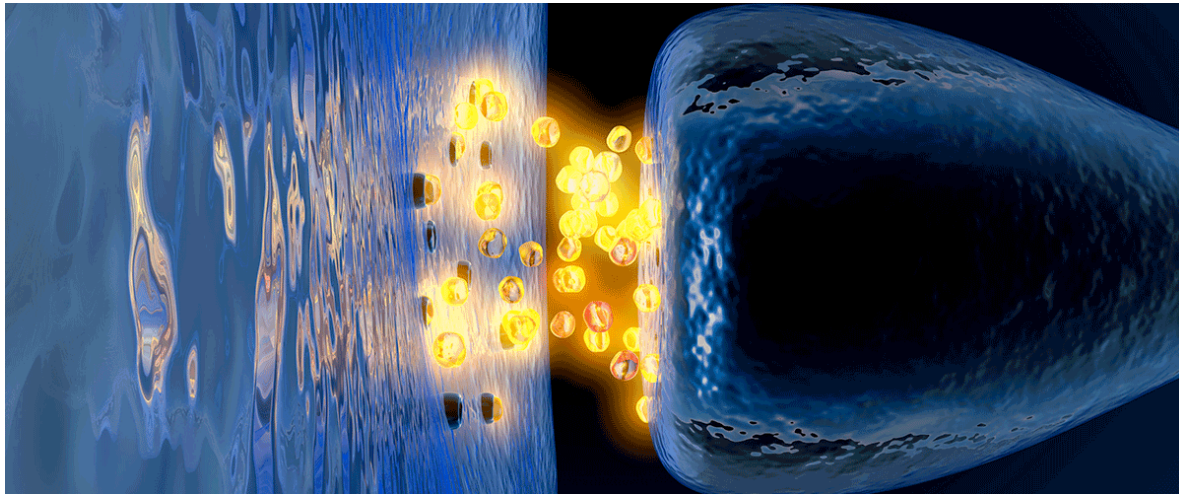


LASCON 2024

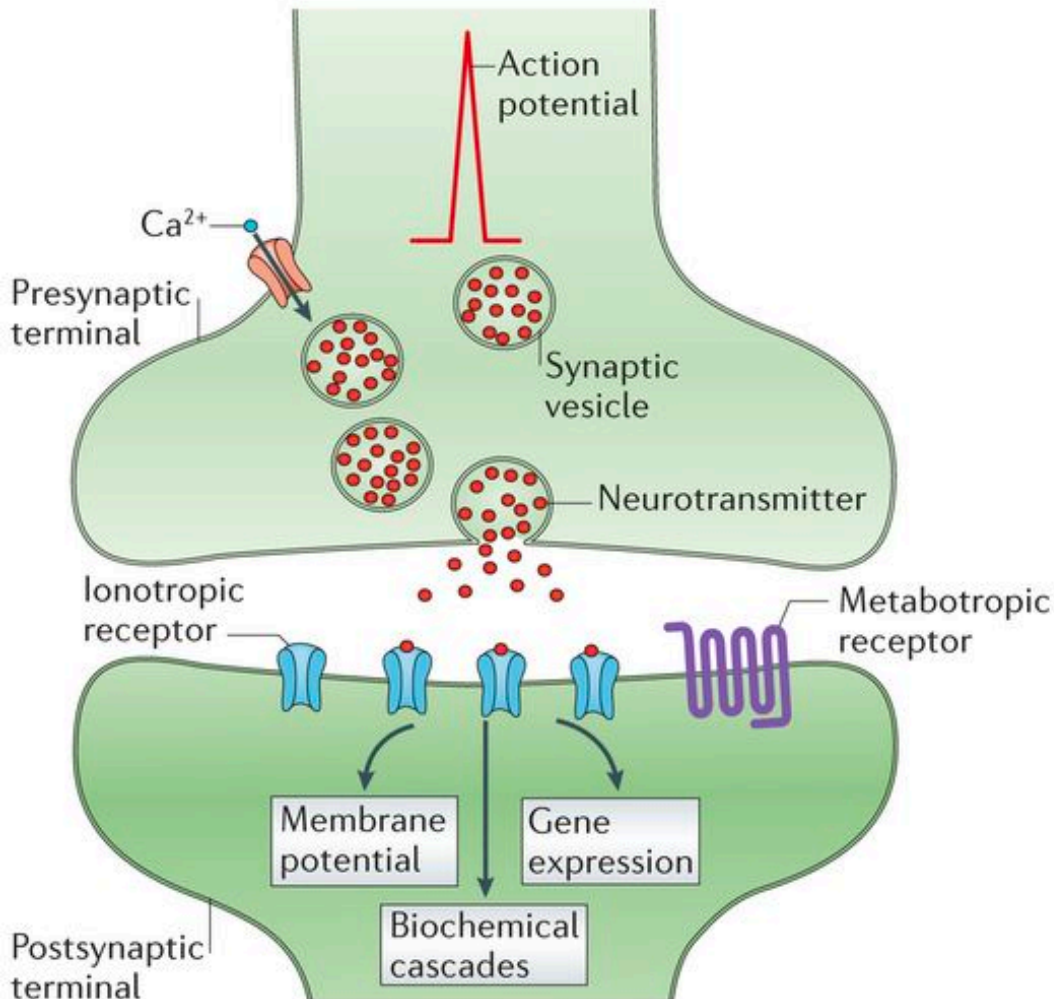
Tutorial: Modeling Synapses and Networks



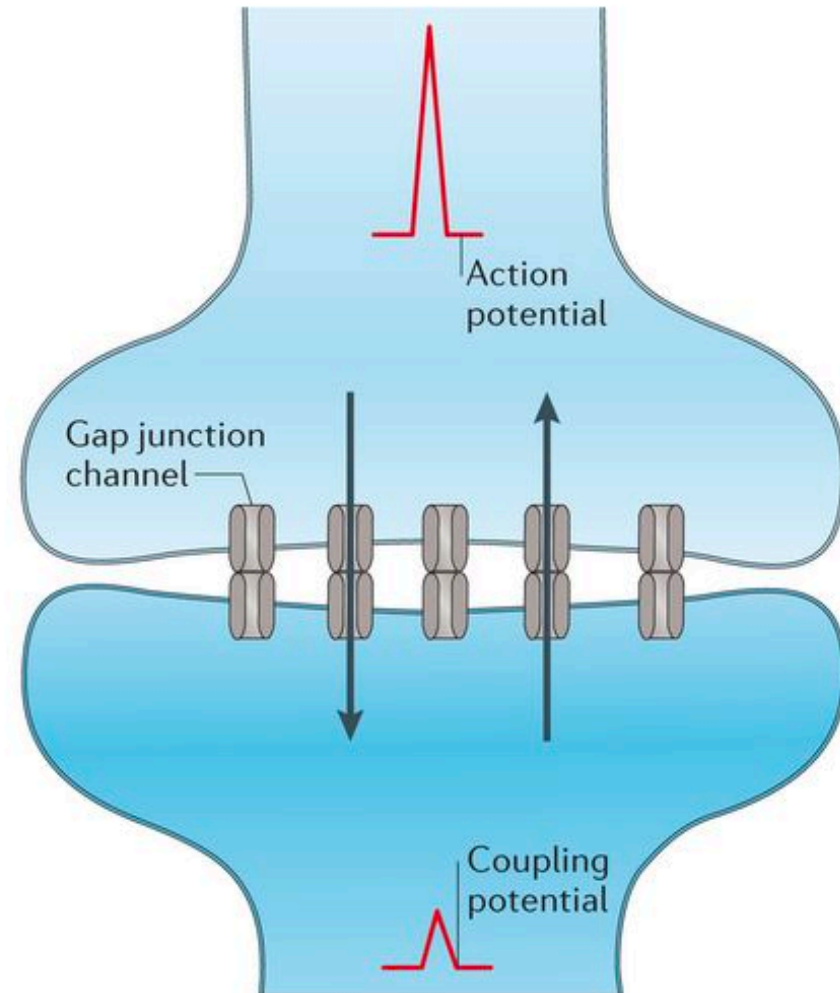
Arnd Roth and Valery Bragin

Types of Synapses

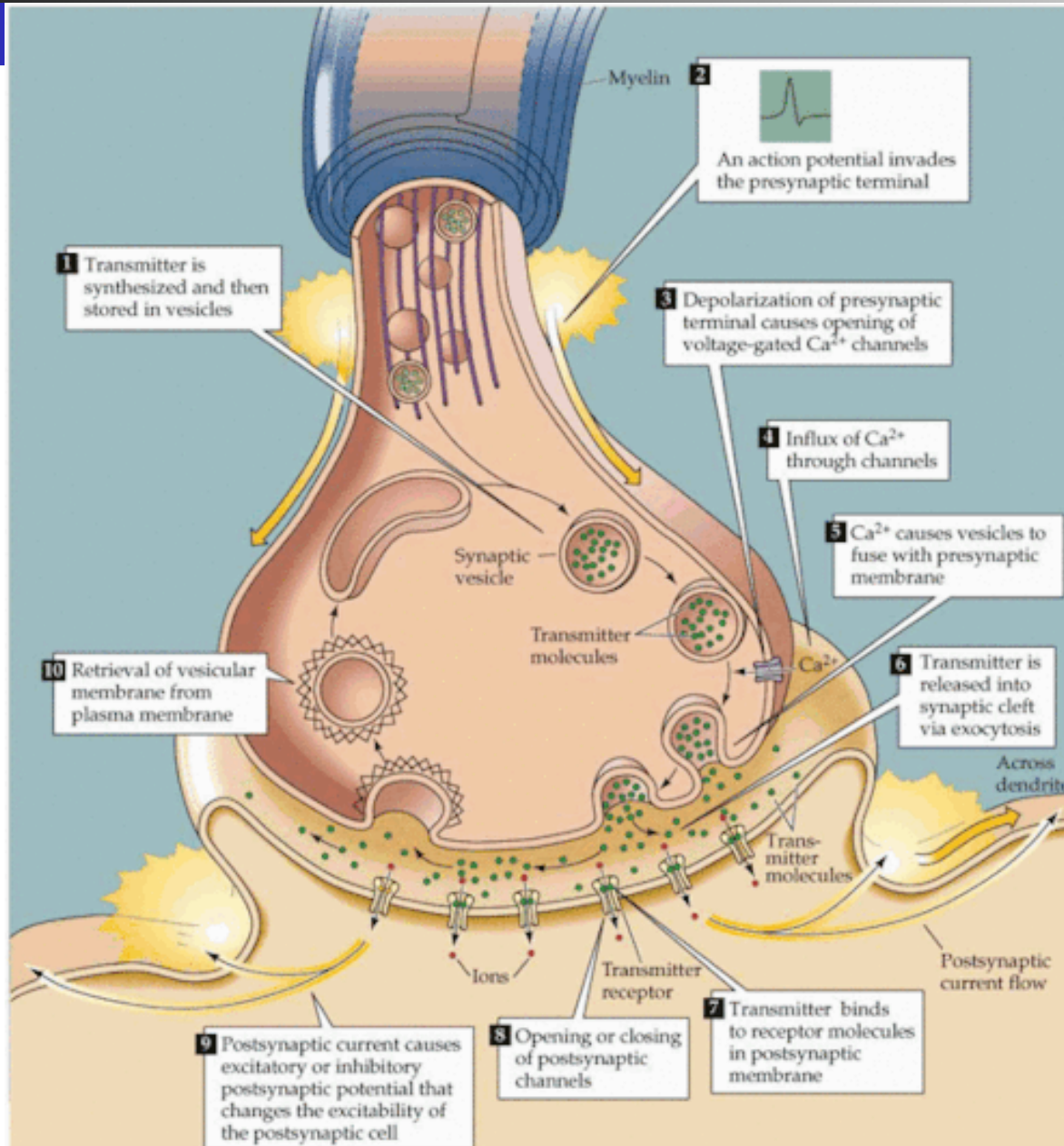
a Chemical synapse



b Electrical synapse



Chemical Synapse

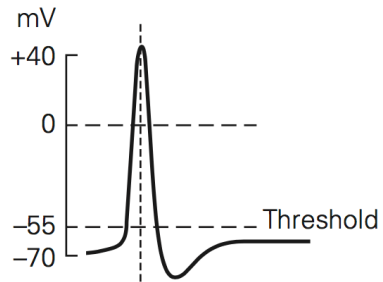


<https://www.youtube.com/watch?v=1nPGKqbeBHo>

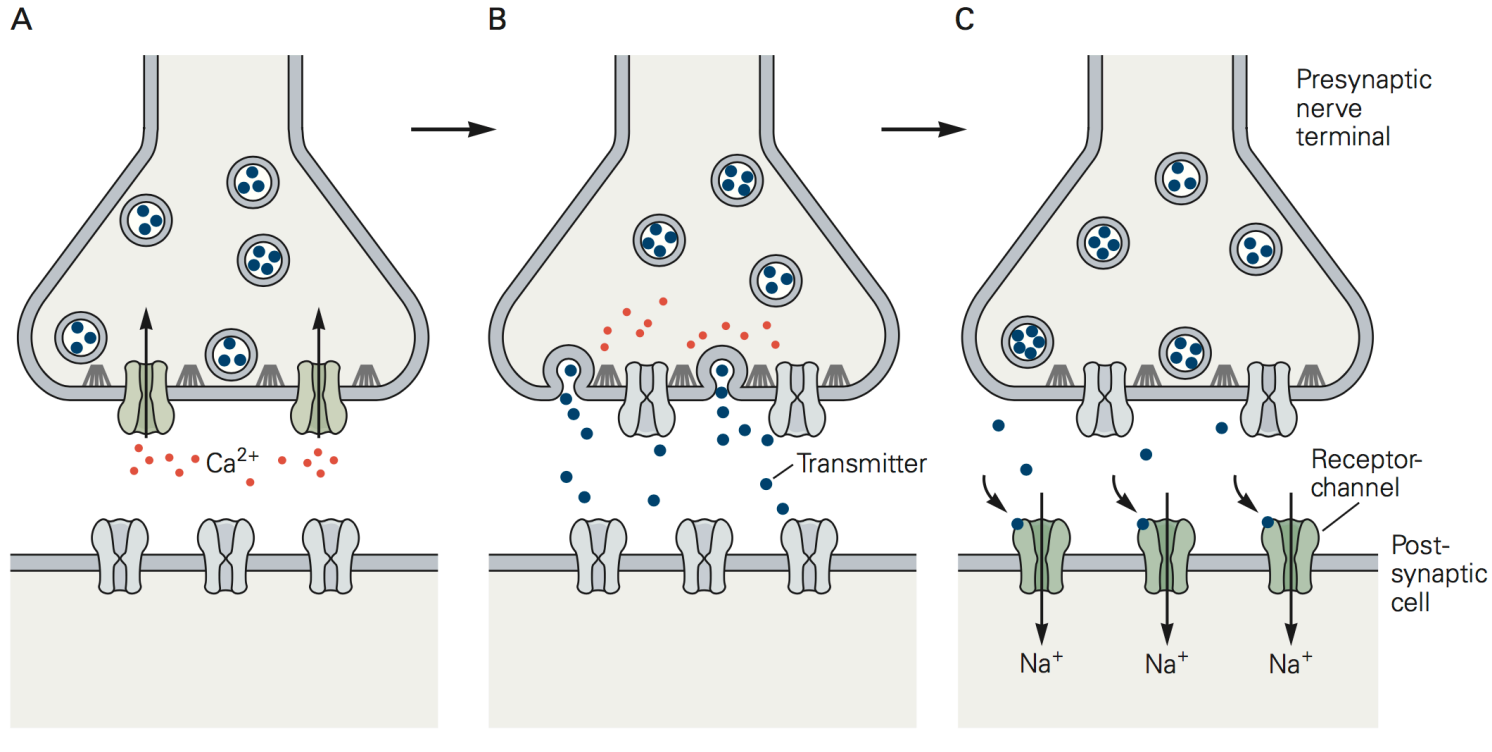
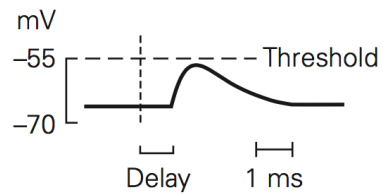
<https://www.youtube.com/watch?v=mltV4rC57kM>

Chemical Synapse

Presynaptic
action potential



Excitatory
postsynaptic
potential





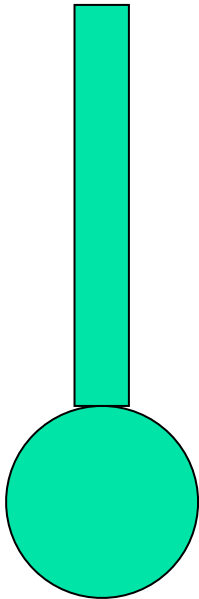
Postsynaptic potentials

- ❑ Binding of neurotransmitters to the post synaptic membrane can either be:
 - ❑ **Excitatory (produces EPSP)**
 - Depolarizes membrane potential
 - ❑ **Inhibitory (produces IPSP)**
 - Hyperpolarizes membrane potential

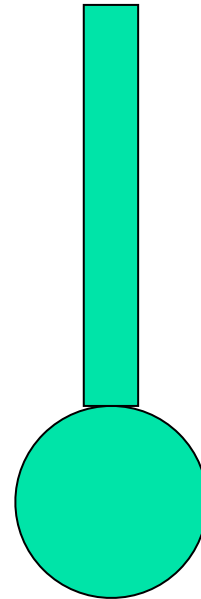
Both types of PSPs are *graded potentials* (as opposed to action potentials)

Synaptic connection model

Pre-synaptic cell

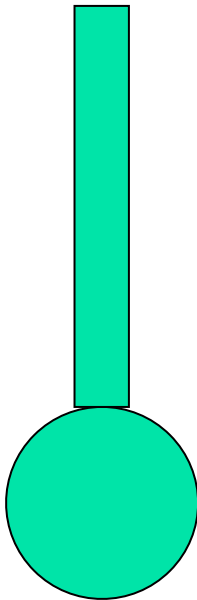


Post-synaptic cell

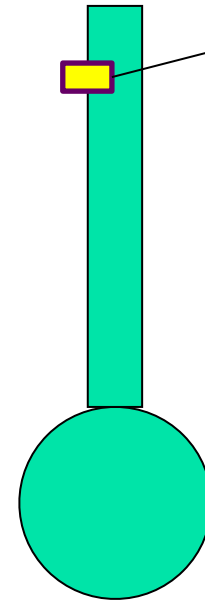


Synaptic connection model

Pre-synaptic cell



Post-synaptic cell



NEURON Synapse
(Ionotropic receptor)

Params:

- e : equilibrium potential (mV)
- τ : time constant (ms)

Function:

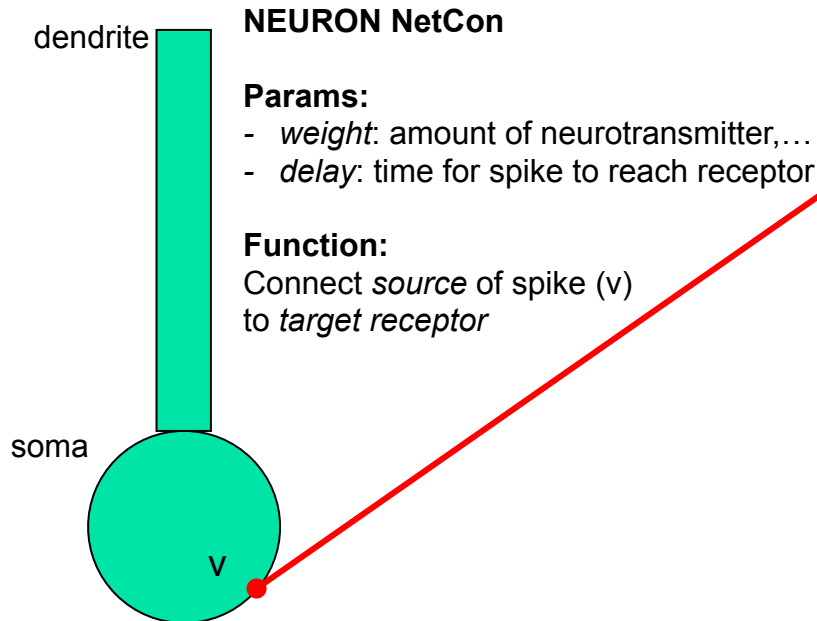
Changes channel conductance (g) when event received (presyn spike).

Generates current that moves V towards e :

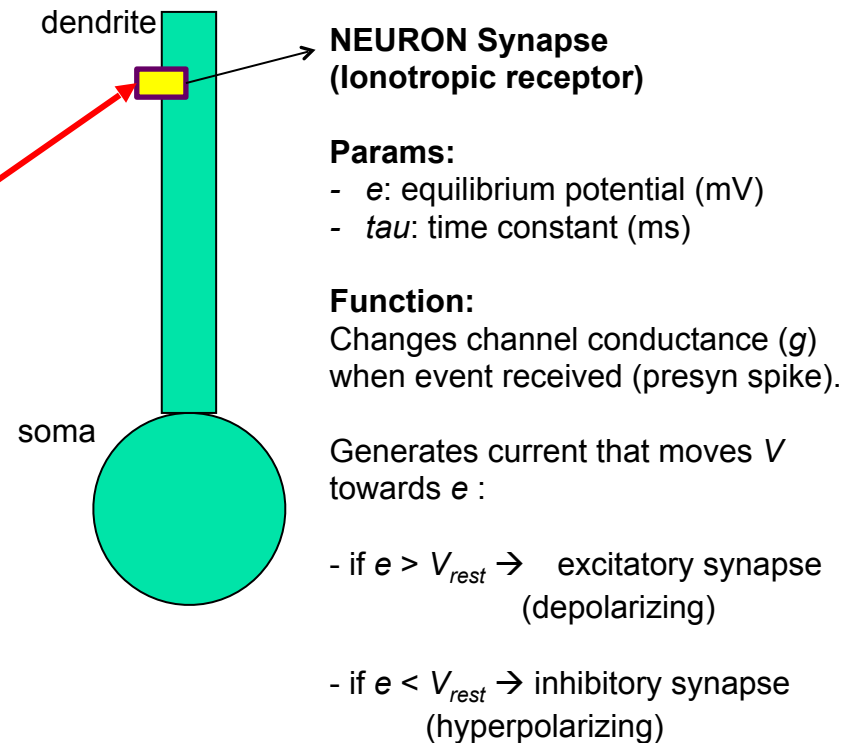
- if $e > V_{rest} \rightarrow$ excitatory synapse (depolarizing)
- if $e < V_{rest} \rightarrow$ inhibitory potential (hyperpolarizing)

Synaptic connection model

Pre-synaptic cell



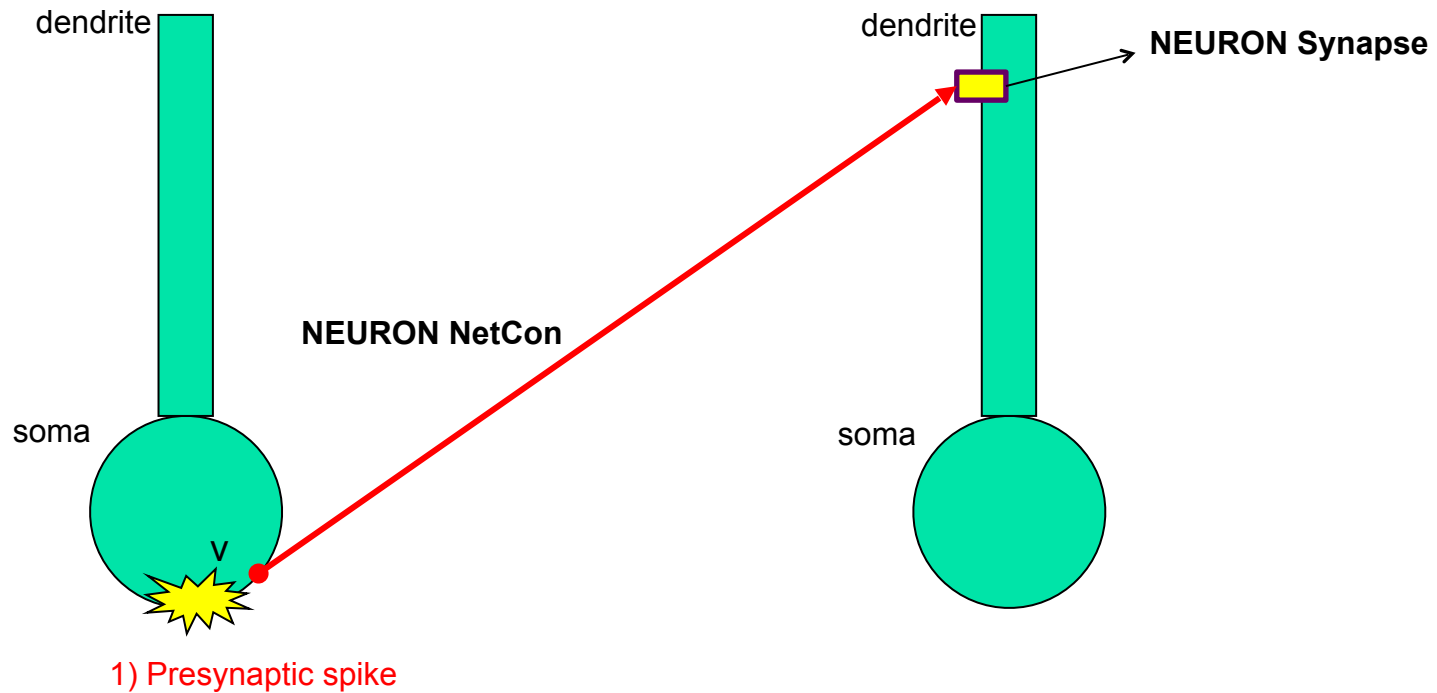
Post-synaptic cell



Synaptic connection model

Pre-synaptic cell

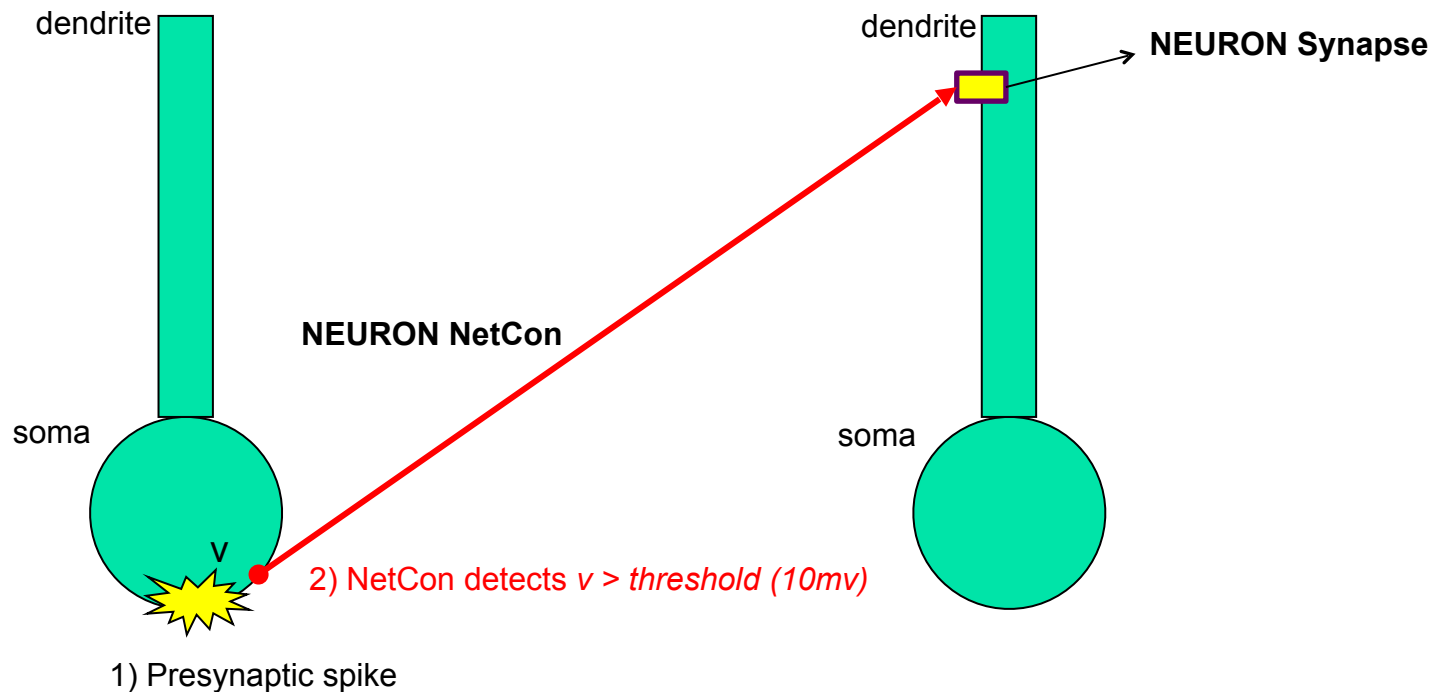
Post-synaptic cell



Synaptic connection model

Pre-synaptic cell

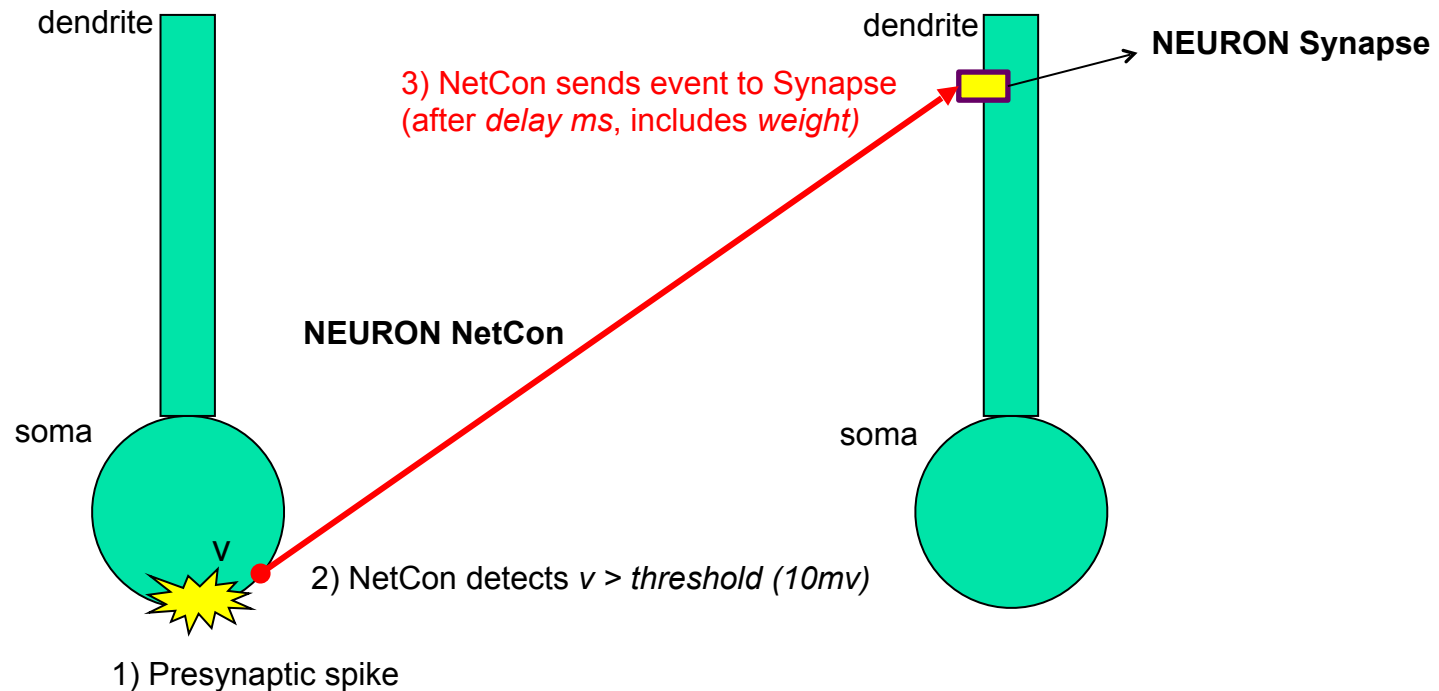
Post-synaptic cell



Synaptic connection model

Pre-synaptic cell

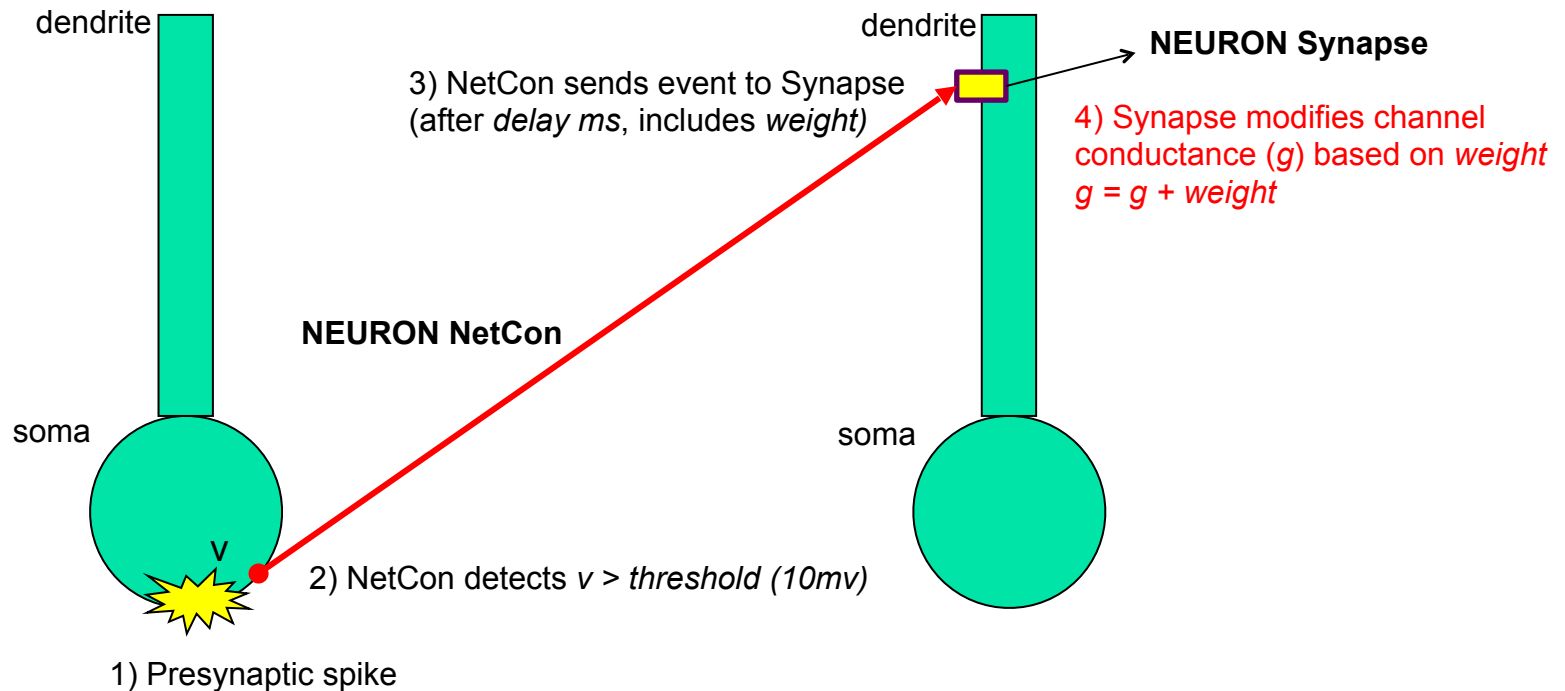
Post-synaptic cell



Synaptic connection model

Pre-synaptic cell

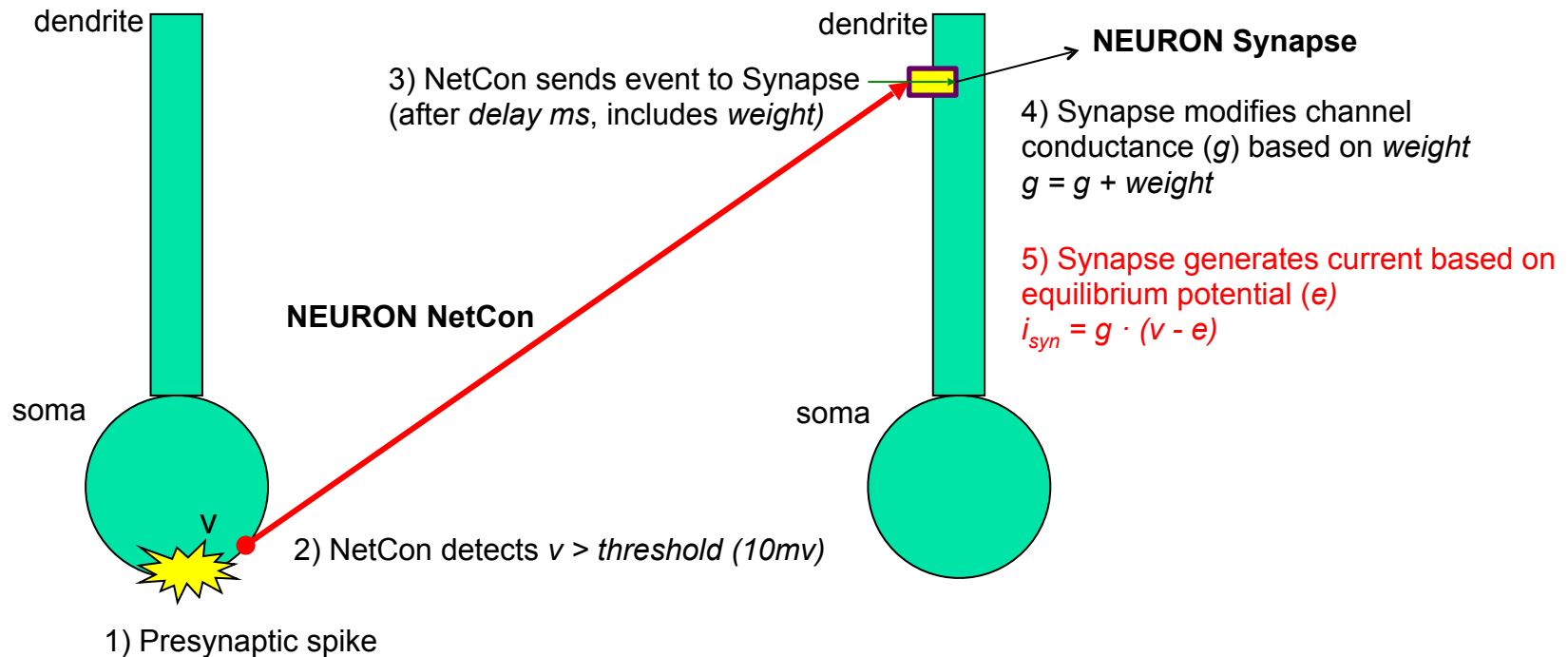
Post-synaptic cell



Synaptic connection model

Pre-synaptic cell

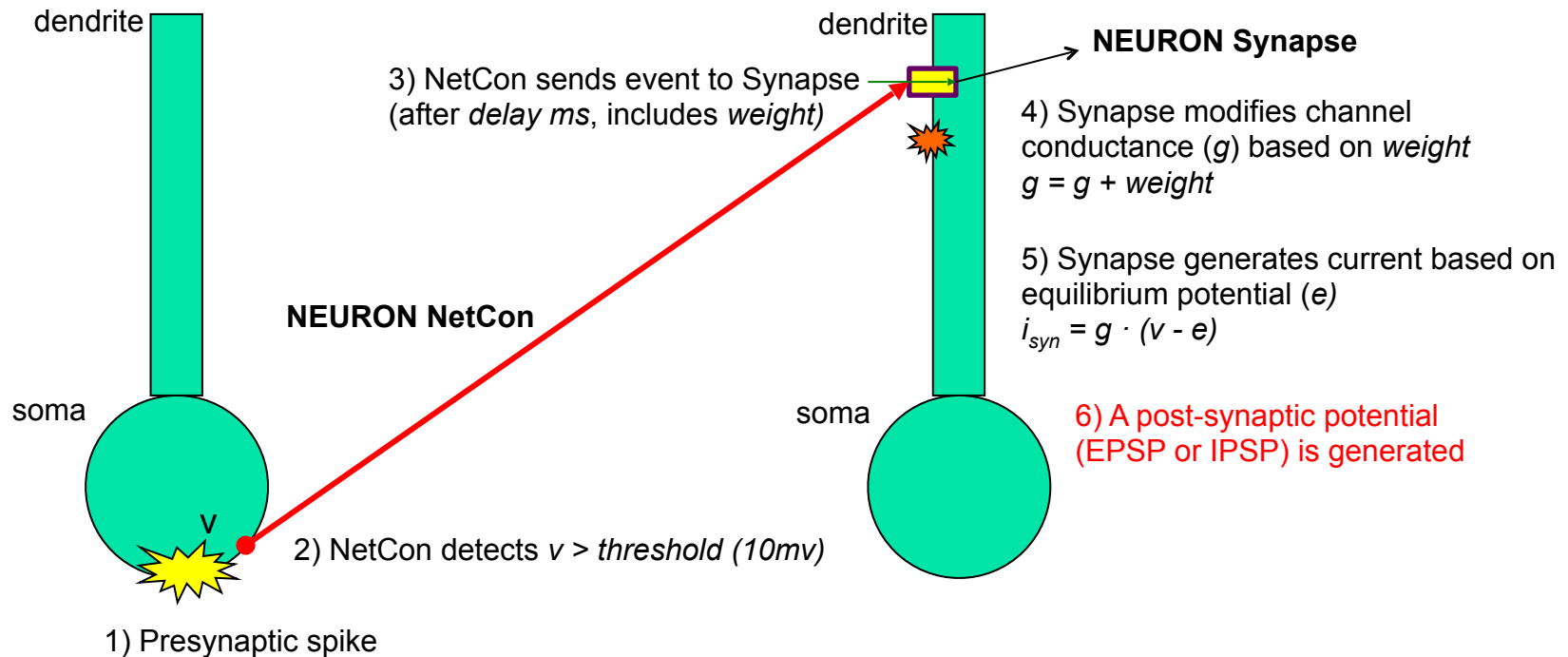
Post-synaptic cell



Synaptic connection model

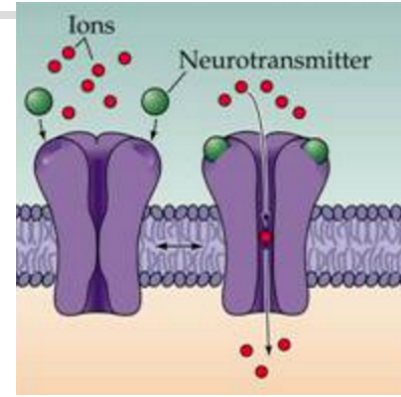
Pre-synaptic cell

Post-synaptic cell



NEURON Synapse

- NEURON synapses correspond to the postsynaptic receptor
- Requires input event (presynaptic spike) to get activated
- If input event, modifies channel conductance (g) based on *weight*:
$$g = g + \text{weight}$$
- Synapse generates current based on equilibrium potential (e):
$$i_{syn} = g \cdot (v - e)$$
- Synaptic current generates a post-synaptic potential:
 - if $e > V_{rest} \rightarrow$ excitatory synapse (EPSP)
 - if $e < V_{rest} \rightarrow$ inhibitory synapse (IPSP)





NEURON Synapses

❑ AlphaSynapse

- ❑ eg. `syn = h.AlphaSynapse(dend(0.5))`
- ❑ Artificial synapse – doesn't receive input from presynaptic cell (activated 'manually')
- ❑ Parameters:
 - ❑ *onset*: active at this time (ms), eg. `syn.onset = 20`
 - ❑ *gmax*: max conductance reached after *onset+tau* (ms), eg. `syn.gmax = 0.1`
 - ❑ *tau*: time for conductance to reach *gmax*, eg. `syn.tau = 1`

❑ ExpSyn

- ❑ eg. `syn = h.ExpSyn(dend(0.5))`
- ❑ Connected to presynaptic cell via NetCon (requires event=spike to activate)
- ❑ Parameters:
 - ❑ *e*: synapse equilibrium potential (mV). , eg. `syn.e = 0` or `syn.e = -80`
 - ❑ *tau*: time for conductance to reach *gmax*, eg. `syn.tau = 1`

❑ More complex synapse models that use eg. Ca^{2+} concentrations

NEURON Netcons

Syntax:

```
con = h.NetCon(source voltage, target, sec = source section)
```

```
eg. con = h.NetCon(soma(0.5)._ref_v, syn, sec=soma)
    con.weight = 0.1
    con.delay = 1
    con.threshold = 10
```

Description:

Network Connection object that defines a synaptic connection between a source and target. When the source variable passes *threshold*, the target will receive an event at time $t + \text{delay}$ along with weight information.

Source:

Normally a reference to a *membrane potential* (v) which is watched during simulation for $v > \text{threshold}$.

Target:

Must be a POINT_PROCESS (eg. synapse)

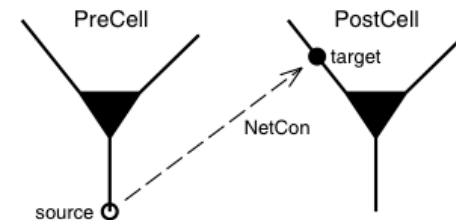


Figure 2.1. A NetCon attached to the presynaptic neuron PreCell detects spikes at the location labeled source, and delivers events to the synapse target which is attached to the postsynaptic neuron PostCell.

Netcons

Parameters:

- *delay*: time between action potential reaching axon terminal and
- *weight*: change of conductance in synaptic ionic channels (open/close channels)
~ = amount of neurotransmitter binding to receptors * num receptors
~ = amount of Ca^{2+} channels, concentration of Ca^{2+} ions

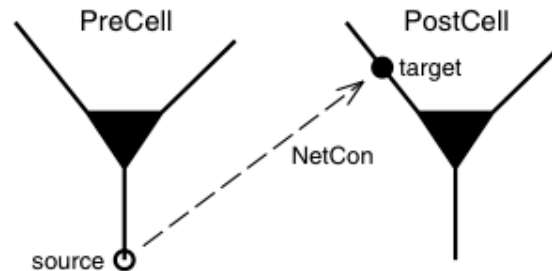


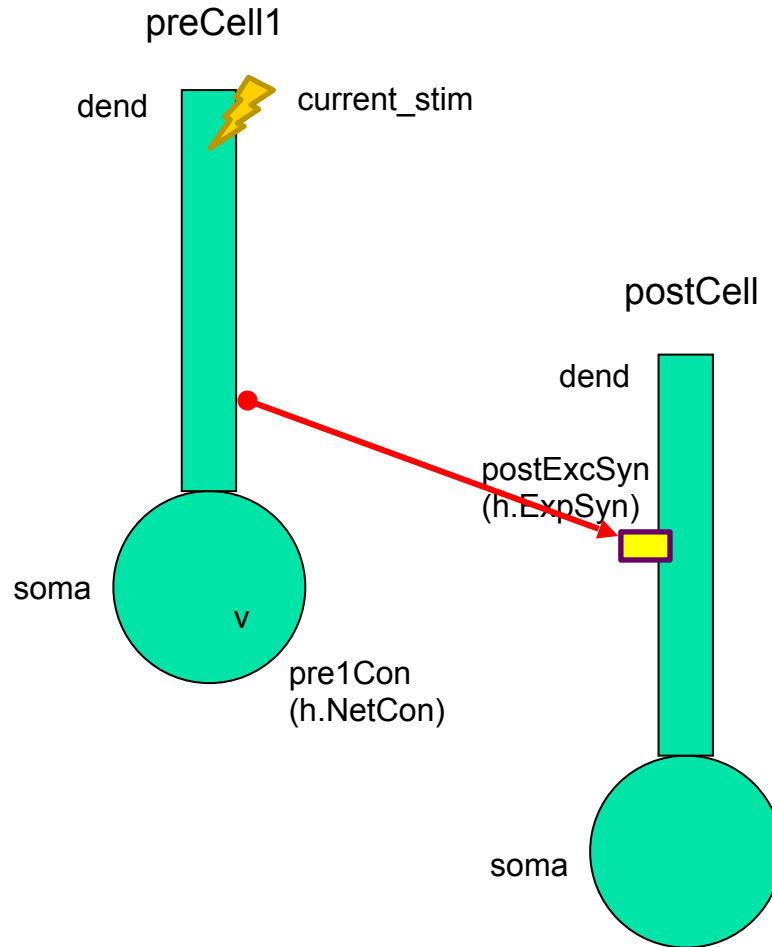
Figure 2.1. A NetCon attached to the presynaptic neuron PreCell detects spikes at the location labeled source, and delivers events to the synapse target which is attached to the postsynaptic neuron PostCell.



Connections Tutorial

- 1) Start with *tutorial_3.py*. It contains a single *postCell*, with no stimulation.
- 2) Set up recording and plot voltage. If needed, set limit on voltage axis, e.g.: `pyplot.ylim(-80,30)`
- 3) Add *preCell1* of same type *HHCell*, add a current stimulation to *preCell1* at 20 ms:
`preCell1.add_current_stim(20) # add stimulation`
- 4) Add an excitatory synaptic receptor at the dendrite of *postCell*, with reversal potential of 0 mV and delay of 2 ms:
`postSyn1 = h.ExpSyn(postCell.dend(0.5)) # add exc synapse`
`postSyn1.e = 0`
`postSyn1.tau = 2`
- 5) Add a connection between the *preCell1* soma and the *postCell* dendrite with weight of 0.002 and delay of 1 ms.
`pre1Con = h.NetCon(preCell1.soma(0.5)._ref_v, postSyn1, sec=preCell1.soma)`
`pre1Con.weight[0] = 0.002`
`pre1Con.delay = 1`
- 6) Run simulation for 60 ms, plot voltage
- 7) Try different values of *ExpSyn* and *NetCon* parameters, to get (1) small EPSP, (2) EPSP that leads to spike, (3) IPSP.

Connections Tutorial



Play with the ExpSyn and Netcon parameters to get:

- 1) Small EPSP
- 2) EPSP that leads to action potential
- 3) IPSP

Note: if get errors when rerunning try adding *h.init()* right before *h.run()*



Connections Tutorial

- 1) Add a *preCell2*
- 2) Add another excitatory synaptic receptor *postSyn2* at the dendrite of *postCell*, with reversal potential of 0 mV and tau of 2 ms
- 3) Add a connection between the *preCell2* soma and the *postSyn2* synapse *postCell* dendrite with weight of 0.002 and delay of 1 ms.
- 4) By commenting out either *preCell1* or *preCell2*, observe that spike in one of them doesn't lead to postsynaptic spike, but spike is generated if both pre-cells are connected (spatial summation)
- 5) Modify *postSyn2* to be inhibitory (change reversal potential)
- 6) Try to show spatial cancellation (EPSP+IPSP)

Connections Tutorial

