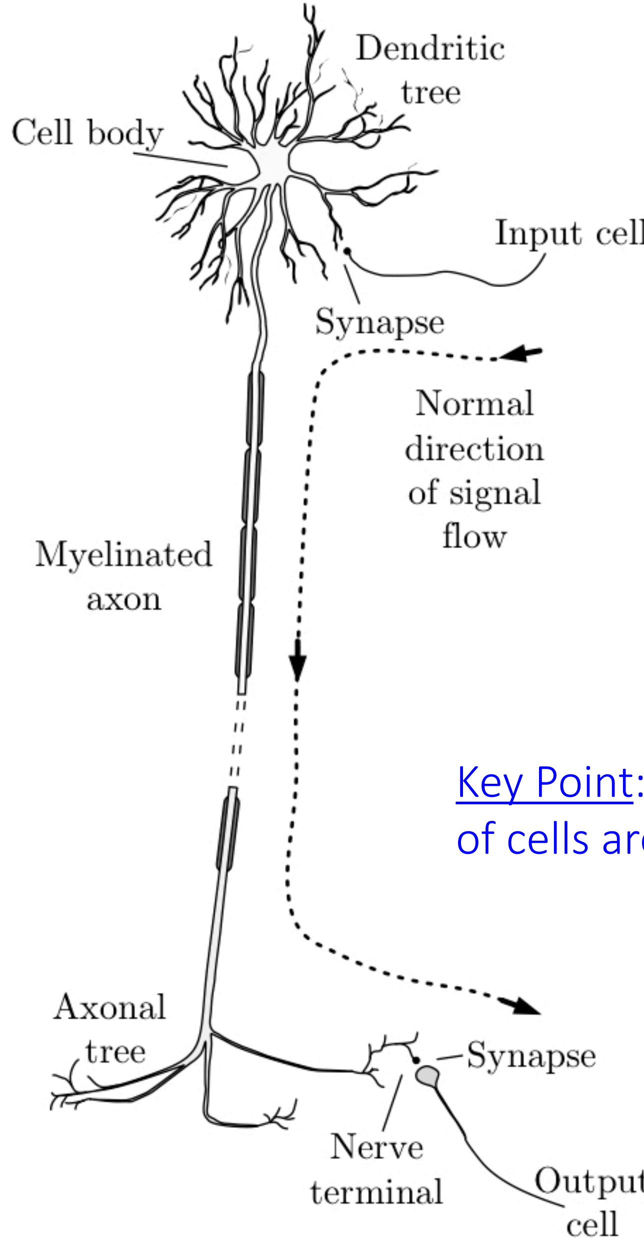


Figure 1.22

Neurons ("fibers")
= Information highway

Key Point: Electrical properties of cells are important

Weiss (1996)

Neurons

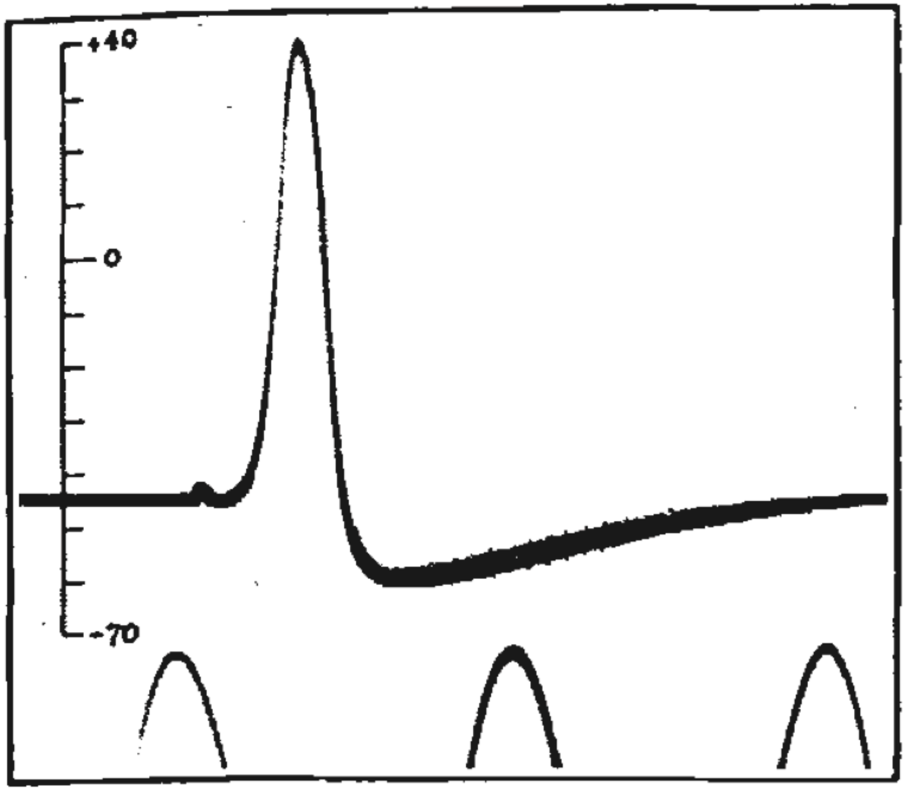
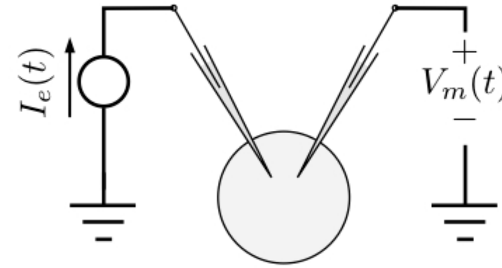


Fig. 1.

Photomicrograph of electrode inside giant axon. 1 scale division = 33 μ.

Hodgkin & Huxley (1939)

Action potentials



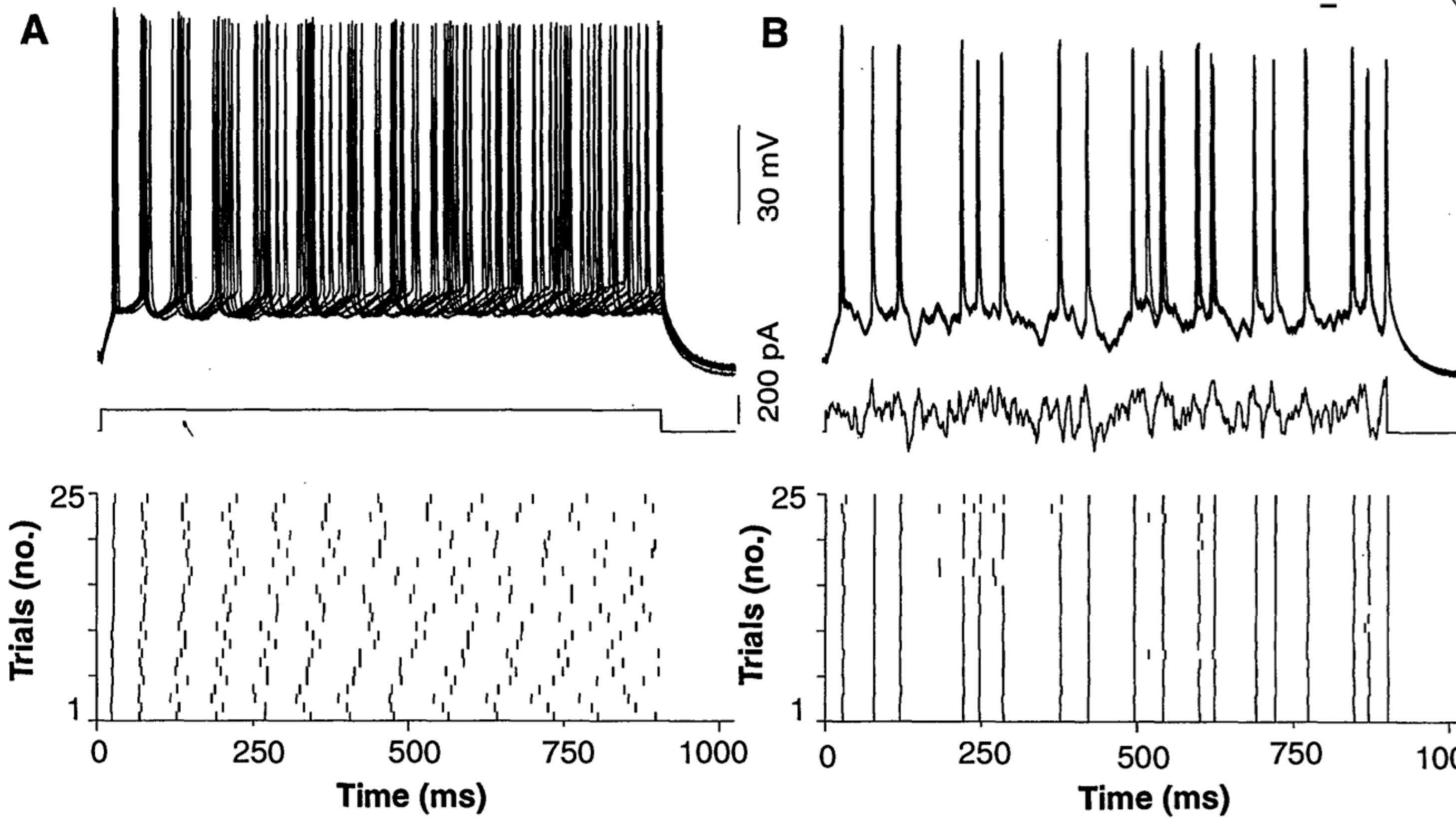
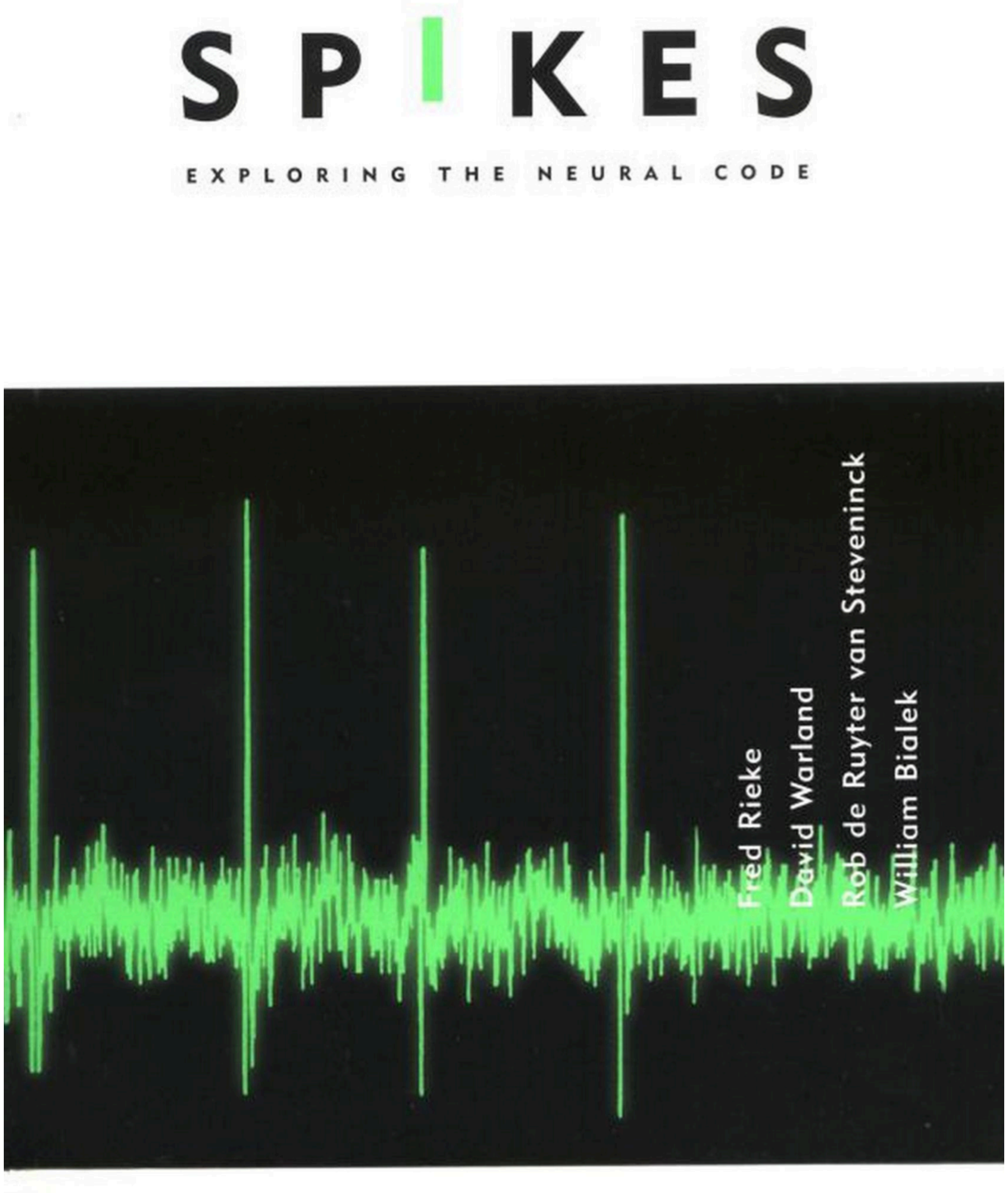


Fig. 1. Reliability of firing patterns of cortical neurons evoked by constant and fluctuating current. (**A**) In this example, a superthreshold dc current pulse (150 pA, 900 ms; middle) evoked trains of action potentials (approximately 14 Hz) in a regular-firing layer-5 neuron. Responses are shown superimposed (first 10 trials, top) and as a raster plot of spike times over spike times (25 consecutive trials, bottom). (**B**) The same cell as in (A) was again stimulated repeatedly, but this time with a fluctuating stimulus [Gaussian white noise, μ_s = 150 pA, σ_s = 100 pA, τ_s = 3 ms; see (*14*)].

SCIENCE • VOL. 268 • 9 JUNE 1995



Somehow, the information is “transformed”, encoded into some other “language”....

“Neural code”

Cell membrane

- Membrane primarily consists of a "lipid bilayer" (to separate inside from outside)

- All sorts of "stuff" embedded inside, to allow for "communication" across membrane

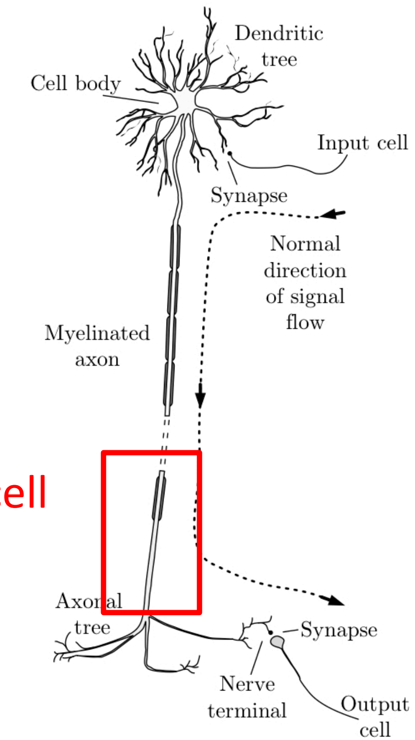


Figure 1.22

zoom in on cell membrane

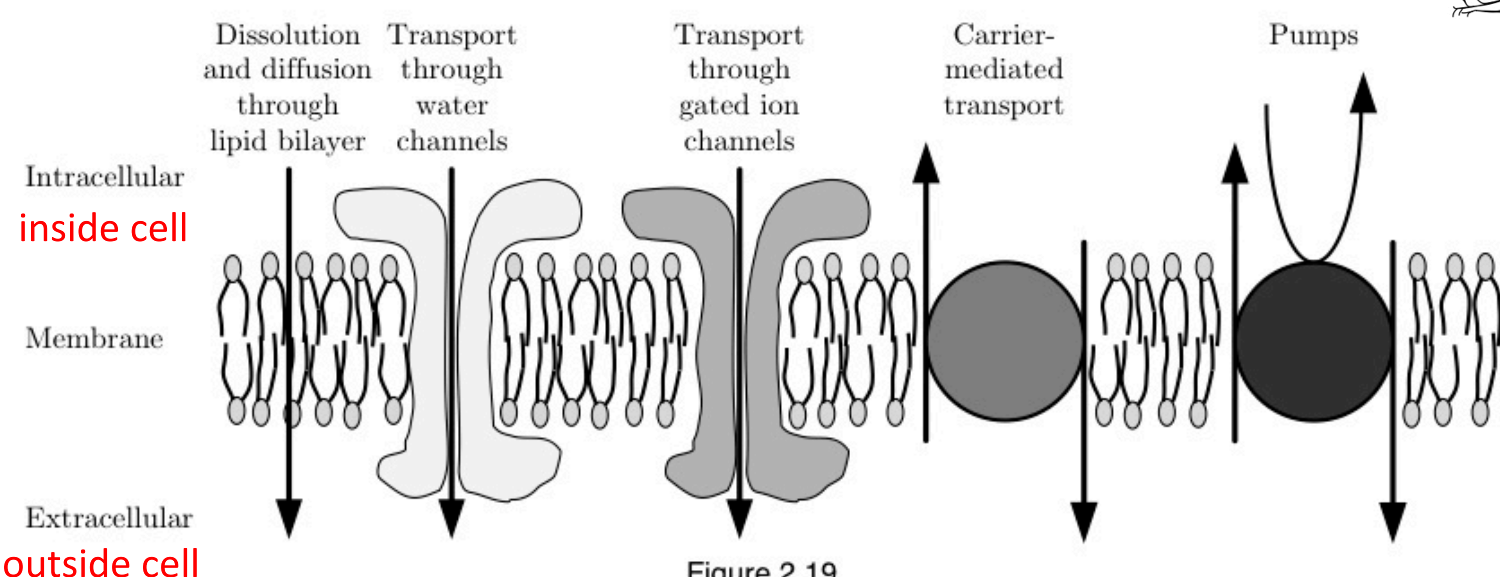


Figure 2.19

Weiss (1996)

Biophysical model of a neuron

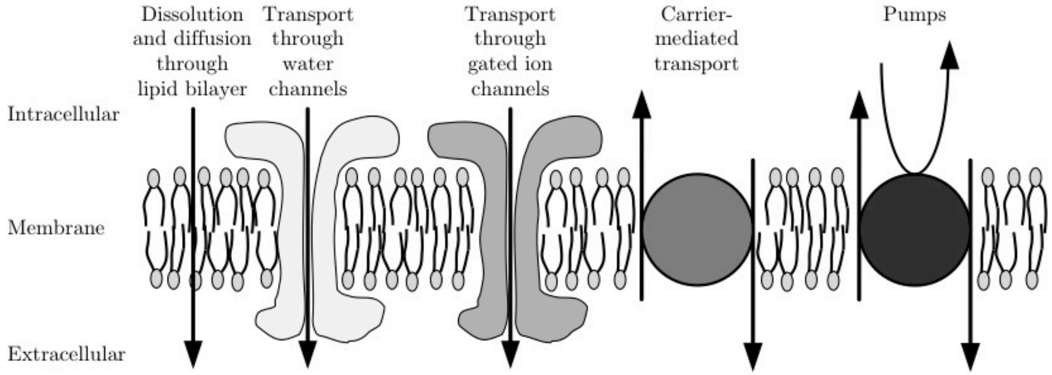
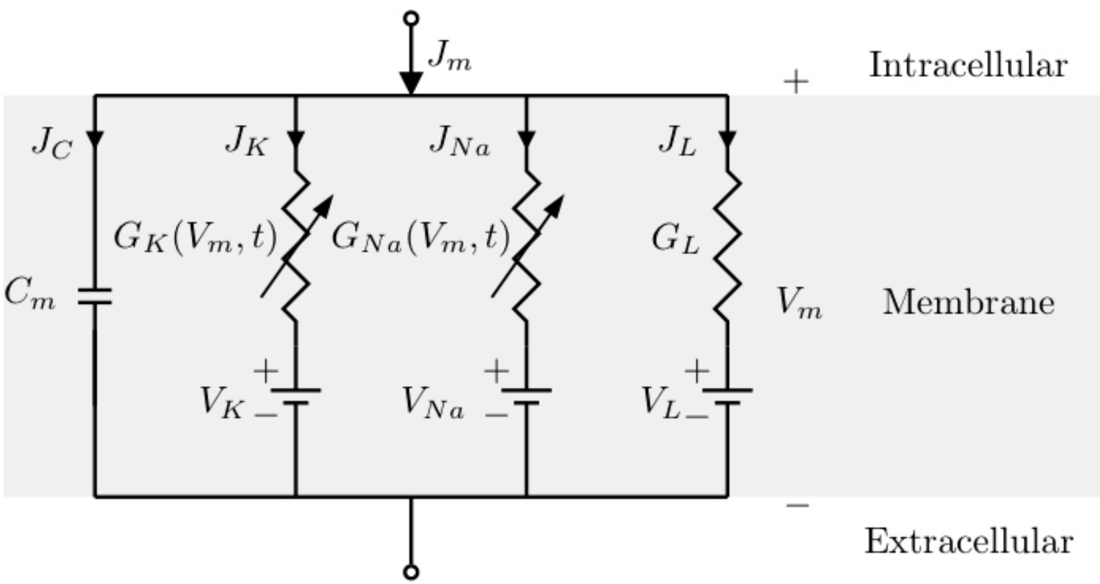


Figure 2.19

Hodgkin Huxley model



Variable Na+ and K+ conductances

Weiss (1996)

Consider how you “process” this picture....

Light

- Definition?

According to the dictionary (various other uses/adverbs/adjectives aside, and there are a LOT):

Light – Electromagnetic radiation that can produce a visual sensation

- We'll use the term "light" a bit more broadly → All *electromagnetic radiation*

- The Greeks started to crystallize the study of light (e.g., Euclid's *Optica*)

e.g., light travels in straight lines, mathematical-based notions of reflection/refraction

- Etymologically, the word "light" derives from notions of brightness/illumination

- The study and use of light is a foundation of all science, historical & modern.....

Light (examples)

- The notion of "light" is such an integral part of our daily lives....

Light (examples)

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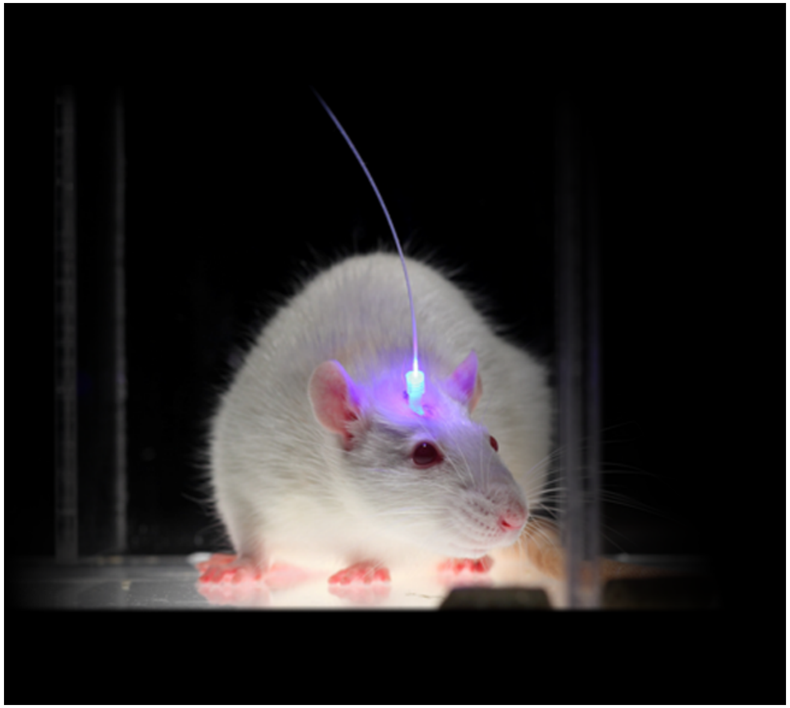
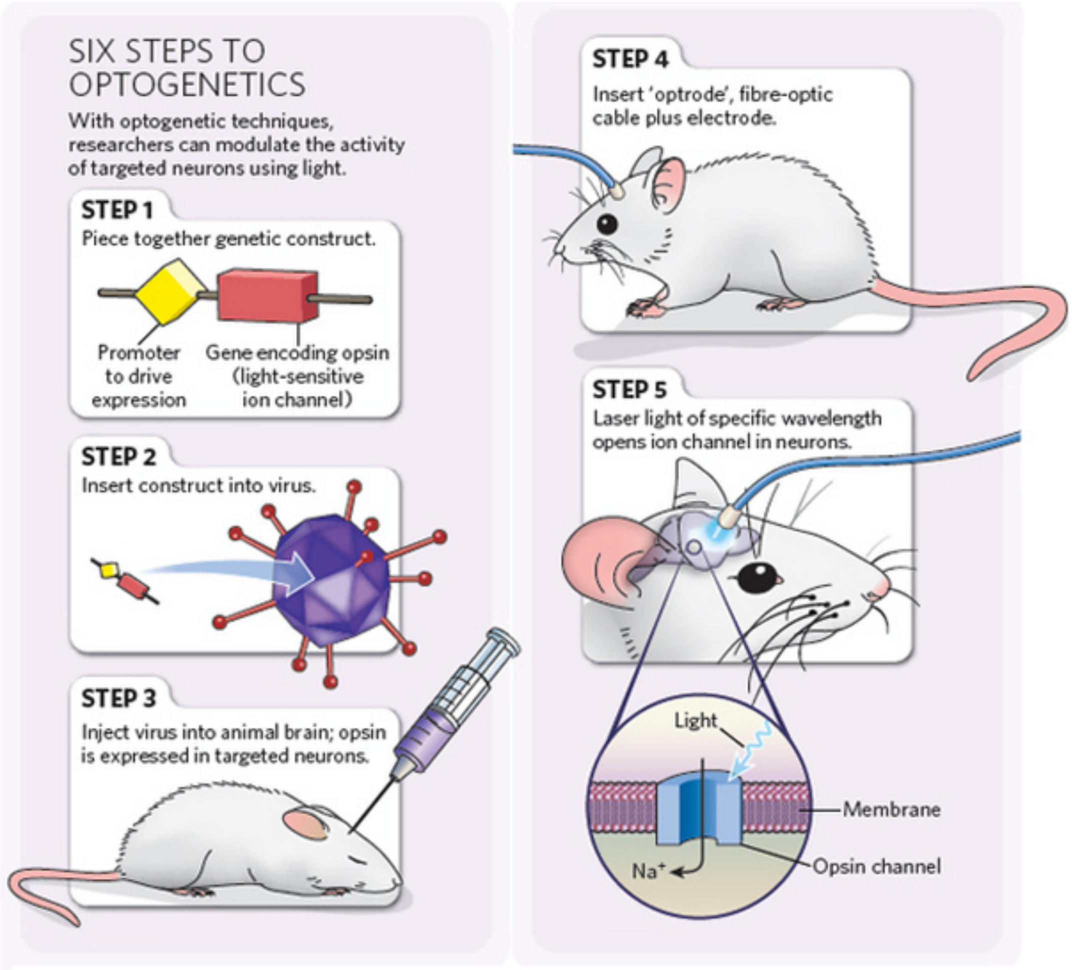
Light (examples)

- Creative use of "light" is now a key approach in neuroscience





http://optogenetics.weebly.com/why--how.html

Light (examples)

http://web.stanford.edu/group/dlab/optogenetics/

So what is light?

- A difficult question. Two (seemingly disparate) answers:

  1. Light is a wave. Specifically, an ***electromagnetic wave***.

  2. Light is a "particle". We call such a ***photon***.

- We do not really have all the tools (yet) to fully understand these notions (let alone their distinction). But we can flesh each out a bit....

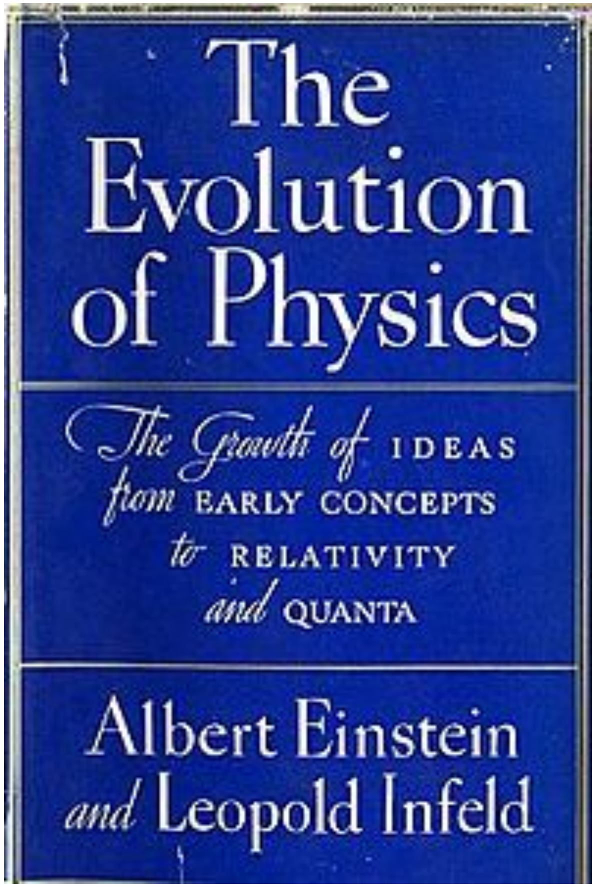
→ We are actually touching upon the dichotomy at the heart of physics: **classical vs. quantum**

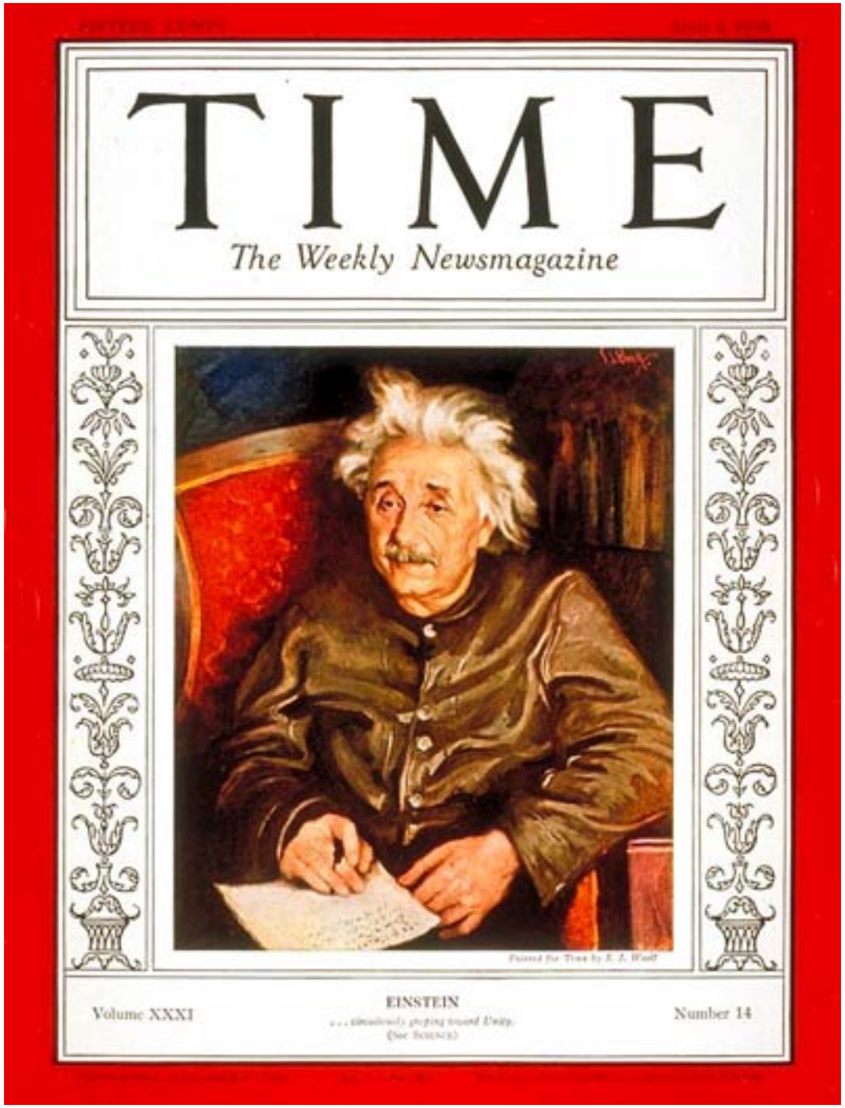
→ This dichotomy above ties directly to what is termed ***wave-particle duality***, a fundamental concept of modern physics

"But what is light really? Is it a wave or a shower of photons? There seems no likelihood for forming a consistent description of the phenomena of light by a choice of only one of the two languages. It seems as though we must use sometimes the one theory and sometimes the other, while at times we may use either. We are faced with a new kind of difficulty. We have two contradictory pictures of reality; separately neither of them fully explains the phenomena of light, but together they do."

- Albert Einstein & Leopold Infeld (1938)

http://www.upscale.utoronto.ca/GeneralInterest/Harrison/Complementarity/CompCopen.html


The Evolution of Physics
The Growth of IDEAS from EARLY CONCEPTS to RELATIVITY and QUANTA
Albert Einstein and Leopold Infeld


TIME
The Weekly Newsmagazine
Volume XXXI
EINSTEIN
Number 14

Consider how you “process” this picture....

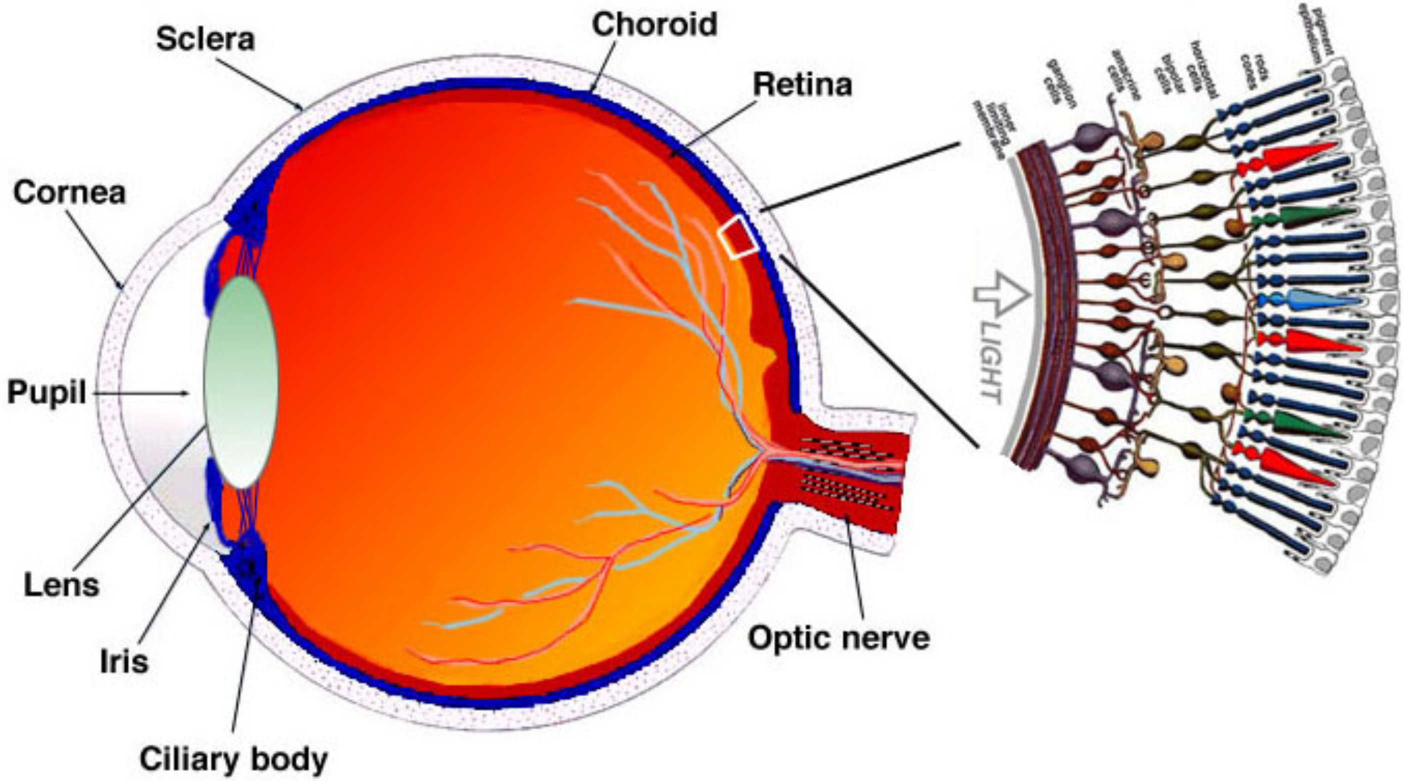


Fig. 1.1. A drawing of a section through the human eye with a schematic enlargement of the retina.

<u>Question</u>: How is information being "transduced" here?

WebVision (Utah)

Receptive field

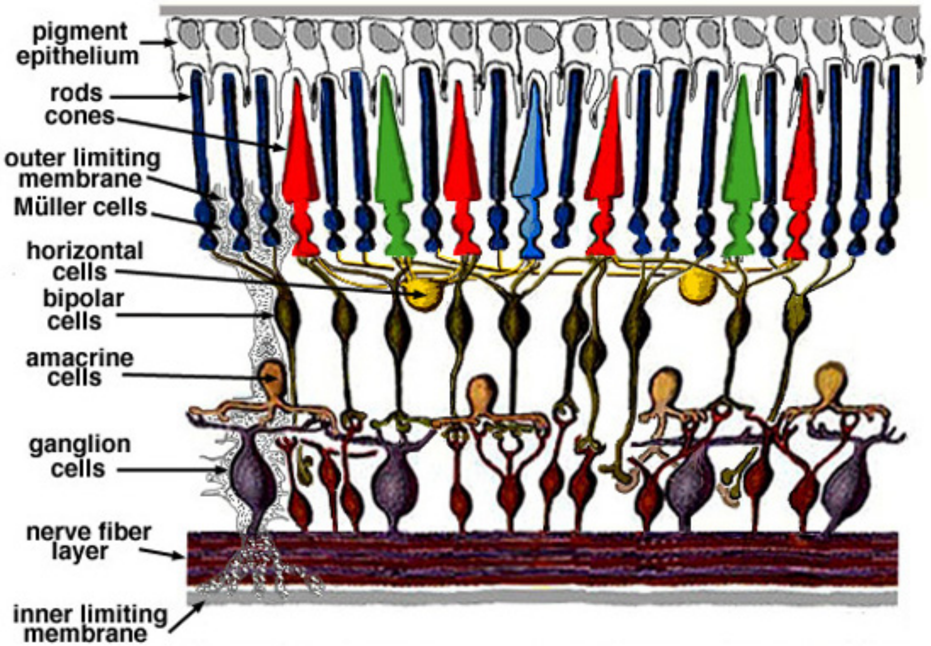


Fig. 2. Simple diagram of the organization of the retina.

WebVision (Utah)

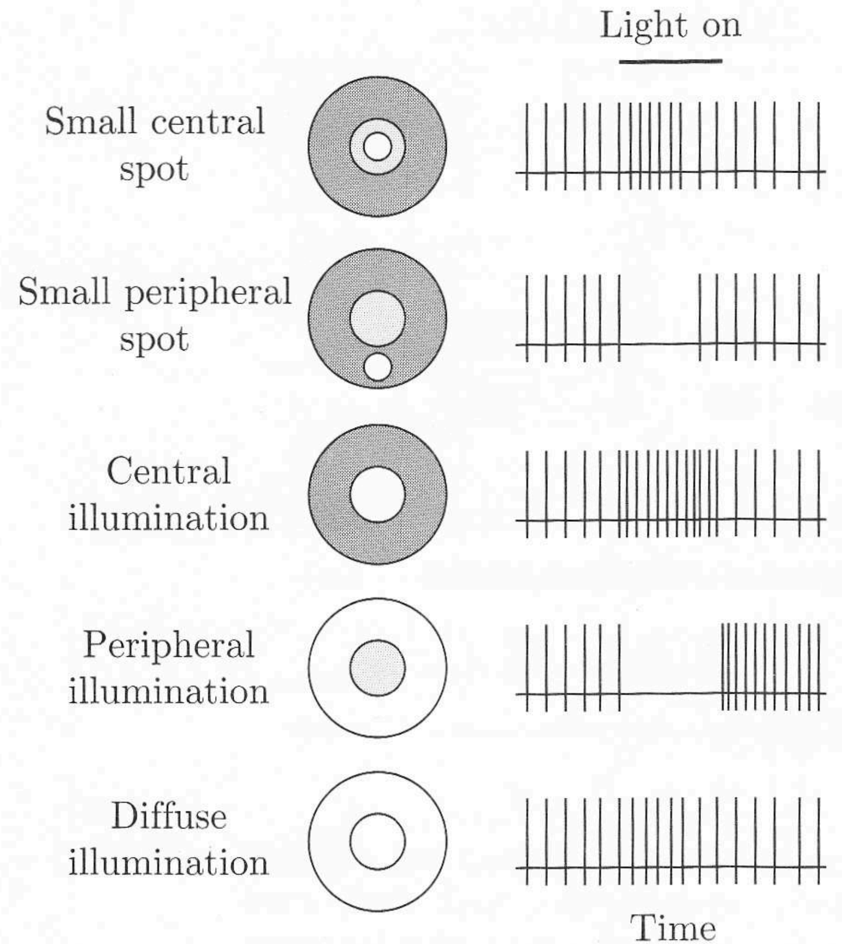
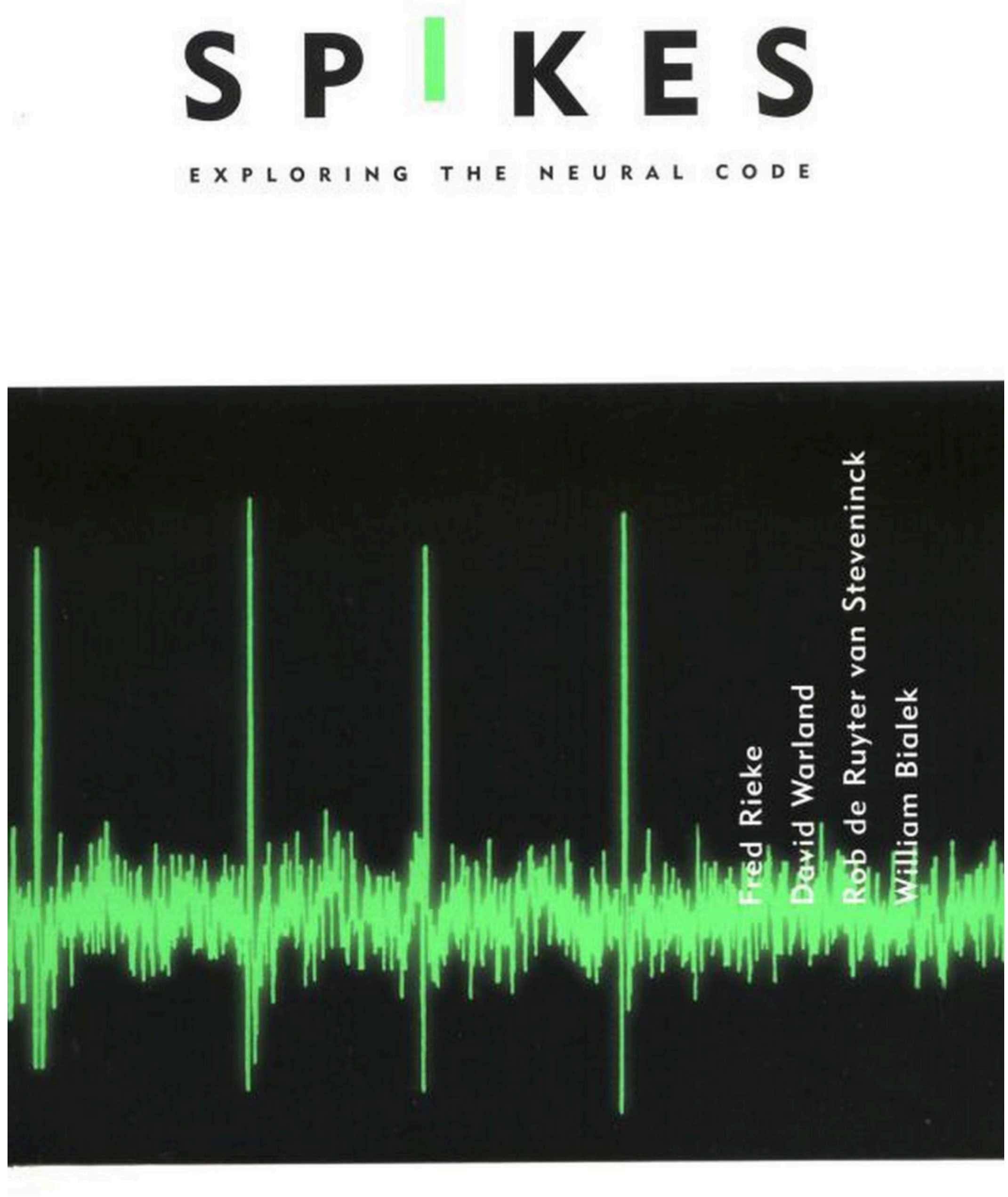


Fig. 1.26

→ Incident pattern on an *area* causes unique optical nerve fiber firing rate from a given *point*

Weiss (1996)

"Neural code"

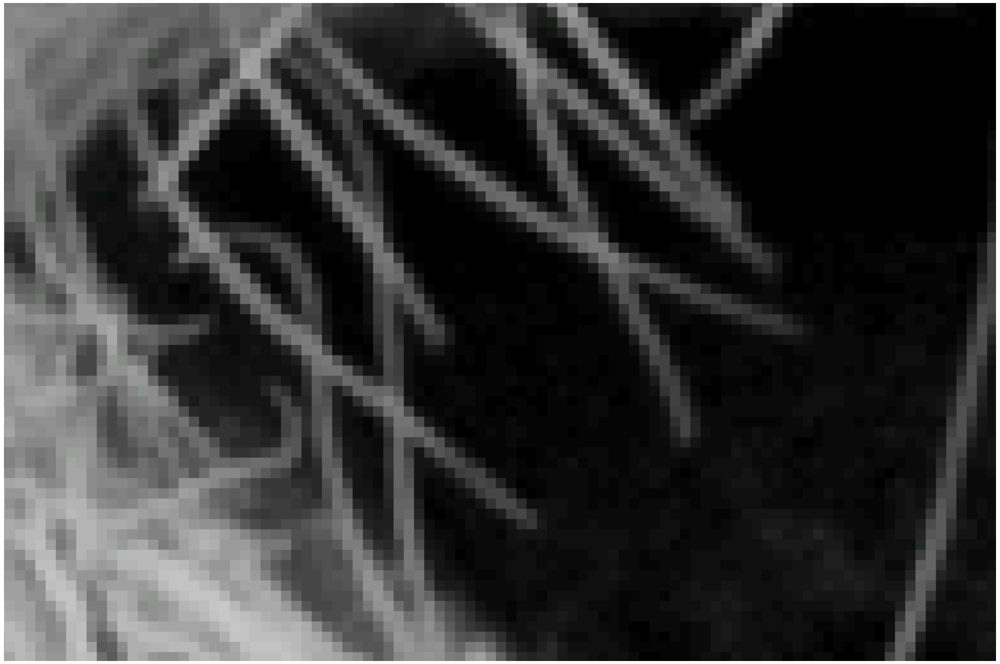

SPIKES
EXPLORING THE NEURAL CODE
Fred Rieke
David Warland
Rob de Ruyter van Steveninck
William Bialek

Pop Quiz #3

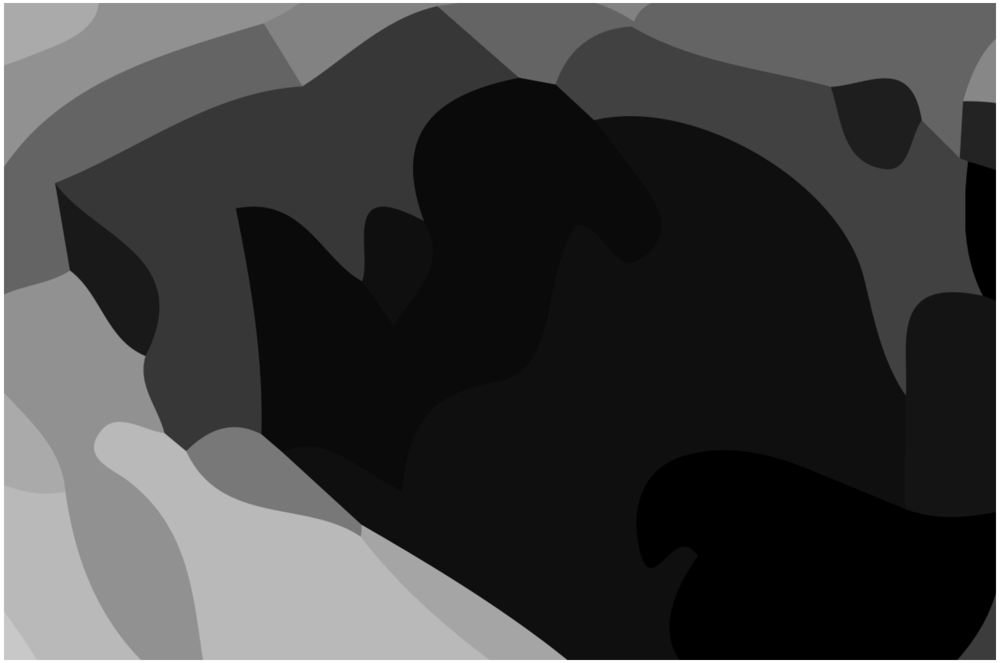
Is this “image” a bitmap or vector-based?

Many ways to "encode" something....

Bitmap version

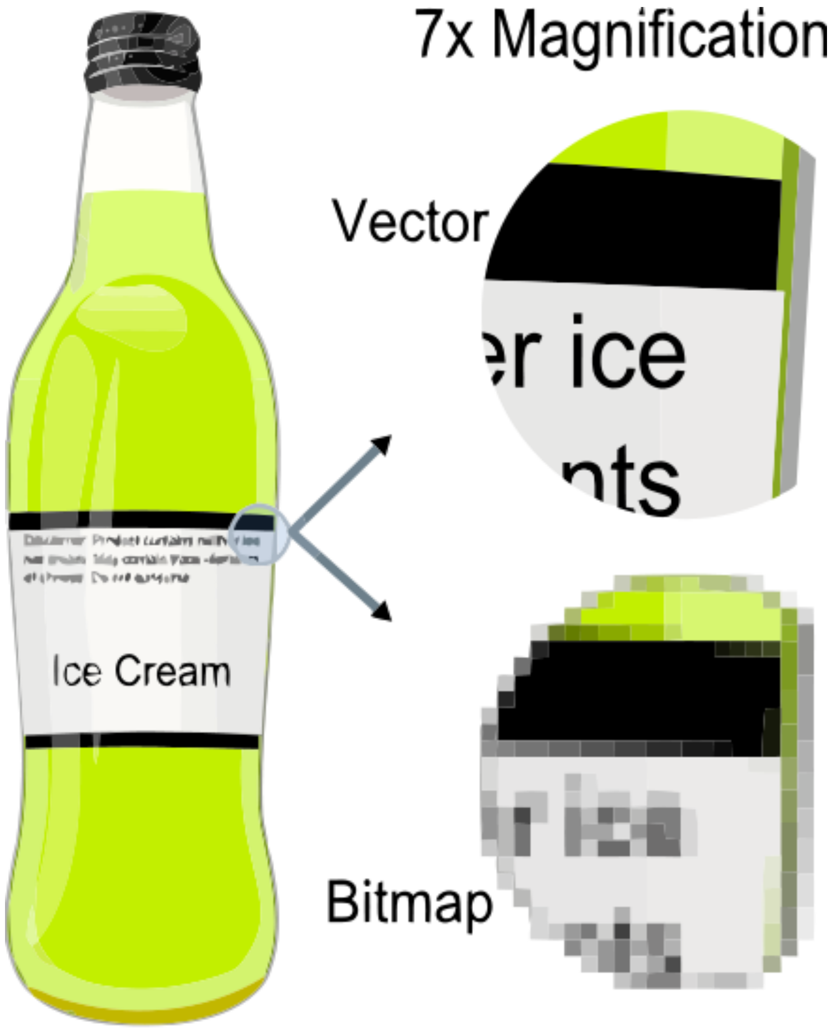


Vector version



zoom-in about corner of eye

Many ways to “encode” something....

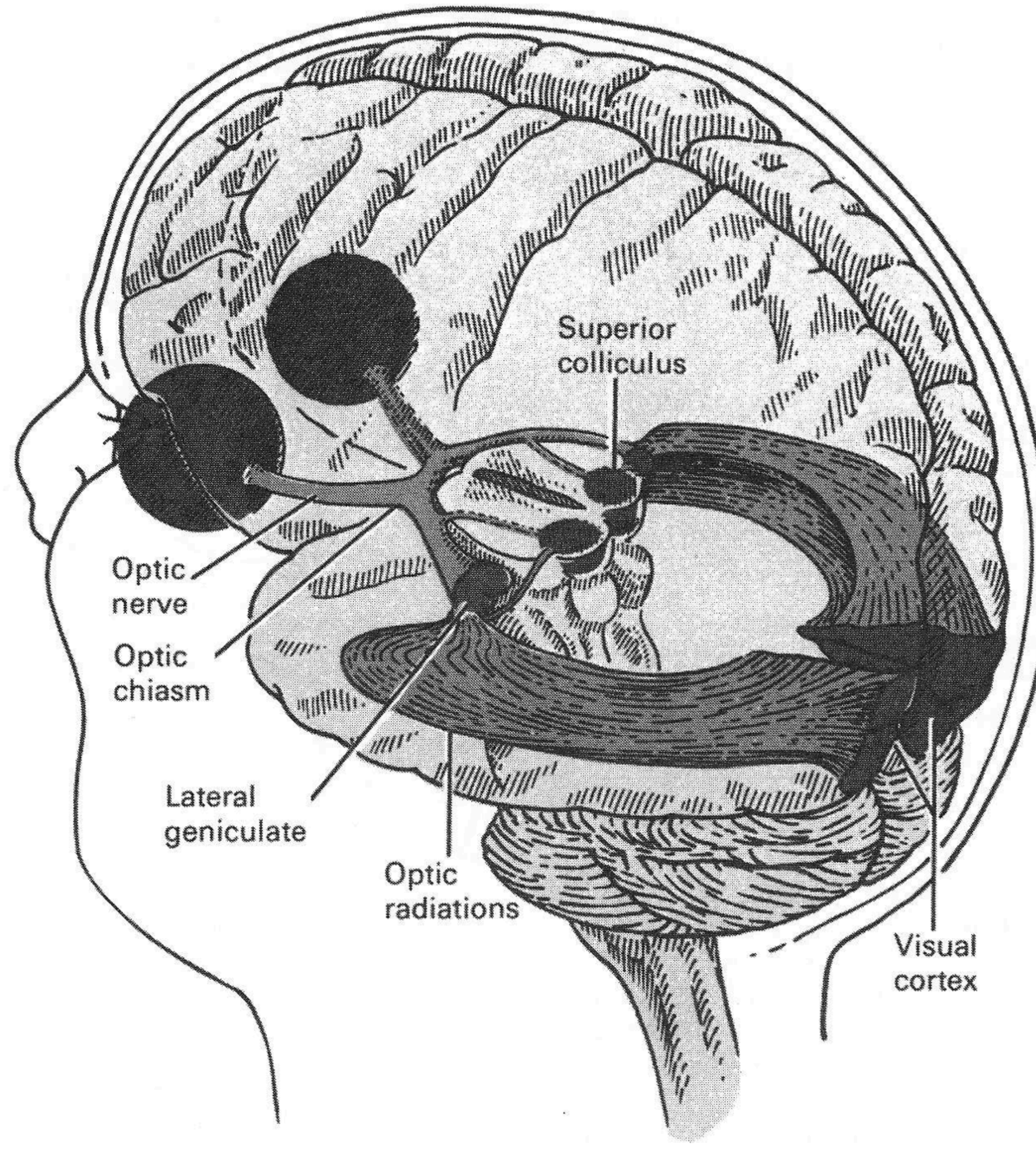


Bitmap version

Vector version

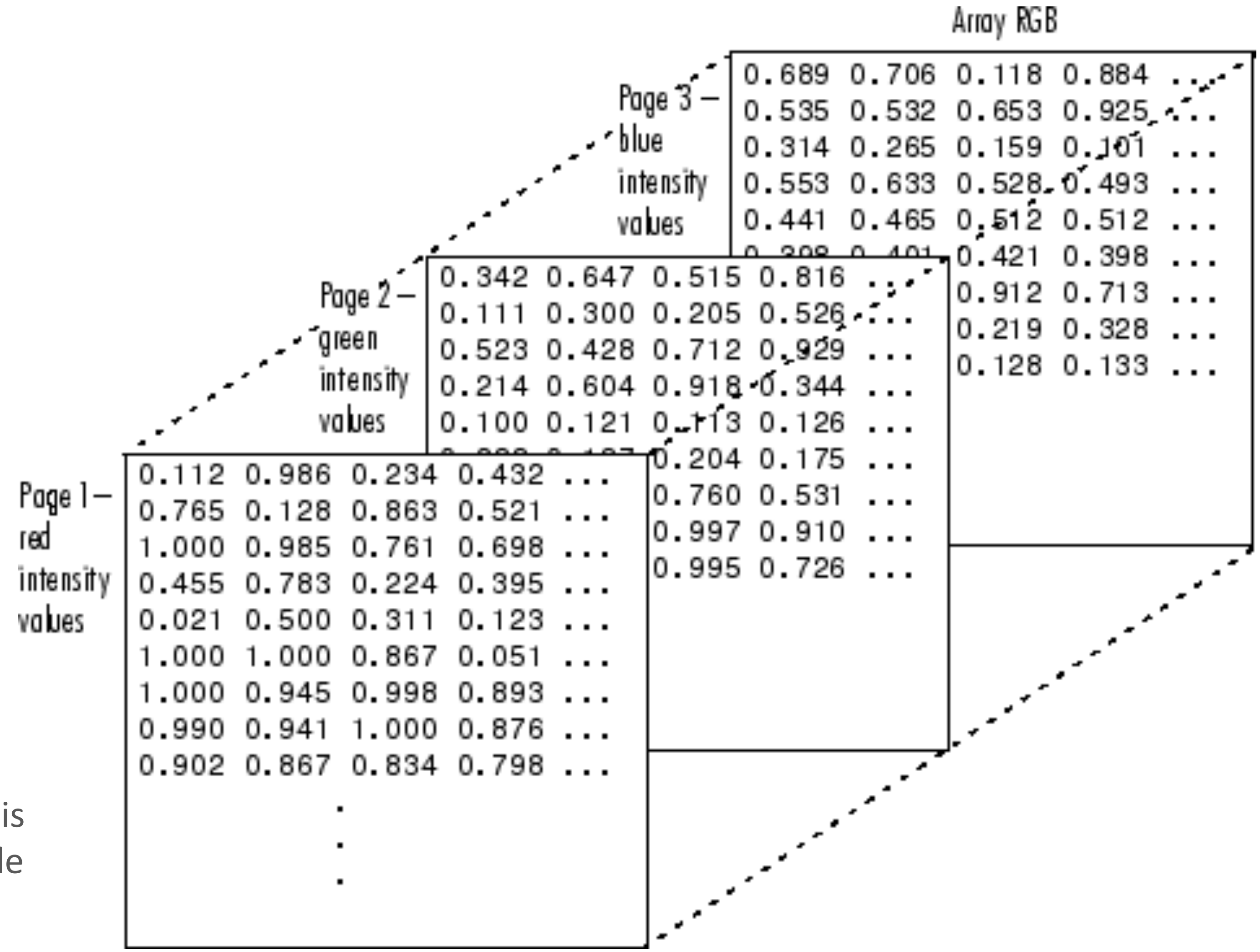
→ “Same” image, two very different representations

Wikipedia


Superior
colliculus
Optic
nerve
Optic
chiasm
Lateral
geniculate
Optic
radiations
Visual
cortex

Palmer (1999)

Aside: Images as numbers (i.e., a "bitmap")



Note
Even this basic picture is too simple for a jpeg file

Does your eye/nervous system process and store this image like a computer does? Probably not.....

http://i.stack.imgur.com/kI65e.gif

Human brain contains ~10^{11} (100 billion) neurons!

(with 100 trillion+ connections inbetween)

→ Understanding this thing is a really (really!) hard problem

Pop Quiz #4

Inverse problems are Ill-posed:
You know the "answer", but not the "question"….

What is the question?

- It is gold
- It has gold balls
- It has gold balls & is glittery
- It has gold balls, is glittery, & has lights
- It has gold balls, is glittery, has lights, & a star on top
- It has gold balls, is glittery, has lights, a star on top, and is shaped like a green cone

Question: What does your neighbor's x-mas tree look like?

Another fine mess…

Nature Vol. 261 June 10 1976

review article

Simple mathematical models with very complicated dynamics

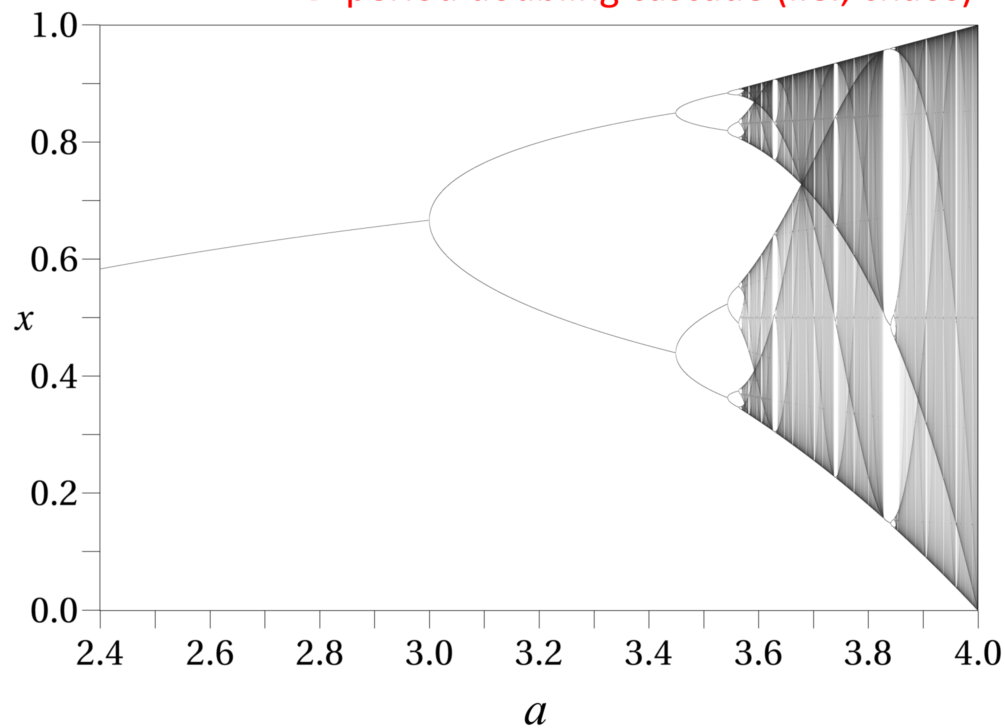
Robert M. May*

Logistic map

$$X_{t+1} = aX_t(1 - X_t)$$

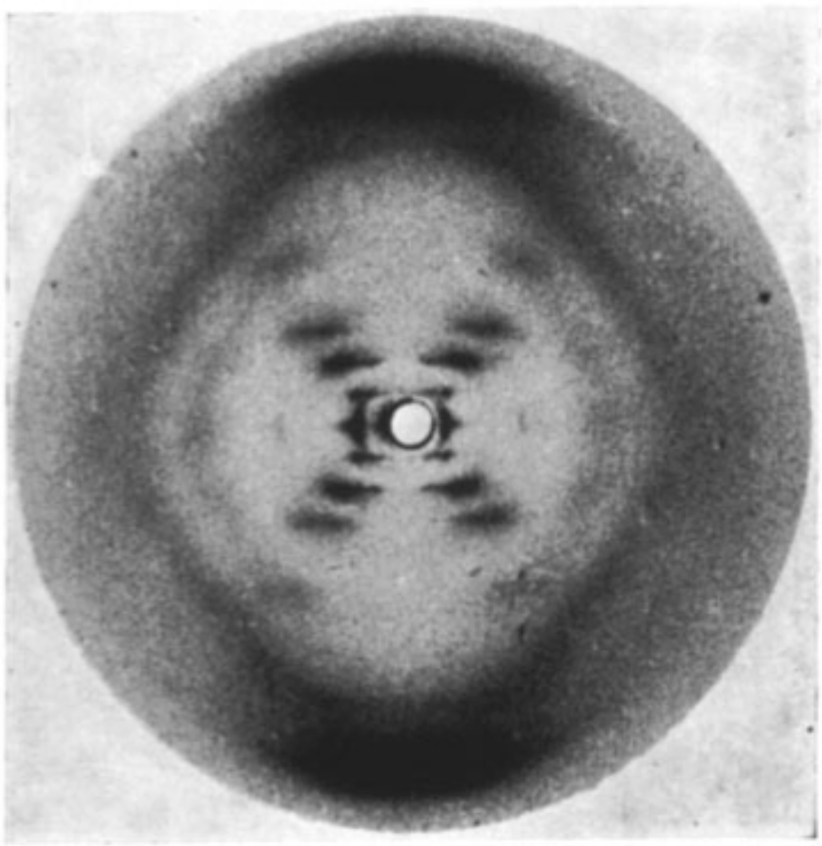
→ Even the simplest nonlinearities can greatly complicate matters!

→ period doubling cascade (i.e., chaos)

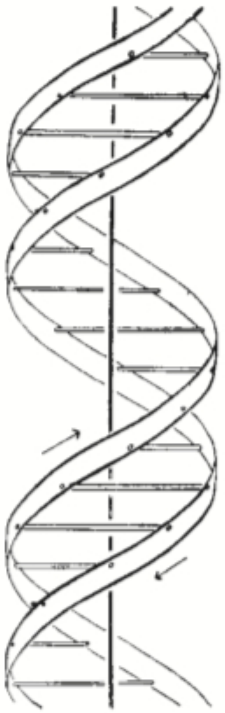


(Pedantic) Aside: What is biophysics?

“It is a remarkable thing that, pulling on the threads of one biological phenomenon, we can unravel so many general physics questions.”
(William Bialek, 2012)



Franklin & Gosling (1953)



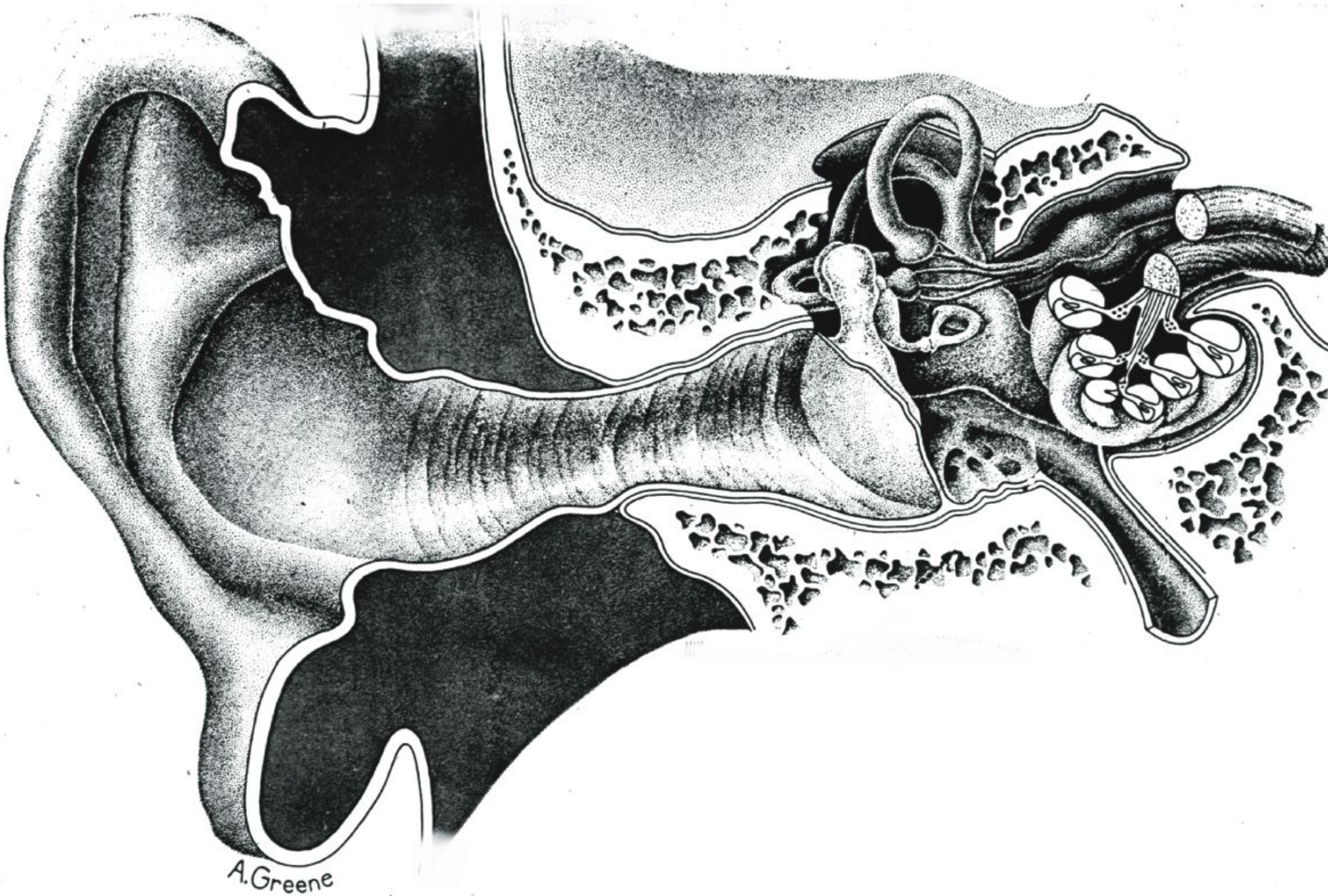
This figure is purely diagrammatic. The two ribbons symbolize the two phosphate—sugar chains, and the horizontal rods the pairs of bases holding the chains together. The vertical line marks the fibre axis

Watson & Crick (1953)

Applying principles of physics to study biological systems

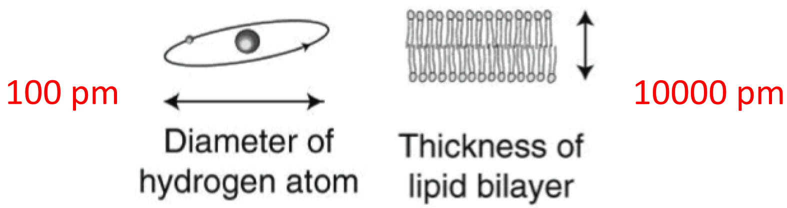
OR

Examining (complex/messy) biological systems to motivate new physics

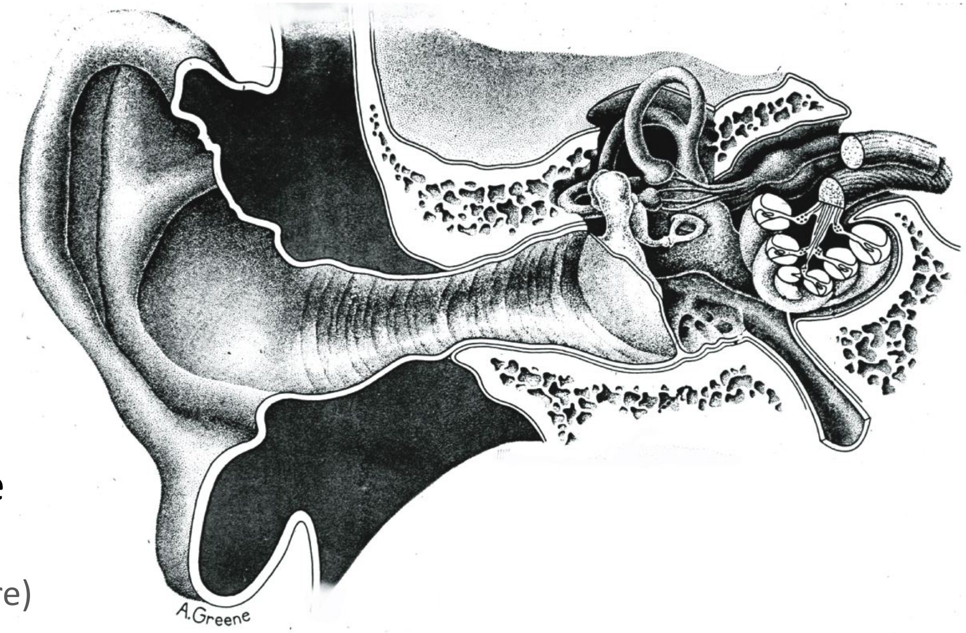

A.Greene

<u>Cool factoids about the ear....</u>

- At threshold, eardrum move ~1 pm



- At threshold, sensory cells move on the order of 100 pm (despite thermal noise agitating them roughly an order of magnitude more)



- Dynamic range spans 12+ orders of magnitude (in terms of incident energy)
- Spectral range spans 6-12 octaves (1 oct = x2 in Hz)
- Highest resting trans-membrane potential in whole body (≈130–170 mV)
- Middle ear contains three smallest bones in the body (ossicles)
- Cochlea encased in the hardest bone in the body (petrous part of temporal bone)

BIOPHYSICS @ YORK

redefine THE POSSIBLE.

UNIVERSITÉ
UNIVERSITY

Slides available at:

http://www.yorku.ca/cberge/

Fini