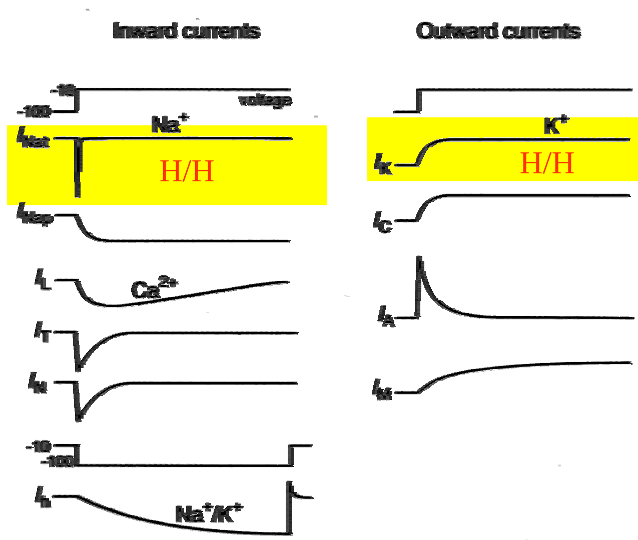
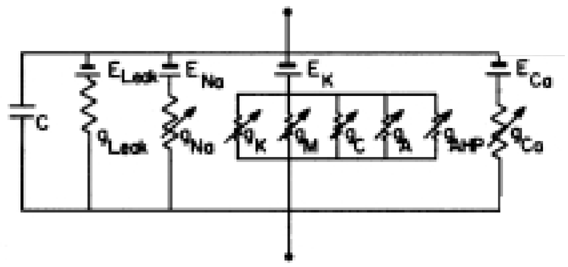
H/H can't generate spikes at low frequency

$$I_A = \bar{g}_{K(A)} m^4 h (V - V_K)$$

Connor & Stevens

m fast, h slow
turns on quickly following current step and slowly inactivates, delaying voltage rise to threshold

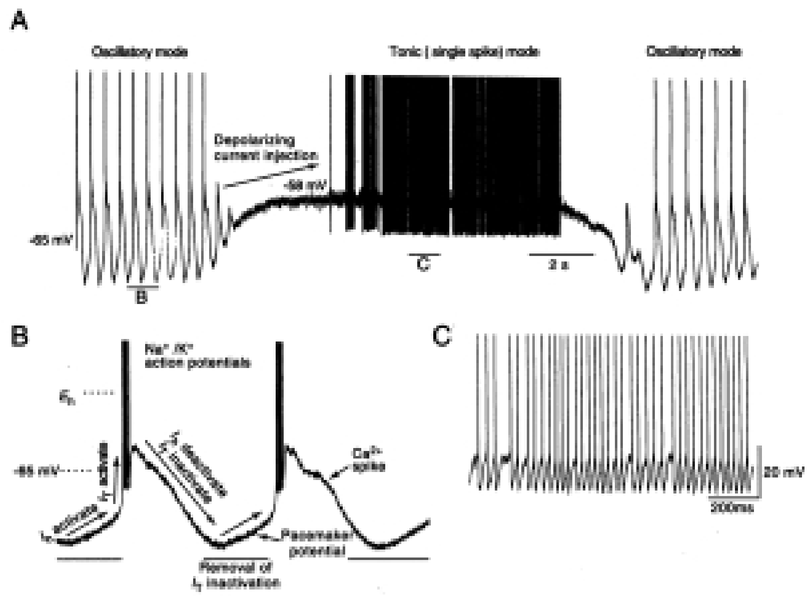




Thalamocortical Neurons Have Two Firing Modes

Calcium Action Potentials

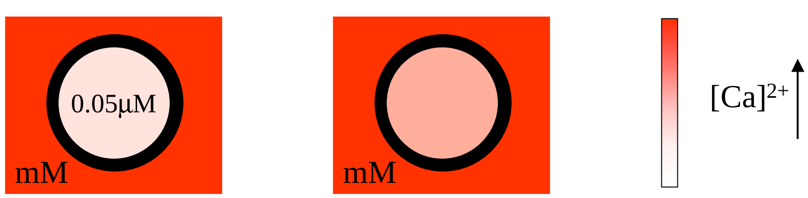
$I_{Ca(T)}$ "T current" in Bursting



Intracellular Calcium

Coupling variable (original H/H) : V_m
New coupling: $[Ca^{2+}]_{int}$

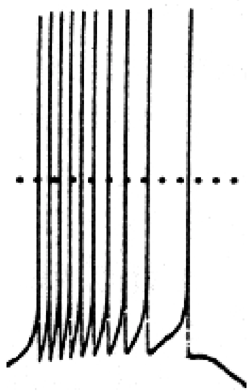
Calcium-activated potassium current: $I_{K(Ca)}$
Builds up with each action potential
Decays slowly



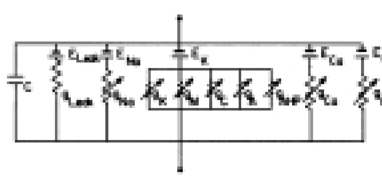
after transmembrane
calcium ion flux

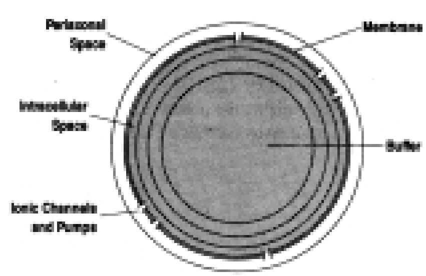
firing rate decays
with little change
In V_m

Adaptation
$I_{K(Ca)}$

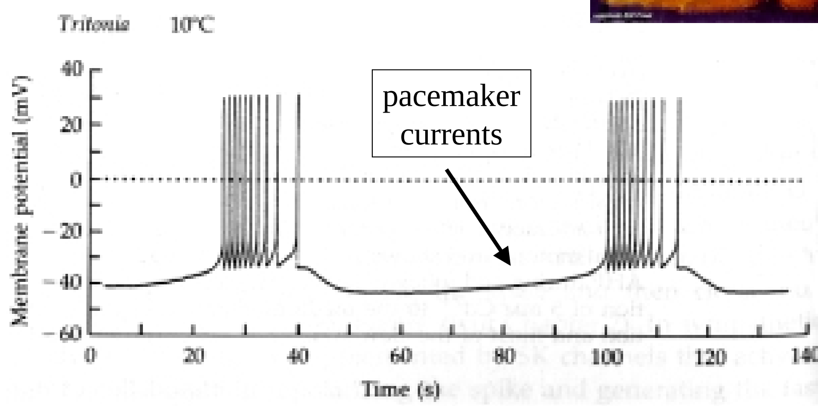


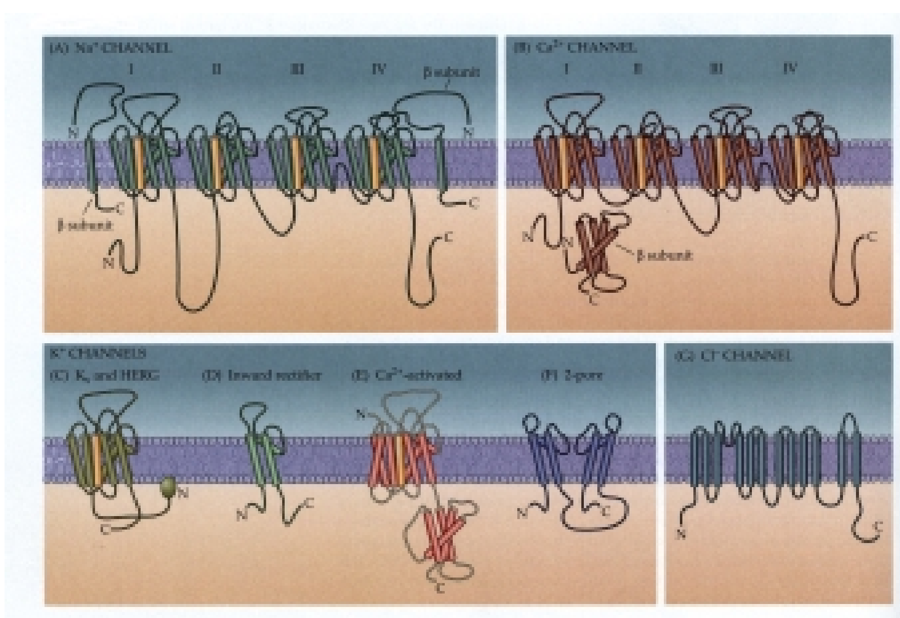
$$I_{K(AHP)} = \bar{g}_{K(AHP)} m([Ca^{2+}])(V_m - V_K)$$

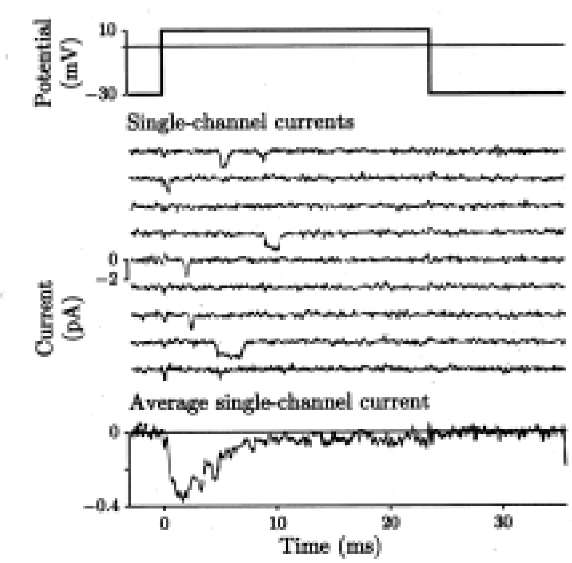




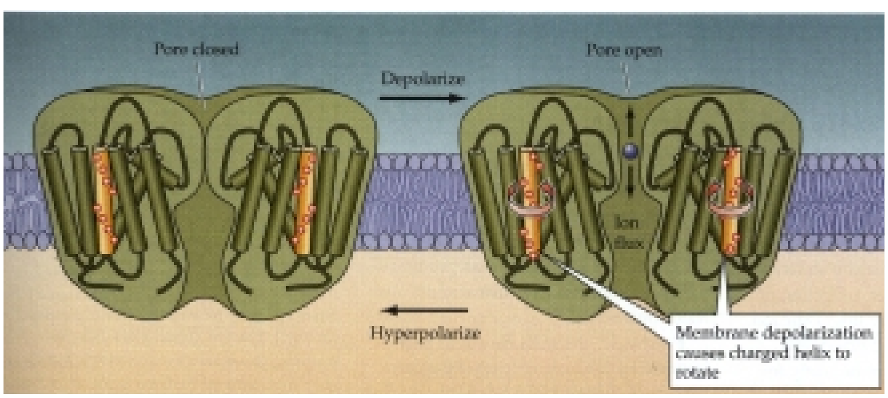
Intrinsically Bursting Neuron in CPG



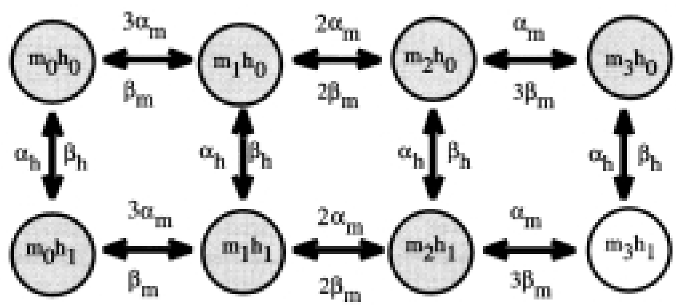




Sigworth and Neher



3 m gates, 1 h gate



open state

closed $\underset{\beta}{\overset{\alpha}{\rightleftarrows}}$ open

Monte-Carlo Simulation

m(t)=probability activation particle in open position

h(t)=probability inactivation particle in open position

$$P(m_2h_1|V_0)=3\left(\frac{\alpha_m(V_0)}{\alpha_m(V_0)+\alpha_m(V_0)}\right)^2\left(1-\frac{\alpha_m(V_0)}{\alpha_m(V_0)+\alpha_m(V_0)}\right)\frac{\alpha_h(V_0)}{\alpha_h(V_0)+\alpha_h(V_0)}$$

Compute $P(m_xh_y|V_0)$for all states, assign state of individual channel based on random number [0,1] with each state probability a portion of real line.

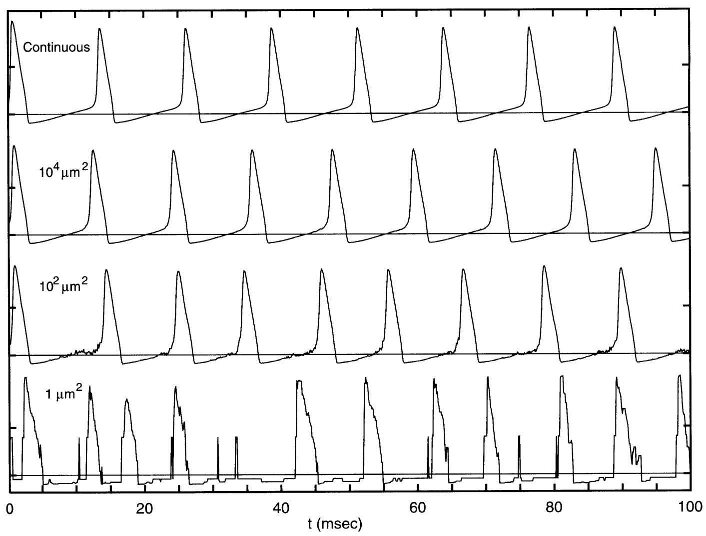
prob m_2h_1 remain open for T: $p_2=e^{-(\alpha_m(V)+\beta_h(V)+2\beta_m(V))T}$

Random p_2 $\Rightarrow$ T

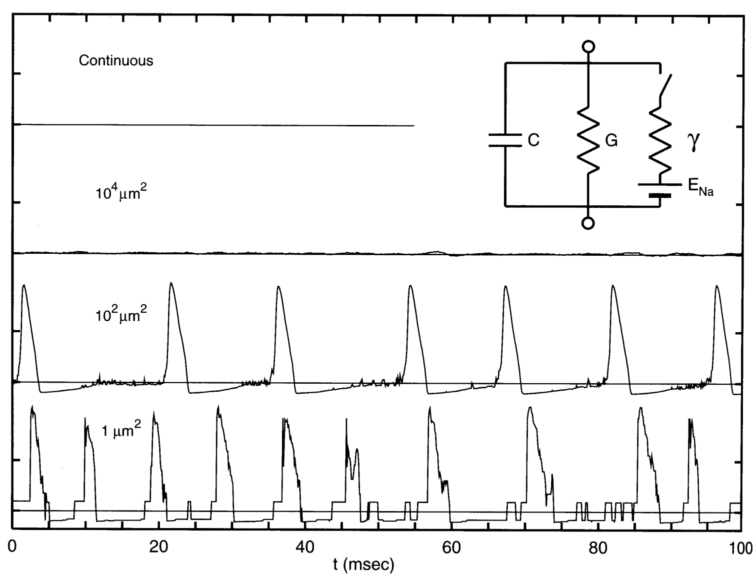
determine which state it goes to:

$$\mathrm{prob}(\mathrm{m_2h_1}\rightarrow\mathrm{m_3h_1})=\frac{\alpha_m}{\alpha_m+\beta_h+2\beta_m}$$

Do transition prob. for all states, choose random number to assign transition



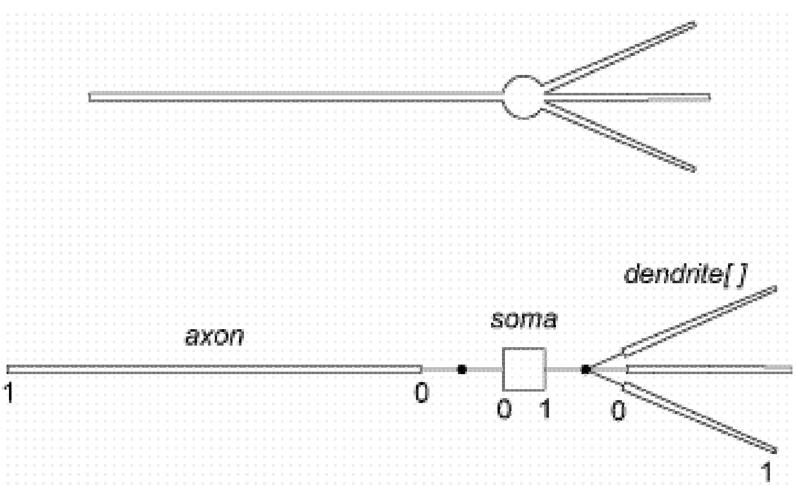
Strassburg & DeFelice, 1993



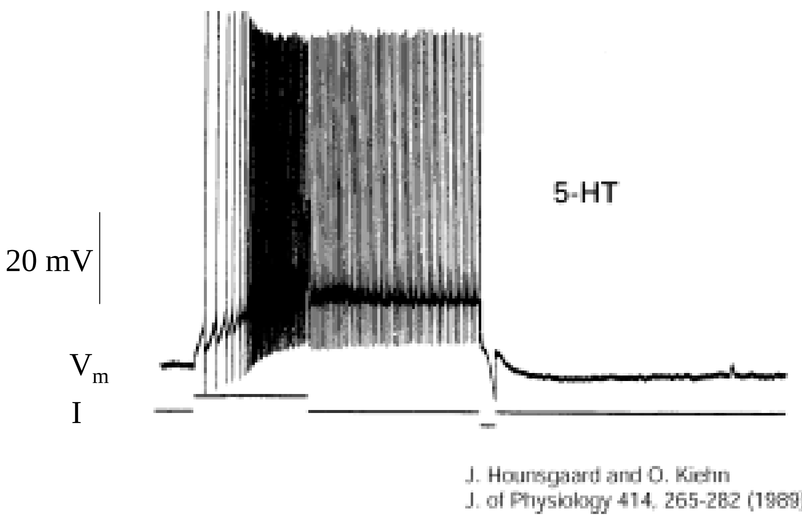
Strassburg & DeFelice, 1993

Neuron Models

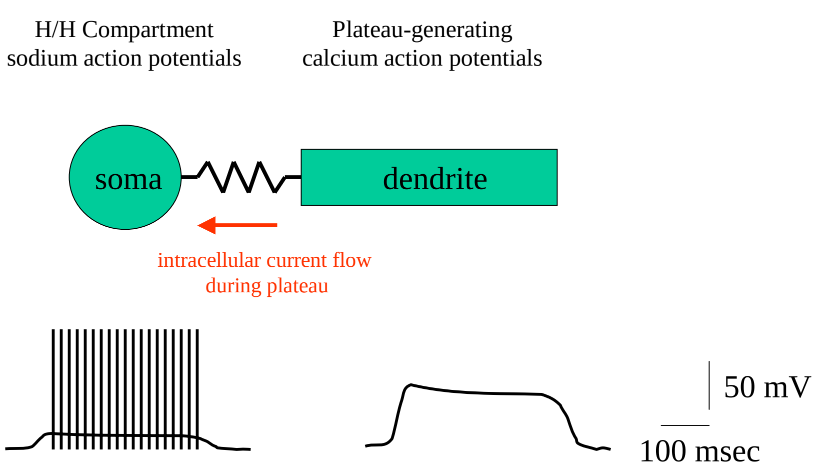
Compartmental Modeling



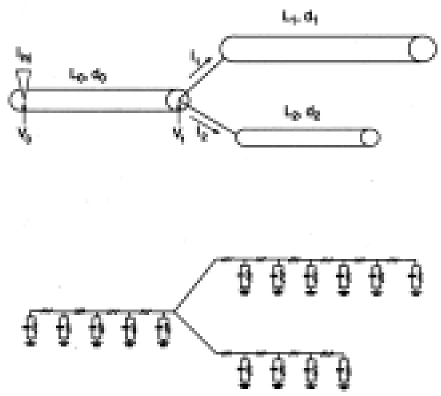
Plateau Potentials



Two compartment model of bistable neuron

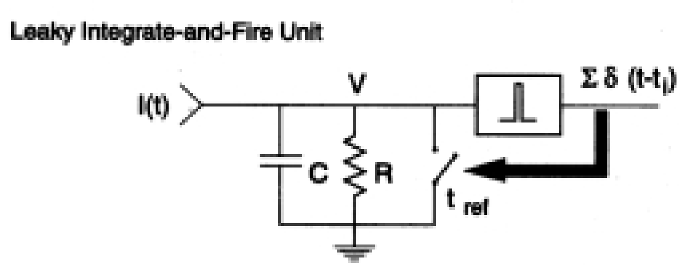


Compartmental Modeling

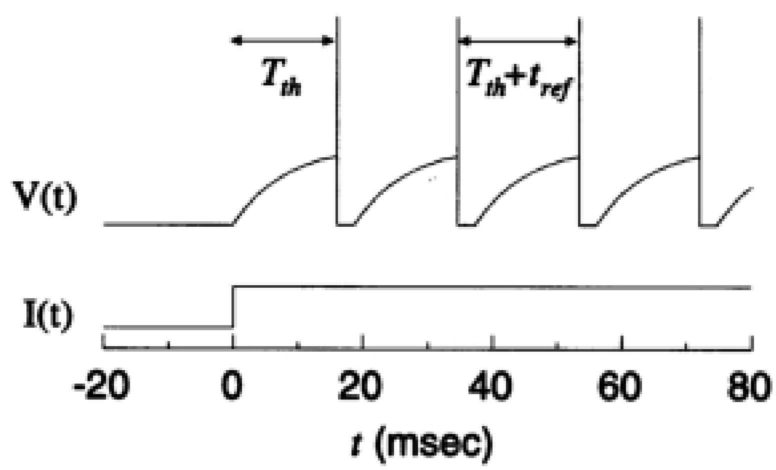


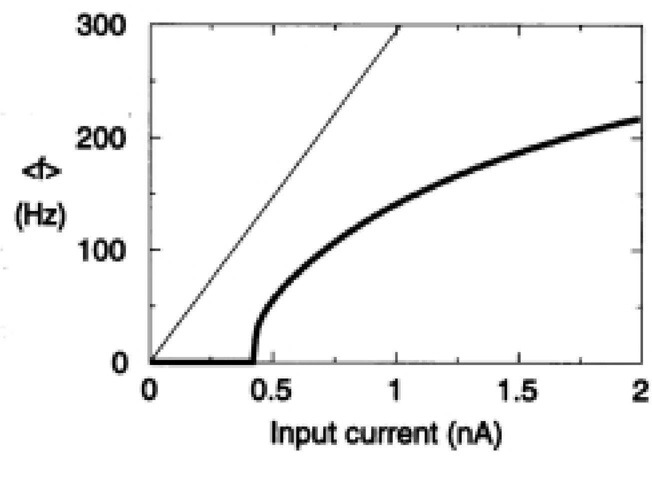
Used primarily for detailed biophysical study of single cells

Software: **Neuron** (Michael Hines)
http://www.neuron.yale.edu



$$C\frac{dV}{dt}+\frac{V}{R}=I(t)$$


T_{th}
$T_{th}+t_{ref}$
V(t)
I(t)
-20
0
20
40
60
80
t (msec)


300
200
100
0
<f>
(Hz)
0
0.5
1
1.5
2
Input current (nA)

Adapting Integrate and Fire Model

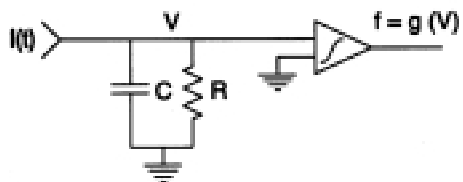
$$C\frac{dV}{dt} = -\frac{V(1+Rg_{adapt})}{R} + I$$

$$\tau_{adapt}\frac{dg_{adapt}}{dt} = -g_{adapt} + G_{inc}\delta(t)$$

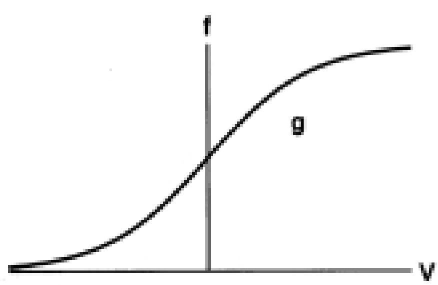
slow

slow conductance (g_{adapt})with memory in parallel with R

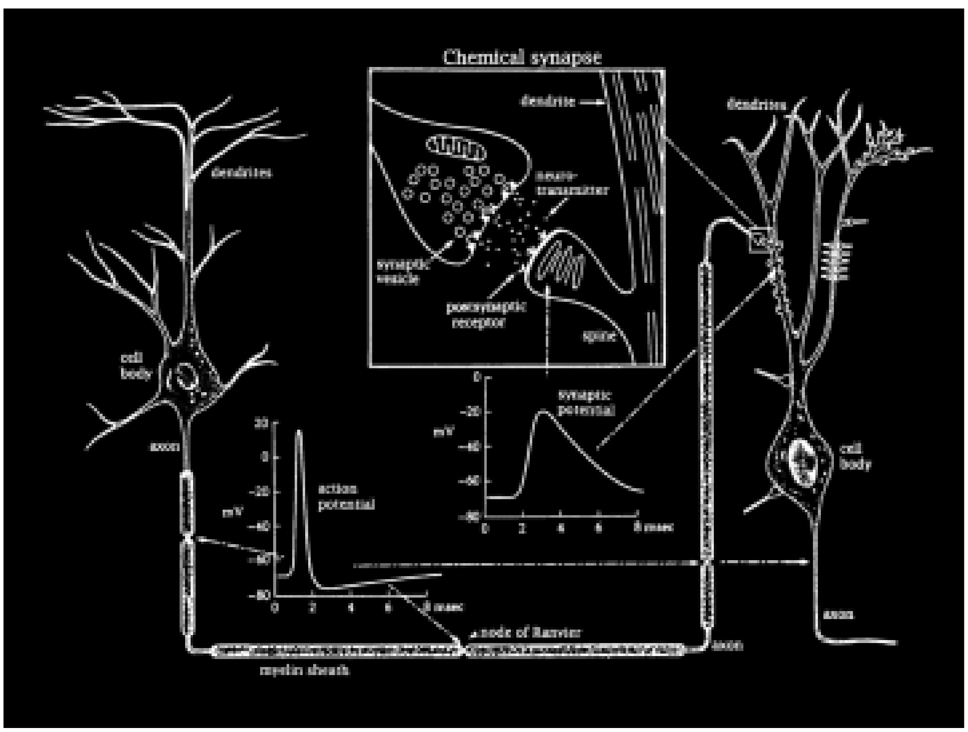
Firing Rate Model



$$f = \frac{1}{1+e^{-2\beta V}}$$



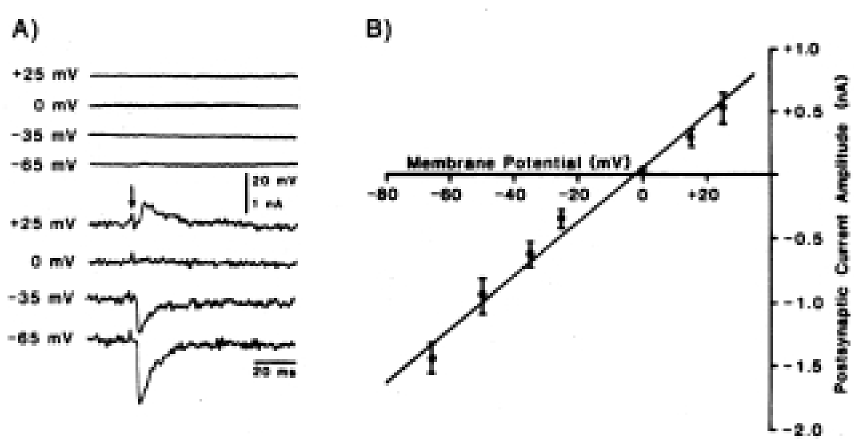
Synapse/Network Models

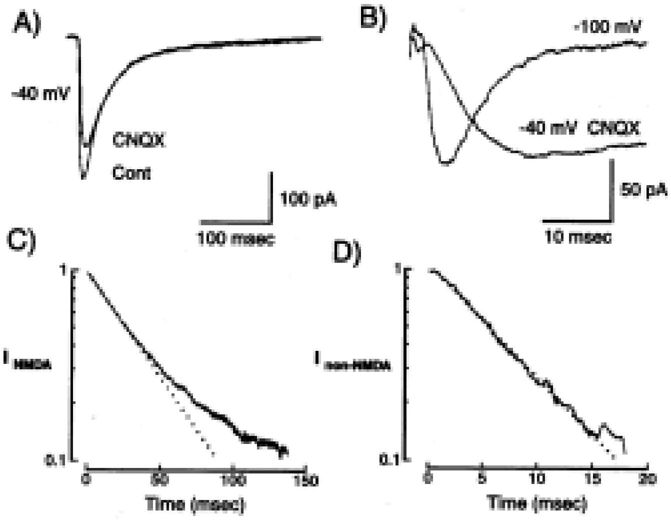


Excitatory
Inhibitory
fast/slow

Important concepts for Networks:
Spatial summation
Temporal summation

voltage clamp of synaptic current





exponential decay of currents

Augment generalized H/H equations with synaptic conductance terms:

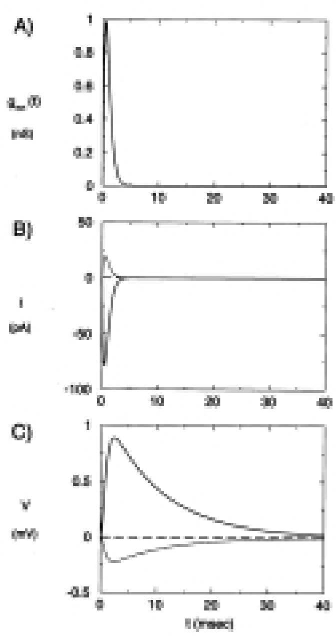
$$I_{syn} = g_{syn}(t)(V_m - V_{syn})$$

α function

$$g_{syn}(t) = \bar{g}_{syn} t e^{-t/t_{peak}}$$

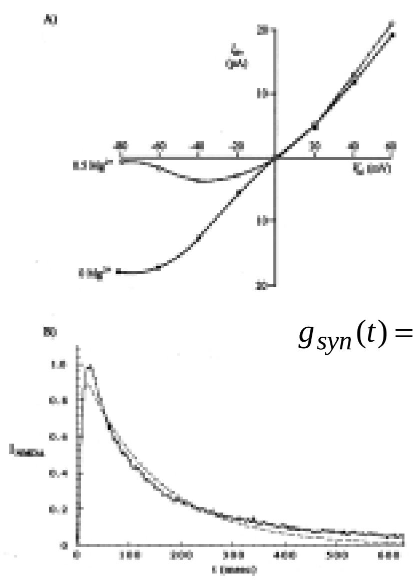
or difference of two exponentials

$$g_{syn}(t) = \bar{g}_{syn}(e^{-t/\tau_1} - e^{-t/\tau_2})$$



If ΔV_m small, use current pulse:

$$I_{syn}(t) = \bar{I}_{syn} t e^{-t/t_{peak}}$$

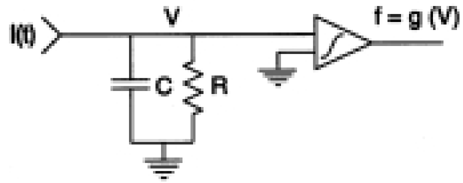


conductance
of NMDA
receptor synapse

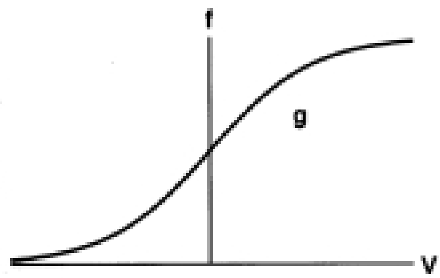
$$g_{syn}(t) = \bar{g}_{syn} \frac{e^{-t/\tau_1} - e^{-t/\tau_2}}{1+\eta[Mg^{2+}]e^{-\gamma V_m}}$$

$\tau_1 = 80\text{msec}$
$\tau_2 = 0.67\text{msec}$
$\eta \ = 0.33/\text{mM}$
$\gamma = 0.06/\text{mV}$
$\bar{g}_{syn} = 0.2 - 0.4\text{nS}$

Firing Rate Model



$$f = \frac{1}{1+e^{-2\beta V}}$$



Rate based “neurodynamics”

external input (bias)

$$C\frac{dV_i(t)}{dt} = -\frac{V_i(t)}{R} + I_i + \sum_{j=1}^{N} w_{ij}\, f_j(t)$$

w_{ij} represents strength of synapse from neuron j to neuron i

synaptic input currents

$f_i(t) = g(V_i(t))$ input/output relation

assumes linear summation of synaptic inputs
precise spike timing ignored

Two neuron firing rate network model