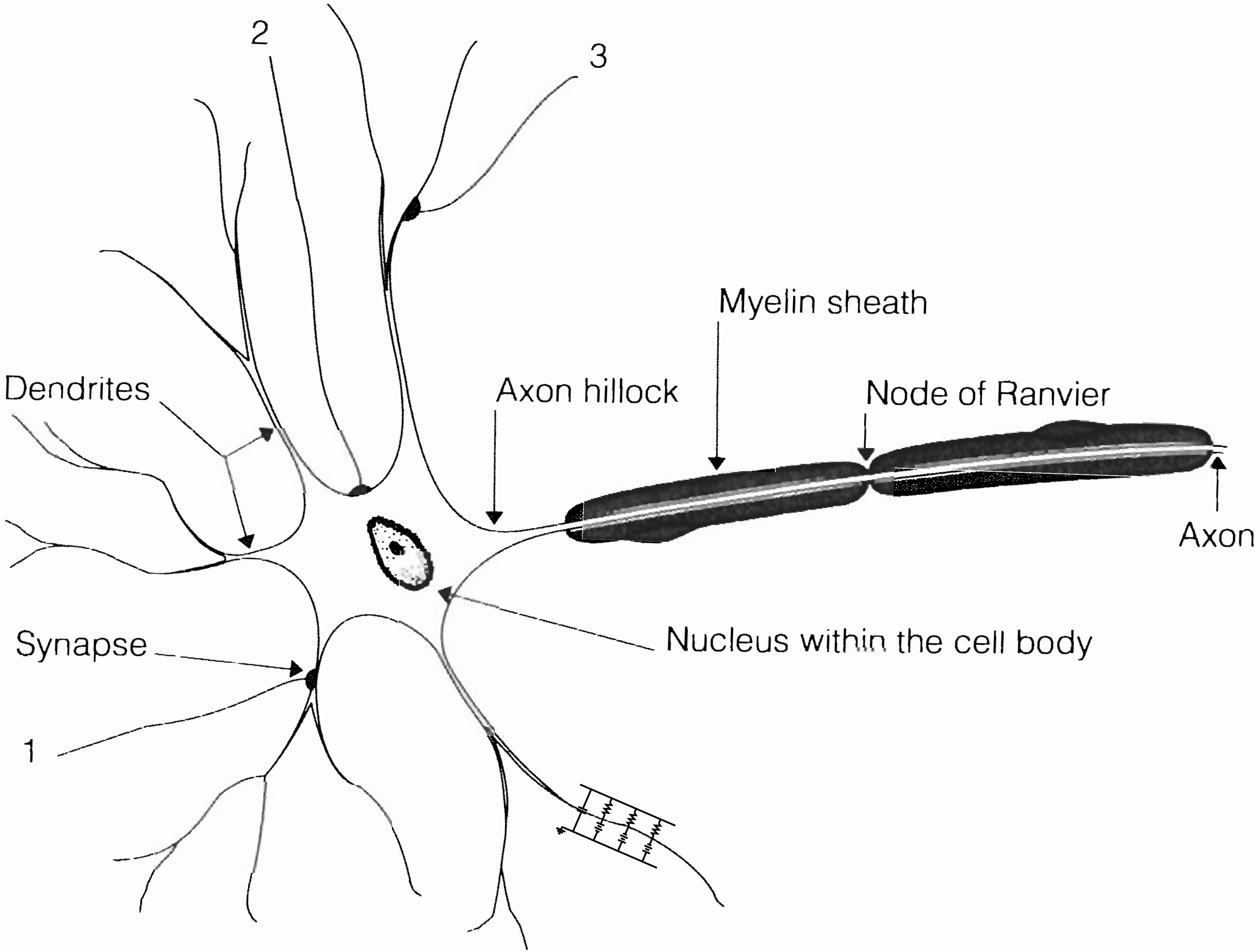
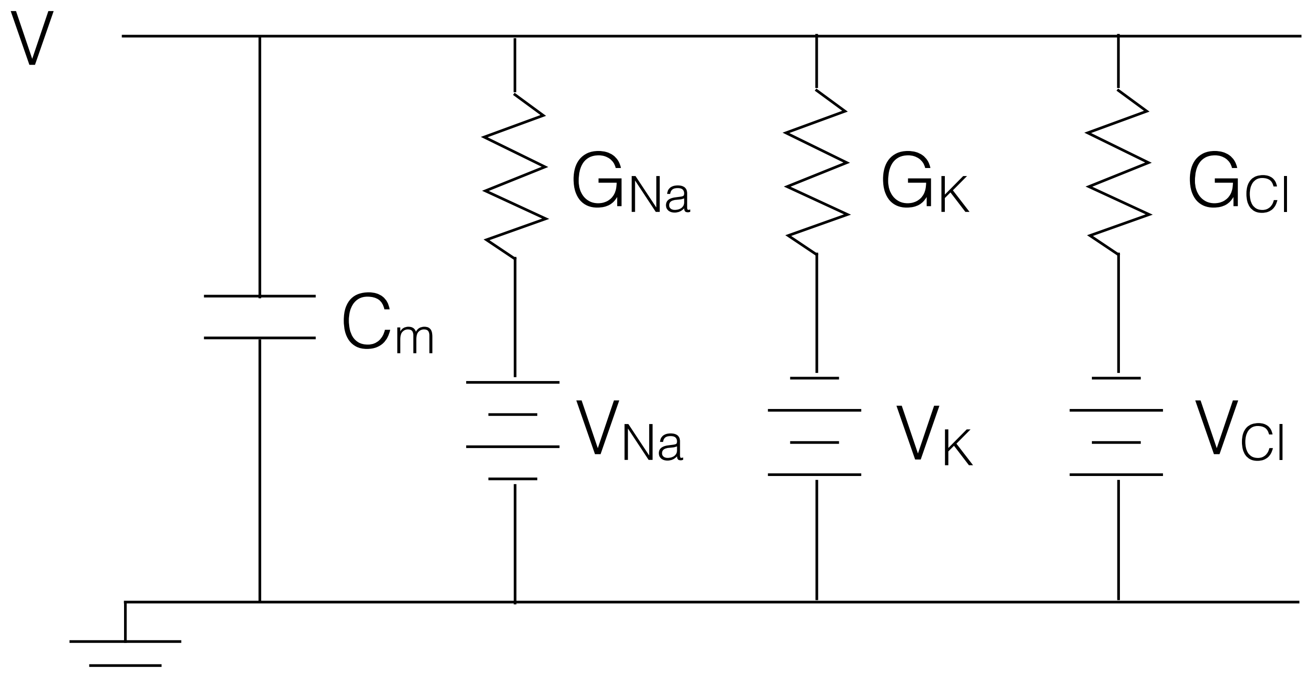
Spiking neurons


2
3
Myelin sheath
Dendrites
Axon hillock
Node of Ranvier
Axon
Synapse
Nucleus within the cell body
1

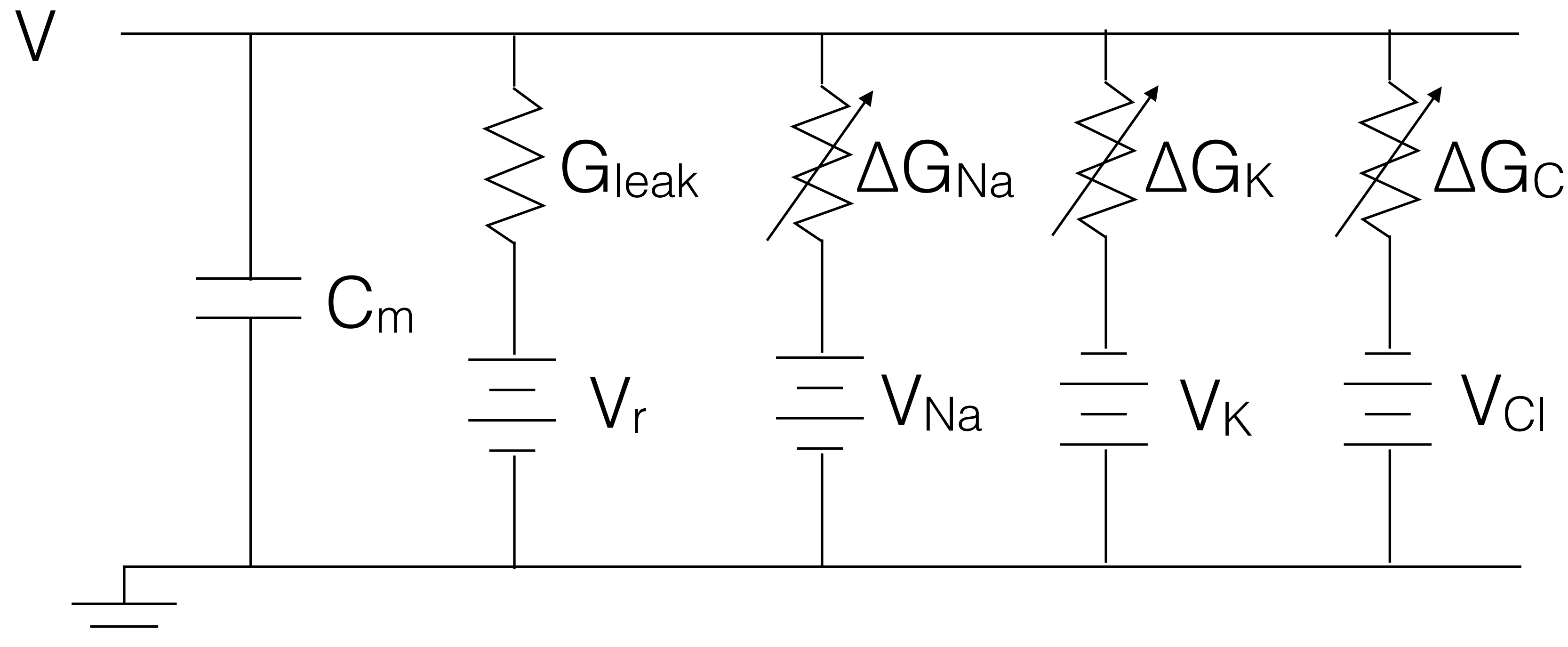
Membrane equation



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

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

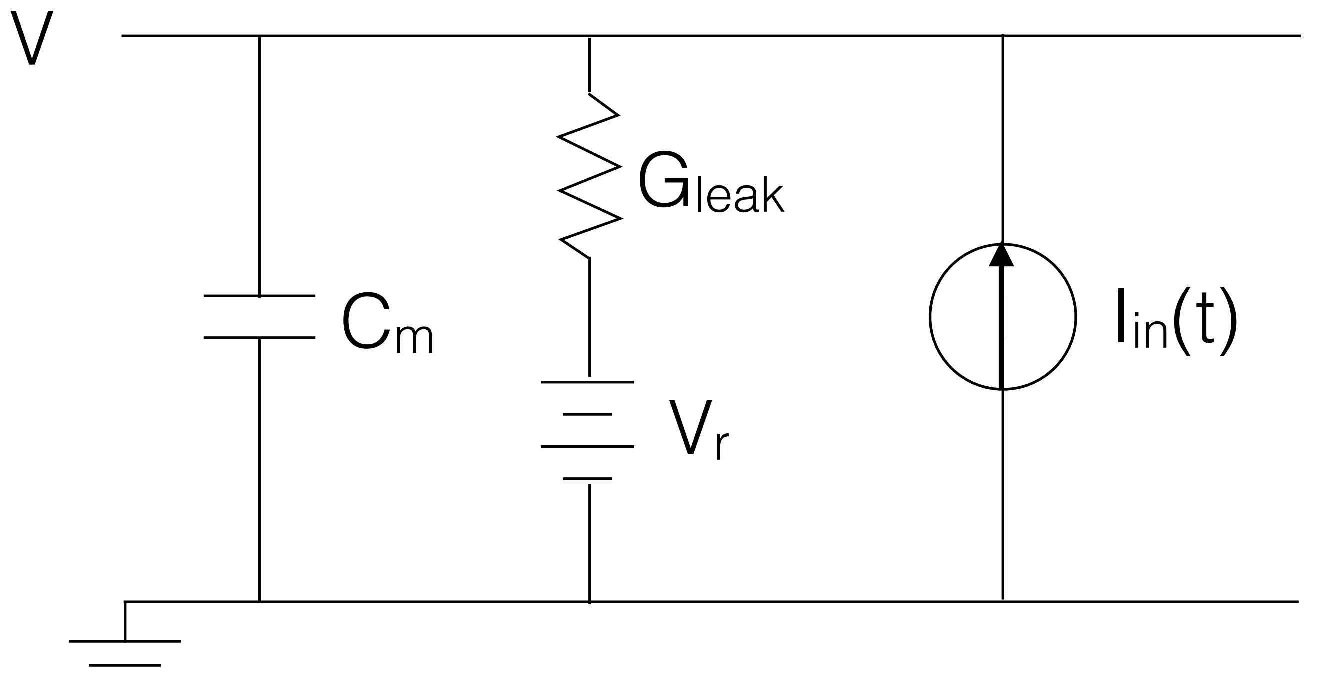
Membrane with synaptic inputs



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

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

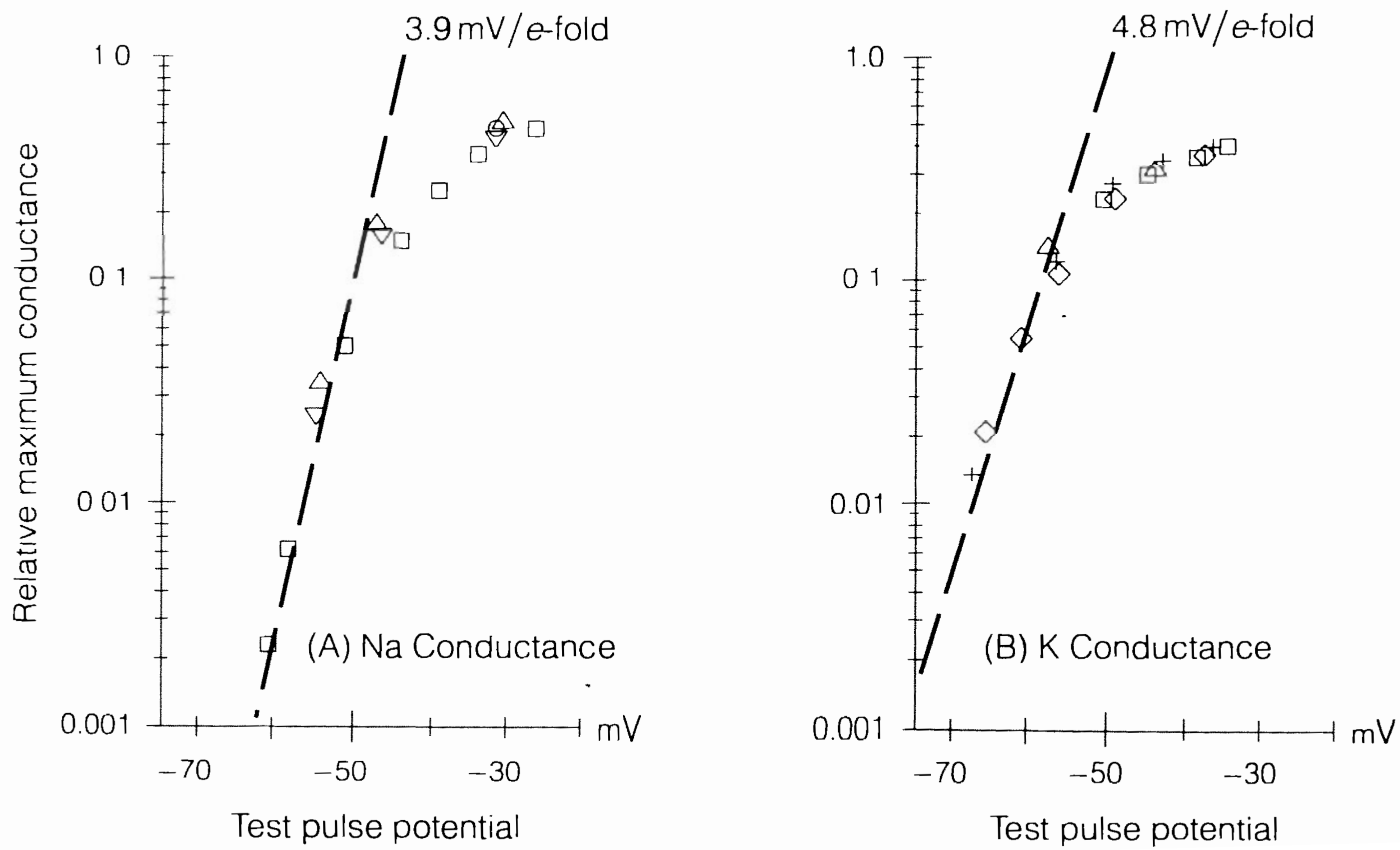
Membrane with input current



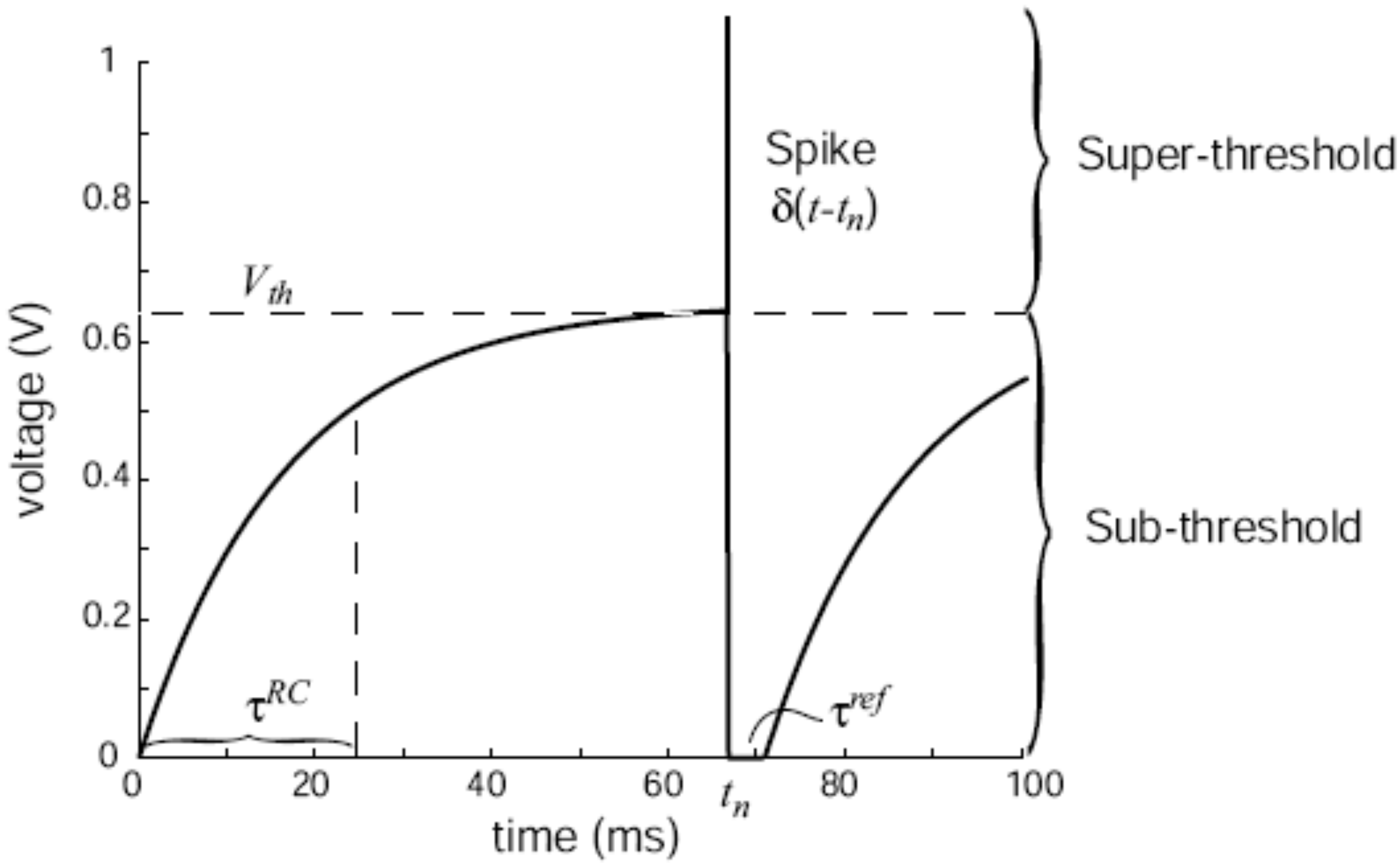
$$\tau \frac{dV}{dt} + V = V_r + \frac{1}{G_{\text{leak}}} I_{\text{in}}(t)$$

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

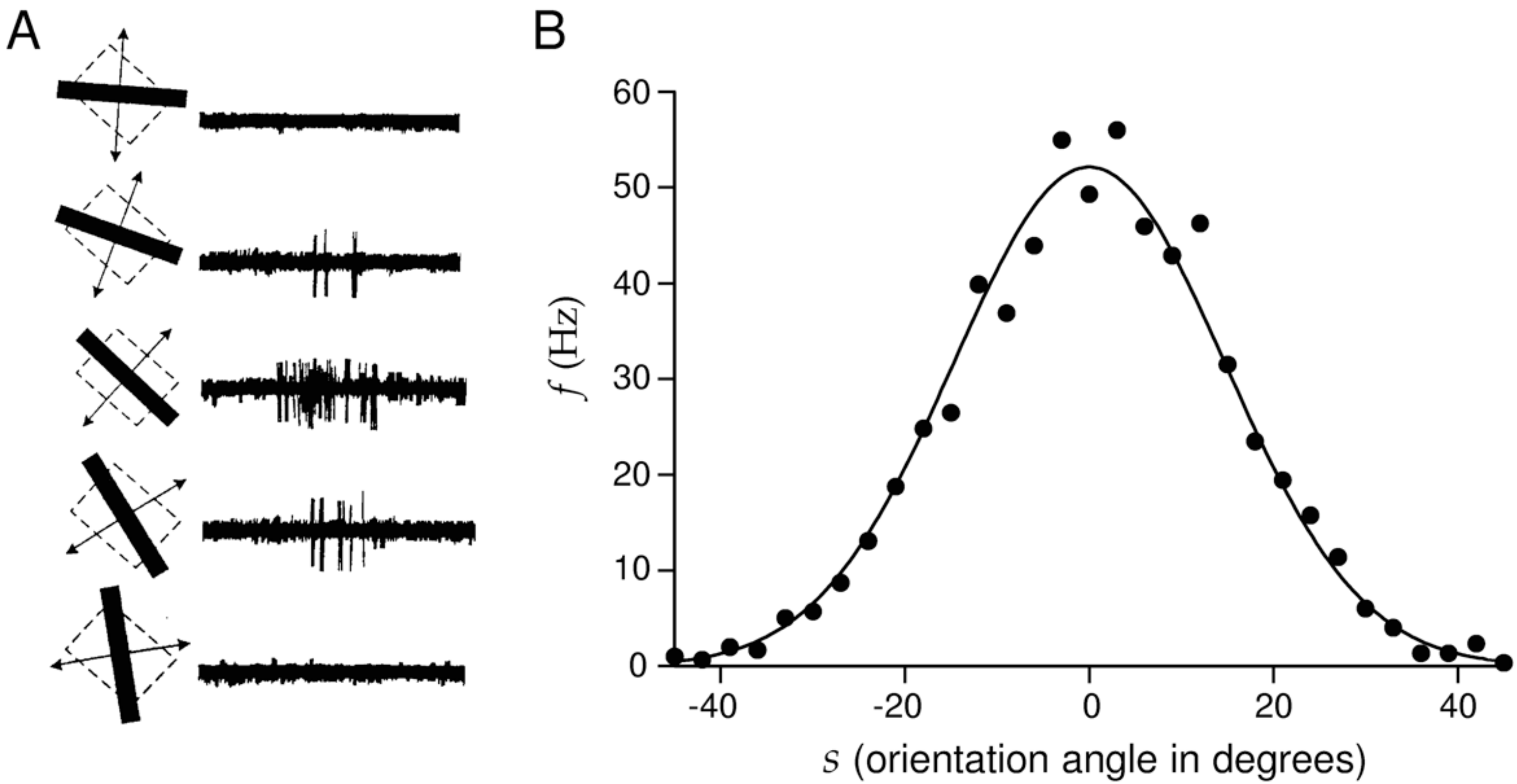
Voltage-gated channels



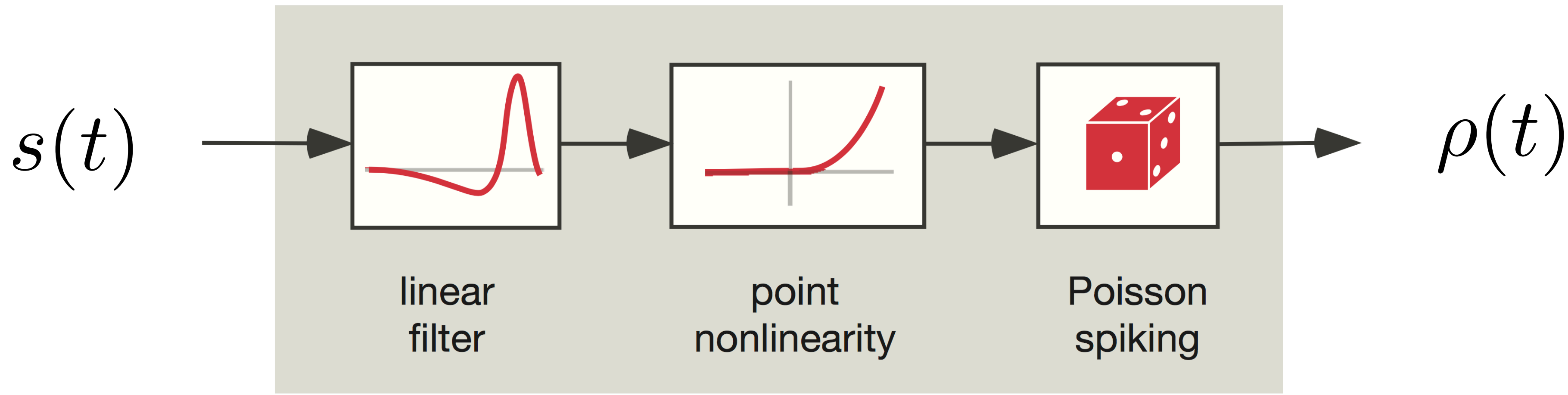
Leaky integrate-and-fire neuron



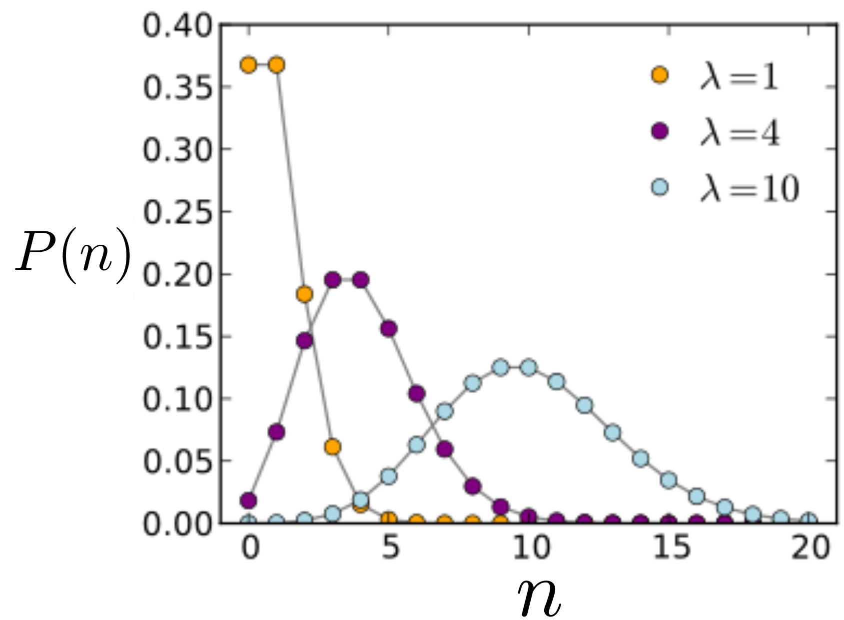
Rate coding hypothesis: the signal conveyed by a neuron is in the *rate* of spiking. Spiking irregularity is largely due to noise and does not convey information.



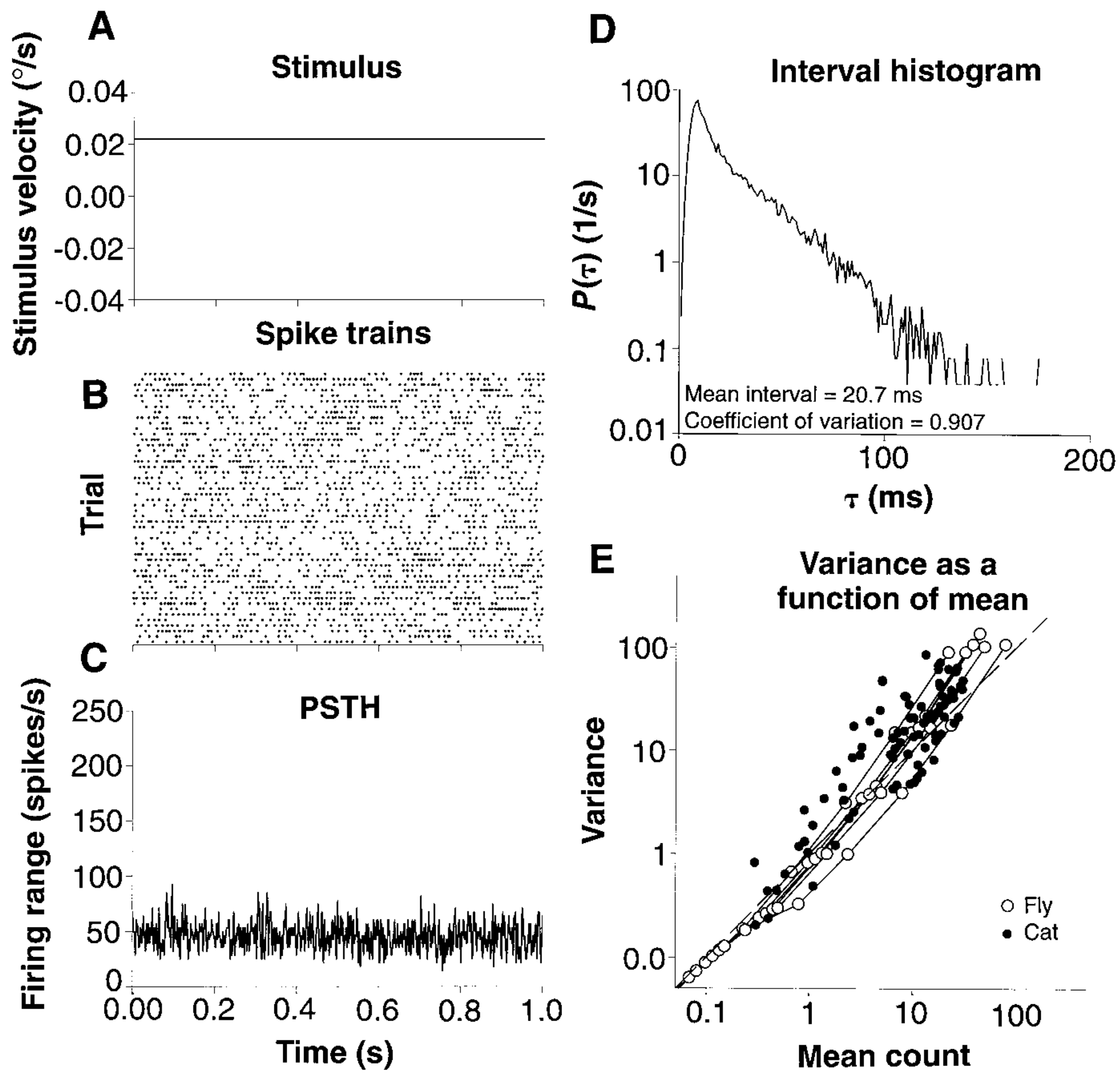
Linear - non-linear - Poisson (LNP) model



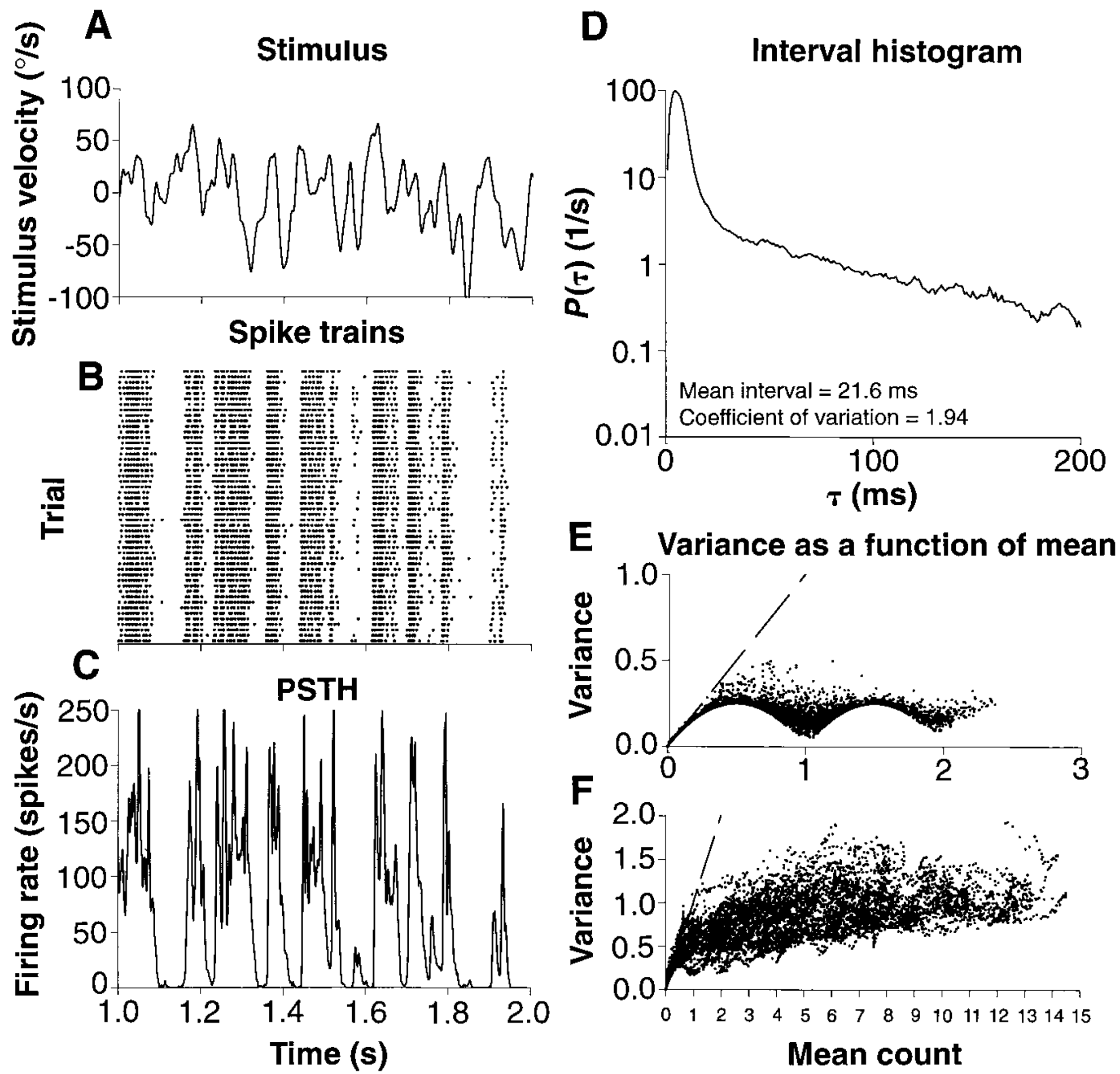
$$P(n) = \frac{\lambda^n e^{-\lambda}}{n!}$$



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

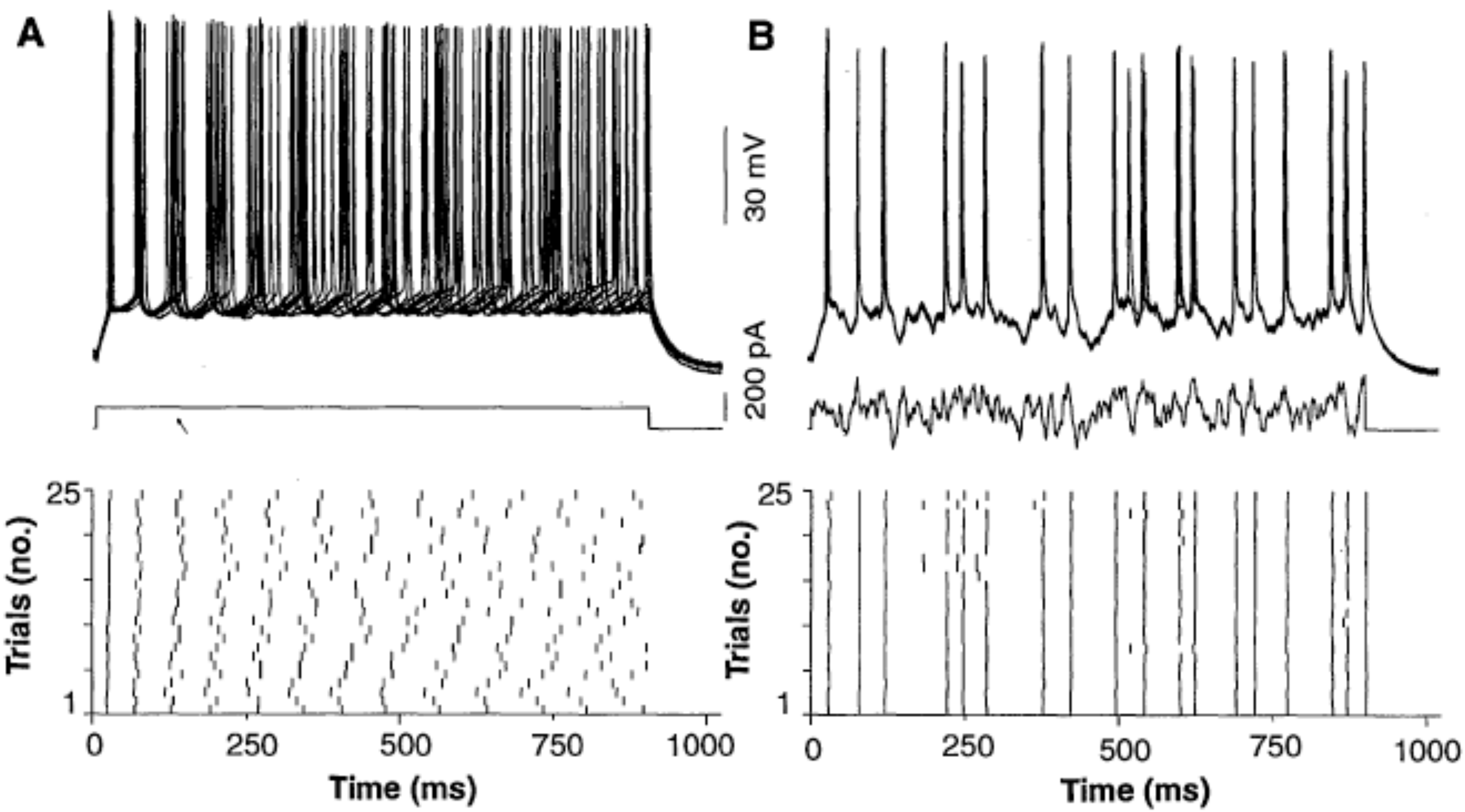


Fly H1 neuron - time-varying stimulus
(de Ruyter et al., 1997)



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

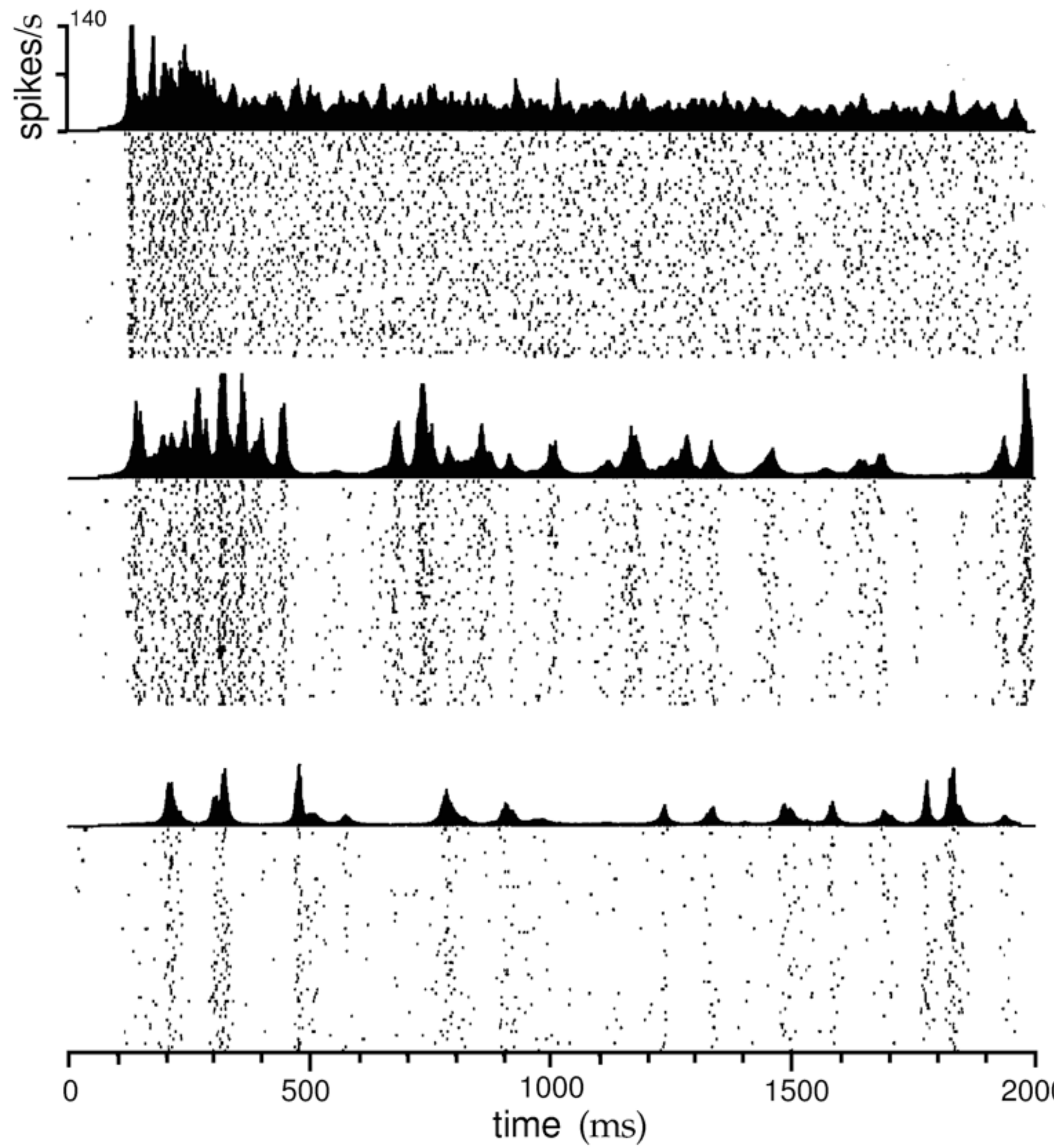
Mainen & Sejnowski (1995)



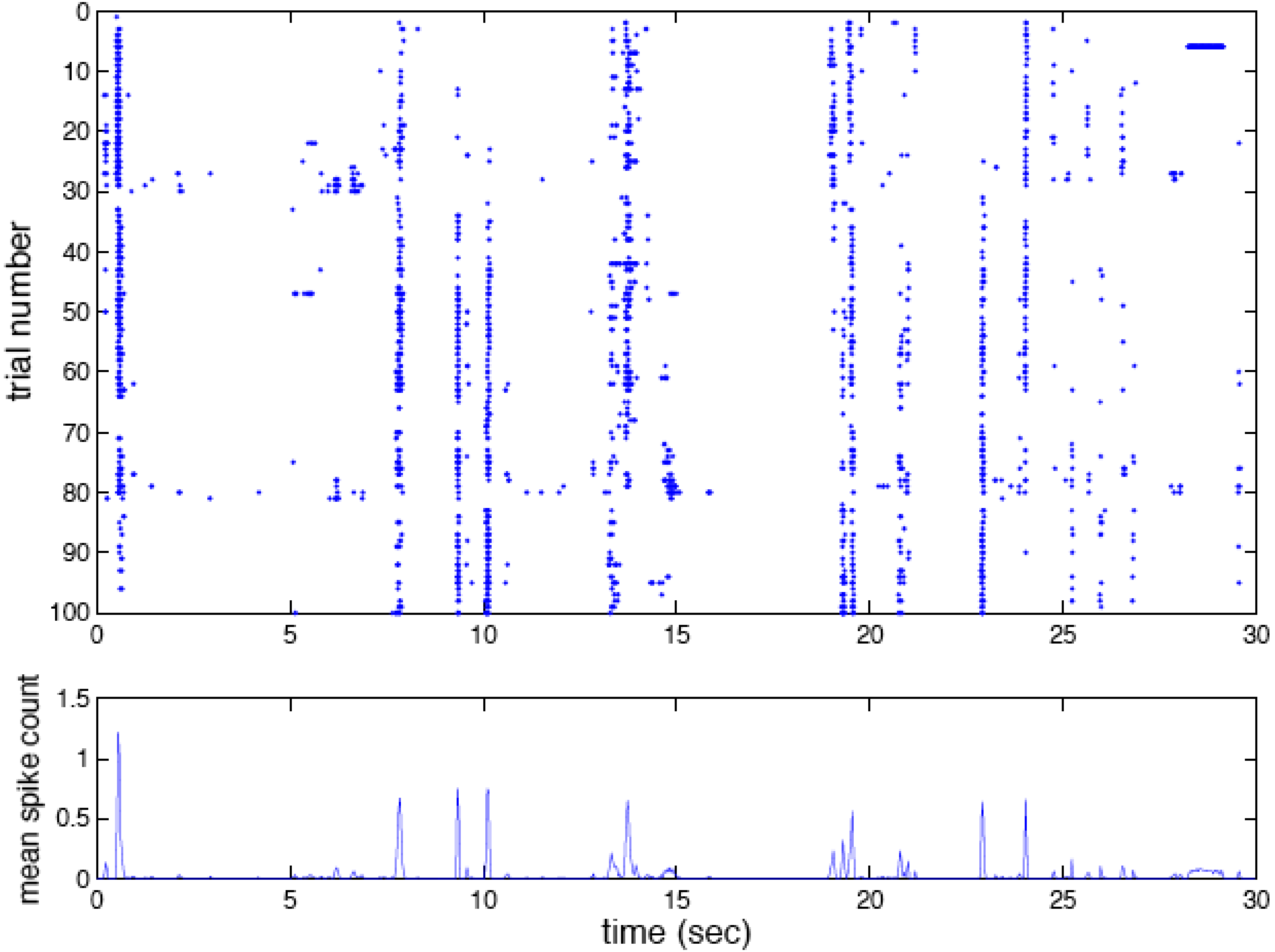
Spike timing can be *very precise* in response to time-varying signals

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

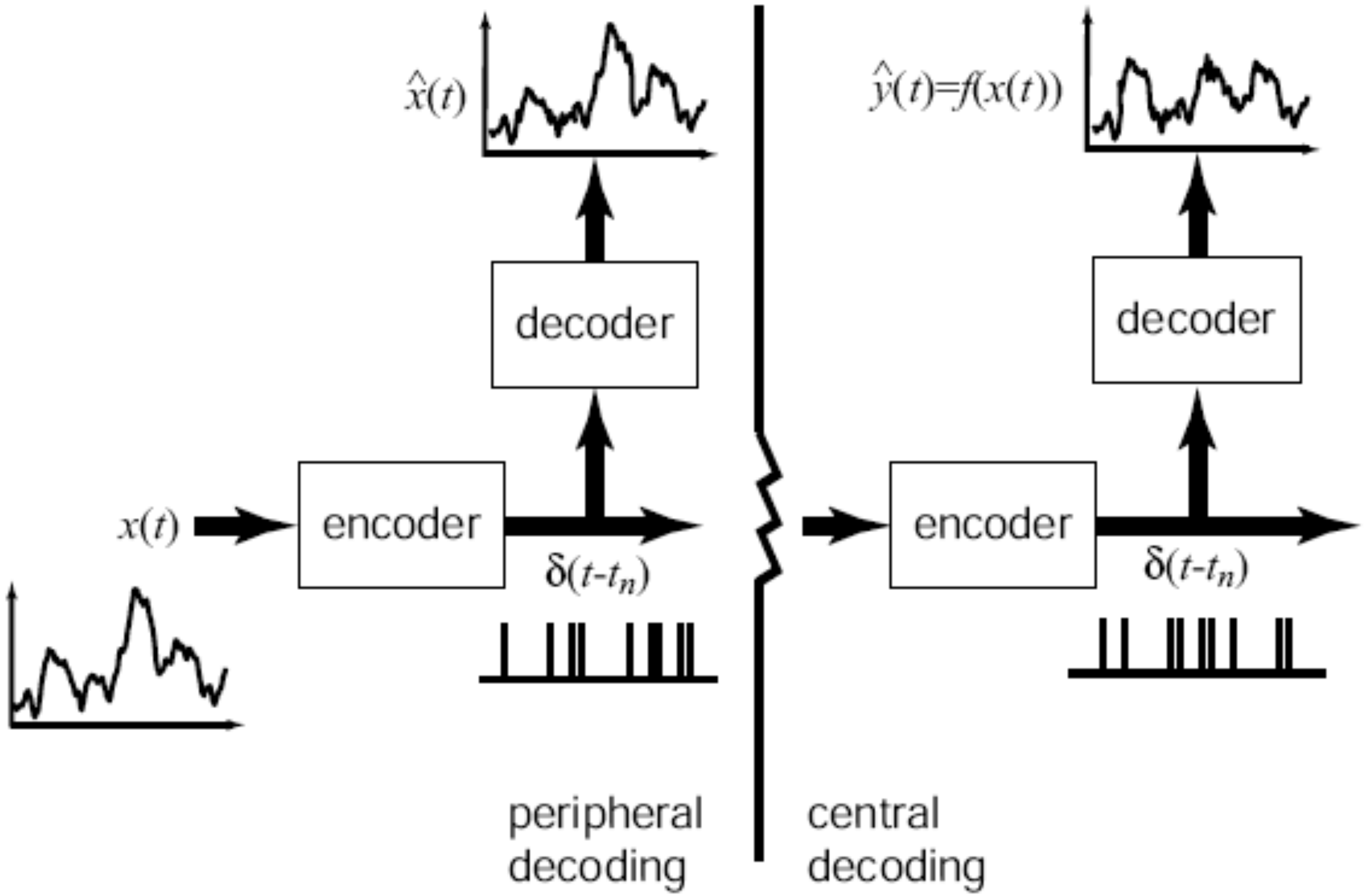
Analysis by Bair & Koch (1996)



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

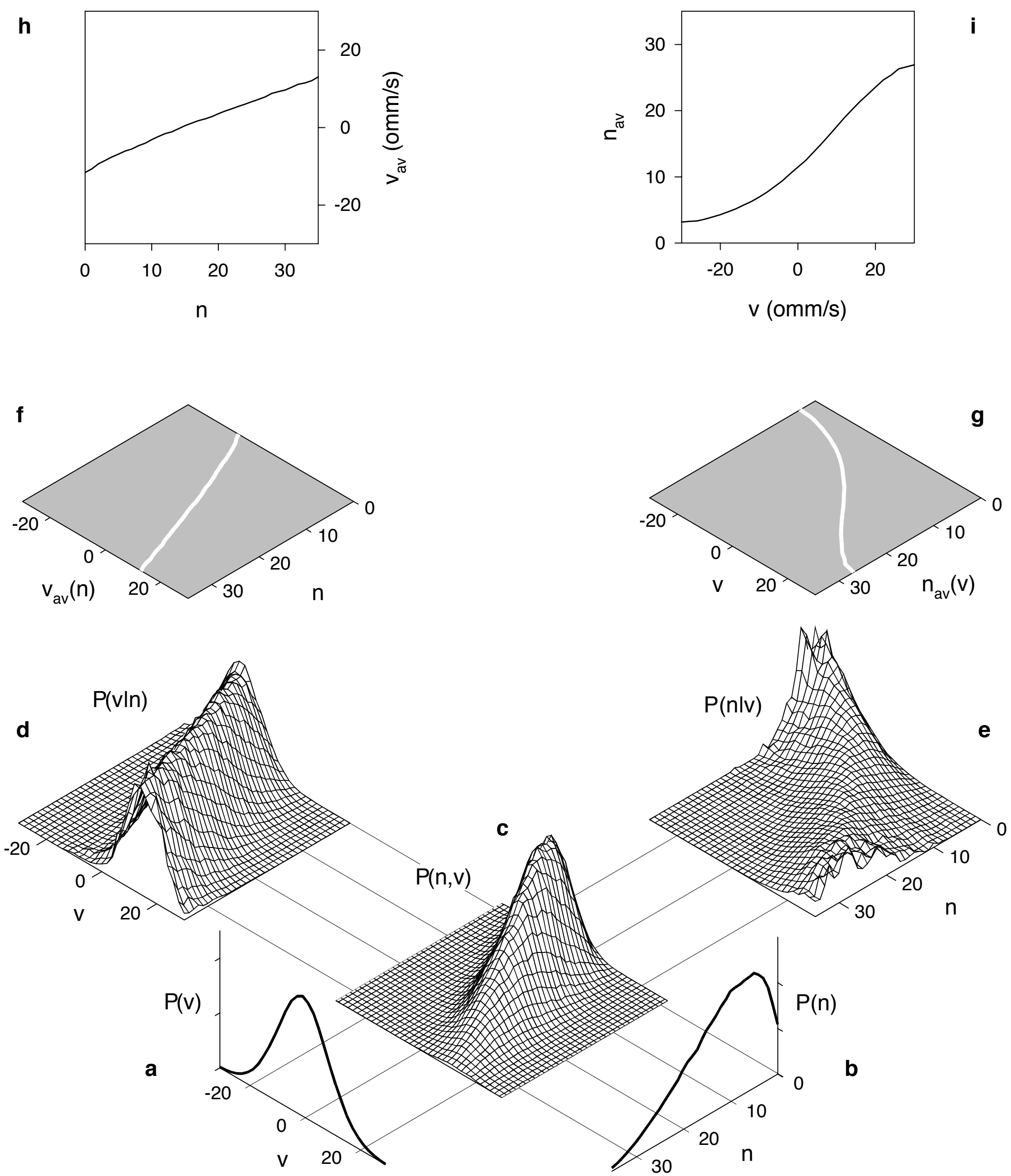


Neural encoding and decoding



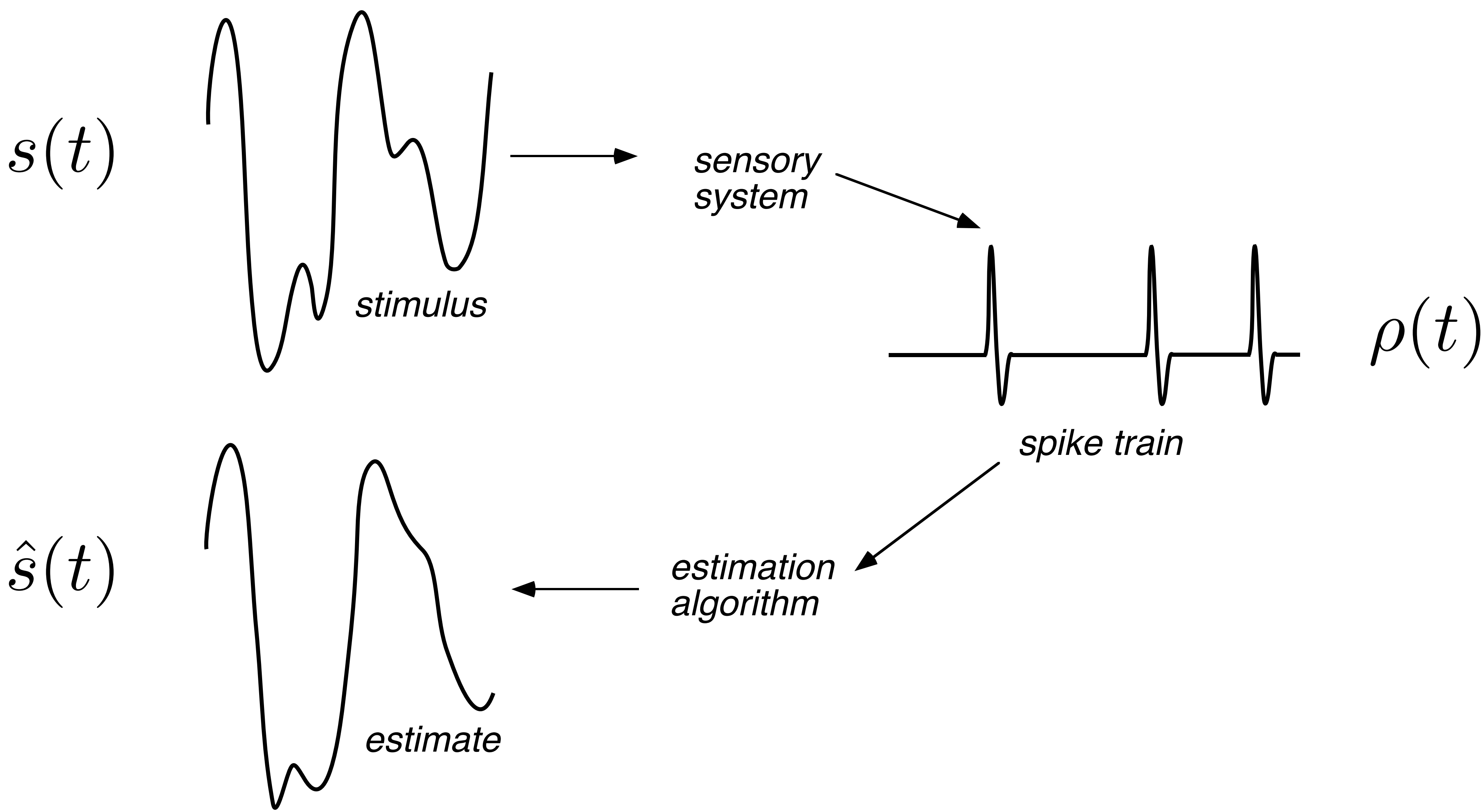
Encoding and decoding are related through the joint distribution over *stimulus* and *response*

decoding



encoding

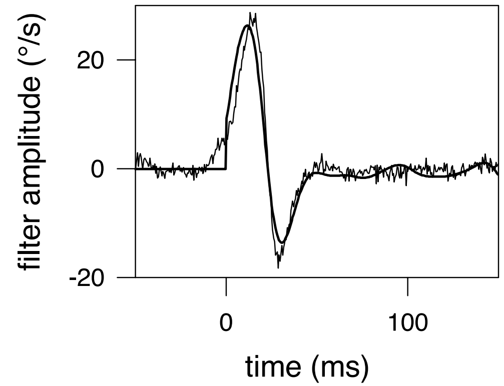
(from *Spikes*)



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

Reconstruction kernel

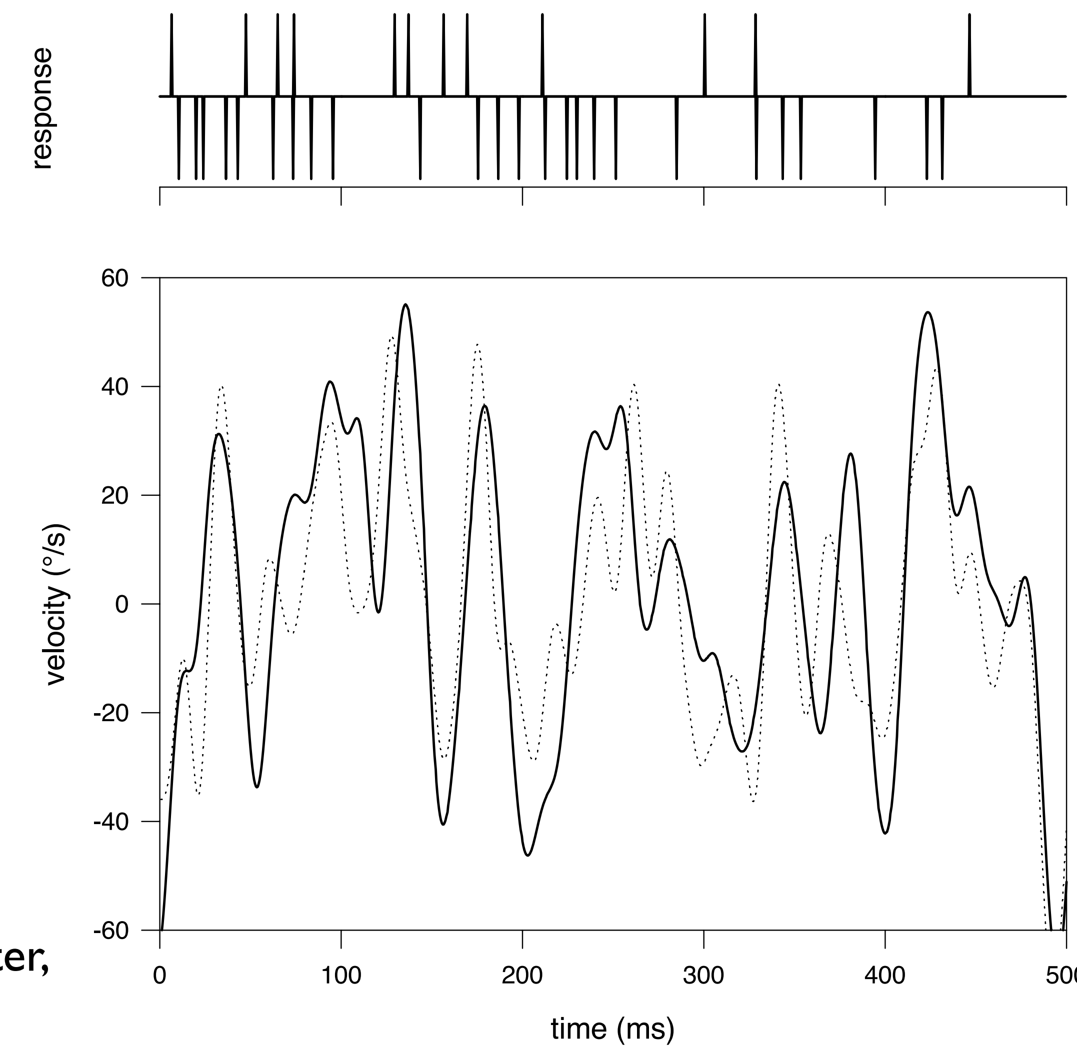
$k(t)$



Fly H1 neuron response

$\rho(t)$

Stimulus reconstruction



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

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

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

Strategy for estimating information rate

1. Estimate signal from spikes

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

2. Compute noise in estimate

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

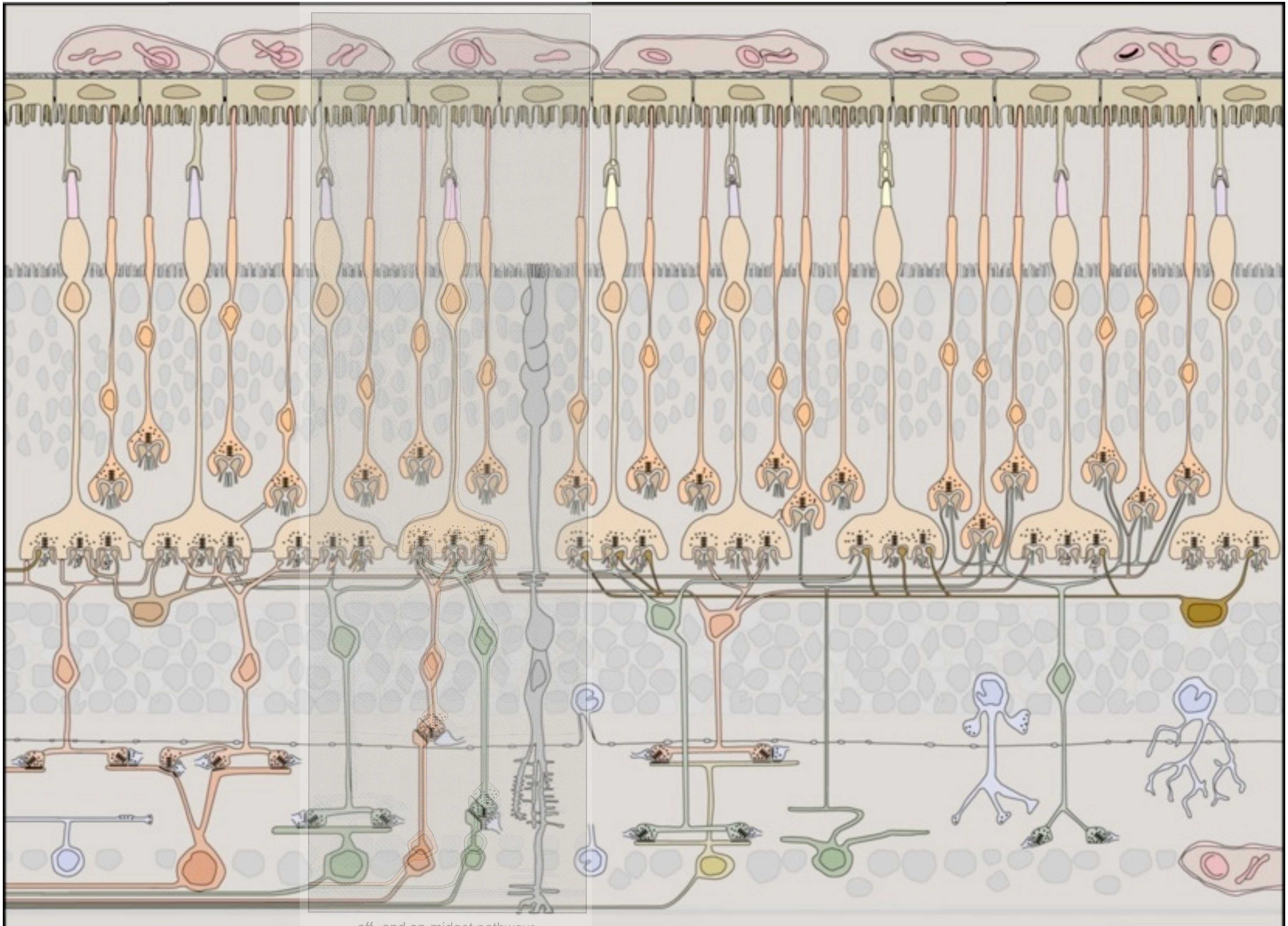
3. Compute SNR

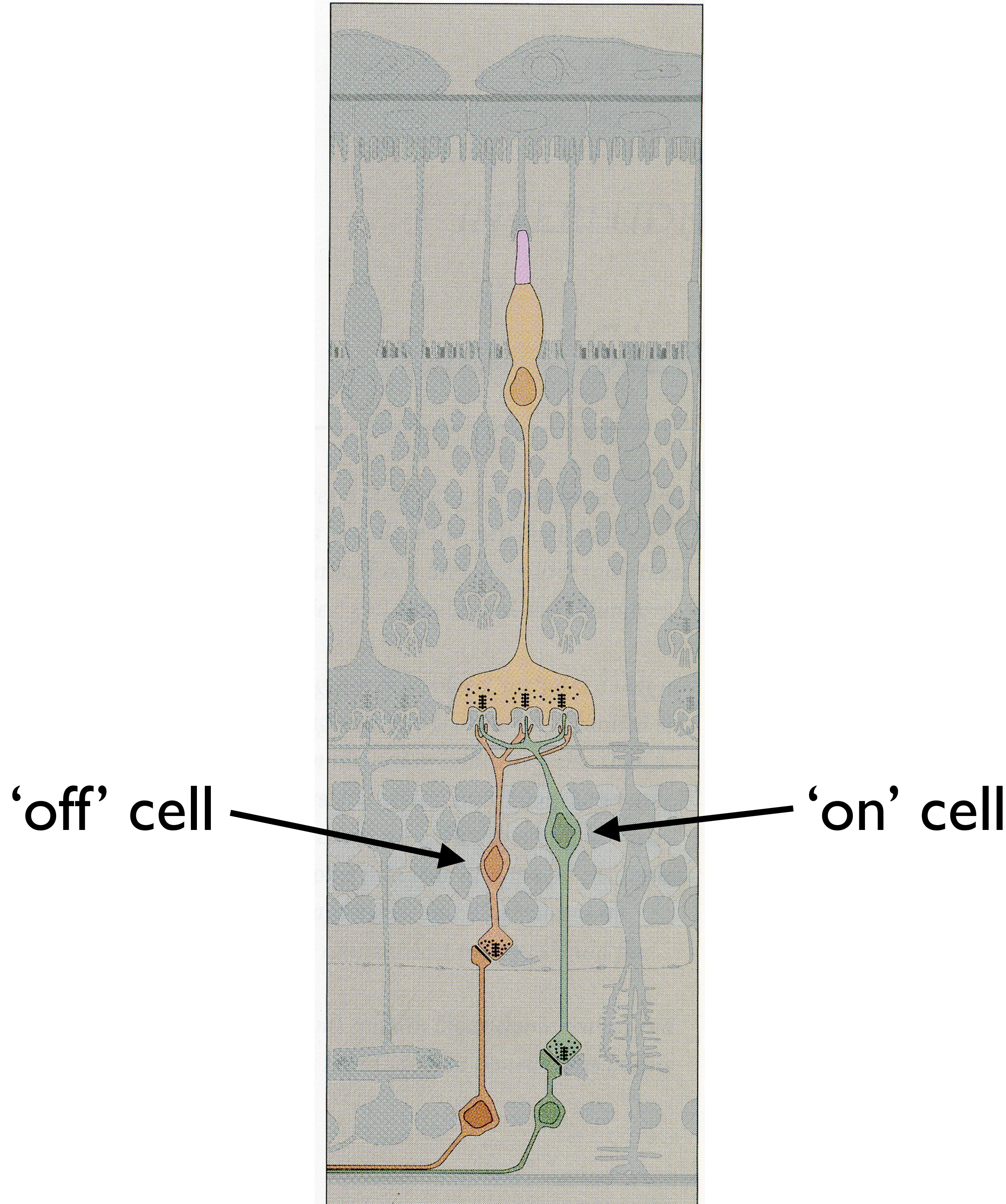
$$\mathrm{SNR}(\omega) = \frac{\langle|\tilde{s}(\omega)|^2\rangle}{\langle|\tilde{n}(\omega)|^2\rangle}$$

4. Calculate lower bound to information rate from SNR

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

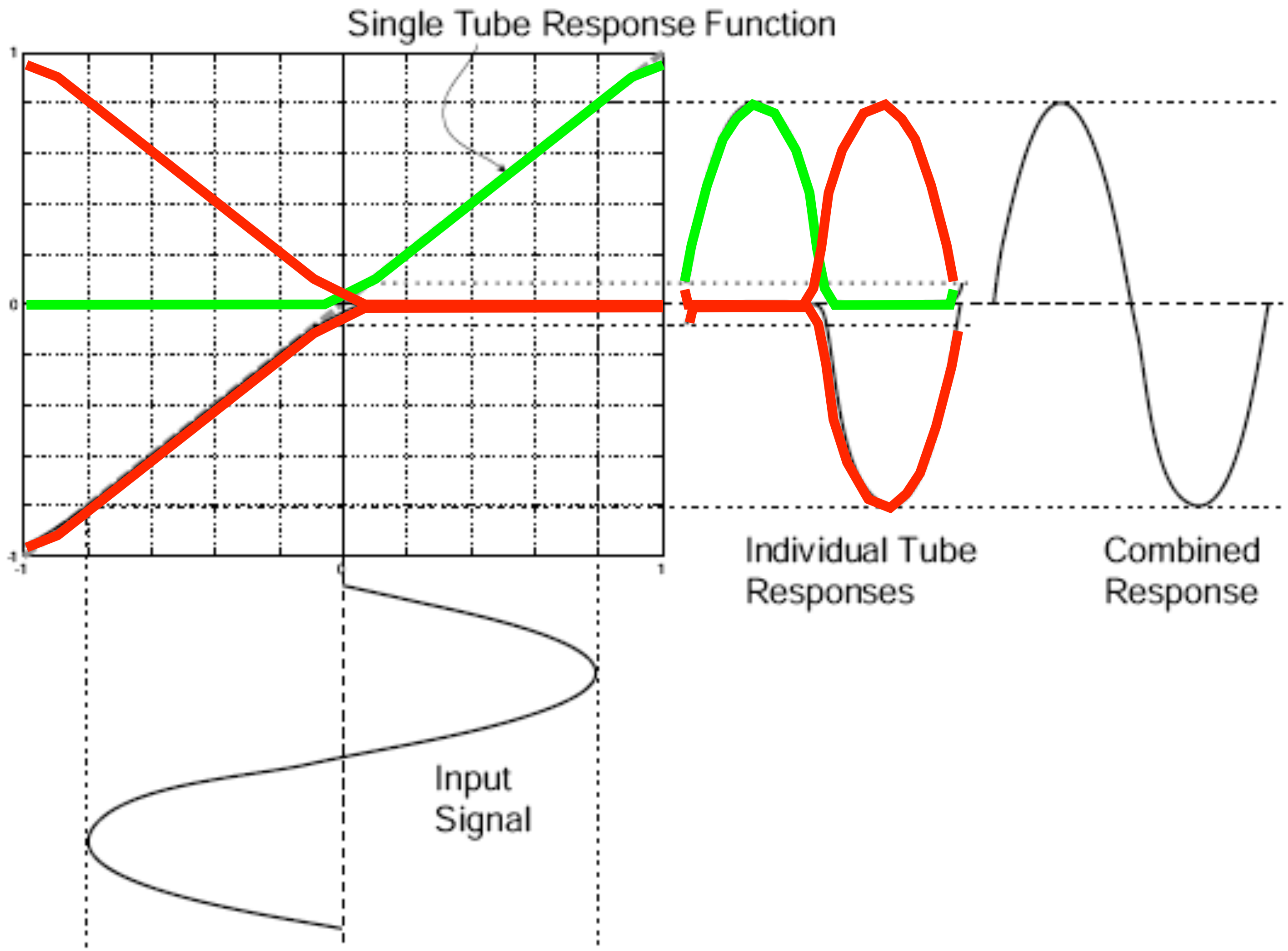
Adapted from *Spikes*, by Rieke, Warland, de Ruyter, & Bialek


off- and on-midget pathways



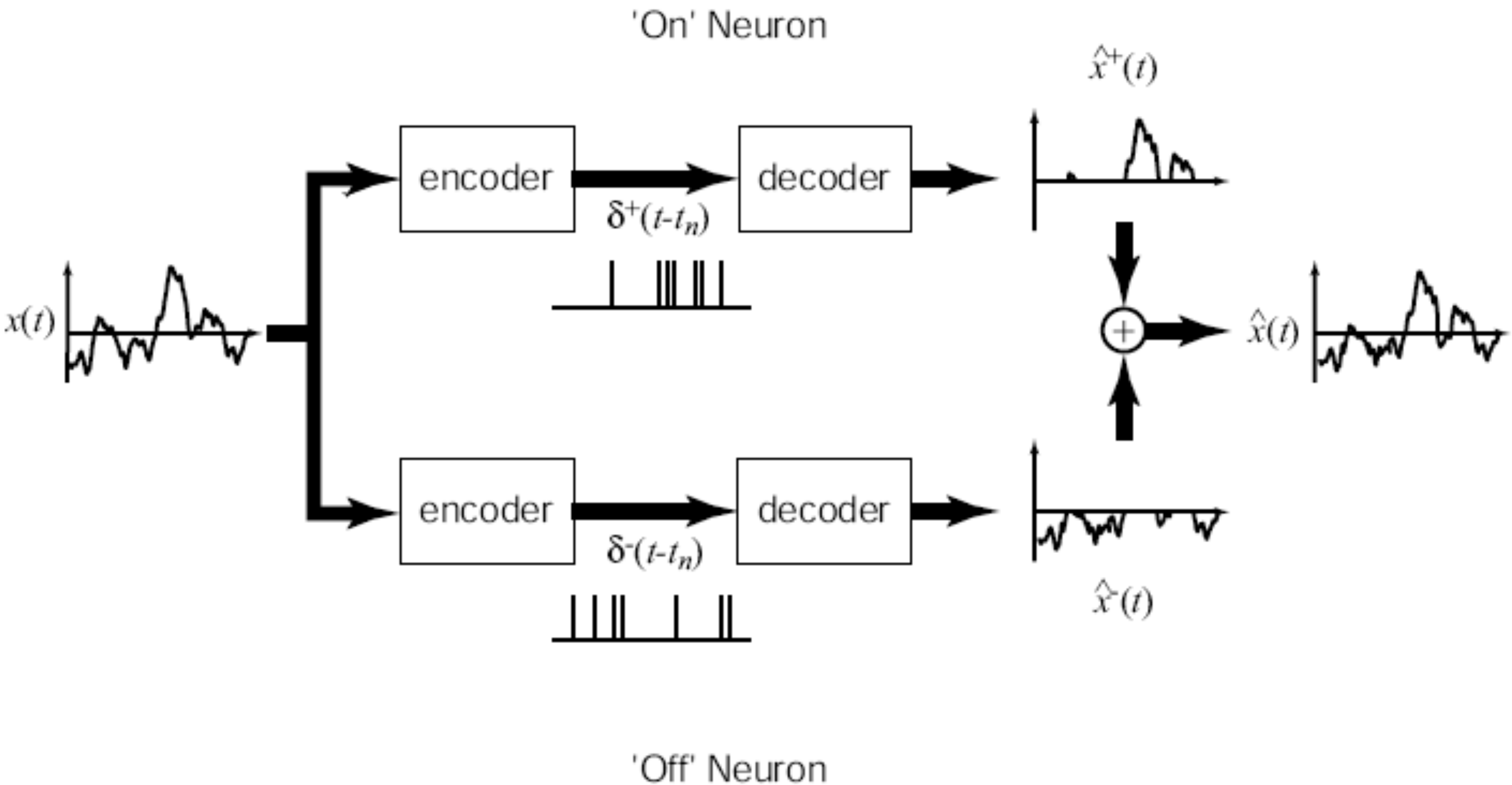
'off' cell
'on' cell

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.



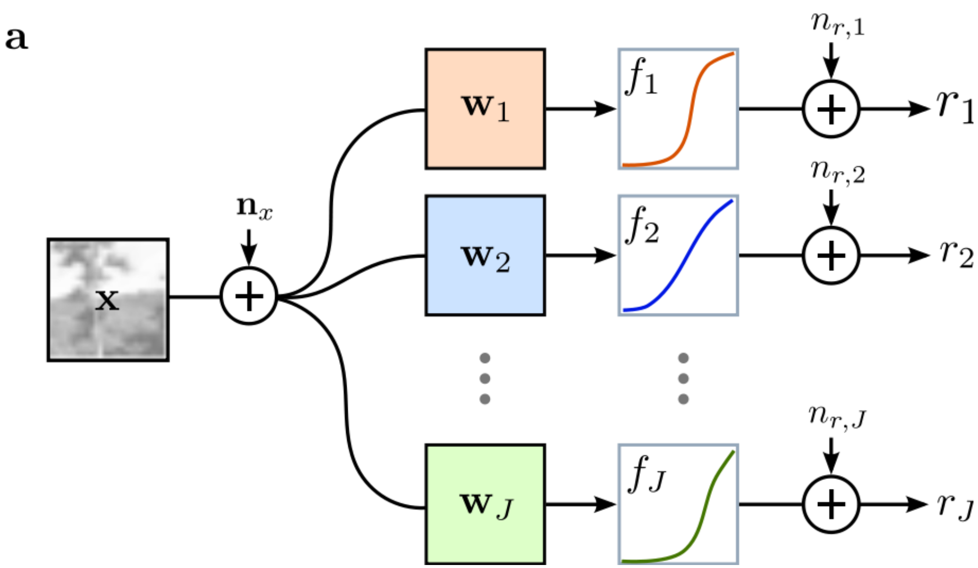
From: *Neural Engineering*, by Eliasmith & Anderson

Push-Pull decoding



Efficient coding model of retina

(Karklin & Simoncelli 2012)



Objective function:

$$I(X;R) - \sum_j \lambda_j \langle r_j \rangle$$