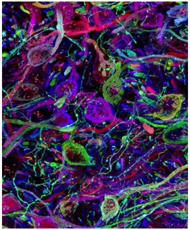
Neuroinformatics 2024, Prague

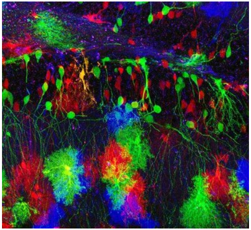
February 28, 2024

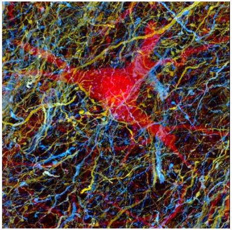
Basic neuron models

Brainbows

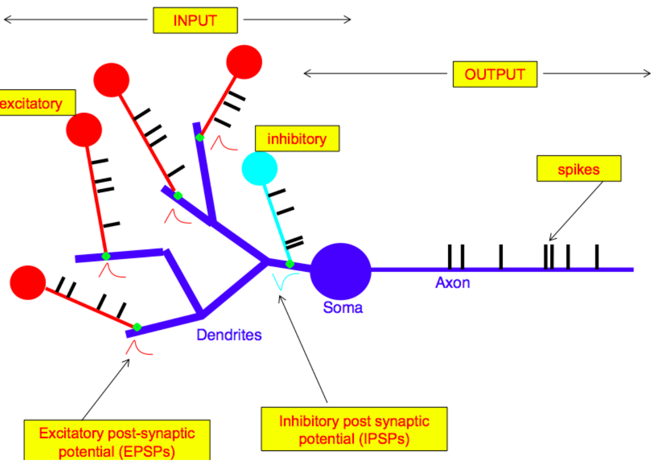
- Auditory portion of a mouse brainstem. A special gene (extracted from coral and jellyfish) was inserted into the mouse in order to map intricate connection. As the mouse thinks, fluorescent proteins spread out along neural pathways
- This view of the hippocampus shows the smaller glial cells (small ovals) in the proximity of neurons (larger with more filaments).
- A single neuron (red) in the brainstem
- `http://www.wired.com/science/discoveries/multimedia/2007/10/gallery_fluorescentneurons`







Neuron as input-output device



Neuron types

Classification by anatomical features ("the face" of dendrites and axons)

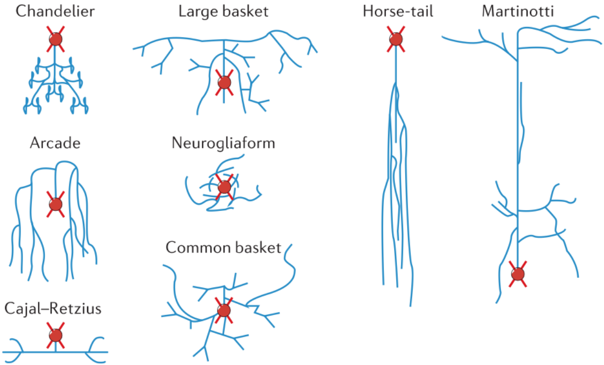
Classification – functional (e.g., Excitatory (principal) vs. Inhibitory (inter) neurons)

Classification using electrical/spiking activity pattern

Classification using chemical characteristics

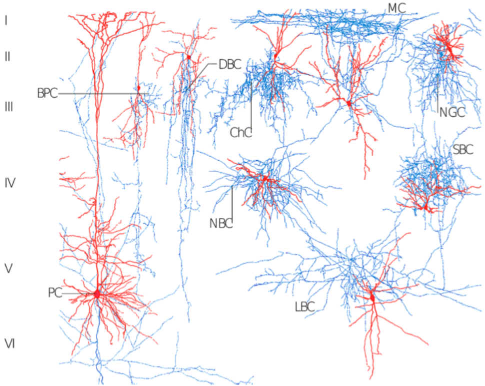
Classification using gene expression

Morphometric-based classification of (inhibitory) interneurons



DeFelipe et al., Nature Review neuroscience, 2013

Microcircuit of the Neocortex

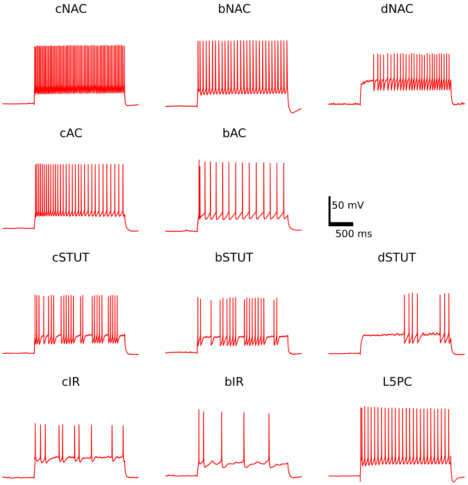


Principal neurons (excitatory) - axon projects to other brain regions

Interneurons (inhibitory) – local axonal projection

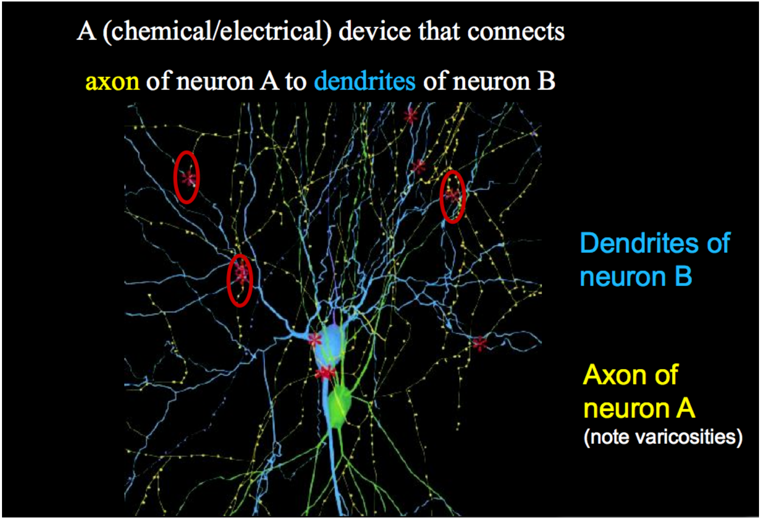
Z. J. Huang, G. Di Cristo & F. Ango
Nature Reviews Neuroscience 8, 673-686 (September 2007)

Electrically based neuron classification

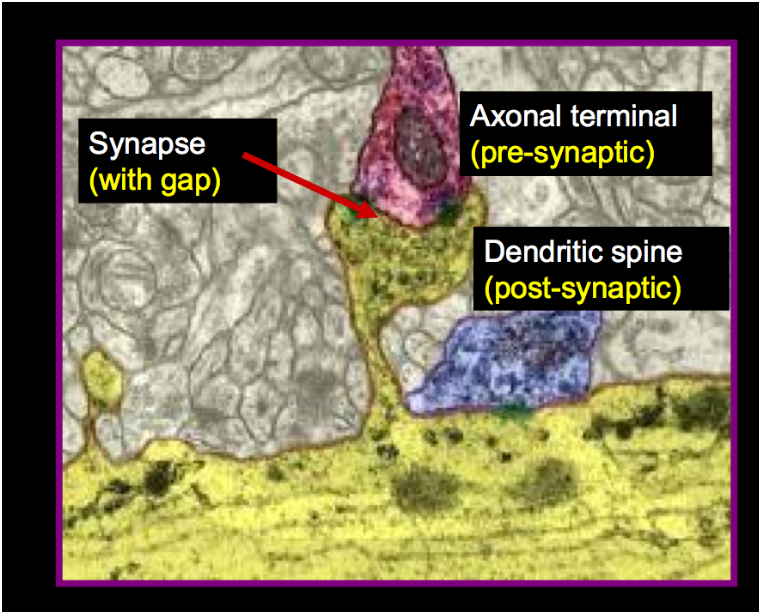


Courtesy of the Blue Brain data-base

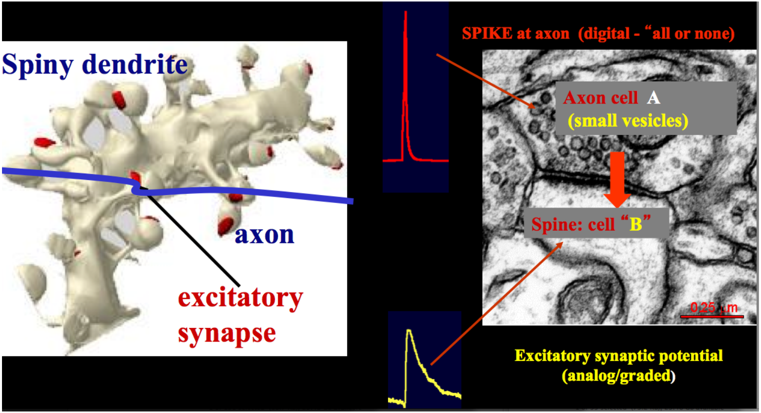
Synapse


A (chemical/electrical) device that connects
axon of neuron A to dendrites of neuron B
Dendrites of neuron B
Axon of neuron A
(note varicosities)

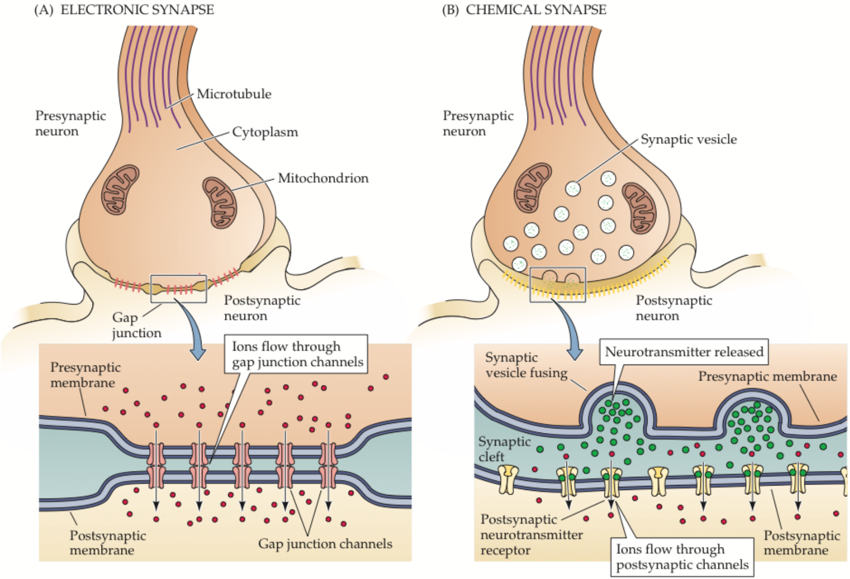
Chemical Synapse



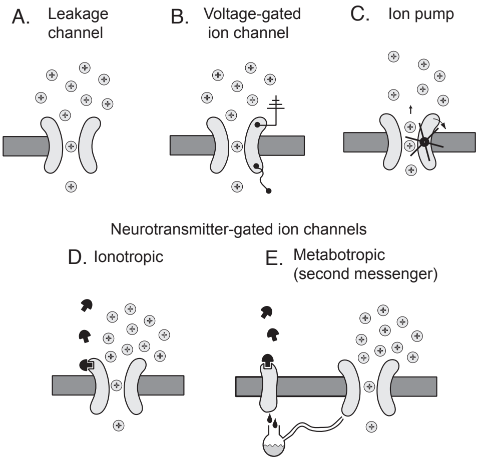
Digital Analog Device



Electrical and Chemical Synapse

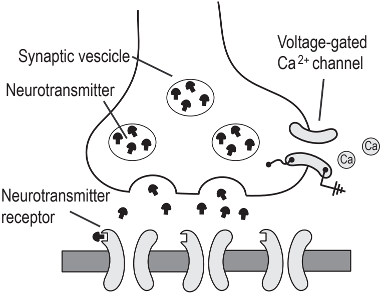


Ion channels



Synapse

- excitatory neurotransimitters-DA (dopamine), Gu (glutamate), GABA (A-fast, B-slow)
- inhibitory-neurotransmitters GABA (Gamma-aminobutyric acid),
- synaptic cleft - 1μ, synaptic vesticles



excitatory and inhibitory potentials

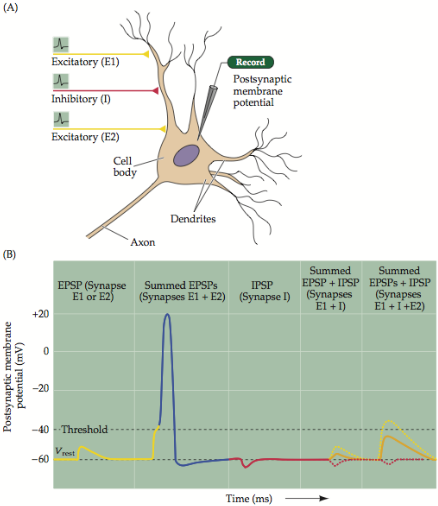
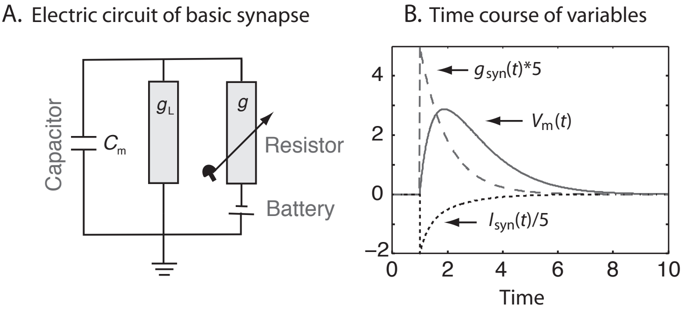


Figure 5.20 Summation of postsynaptic potentials. (A) A microelectrode records the postsynaptic potentials produced by the activity of two excitatory synapses (E1 and E2) and an inhibitory synapse (I). (B) Electrical responses to synaptic activation. Stimulating either excitatory synapse (E1 or E2) produces a subthreshold EPSP, whereas stimulating both synapses at the same time (E1 + E2) produces a suprathreshold EPSP that evokes a postsynaptic action potential (shown in blue). Activation of the inhibitory synapse alone (I) results in a hyperpolarizing IPSP. Summing this IPSP (dashed red line) with the EPSP (dashed yellow line) produced by one excitatory synapse (E1 + I) reduces the amplitude of the EPSP (orange line), while summing it with the suprathreshold EPSP produced by activating synapses E1 and E2 keeps the postsynaptic neuron below threshold, so that no action potential is evoked.

Conductance-based models

$$
\begin{aligned}
-I_C(t) &= c_m \frac{\mathrm{d}V_m(t)}{dt} \\
I_C(t) &= g_L V_m(t) + I_{syn}(t),\ I_{ext} = 0 \\
I_{syn} &= g_{syn}(t)(V_m(t) - E_{\mathrm{syn}}) \\
\tau_{\mathrm{syn}} \frac{\mathrm{d}g_{syn}(t)}{\mathrm{d}t} &= -g_{syn}(t) + \delta(t - t_{\mathrm{pre}} - t_{\mathrm{delay}})
\end{aligned}
$$



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:')
```

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.