

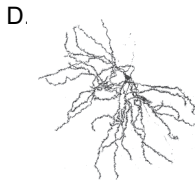
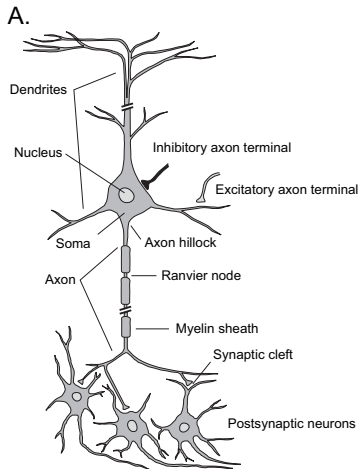
Fundamentals of Computational Neuroscience 2e

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January 16, 2009

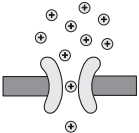
Chapter 2: Neurons and conductance-based model

Biological background

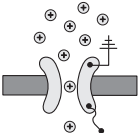


Ion channels

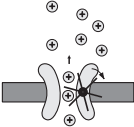
A. Leakage channel



B. Voltage-gated ion channel

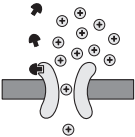


C. Ion pump

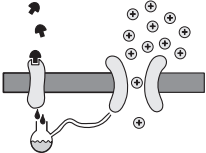


Neurotransmitter-gated ion channels

D. Ionotropic

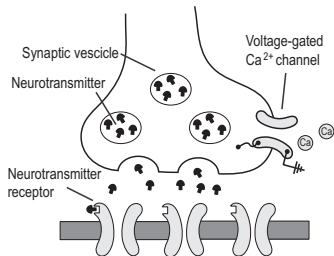


E. Metabotropic (second messenger)



Synapse

A. Schematic synapse



B. Microscope image of synapse



non-NMDA: GABA, AMPA

$$\Delta V_m^{\text{non-NMDA}} \propto t e^{-t/t^{\text{peak}}}$$

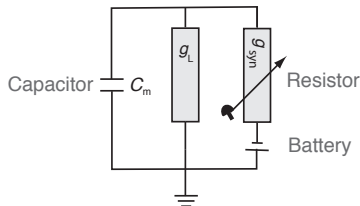
Conductance-based models

$$C_m \frac{dV(t)}{dt} = -I \quad (1)$$

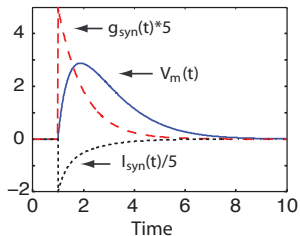
$$I(t) = g_0 V(t) - g(t)(V(t) - E_{\text{syn}}) \quad (2)$$

$$\tau_{\text{syn}} \frac{dg(t)}{dt} = -g(t) + \delta(t - t_{\text{pre}} - t_{\text{delay}}) \quad (3)$$

A. Electric circuit of basic synapse



B. Time course of variables



MATLAB Program

```
1  %% Synaptic conductance model to simulate an EPSP
2  clear; clf; hold on;
3
4  %% Setting some constants and initial values
5  c_m=1; g_L=1; tau_syn=1; E_syn=10; delta_t=0.01;
6  g_syn(1)=0; I_syn(1)=0; v_m(1)=0; t(1)=0;
7
8  %% Numerical integration using Euler scheme
9  for step=2:10/delta_t
10     t(step)=t(step-1)+delta_t;
11     if abs(t(step)-1)<0.001; g_syn(step-1)=1; end
12     g_syn(step)= (1-delta_t/tau_syn) * g_syn(step-1);
13     I_syn(step)= g_syn(step) * (v_m(step-1)-E_syn);
14     v_m(step) = (1-delta_t/c_m*g_L) * v_m(step-1) ...
15                 - delta_t/c_m * I_syn(step);
16 end
17
18 %% Plotting results
19 plot(t,v_m); plot(t,g_syn*5,'r--'); plot(t,I_syn/5,'k:')
```

Hodgkin–Huxley model

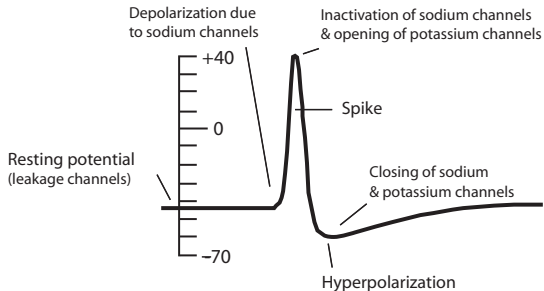
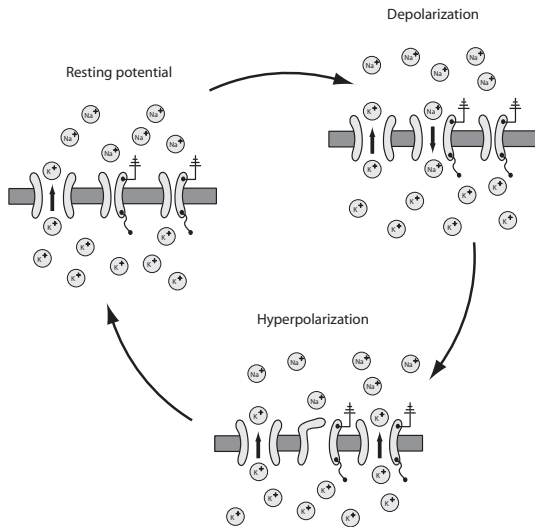


Figure: Typical form of an action potential; redrawn from an oscilloscope picture from Hodgkin and Huxley (1939).

The minimal mechanisms



Hodgkin–Huxley equations and simulation

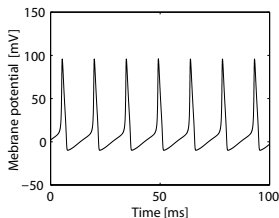
$$C \frac{dV}{dt} = -g_K n^4 (V - E_K) - g_{Na} m^3 h (V - E_{Na}) - g_L (V - E_L) + I(t)$$

$$\tau_n(V) \frac{dn}{dt} = -[n - n_0(V)]$$

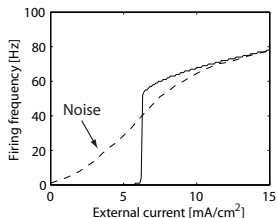
$$\tau_m(V) \frac{dm}{dt} = -[m - m_0(V)]$$

$$\tau_h(V) \frac{dh}{dt} = -[h - h_0(V)]$$

A. Spike train with constant input



B. Frequency-current plot

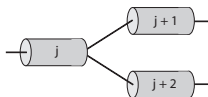


Compartmental models

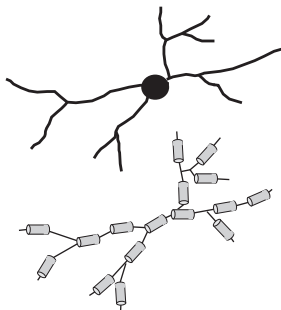
A. Chain of compartments



B. Branching compartments



C. Compartmental reconstruction



Simulators

The screenshot displays the NEURON simulation environment with several key components:

- NEURON Main Menu:** A menu bar with options: Iconify, File, Edit, Build, Tools, Graph, Vector, Window.
- Graph:** A plot window titled "Graphs x:0.5 y:5.5 z:0.0" showing a membrane potential trace. The y-axis ranges from -60 to 40 mV. The trace shows a step from -60 mV to -55 mV, followed by a sharp peak reaching approximately 20 mV between time points 2 and 3. The plot is labeled "soma.v(5)".
- PanelProcessManager:** A window showing a list of processes: "SolenoidProcess", "Show", and "IClamp[0]". The "IClamp[0]" process is active at "at: dendrite_1[0](0.785714)". Below the list is a diagram of a neuron with a dendrite and soma.
- Command Window:** A terminal window showing the following text:

```
NEURON -all nbranch all dena hoc.  
hs %hs  
Setting NEURONHOME-C:\n  
NEURON Version 4.3.1 2000/09/06  
By John W. Moore, Michael Hines, and Ted Carnevale  
Duke and Yale University -- Copyright 2000  
  
Loading membrane mechanisms from nbranch.dll  
Additional mechanisms from files  
cabump.mod cacachi.mod canchan.mod capump.mod khchan  
Allow single channel model for HCNs  
Meth CVode  
oc>
```
- RunControl:** A control panel for running simulations. It includes:
 - Buttons: Class, Hide, Init & Run, Stop, Single Stop, Quiet.
 - Fields: "Init (mV)" set to -55, "Continue till (ms)" set to 5, "Continue for (ms)" set to 1, "t (ms)" set to 5, "tstop (ms)" set to 0, "dt (ms)" set to 0.025, "Plots plotted/ms" set to 40, and "Real Time (s)" set to 0.

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.