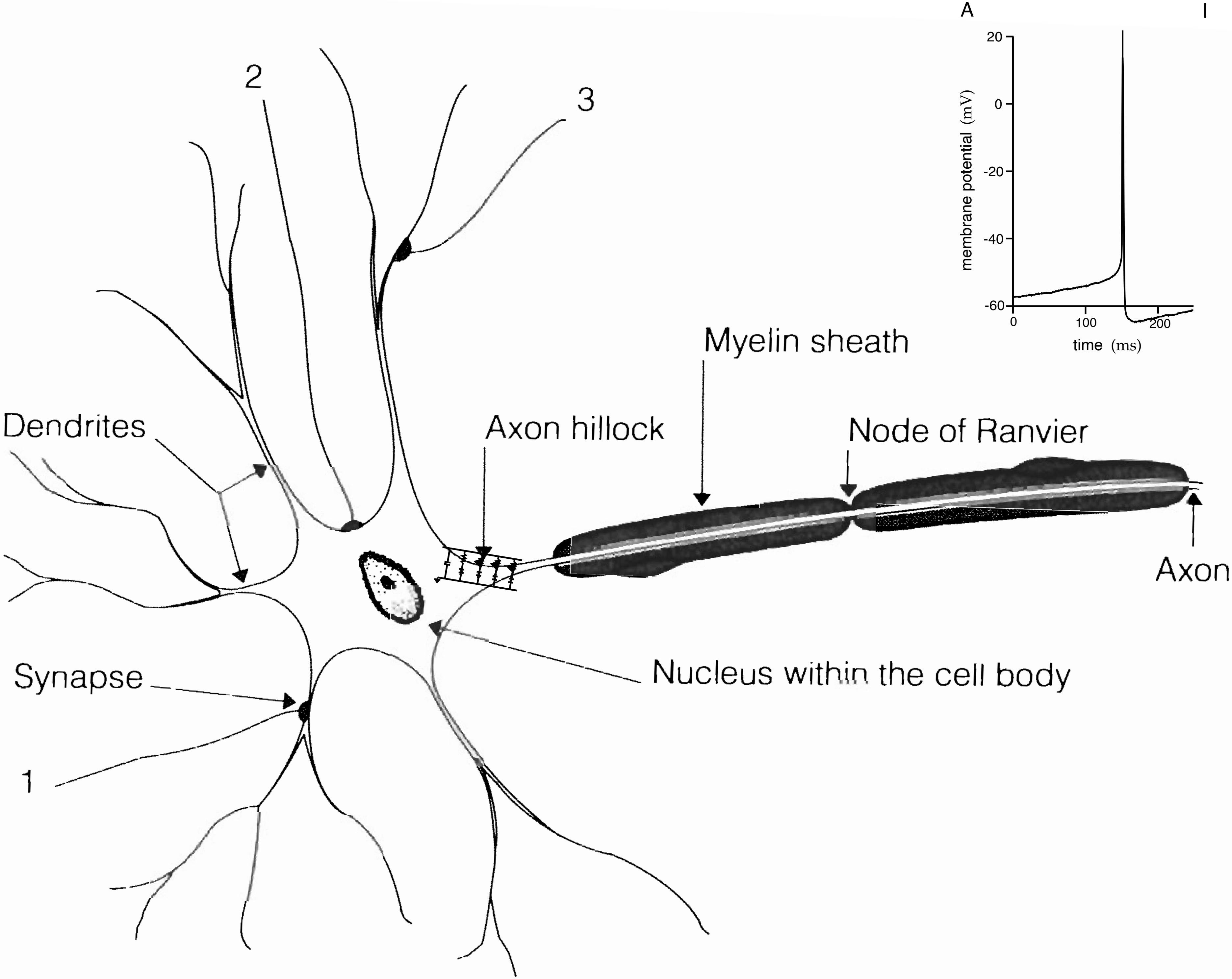
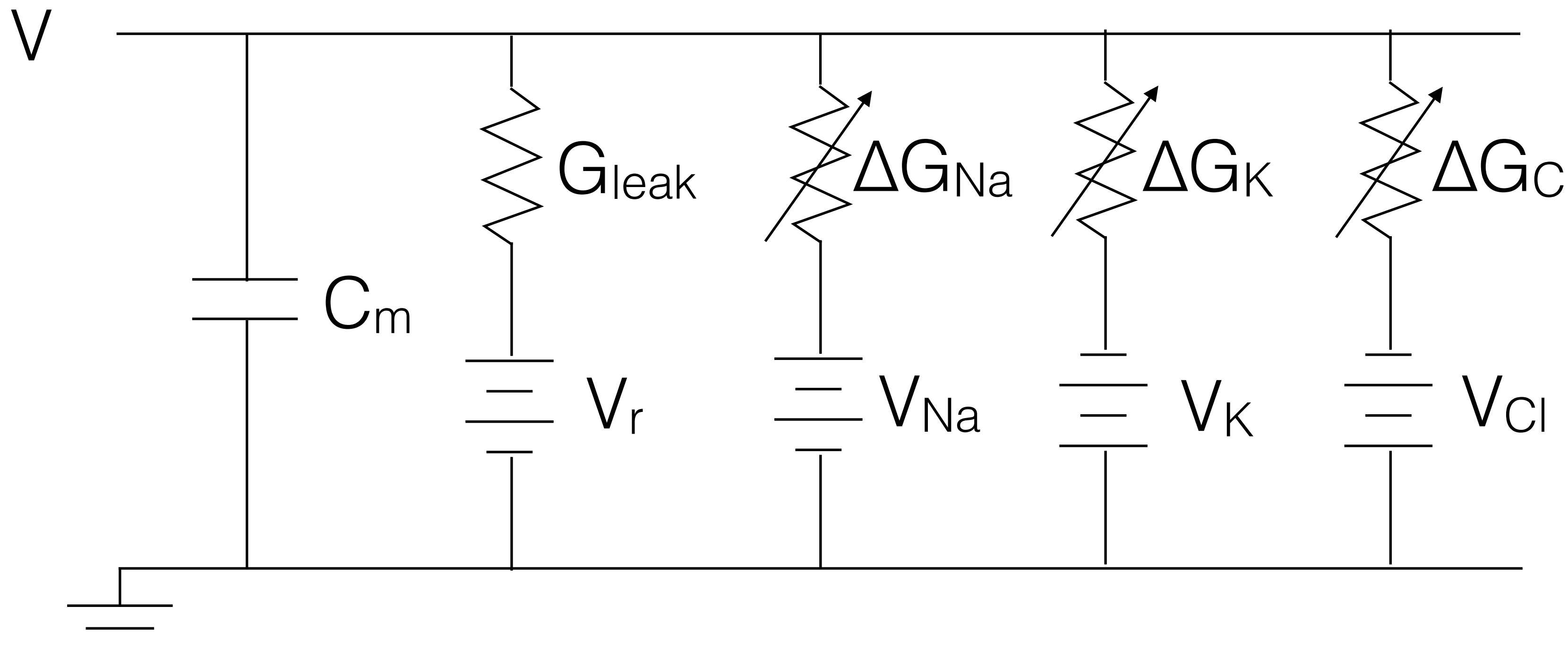
Spikes


A
I
20
0
-20
-40
-60
membrane potential (mV)
0
100
200
time (ms)
2
3
Myelin sheath
Dendrites
Axon hillock
Node of Ranvier
Axon
Synapse
Nucleus within the cell body
1

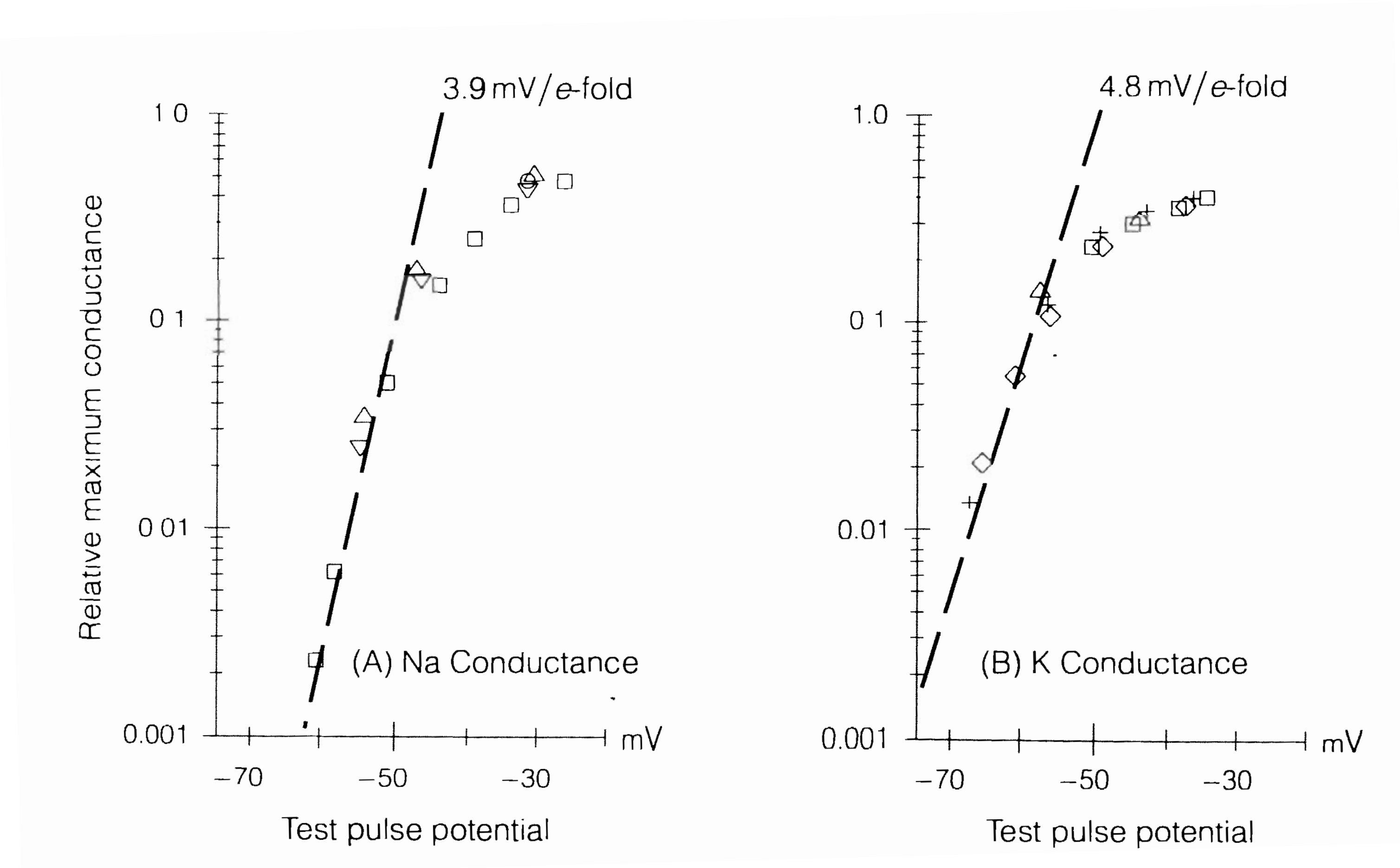
Membrane with synaptic inputs



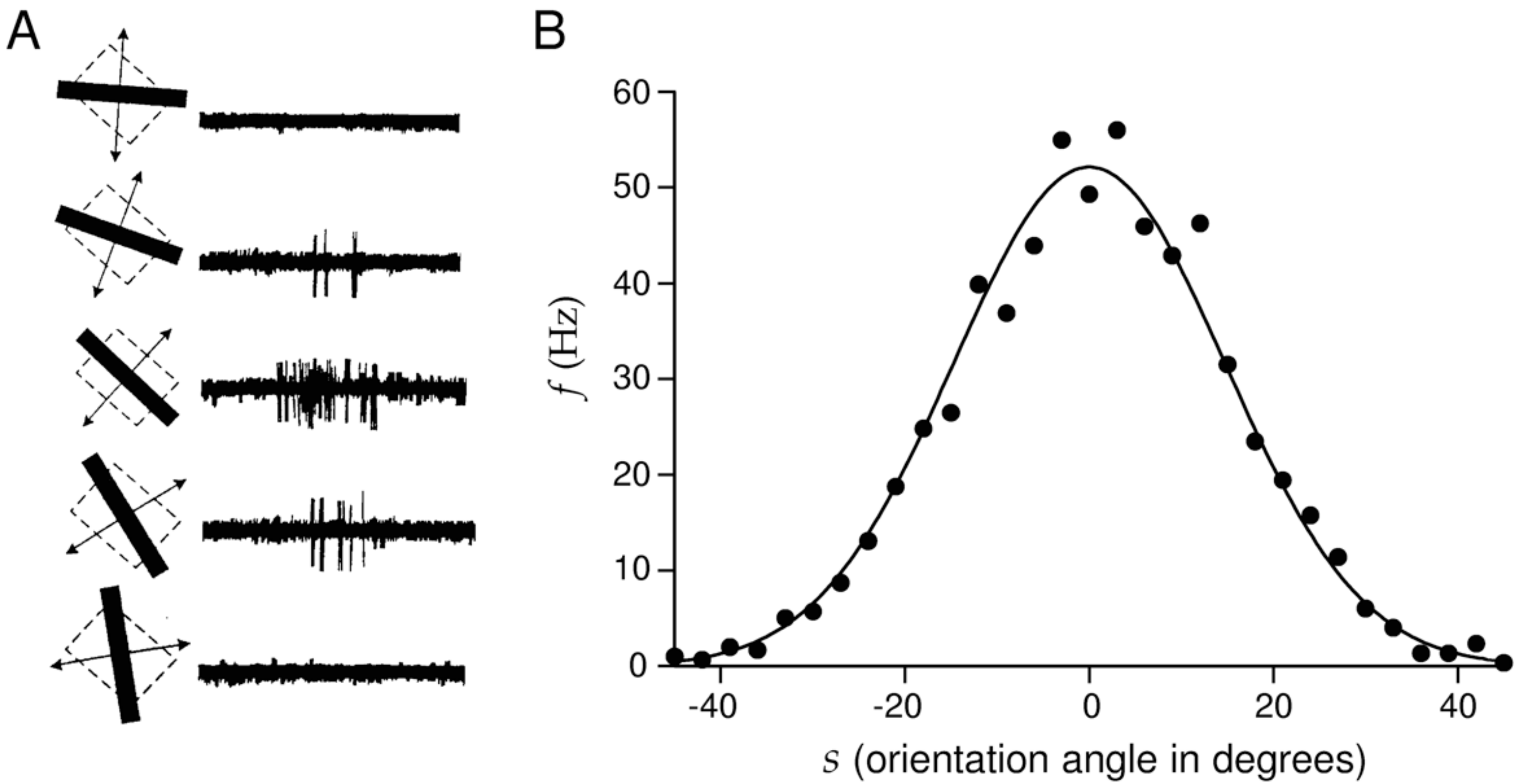
$$\tau \frac{dV}{dt} + V = \frac{V_r\, G_{\text{leak}} + V_{Na}\, \Delta G_{Na} + V_K\, \Delta G_K + V_{Cl}\, \Delta G_{Cl}}{G_{\text{total}}}$$

$$G_{\text{total}} = G_{\text{leak}} + \Delta G_{Na} + \Delta G_K + \Delta G_{Cl} \qquad \tau = \frac{C_m}{G_{\text{total}}}$$

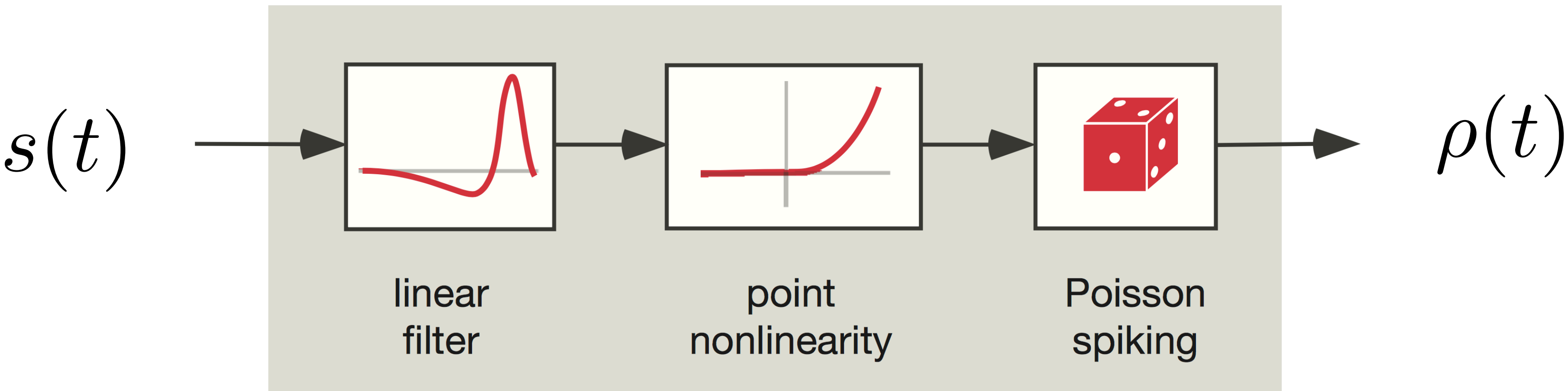
Voltage-gated channels



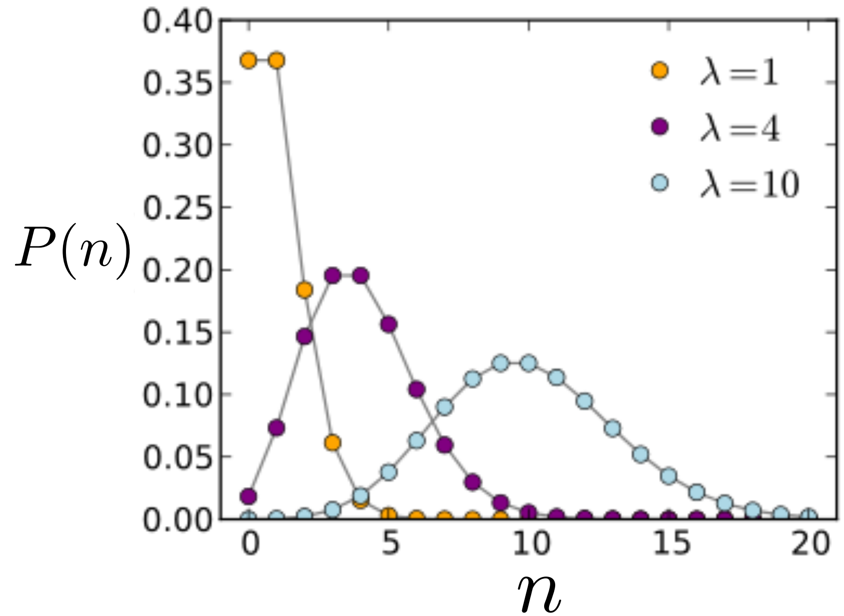
Rate coding hypothesis: the signal conveyed by a neuron is in the *rate* of spiking. Spiking irregularity is largely due to noise and does not convey information.



Linear - non-linear - Poisson (LNP) model

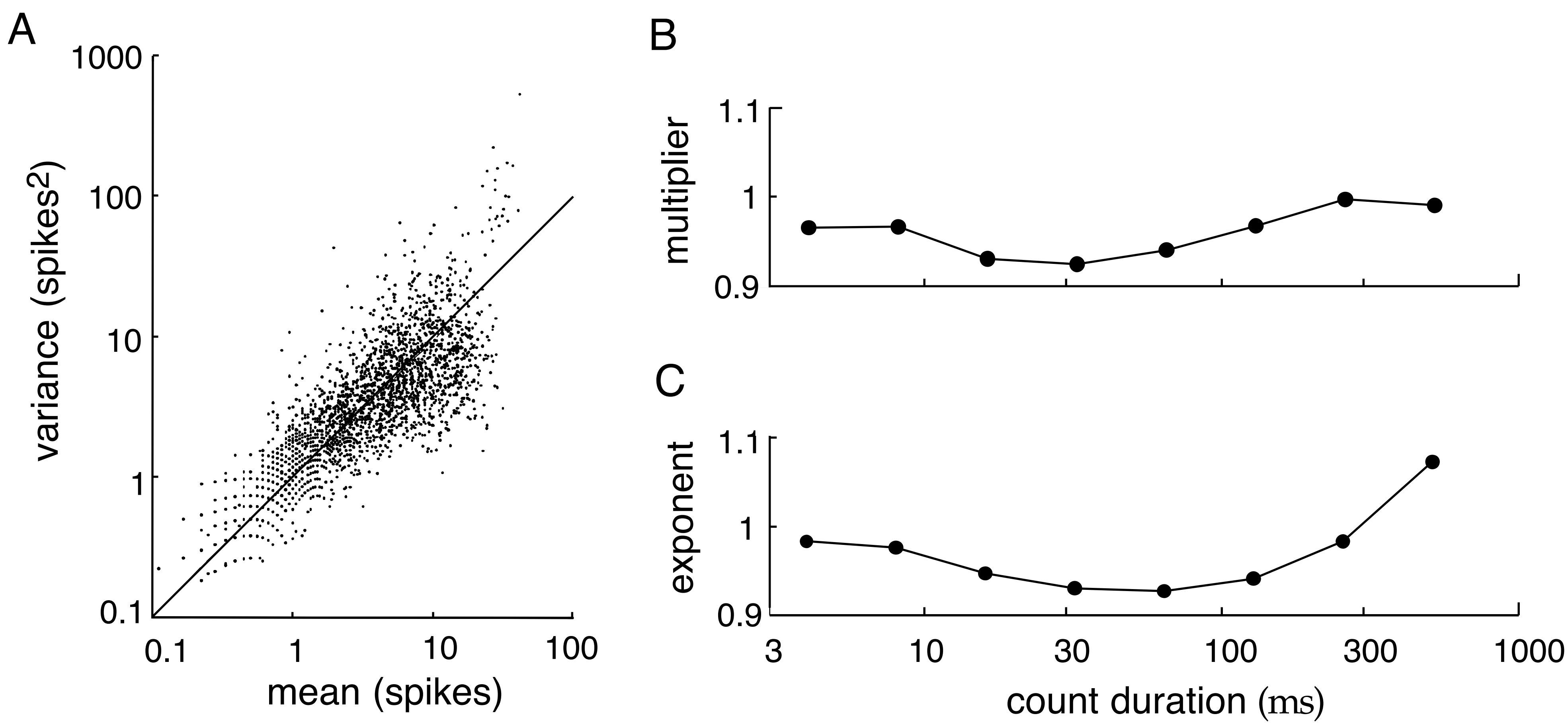


$$P(n) = \frac{\lambda^n \, e^{-\lambda}}{n!}$$



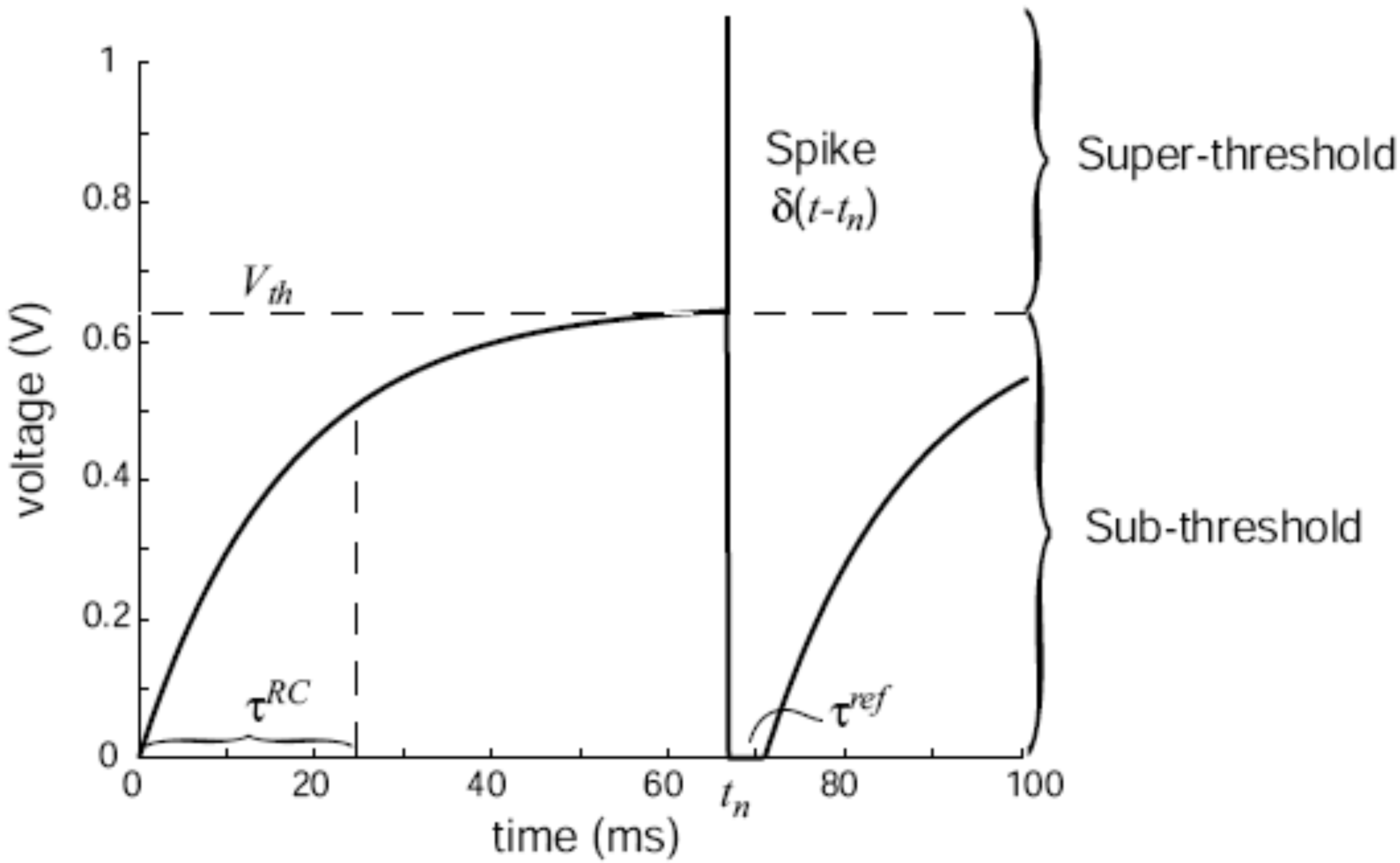
MT neurons
Alert macaque monkey
256 ms window

Fit of $\sigma^2(n) = A \langle n \rangle^B$

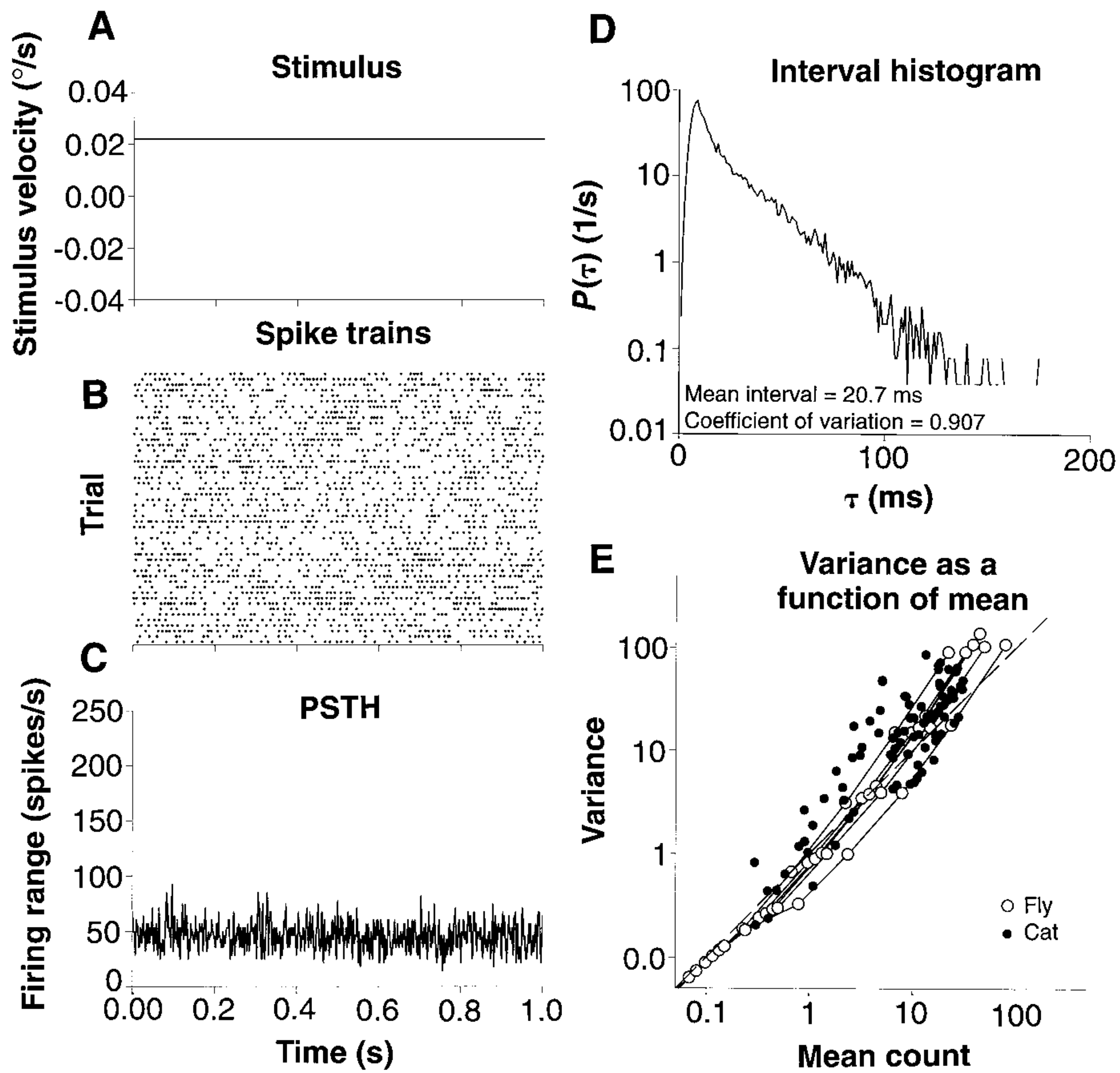


Dayan & Abbott, Figure 1.14

Leaky integrate-and-fire neuron

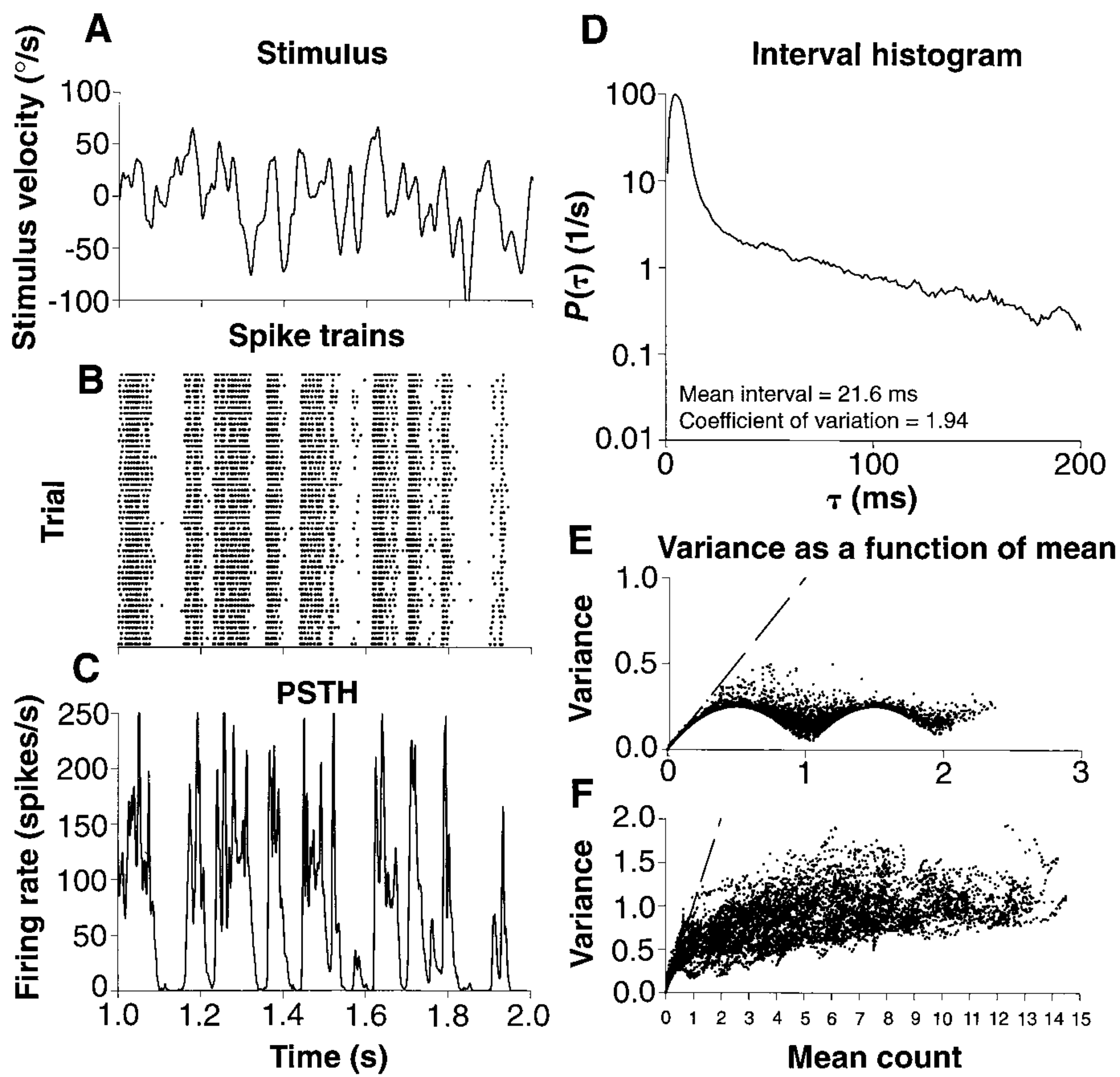


Fly H1 neuron - constant stimulus
(de Ruyter et al., 1997)



Fly H1 neuron - time-varying stimulus

(de Ruyter et al., 1997)

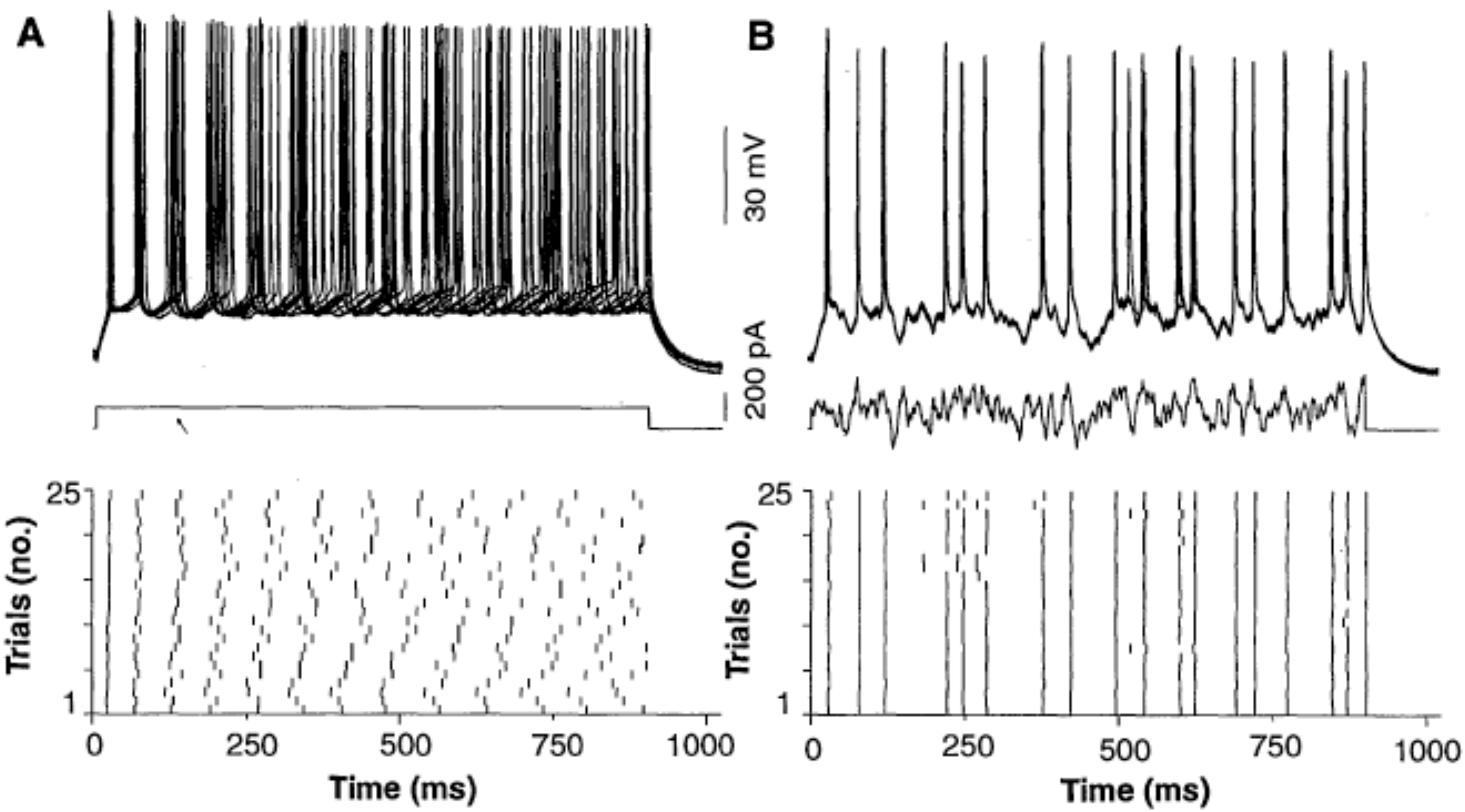


10 ms window

100 ms window

Spike timing can be very precise in response to *time-varying* signals

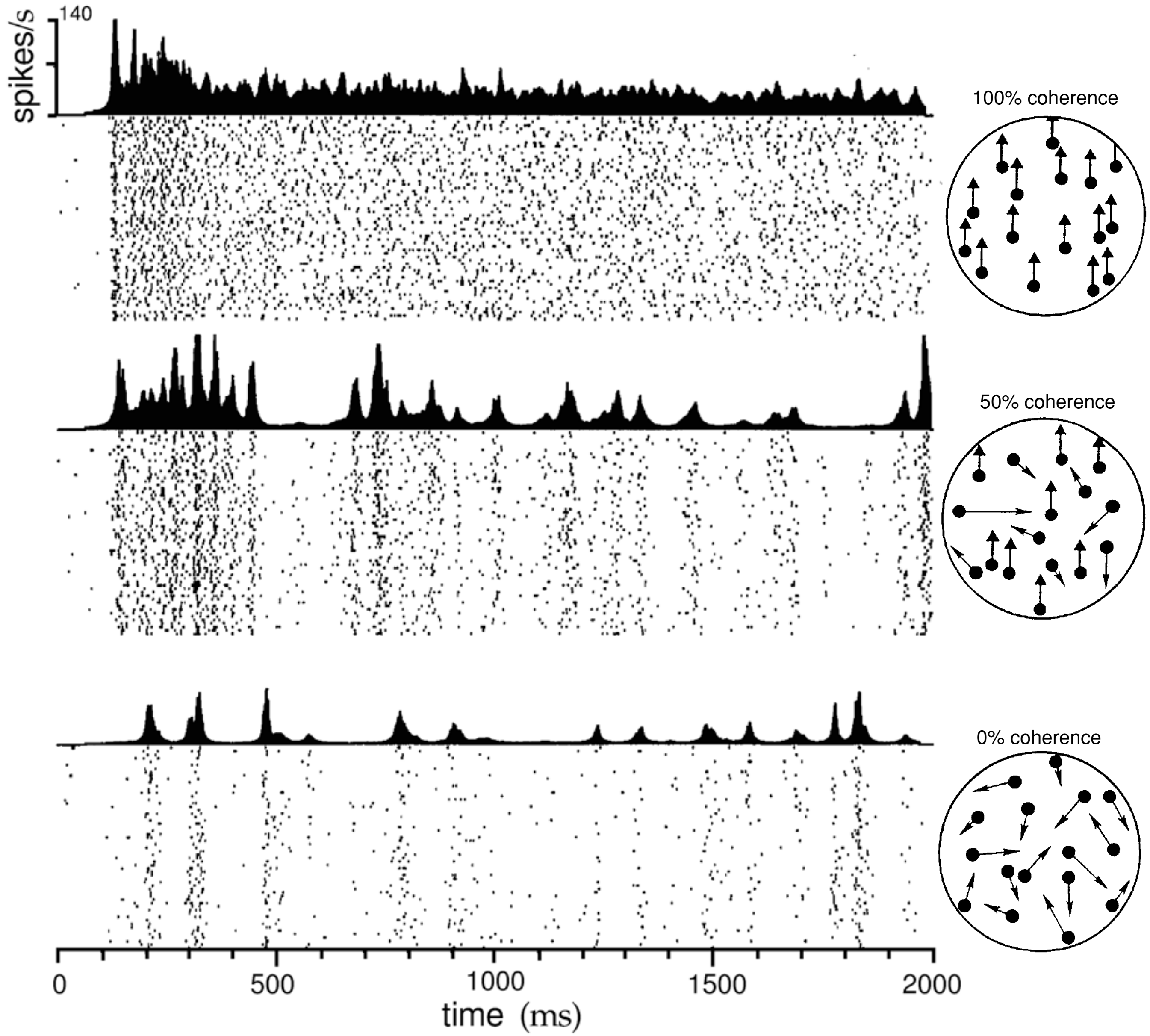
Mainen & Sejnowski (1995)



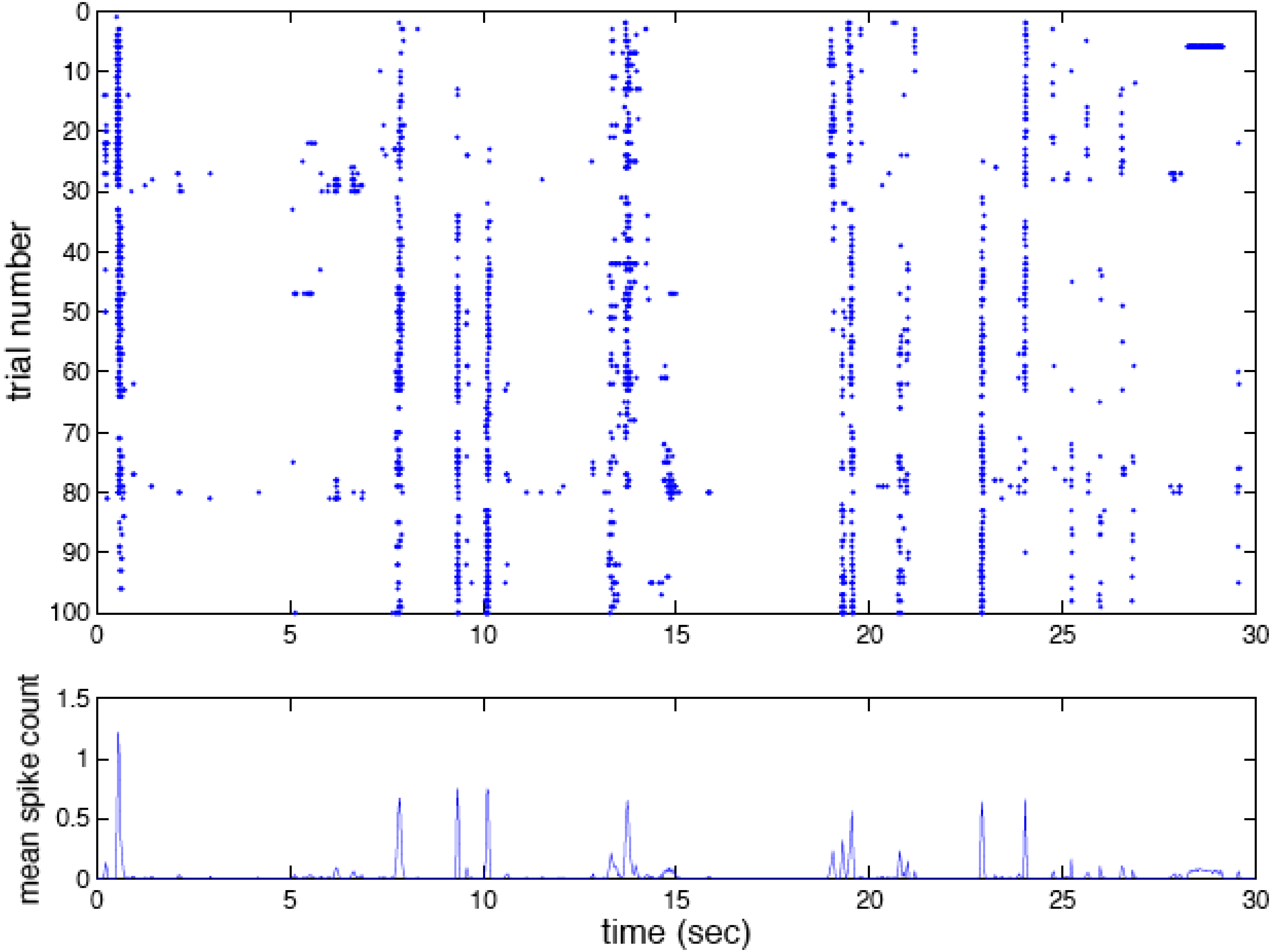
Spike timing can be *very precise* in response to time-varying signals

MT neuron response to stochastic moving dot stimuli at different levels of coherence (Newsom lab)

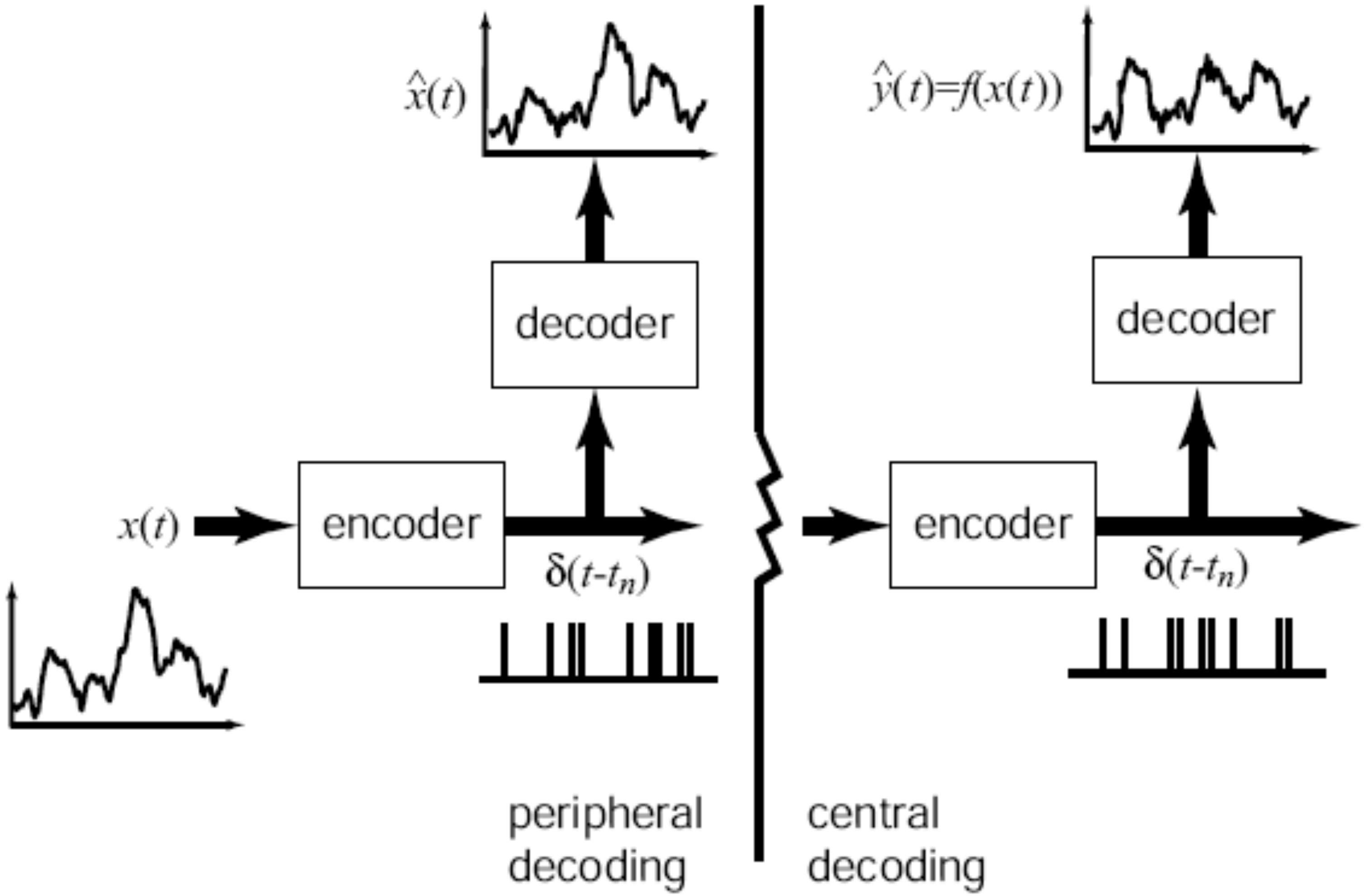
Analysis by Bair & Koch (1996)
"This suggests that temporal dynamics of a higher order than those found in rigid translation are necessary to induce a specific and unique time course in the spike discharge pattern."

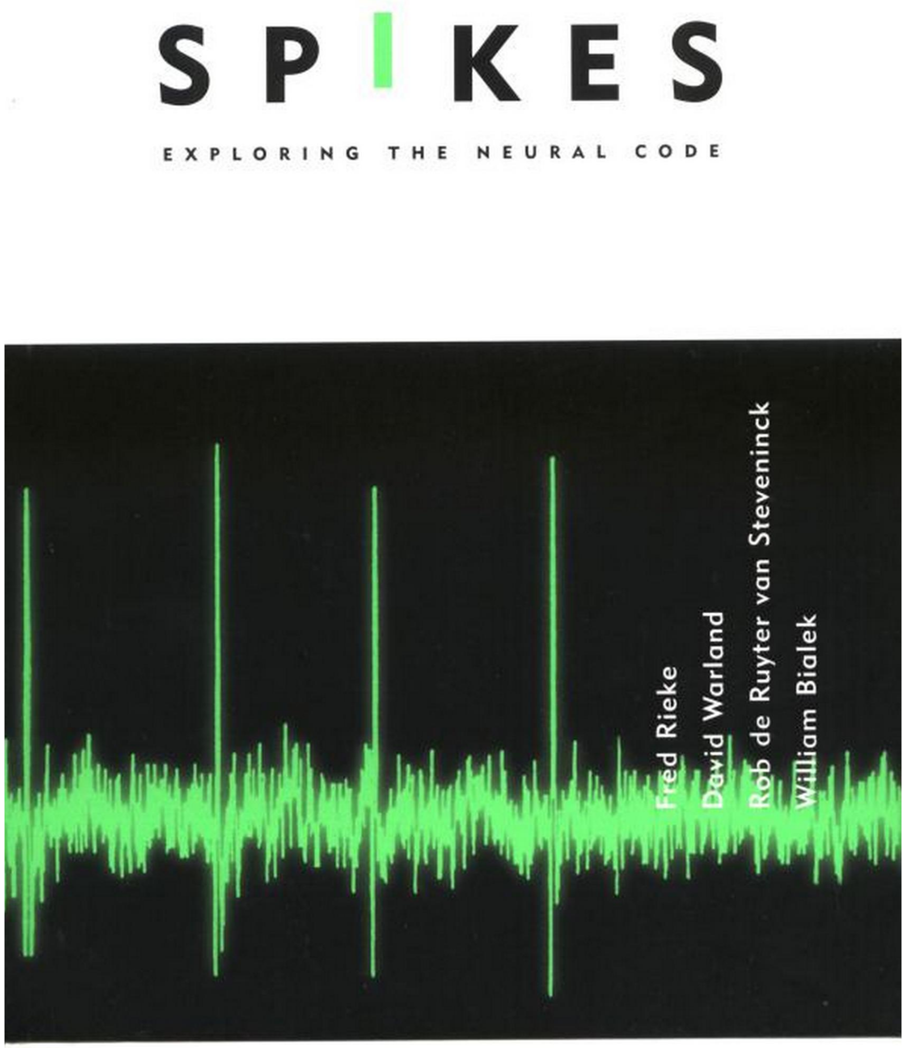


Cat V1 - natural movies (J. Baker, S.C. Yen, C.M. Gray, MSU Bozeman)



Neural encoding and decoding

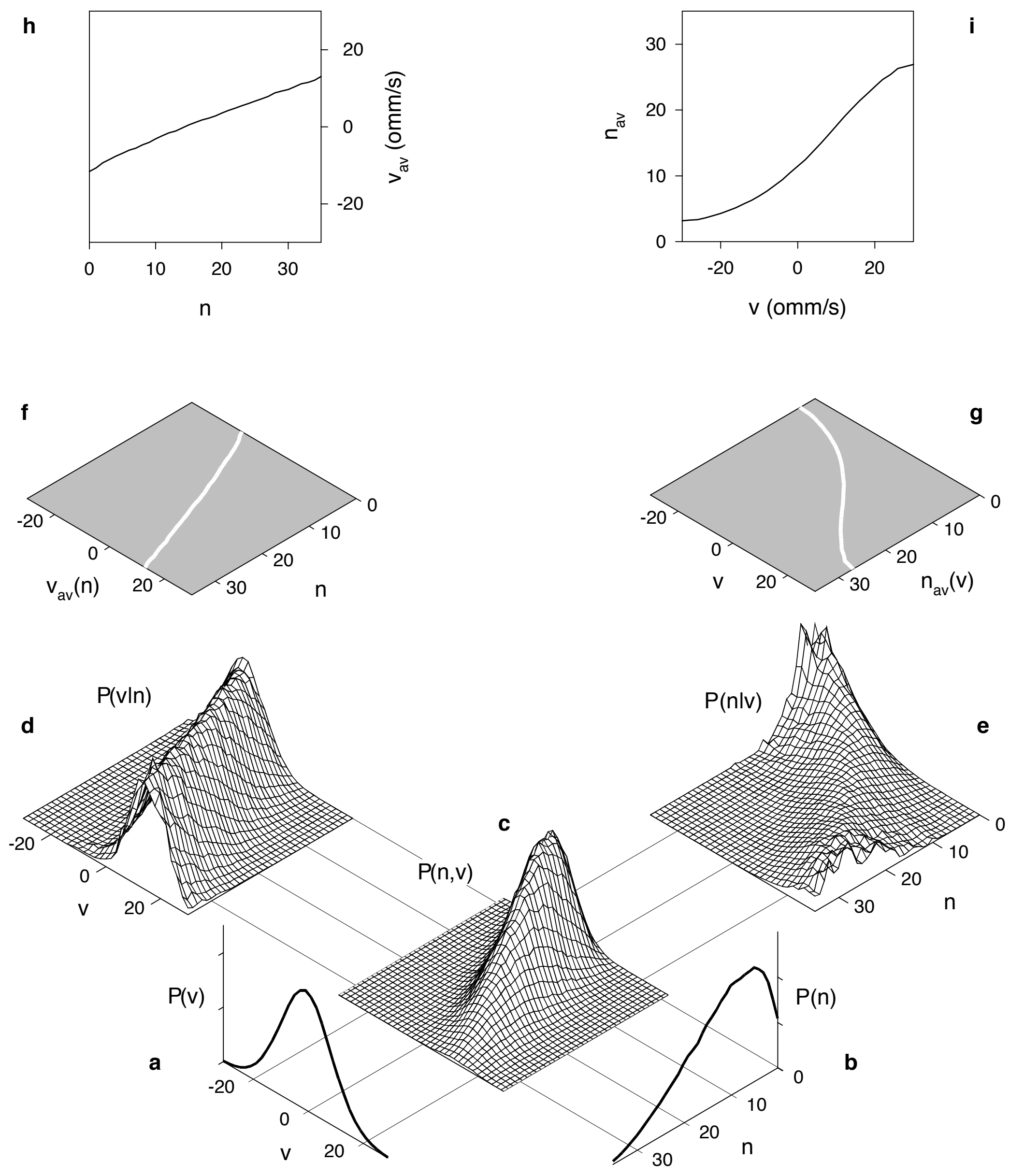




MIT Press (1997)

MIT Press (2002)

Encoding and decoding are related through the joint distribution over *stimulus* (v) and *response* (n)



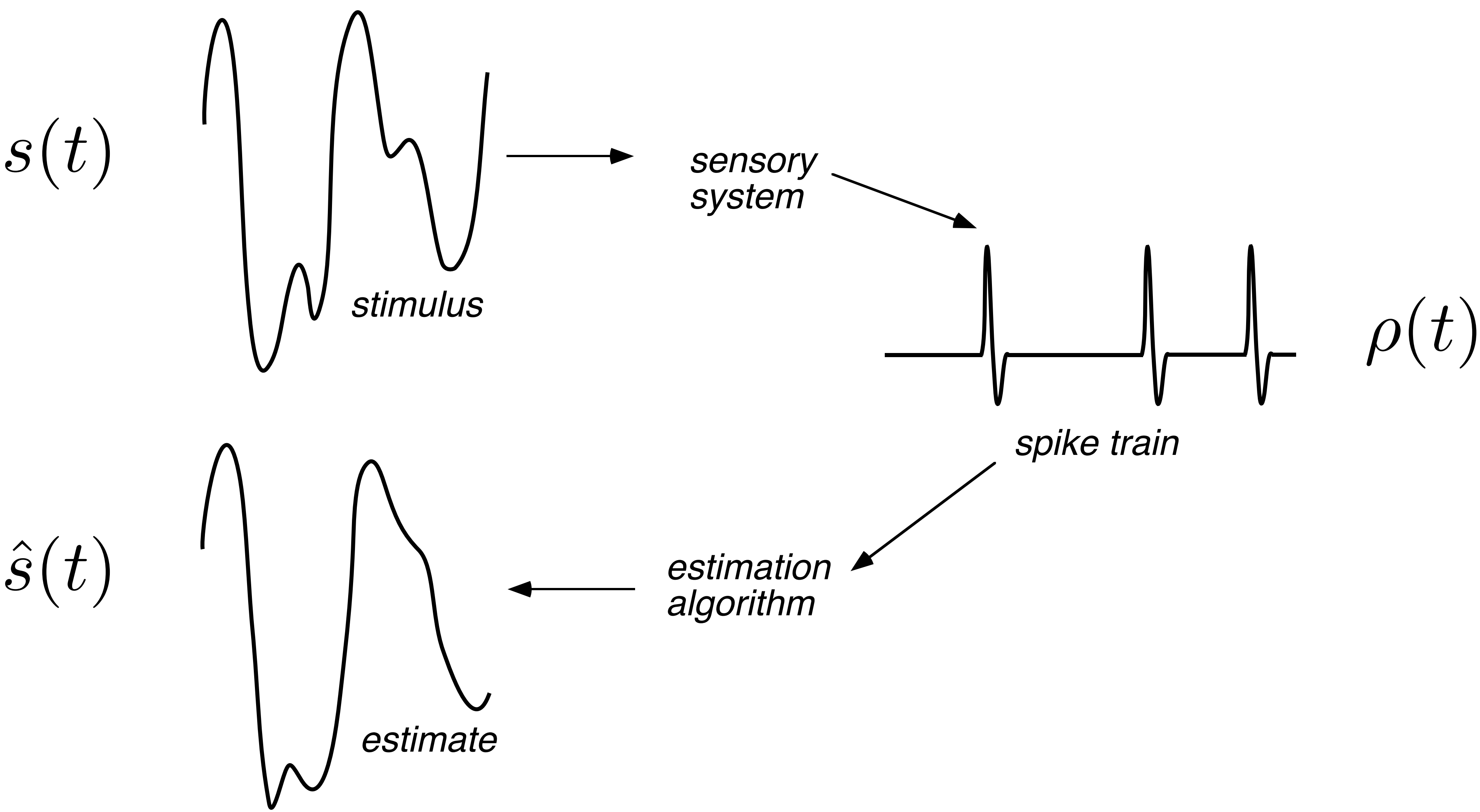
decoding

$\hat{v} = g(n)$

encoding

$n = f(v)$

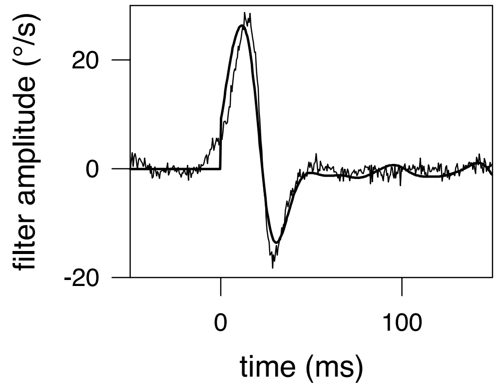
(from *Spikes*)



From *Spikes*, by Rieke, Warland, de Ruyter, & Bialek

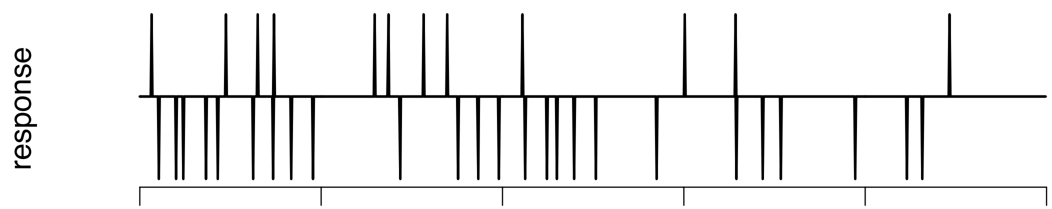
Reconstruction kernel

$k(t)$



Fly H1 neuron response

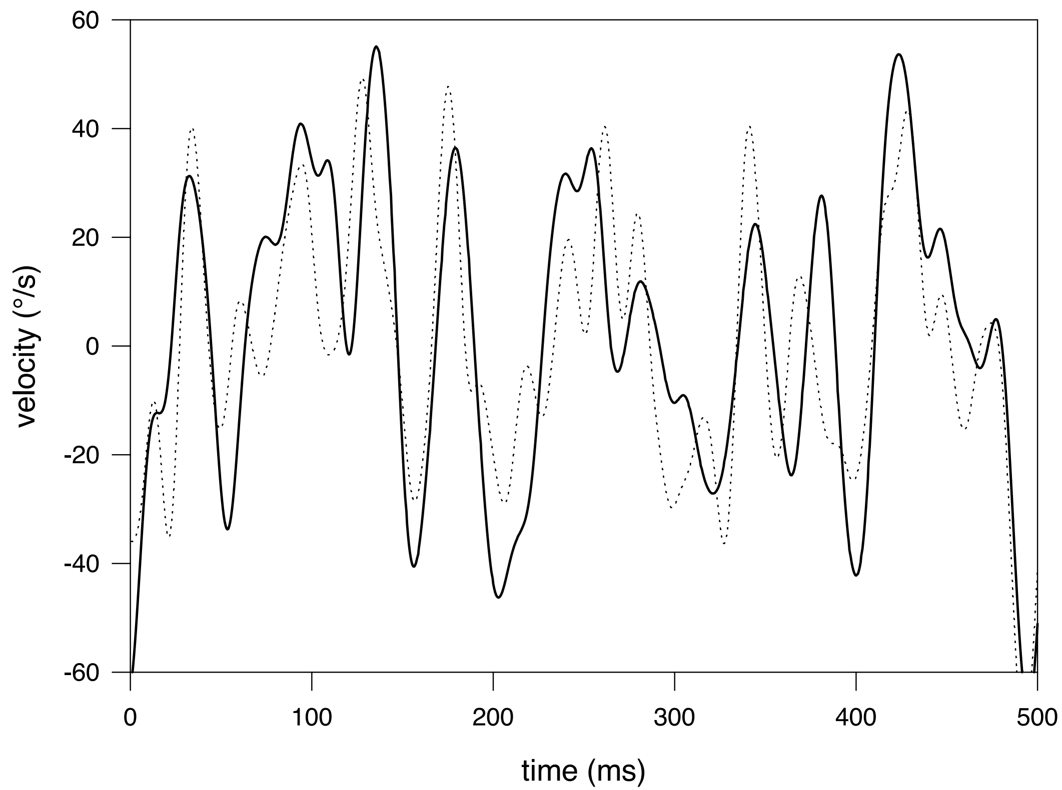
$\rho(t)$



Stimulus reconstruction

$$\hat{s}(t) = \rho(t) * k(t)$$

$$\hat{k}(t) = \arg\min_{k(t)} \left\langle [s(t) - \rho(t) * k(t)]^2 \right\rangle$$



From *Spikes*, by Rieke, Warland, de Ruyter, & Bialek

Strategy for estimating information rate

1. Estimate signal from spikes

$$\rho(t) \to \hat{s}(t)$$

2. Compute noise in estimate

$$\tilde{n}(\omega) = \tilde{s}(\omega) - \hat{\tilde{s}}(\omega)$$

3. Compute SNR

$$\mathrm{SNR}(\omega) = \frac{\langle |\tilde{s}(\omega)|^2 \rangle}{\langle |\tilde{n}(\omega)|^2 \rangle}$$

4. Calculate lower bound to information rate from SNR

$$R = \frac{1}{2} \int \frac{d\omega}{2\pi} \log_2 [1 + \mathrm{SNR}(\omega)]$$

Adapted from *Spikes*, by Rieke, Warland, de Ruyter, & Bialek

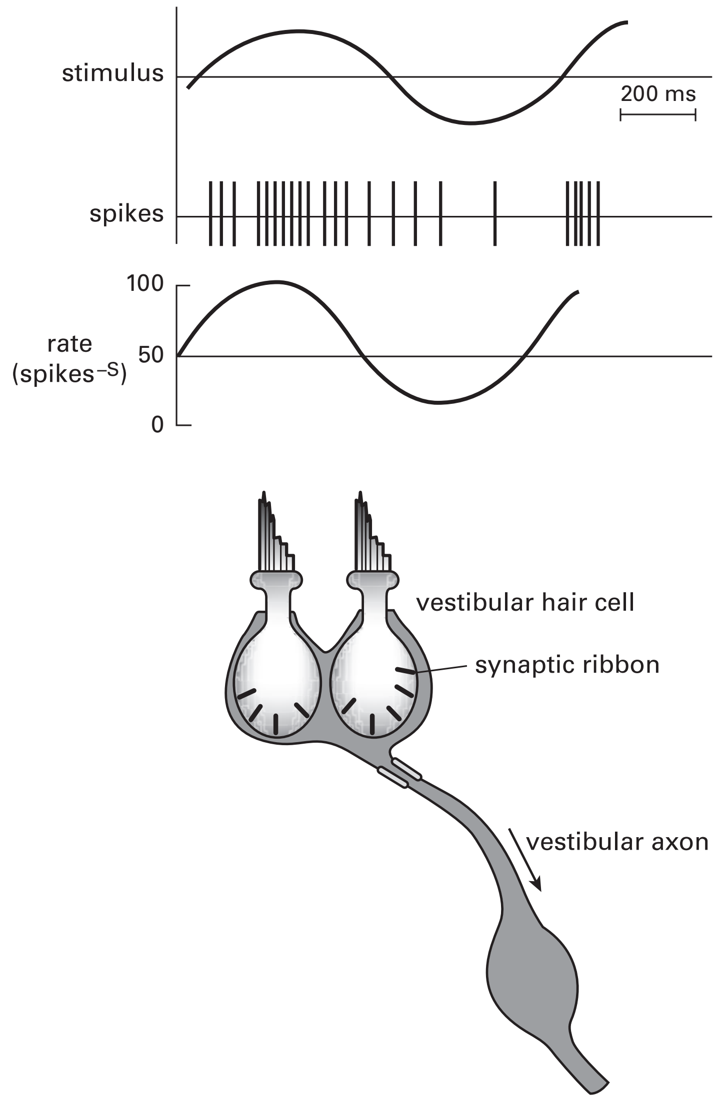
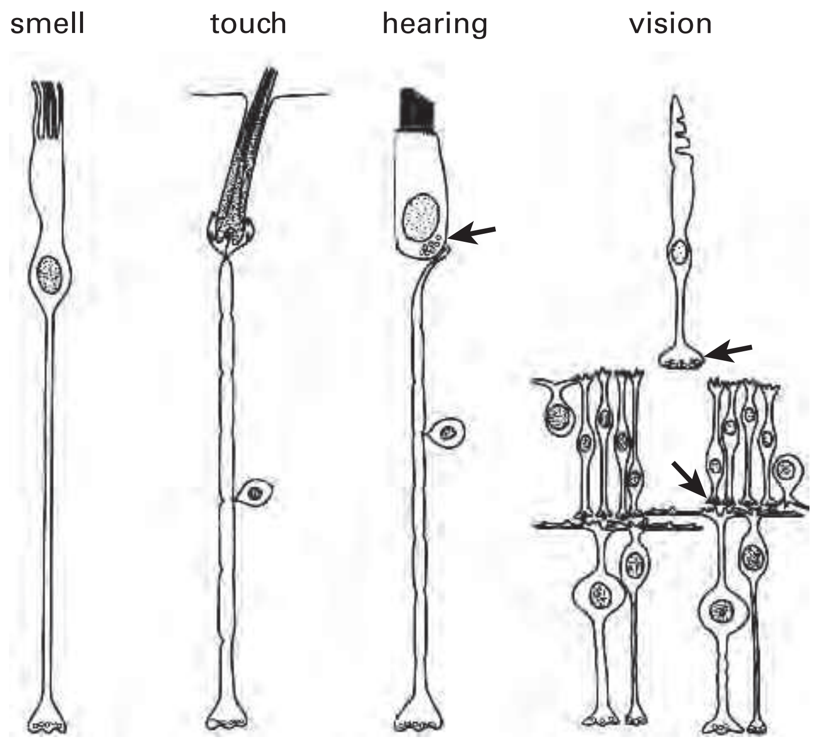
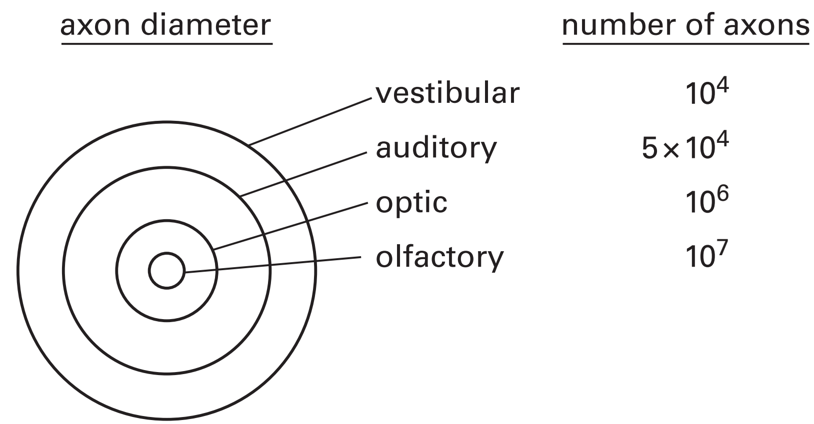


Figure 10.5

Vestibular hair cells, transducing low frequencies, can sum their analogue signals before recoding to spikes. Upper: Head rotates slowly (1 Hz). Spikes from second-order vestibular axon are modulated linearly through the full cycle around 50 spikes per second. **Lower:** Adjacent hair cells each converge multiple active zones onto single afferent fiber. Modified from Eatock et al. (2008).

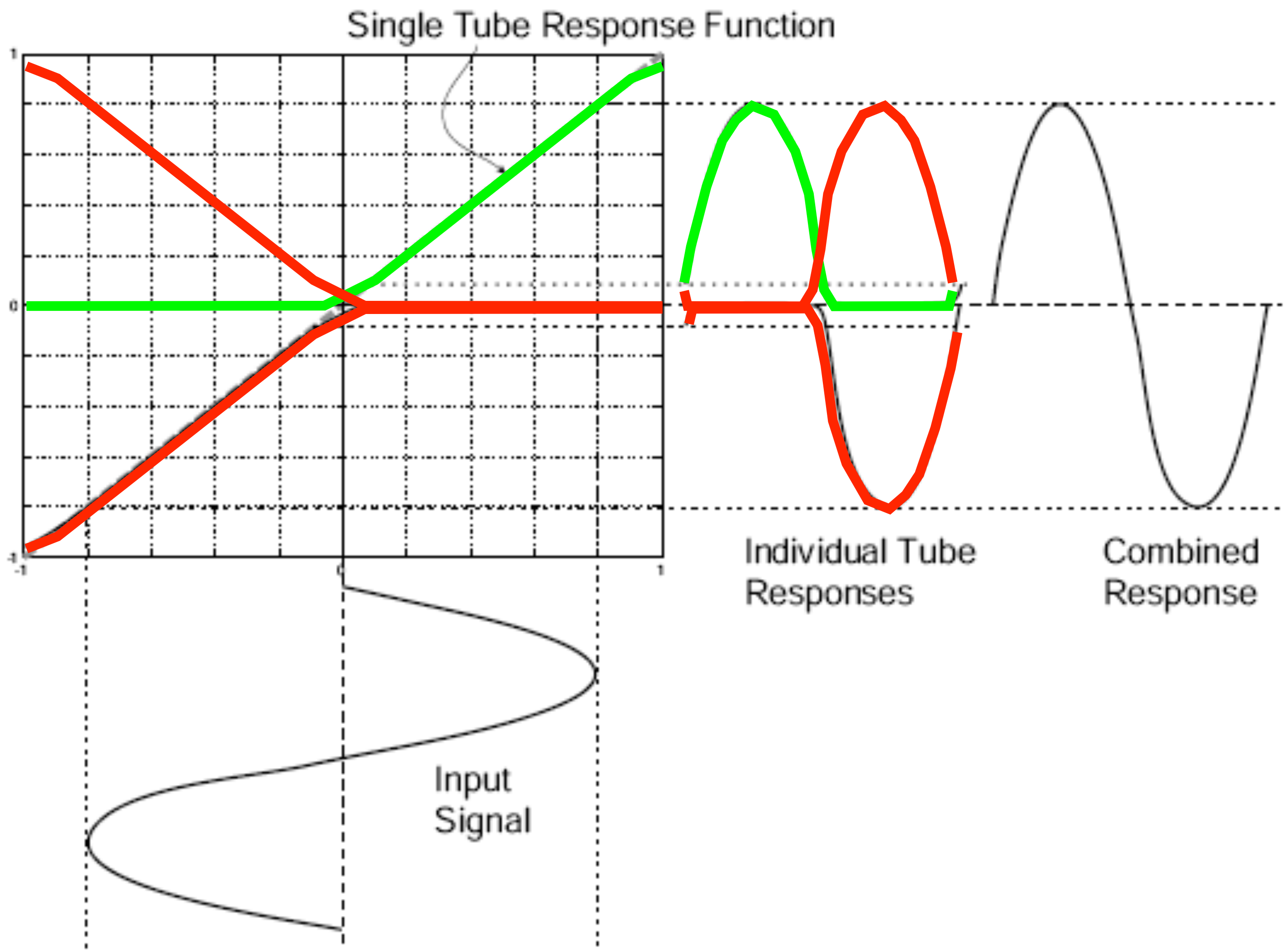
From Sterling & Laughlin





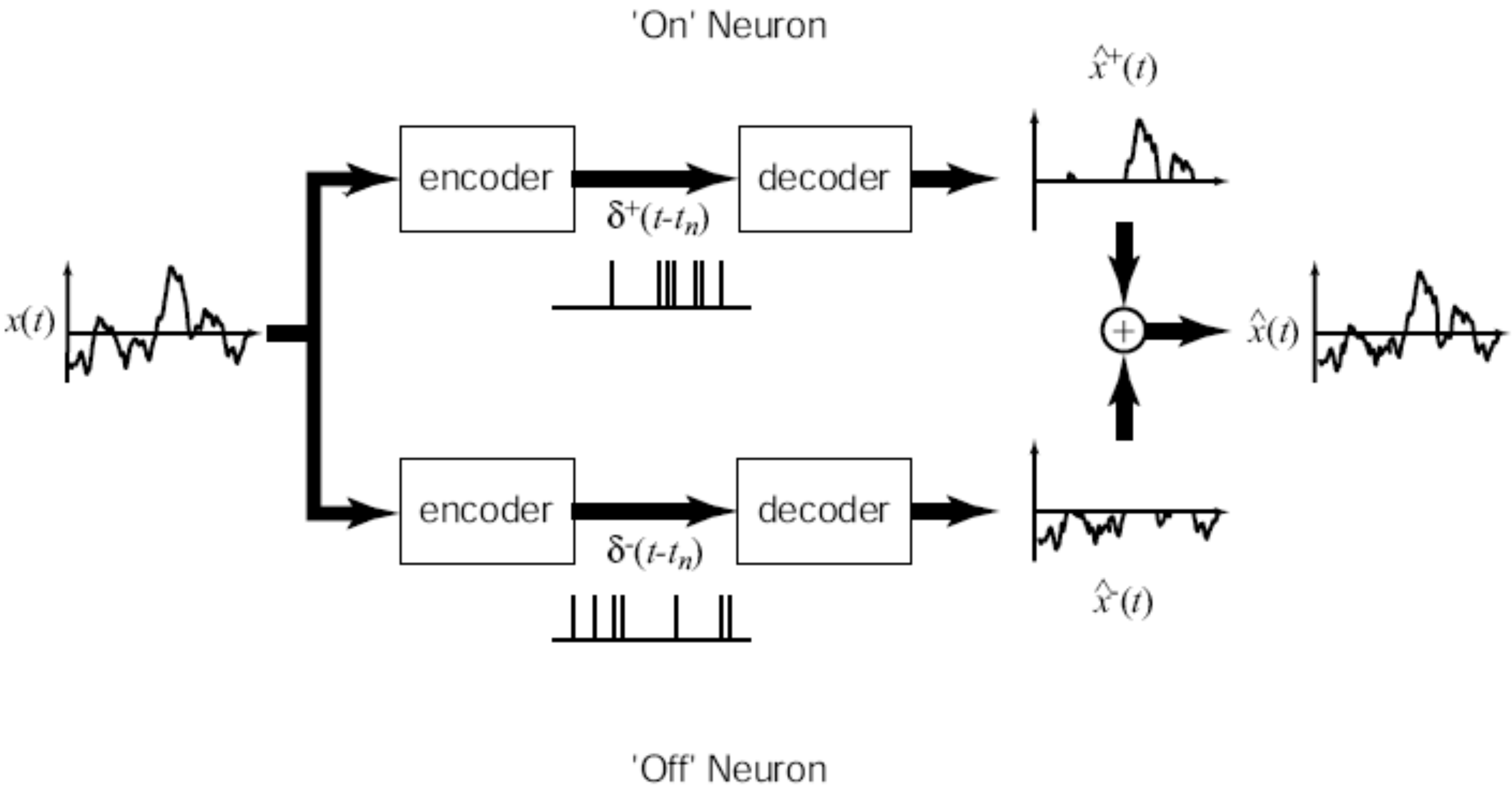
From Sterling & Laughlin

Neural responses are half-wave rectified (action potentials are positive-only). Signals are thus combined in a push-pull fashion, similar to push-pull amplifiers.



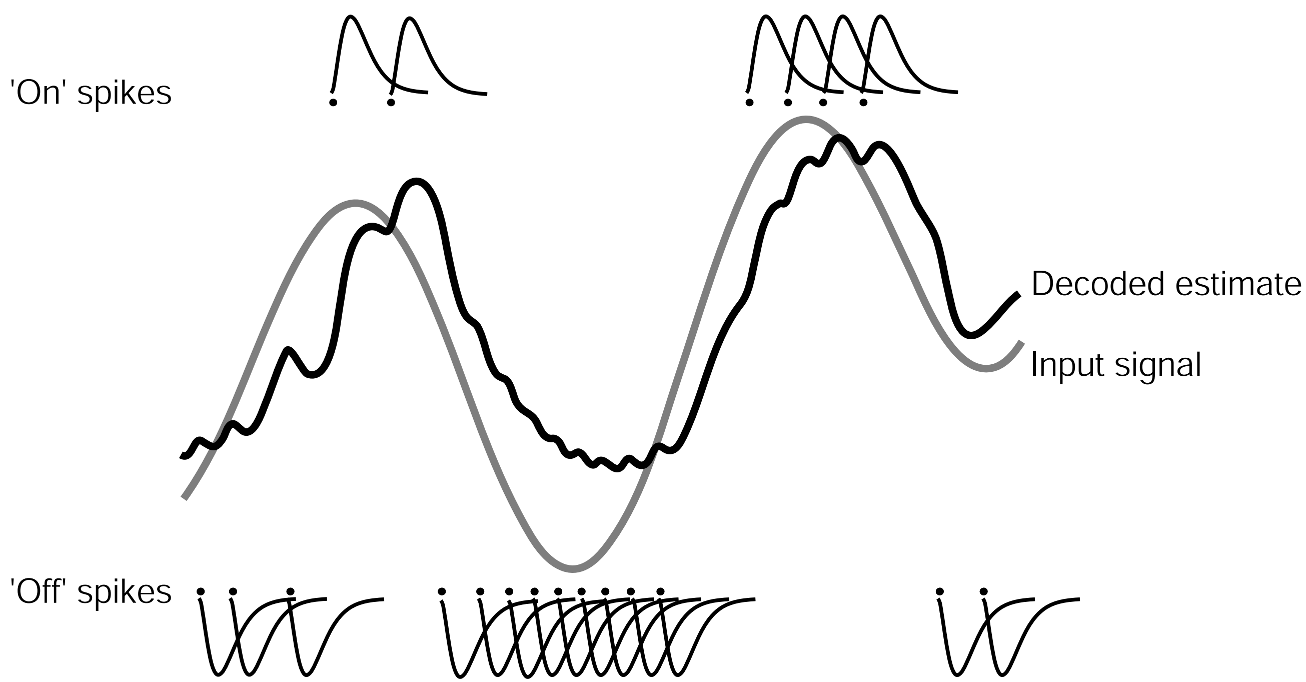
From: *Neural Engineering*, by Eliasmith & Anderson

Push-Pull decoding



From: *Neural Engineering*, by Eliasmith & Anderson

$$\hat{x}(t) = \sum_{i,k}^{M} \phi_i \delta(t - t_{ik}) * h(t)$$
$$= \sum_{i,k}^{M} \phi_i h(t - t_{ik}).$$



LIF encoding and decoding
(Eliasmith & Anderson, 2003)