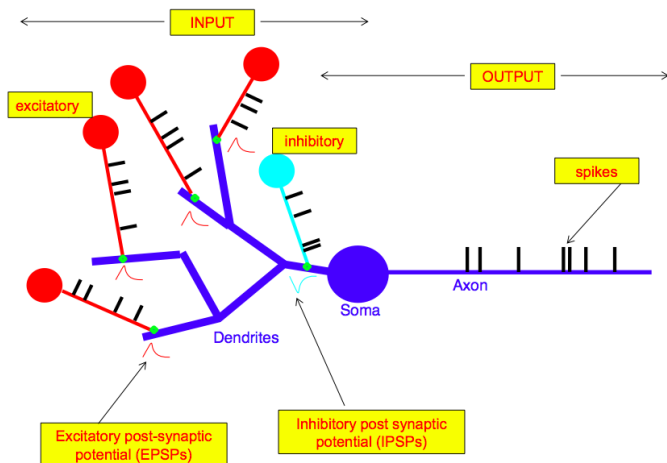


Neuroinformatics 2022, Prague

February 23, 2022

Basic neuron models

Neuron as input-output device



Neuron types

Classification by **anatomical features** (“the face” of dendrites and axons)

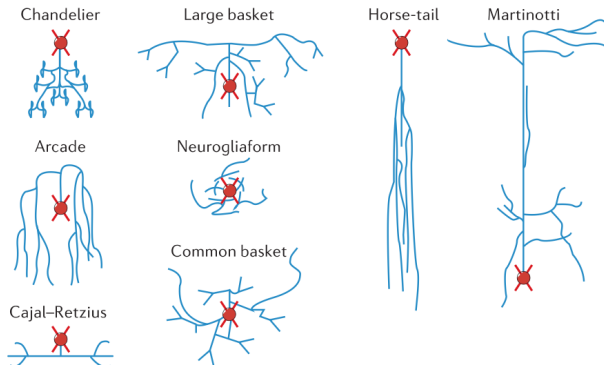
Classification – functional (e.g., **Excitatory** (principal) vs. **Inhibitory** (inter) neurons)

Classification using **electrical/spiking activity pattern**

Classification using **chemical characteristics**

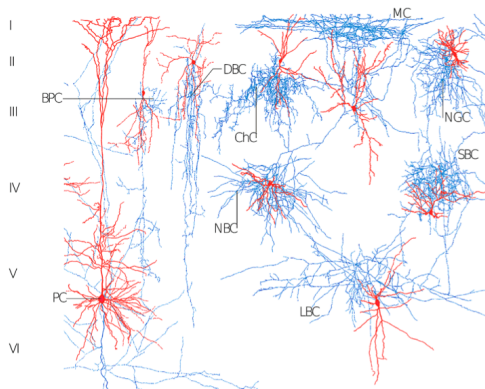
Classification using **gene expression**

Morphometric-based classification of (inhibitory) interneurons



DeFelipe et al., Nature Review neuroscience, 2013

Microcircuit of the Neocortex

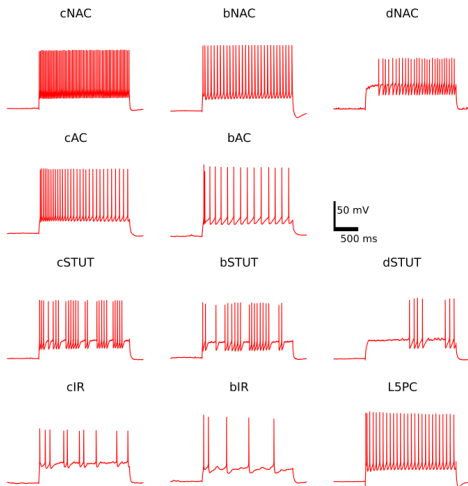


Principal neurons
(excitatory) - axon projects
to other brain regions

Interneurons (inhibitory) –
local axonal projection

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

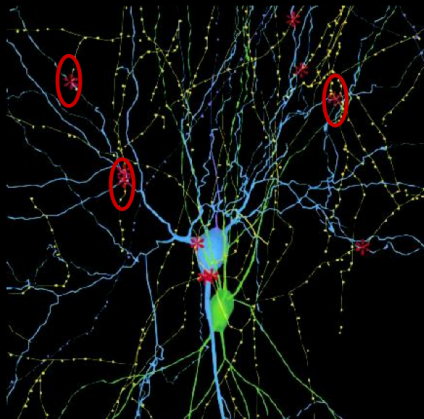
Electrically based neuron classification



Courtesy of the Blue Brain data-base

Synapse

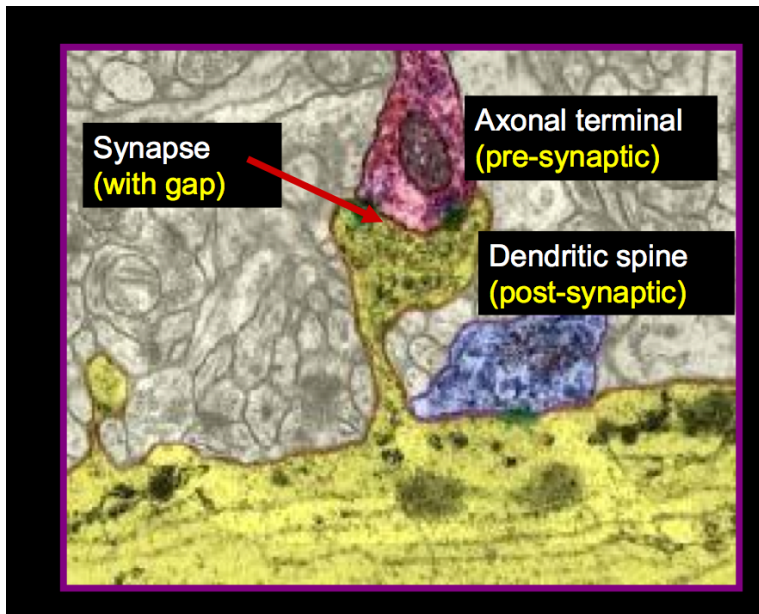
A (chemical/electrical) device that connects
axon of neuron A to **dendrites** of neuron B



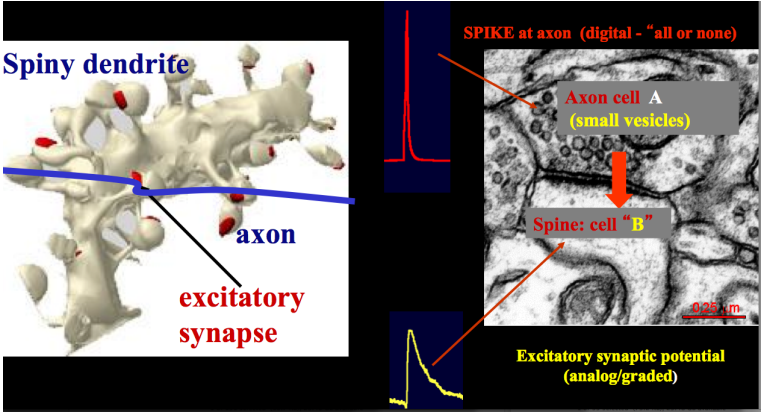
Dendrites of
neuron B

Axon of
neuron A
(note varicosities)

Chemical Synapse

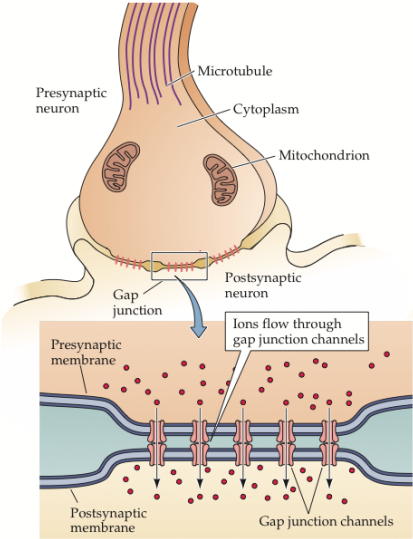


Digital Analog Device

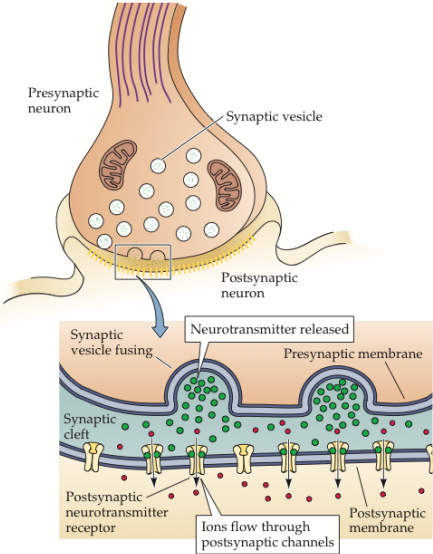


Electrical and Chemical Synapse

(A) ELECTRONIC SYNAPSE

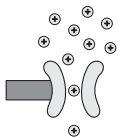


(B) CHEMICAL SYNAPSE

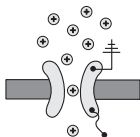


Ion channels

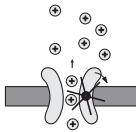
A. Leakage channel



B. Voltage-gated ion channel

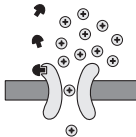


C. Ion pump

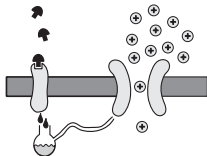


Neurotransmitter-gated ion channels

D. Ionotropic

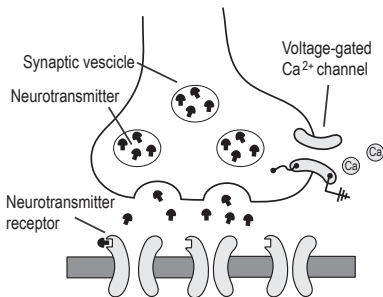


E. Metabotropic (second messenger)



Synapse

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



excitatory and inhibitory potentials

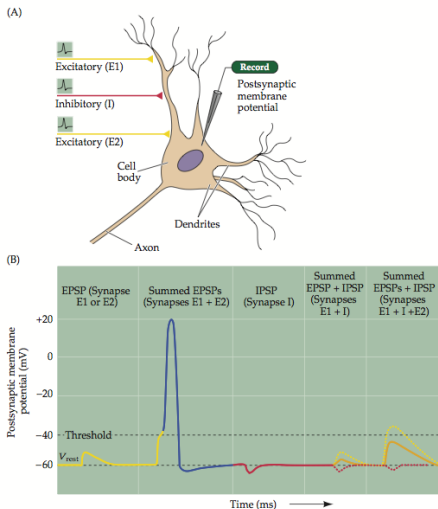
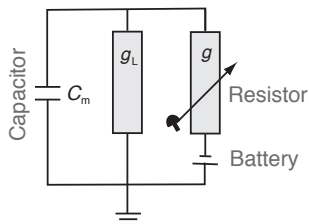


Figure 5.20 Summation of postsynaptic potentials. (A) A microelectrode records the postsynaptic potentials produced by the activity of two excitatory synapses (E1 and E2) and an inhibitory synapse (I). (B) Electrical responses to synaptic activation. Stimulating either excitatory synapse (E1 or E2) produces 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.

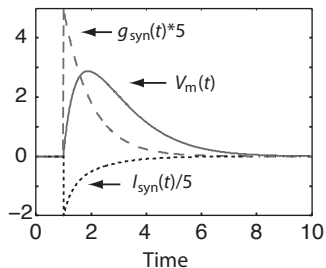
Conductance-based models

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

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:')
```


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.