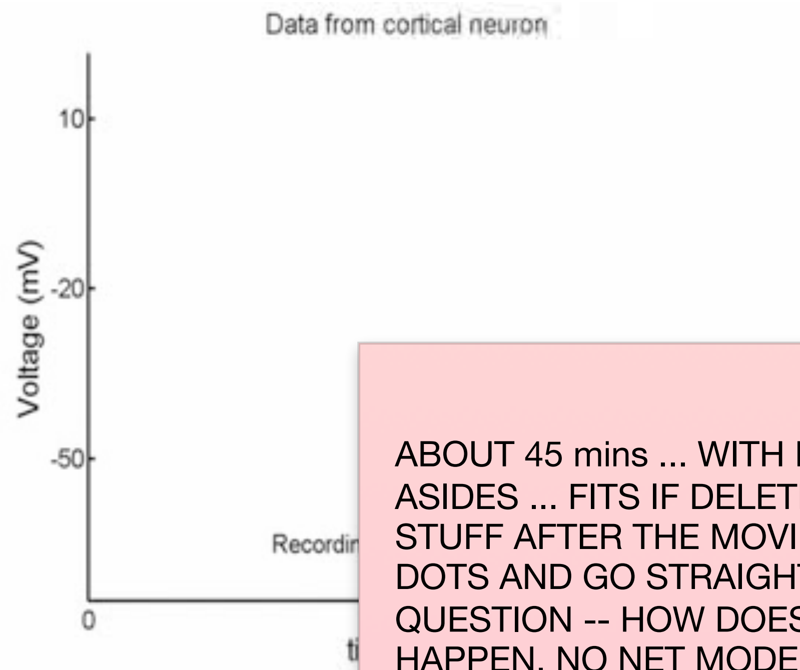


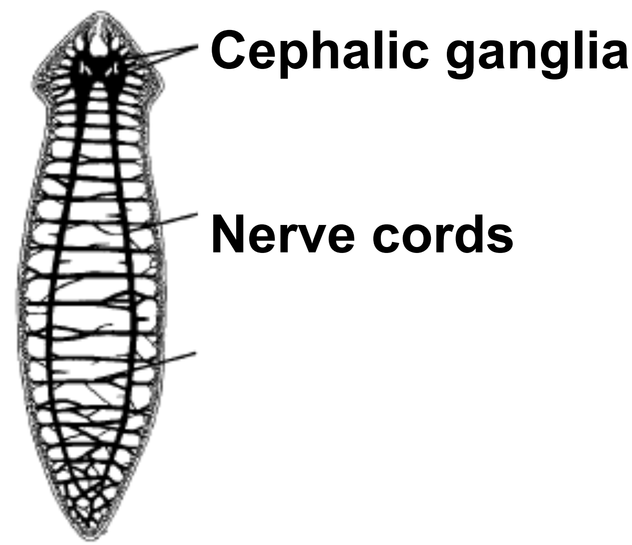
ABOUT 45 mins ... WITH LOTS OF ASIDES ... FITS IF DELETE THE STUFF AFTER THE MOVIE OF DOTS AND GO STRAIGHT TO QUESTION -- HOW DOES THIS HAPPEN, NO NET MODEL NEEDED HERE.

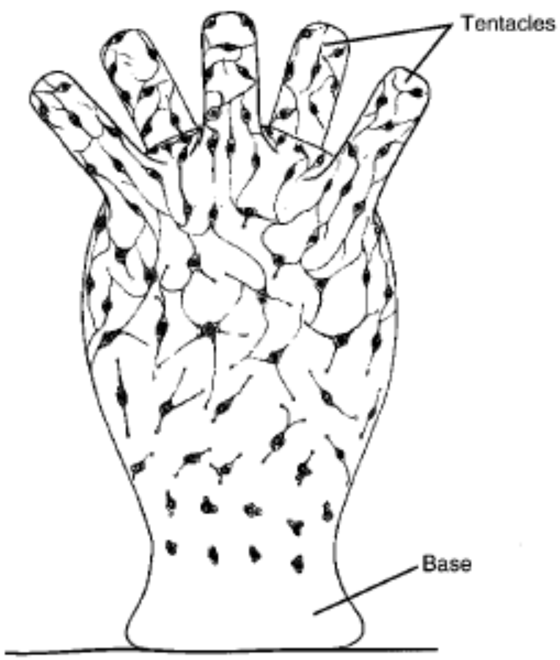
Chasing down the neural code with mathematics and modeling

Eric Shea-Brown

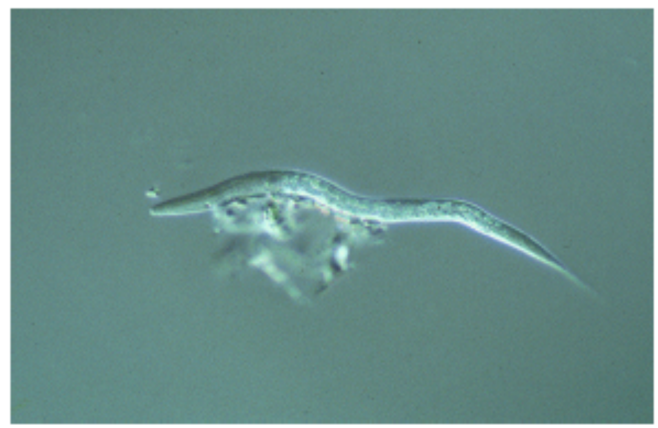
Invertebrates – nerve nets and ganglia

(thanks to David Tank)





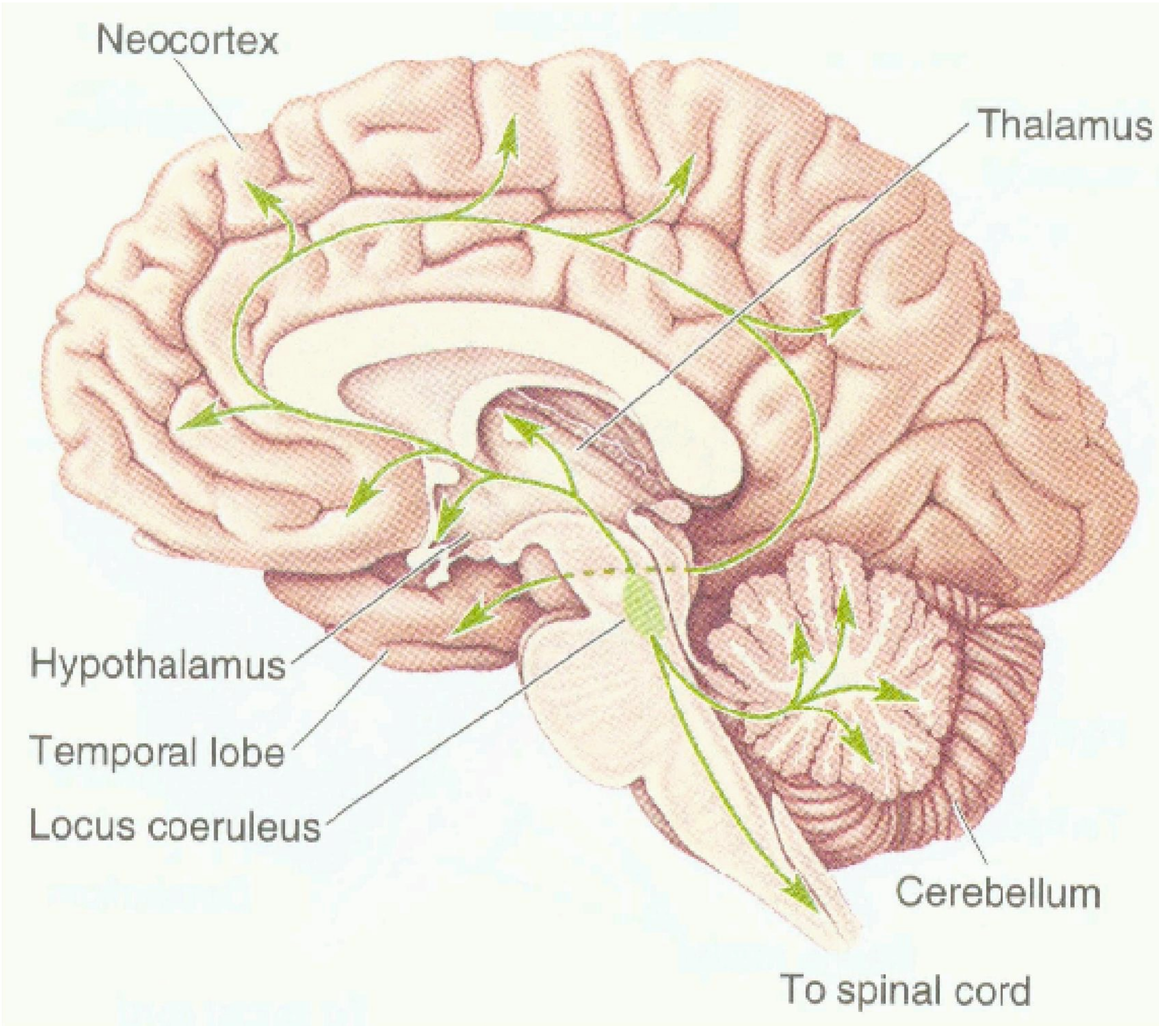
nerve net
in hydra



c. elegans

302 neurons (32 chemosensory)

Us



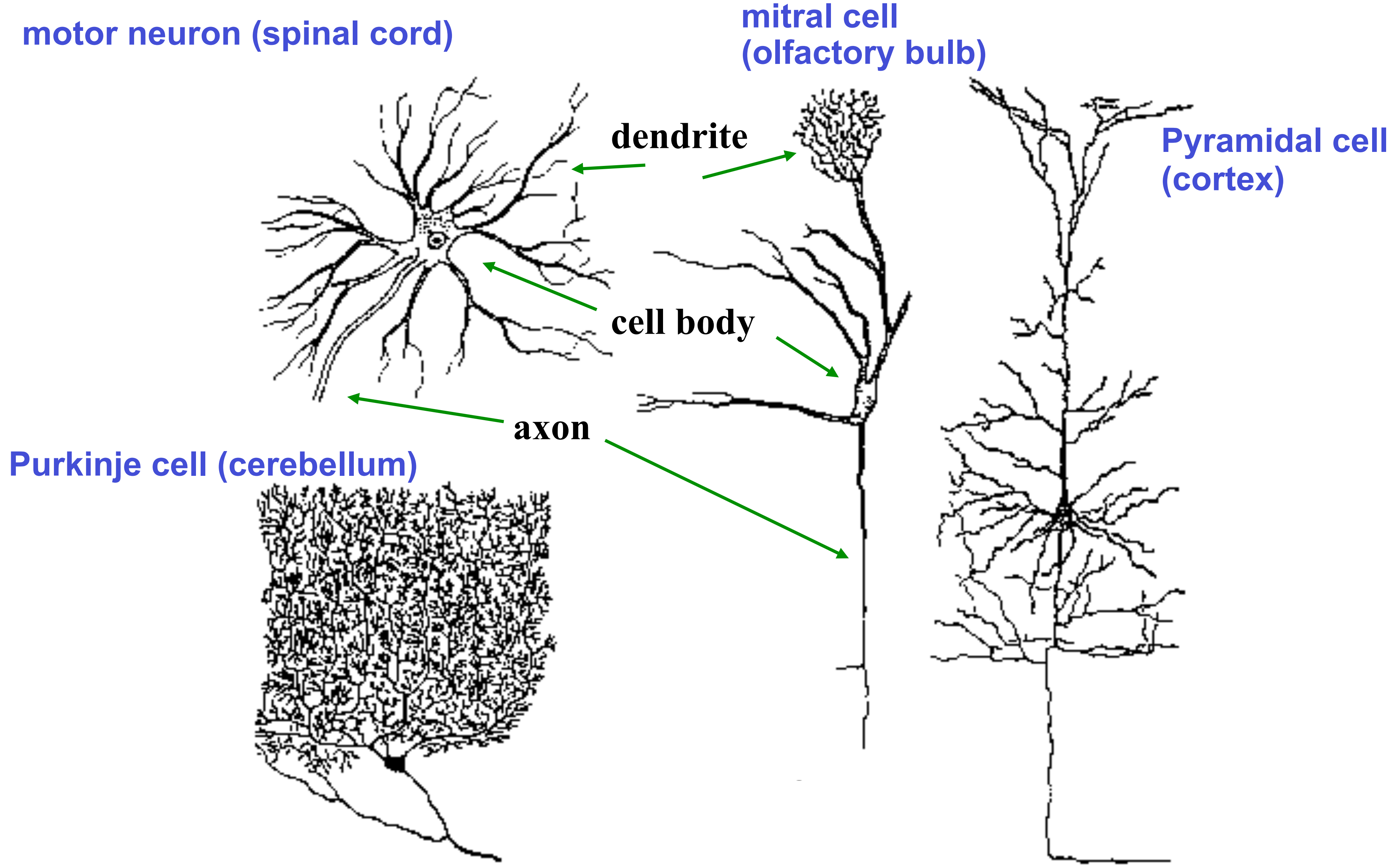
from *Neuroscience: Exploring the Brain* by M.F. Bear, B.W. Connors, and M.A. Paradiso, 2001

10^{11} neurons

(10^5 per mm^3)

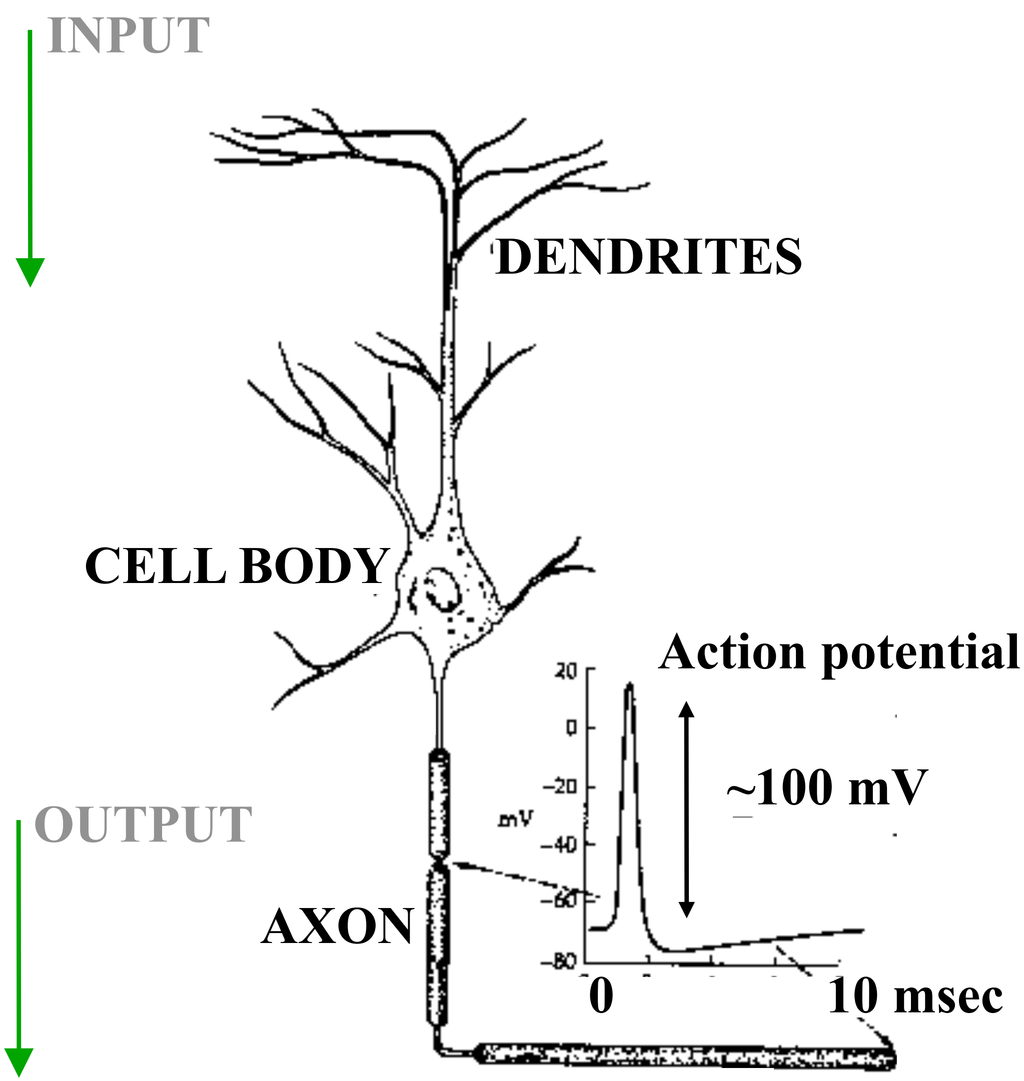
10^{15} synapses

Electrical signals come IN to dendrites, are "integrated" in cell body, result goes OUT axon



From Nicholls et al, 1992, Fisher and Boycott, 1974, Johnston and Wu, 1997

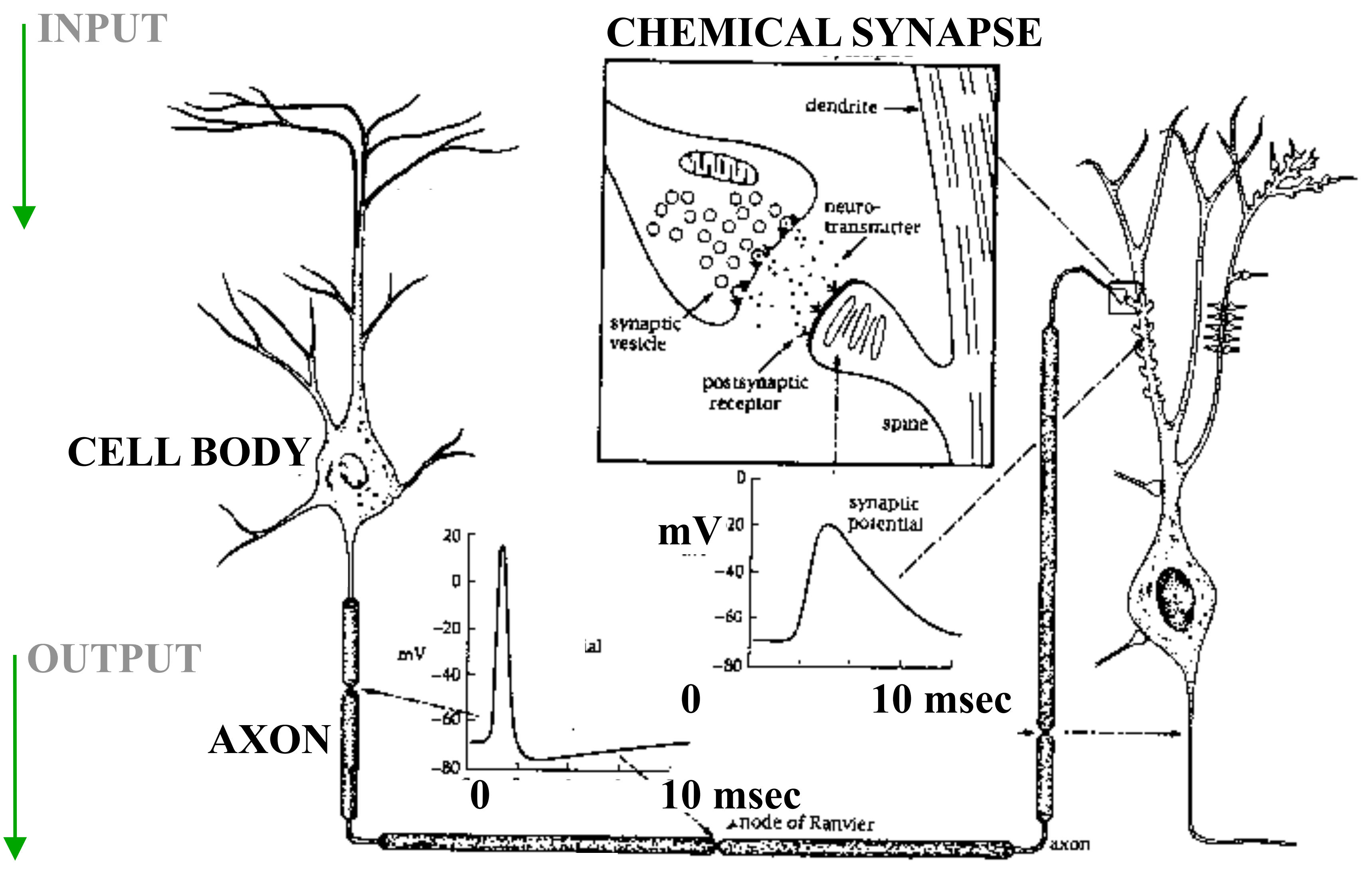
Given sufficient input, neurons “fire SPIKES”



Johnston and Wu, 1997

Given sufficient input, neurons "fire SPIKES"

… communicated downstream



Johnston and Wu, 1997

A.L. Hodgkin and A.F. Huxley

J. Physiol. **117**:500, 1952

(Nobel Prize in Physiology and Medicine, 1963)

Hodgkin-Huxley: Giant Squid Axon or Squid Giant Axon?

A.L. Hodgkin and A.F. Huxley
J. Physiol. **117**:500, 1952
(Nobel Prize in Physiology and Medicine, 1963)

whydomath.org

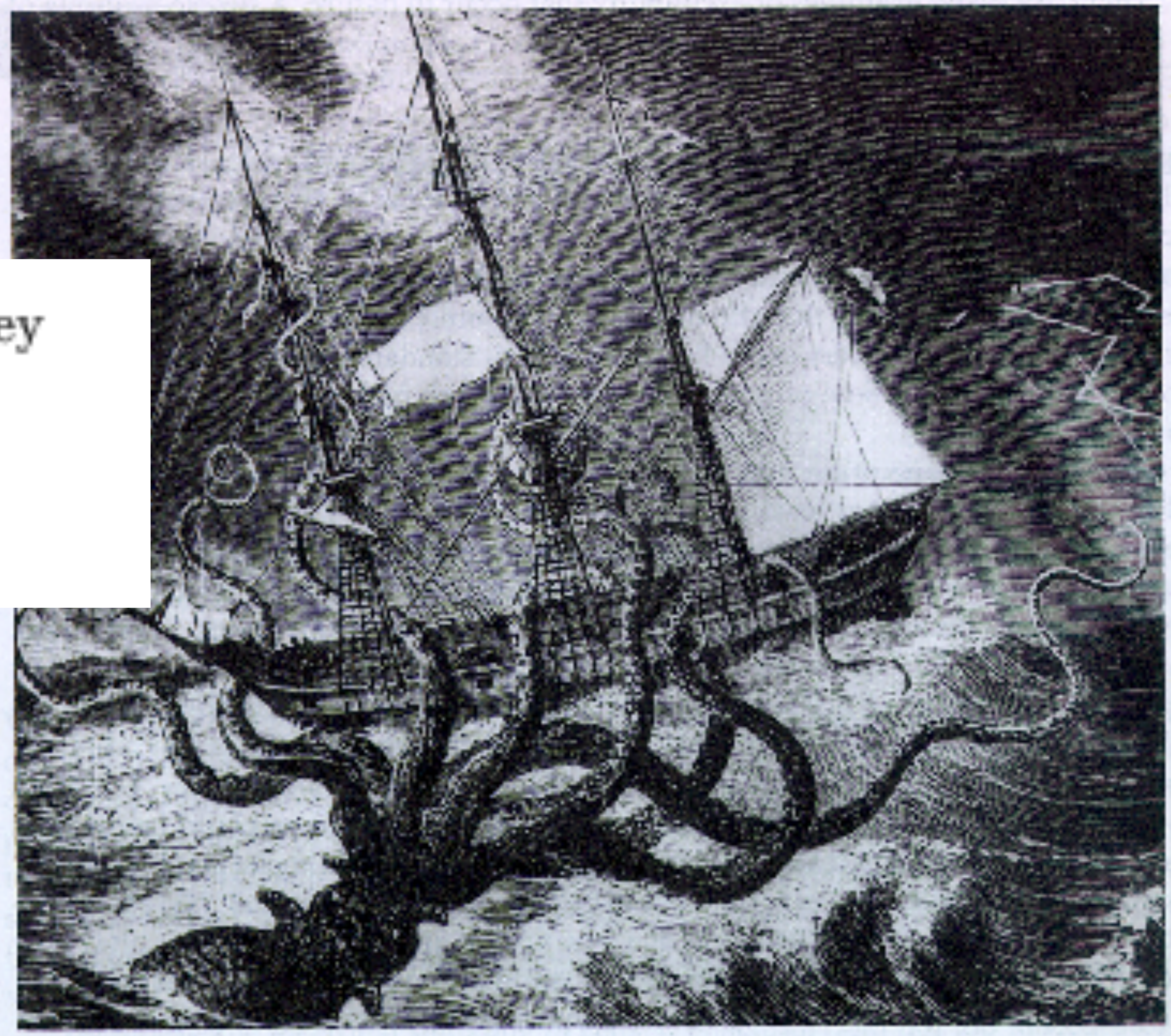


Figure 4.1 The infamous giant squid, having nothing to do with the work of Hodgkin and Huxley on squid giant axon. From *Dangerous Sea Creatures*, © 1976, 1977 Time-Life Films, Inc.

from *Mathematical Physiology* by J. Keener and J. Sneyd, 1998

The secret ingredient: differential equations!

t: time now

$t + \Delta t$: time one "step" into future

$v(t)$: voltage at time t

$F(v)$: how fast v is changing
(i.e., twelve units per timestep)

$$v(t + \Delta t) = v(t) + F(v(t))\Delta t$$

$$\frac{v(t+\Delta t)-v(t)}{\Delta t} = F(v(t))$$

$$\frac{dv(t)}{dt} = F(v(t))$$

Hodgkin and Huxley's equations ...

dv(t)/dt=(I - gna*h*(v-vna)*m^3-gk*(v-vk)*n^4-gl*(v-vl))/c

dm(t)/dt= am(v)*(1-n

dh(t)/dt=ah(v)*(1-h)-

dn(t)/dt=an(v)*(1-n)-

These experiments were brought to an end by the first of our many energy crises, in this case precipitated by an exceptionally prolonged cold spell which lasted until the end of March 1947. It was soon found that national coal stocks were exhausted and the central heating was switched off in many buildings, including university laboratories. We then had no cold room in our part of the laboratory and I remember that David Hill took the opportunity of carrying out a series of experiments at 4° C. But you can't dissect single fibres at such temperatures and I spent the time writing at home or talking with Andrew Huxley in Trinity where he could be seen cranking a Brunsviga calculating machine with mitten-covered fingers. I started experimenting again in April but by then the summer

am(v) = .1*(v+40)/(1

bm(v) = 4*exp(-(v+6

ah(v) = .07*exp(-(v+

bh(v) = 1/(1+exp(-(v+35)/10))

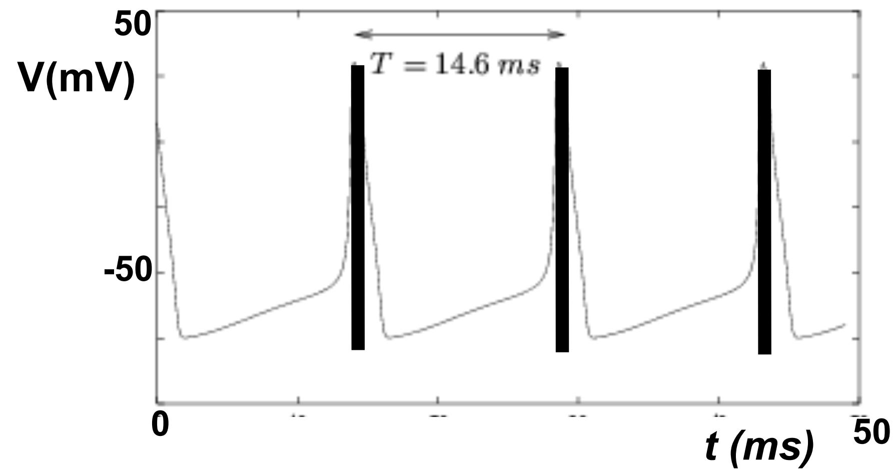
an(v) = .01*(v+55)/(1-exp(-(v+55)/10))

bn(v) = .125*exp(-(v+65)/80)

\+ spatial "diffusion" terms

Then: **using a Brunsviga 20 manually cranked calculator with numbers entered by a set of adjusting levers (projecting from the wheels that were rotated by the hand crank). The output was a line of digits on the wheels to be read and transcribed to paper.**

Now: **hh.m**



A.L. Hodgkin and A.F. Huxley

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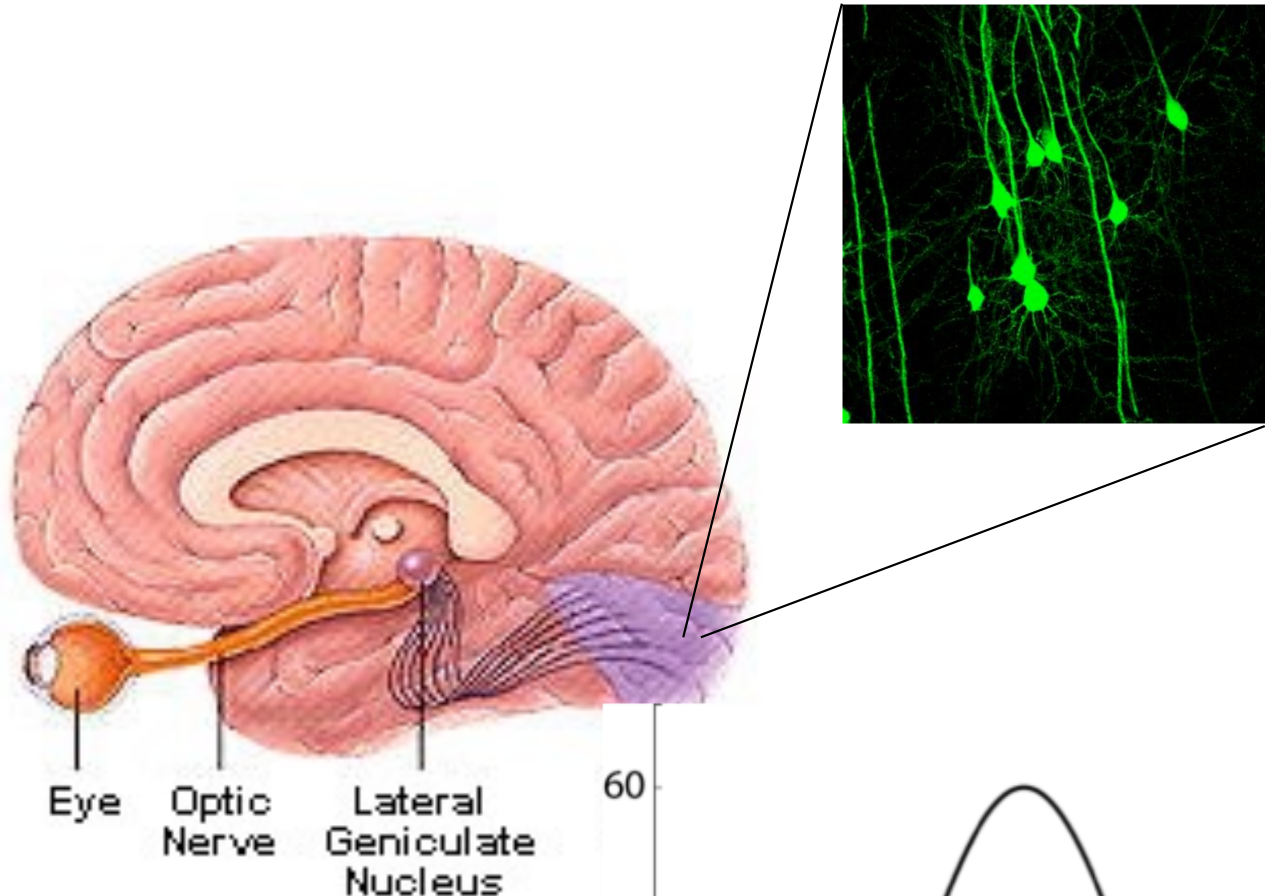
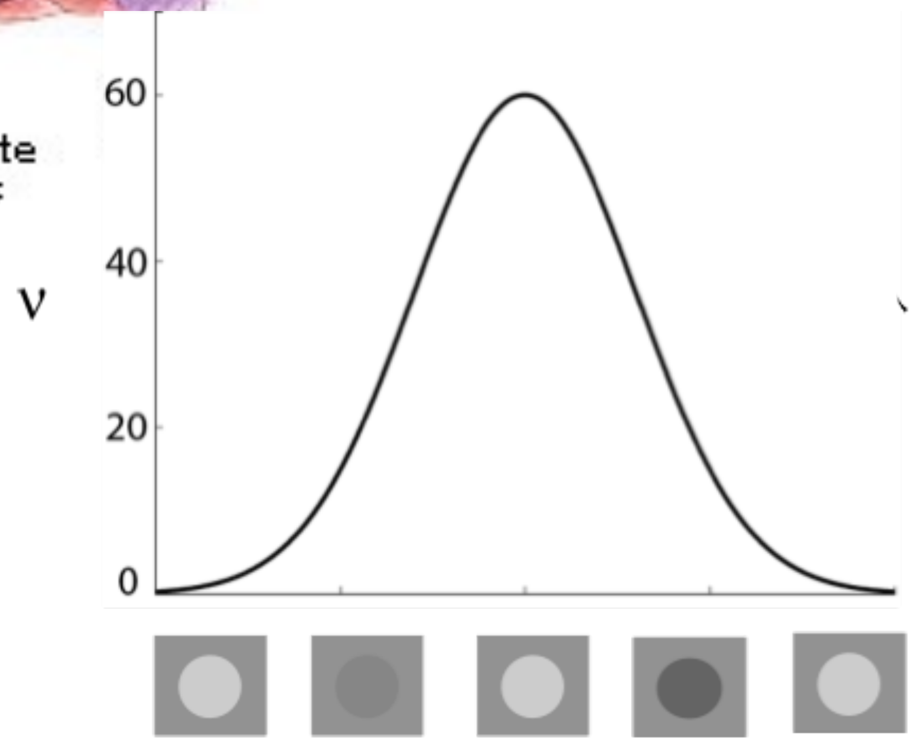
Given spikes … Where's the information?

Given spikes … Where's the information?

1. Averaged spike statistics

Cortical encoding via spiking rates





Hubel and Weisel. J. Physiol.,1962

Reddy, Kreiman, Koch, and Fried (2005)

Given spikes … Where's the information?

1. Averaged spike statistics

vs.

Frequency, …

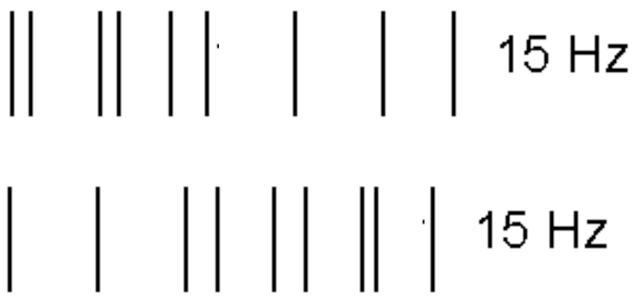
Given spikes … Where's the information?

1. Averaged spike statistics

vs.

Frequency, …

2. Precise spike timing



vs.

Spike times $\{t_j\}$

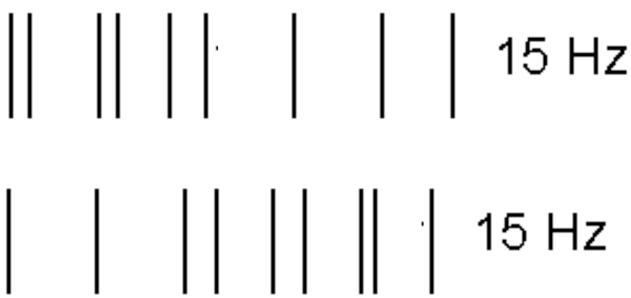
Given spikes … Where's the information?

1. Averaged spike statistics

vs.

Frequency, …

2. Precise spike timing



vs.

Spike times $\{t_j\}$

Biology: BOTH.

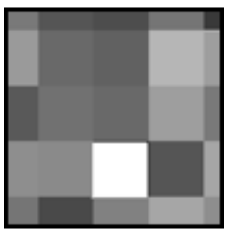
Metrics: Fisher Information, Mutual Information …

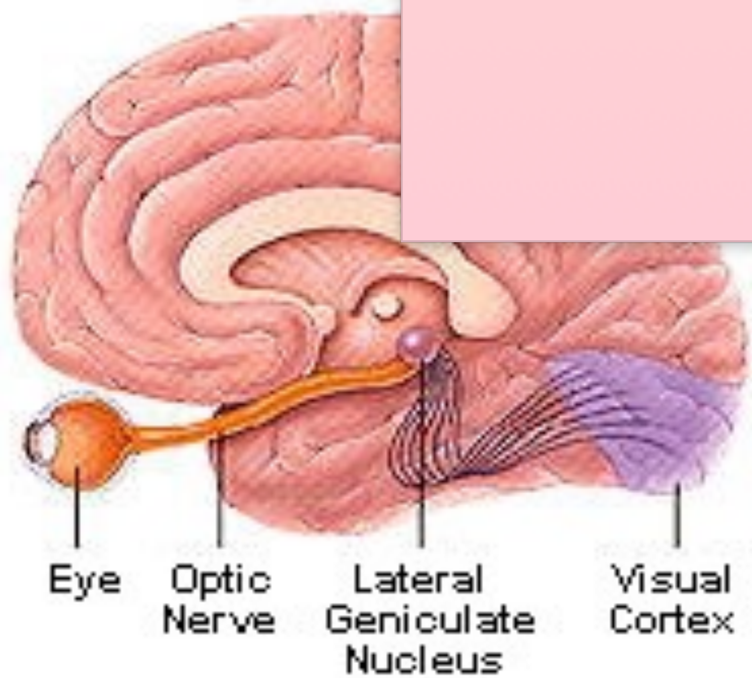
Neural coding in general!

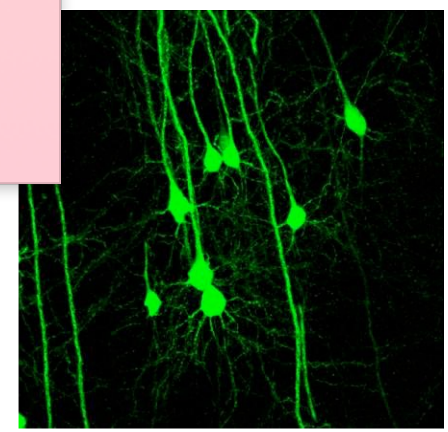
Dynamics of neural circuits are central to problem of neural coding ...

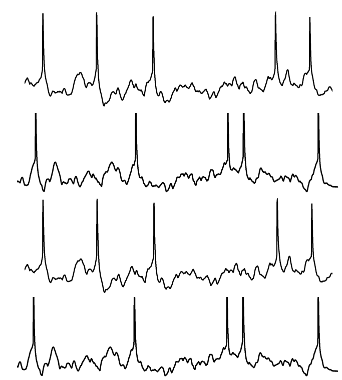
stimulus

s









...

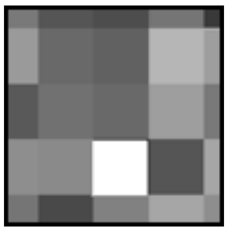
In between of course is big nonlinear stochastic ... fascinating object to me as an applied mathematician. I'll talk about one aspect of our work here ...

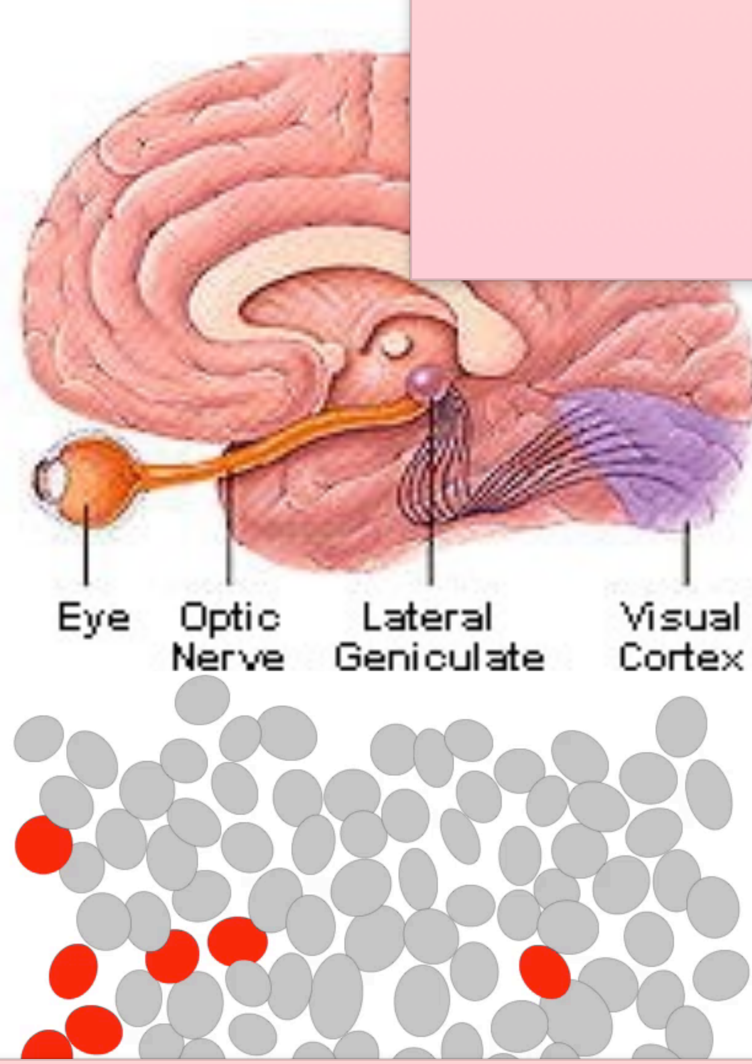
Neural coding in general!

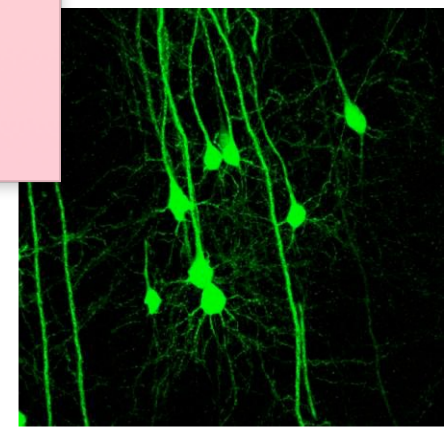
Dynamics of neural circuits are central to problem of neural coding ...

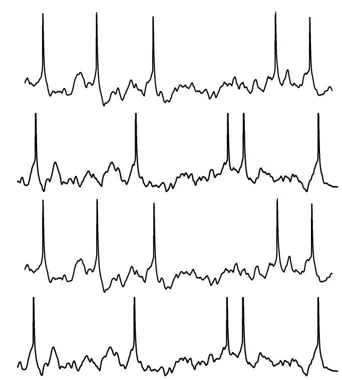
stimulus

s









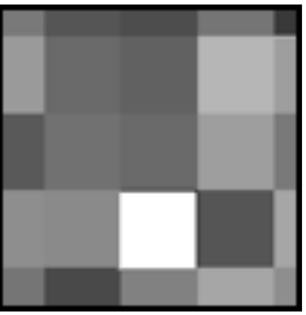
...

In between of course is big nonlinear stochastic ... fascinating object to me as an applied mathematician. I'll talk about one aspect of our work here ...

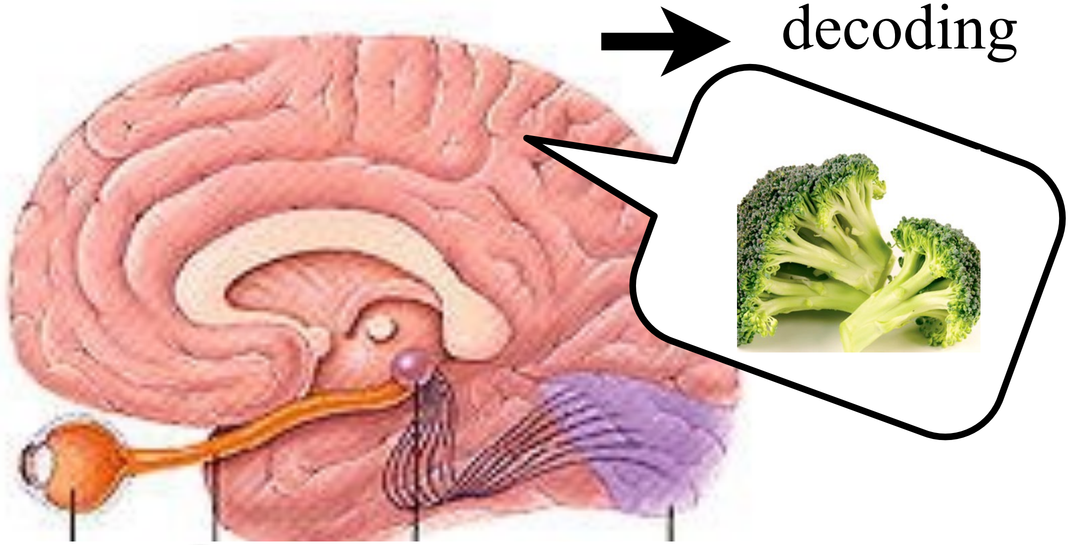
et al '09

Neural coding

encoding



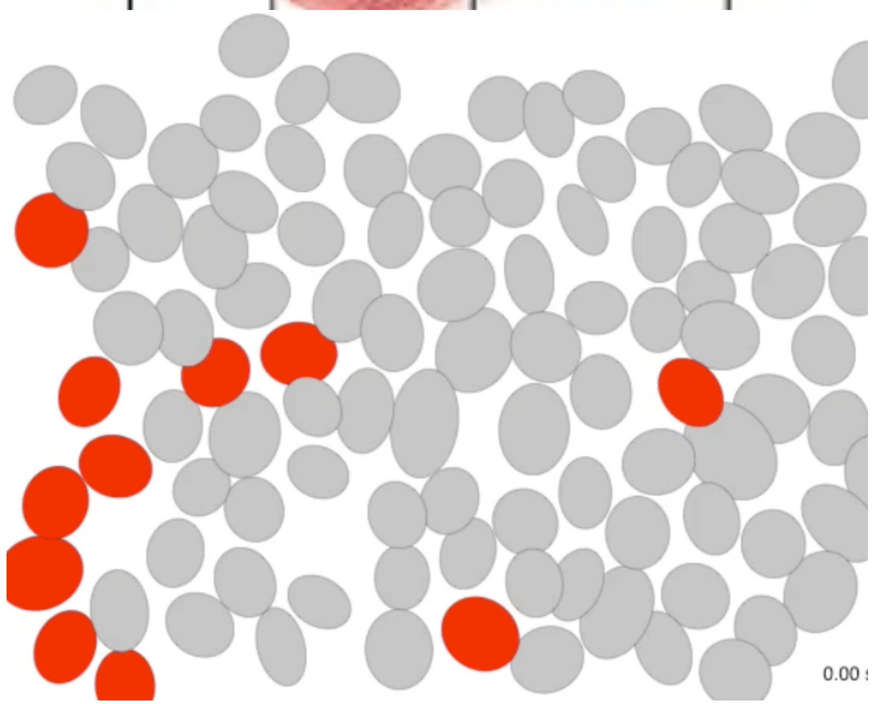
s(t)



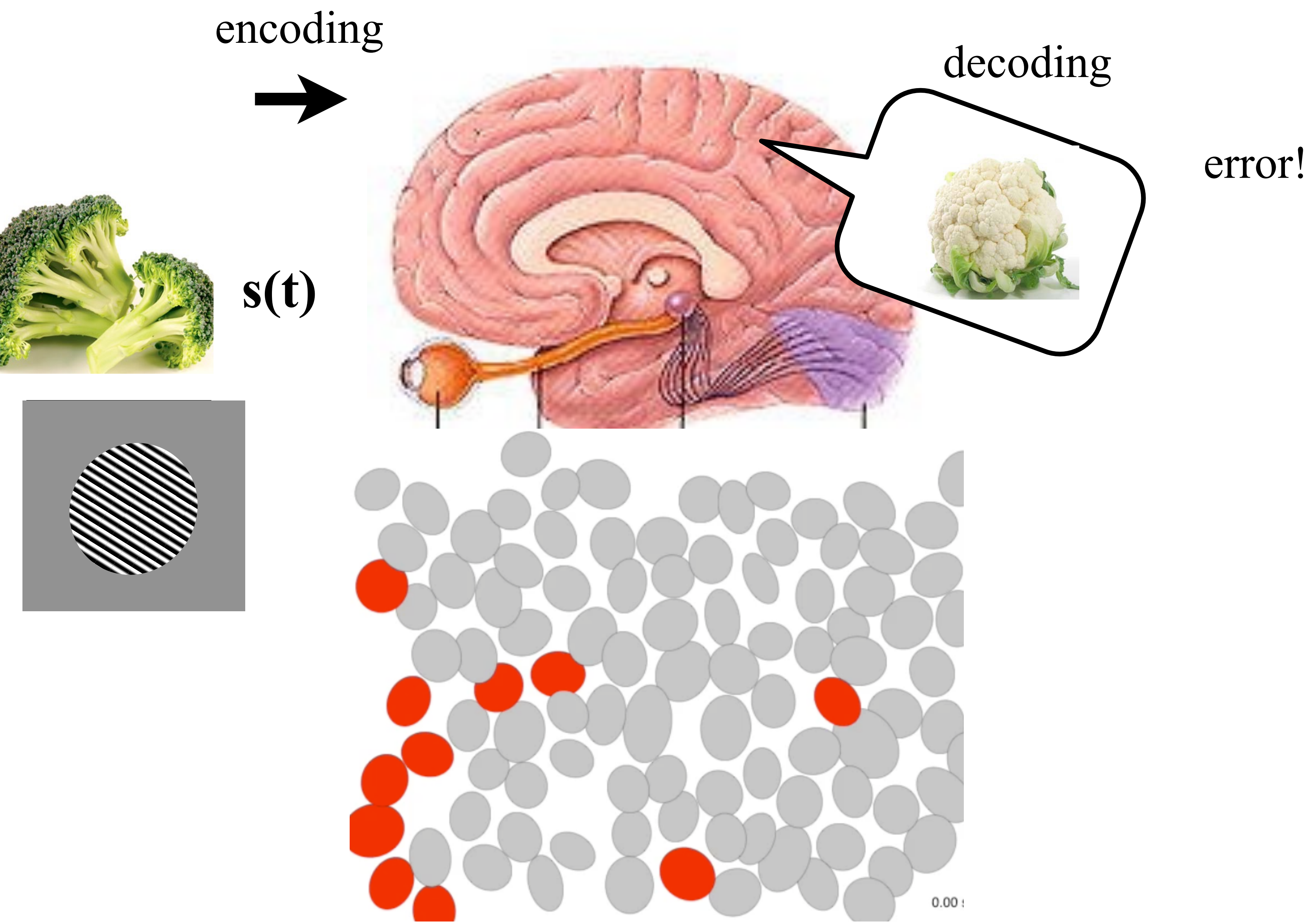
decoding

correct!

Guillaume Lajoie



Neural coding



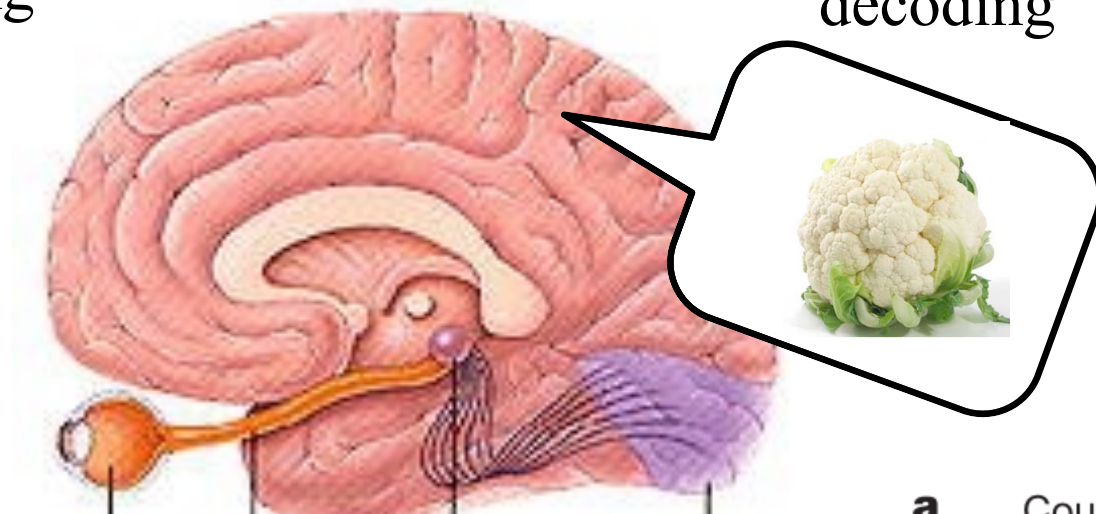
Spatio-temporal correlations and visual signalling in a complete neuronal population

Jonathan W. Pillow[1], Jonathon Shlens[2], Liam Paninski[3], Alexander Sher[4], Alan M. Litke[4], E. J. Chichilnisky[2] & Eero P. Simoncelli[5]

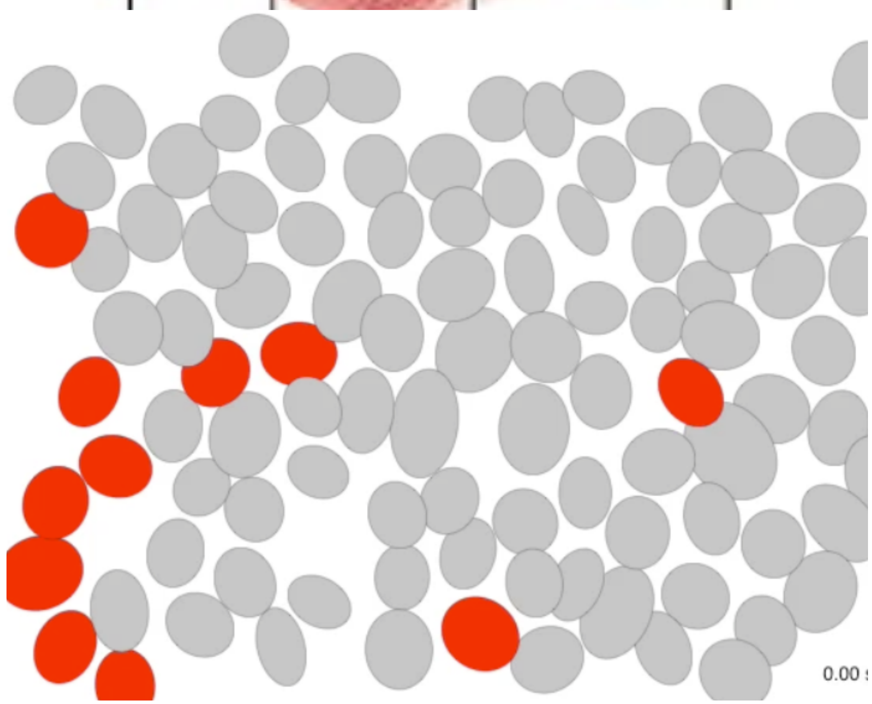
encoding →

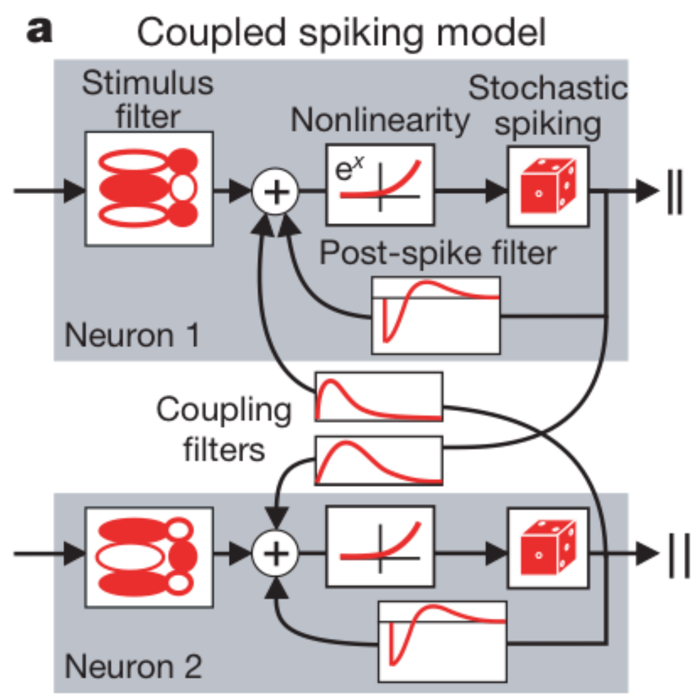
decoding

s(t)



error!





Scientific computing + numerical analysis

Dynamical systems

Statistics and Probability (stochastic processes)

whydomath.org

... click on spinning brain

compneuro.washington.edu

or

faculty.washington.edu/etsb