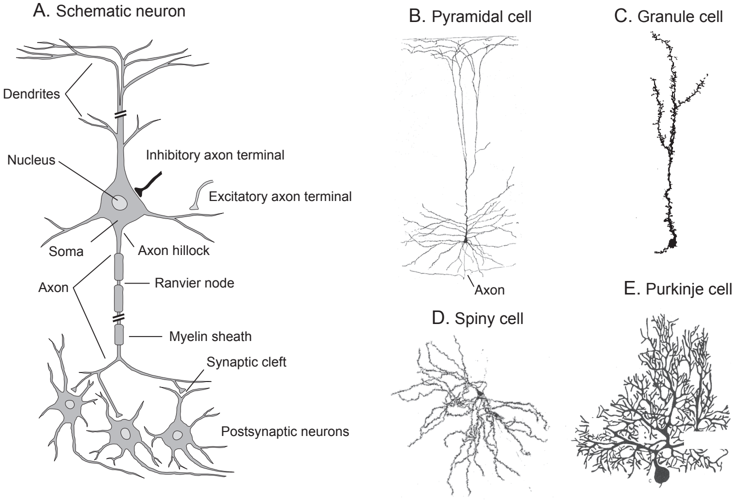
Fundamentals of Computational Neuroscience 2e

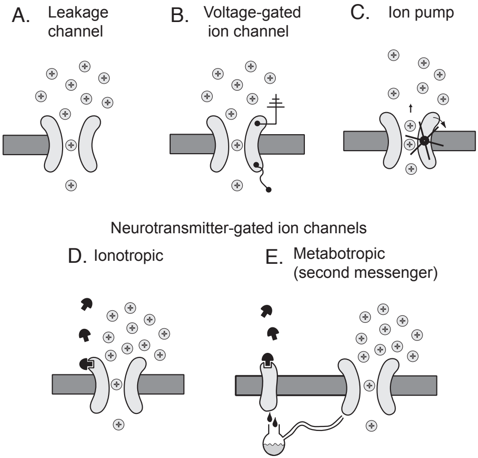
December 26, 2009

Chapter 2: Neurons and conductance-based model

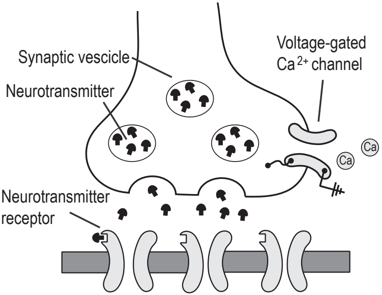
Biological background



Ion channels



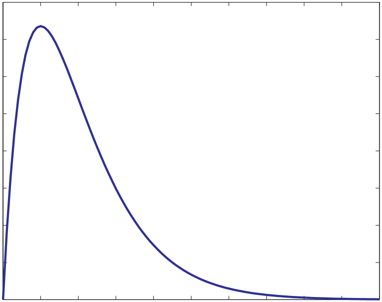
Synapse



Synaptic vescicle
Neurotransmitter
Voltage-gated
Ca 2+ channel
Ca
Ca
Neurotransmitter
receptor

non-NMDA: GABA, AMPA

$$\Delta V_{\mathrm{m}}^{\mathrm{non-NMDA}} \propto t\, \mathrm{e}^{-t/t^{\mathrm{peak}}}$$

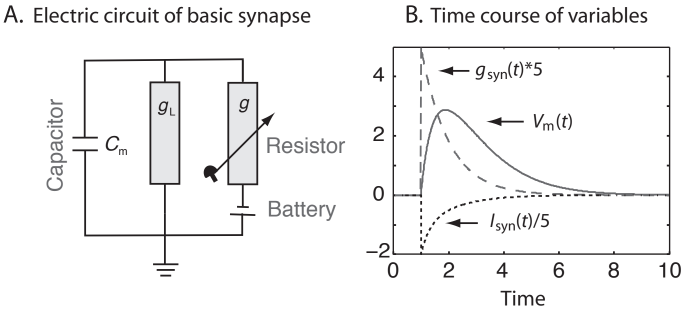


Conductance-based models

$$c_m \frac{\mathrm{d}V(t)}{dt} = -I \tag{1}$$

$$I(t) = g_0 V(t) - g(t)(V(t) - E_{\mathrm{syn}}) \tag{2}$$

$$\tau_{\mathrm{syn}} \frac{\mathrm{d}g(t)}{\mathrm{d}t} = -g(t) + \delta(t - t_{\mathrm{pre}} - t_{\mathrm{delay}}) \tag{3}$$



MATLAB Program

```
%% Synaptic conductance model to simulate an EPSP
 clear; clf; hold on;

%% Setting some constants and initial values
 c_m=1; g_L=1; tau_syn=1; E_syn=10; delta_t=0.01;
 g_syn(1)=0; I_syn(1)=0; v_m(1)=0; t(1)=0;

%% Numerical integration using Euler scheme
 for step=2:10/delta_t
   t(step)=t(step-1)+delta_t;
   if abs(t(step)-1)<0.001; g_syn(step-1)=1; end
   g_syn(step)= (1-delta_t/tau_syn) * g_syn(step-1);
   I_syn(step)= g_syn(step) * (v_m(step-1)-E_syn);
   v_m(step) = (1-delta_t/c_m*g_L) * v_m(step-1) ...
                      - delta_t/c_m * I_syn(step);
 end

%% Plotting results
 plot(t,v_m); plot(t,g_syn*5,'r--'); plot(t,I_syn/5,'k:')
```

Hodgkin–Huxley model

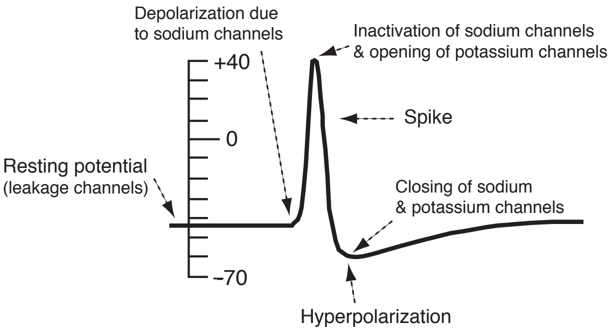
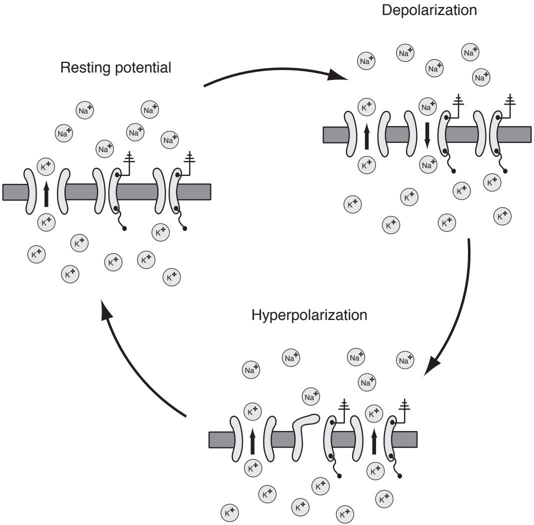


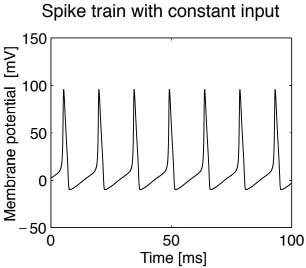
Figure: Typical form of an action potential; redrawn from an oscilloscope picture from Hodgkin and Huxley (1939).

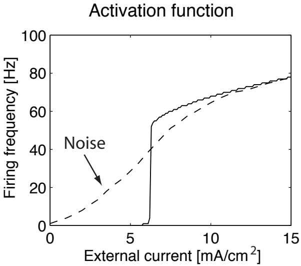
The minimal mechanisms



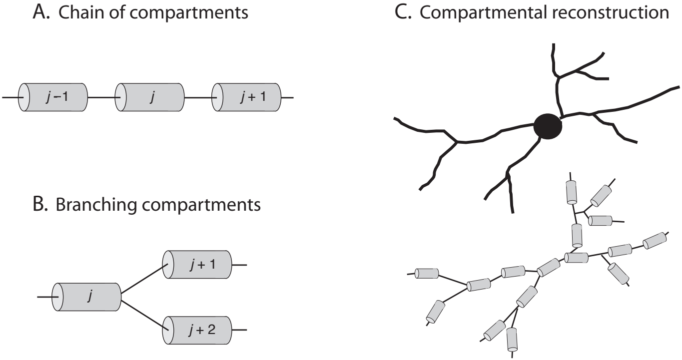
Hodgkin–Huxley equations and simulation

$$
\begin{aligned}
C\frac{\mathrm{d}V}{\mathrm{d}t} &= -g_{\mathrm{K}}n^4(V-E_{\mathrm{K}}) - g_{\mathrm{Na}}m^3h(V-E_{\mathrm{Na}}) - g_{\mathrm{L}}(V-E_{\mathrm{L}}) + I(t) \\
\tau_{\mathrm{n}}(V)\frac{\mathrm{d}n}{\mathrm{d}t} &= -[n - n_0(V)] \\
\tau_{\mathrm{m}}(V)\frac{\mathrm{d}m}{\mathrm{d}t} &= -[m - m_0(V)] \\
\tau_{\mathrm{h}}(V)\frac{\mathrm{d}h}{\mathrm{d}t} &= -[h - h_0(V)]
\end{aligned}
$$

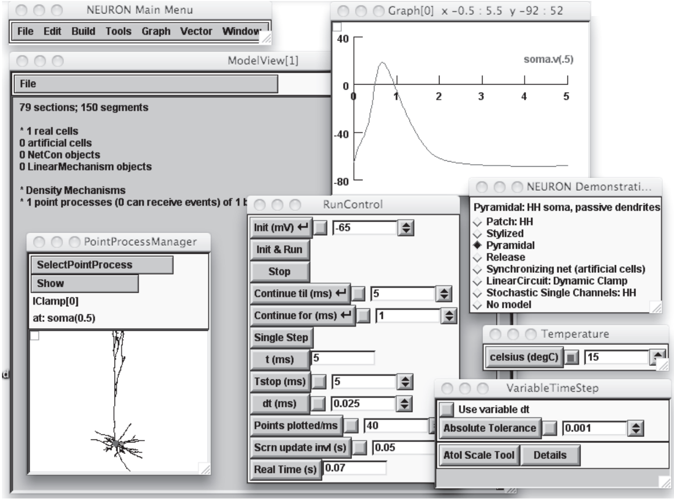




Compartmental models



Simulators



NEURON Main Menu
File Edit Build Tools Graph Vector Window
ModelView[1]
File
79 sections; 150 segments
* 1 real cells
0 artificial cells
0 NetCon objects
0 LinearMechanism objects
* Density Mechanisms
* 1 point processes (0 can receive events) of 1
PointProcessManager
SelectPointProcess
Show
IClamp[0]
at: soma(0.5)
Graph[0] x -0.5 : 5.5 y -92 : 52
soma.v(.5)
40
0
-40
-80
0
1
2
3
4
5
RunControl
Init (mV)
-65
Init & Run
Stop
Continue til (ms)
5
Continue for (ms)
1
Single Step
t (ms)
5
Tstop (ms)
5
dt (ms)
0.025
Points plotted/ms
40
Scrn update invl (s)
0.05
Real Time (s)
0.07
NEURON Demonstrati...
Pyramidal: HH soma, passive dendrites
Patch: HH
Stylized
Pyramidal
Release
Synchronizing net (artificial cells)
LinearCircuit: Dynamic Clamp
Stochastic Single Channels: HH
No model
Temperature
celsius (degC)
15
VariableTimeStep
Use variable dt
Absolute Tolerance
0.001
Atol Scale Tool
Details

Further Readings

Mark F. Bear, Barry W. Connors, and Michael A. Paradiso (2006), **Neuroscience: exploring the brain**, Lippincott Williams & Wilkins , 3rd edition.

Eric R. Kandel, James H. Schwartz, and Thomas M. Jessell (2000), **Principles of neural science**, McGraw-Hill, 4th edition

Gordon M. Shepherd (1994), **Neurobiology**, Oxford University Press, 3rd edition.

Christof Koch (1999), **Biophysics of computation; information processing in single neurons**, Oxford University Press

Christof Koch and Idan Segev (eds.) (1998), **Methods in neural modelling**, MIT Press, 2nd edition.

C. T. Tuckwell (1988), **Introduction to theoretical neurobiology**, Cambridge University Press.

Hugh R. Wilson (1999) **Spikes, decisions and actions: dynamical foundations of neuroscience**, Oxford University Press. See also his paper in J. Theor. Biol. 200: 375–88, 1999.