COMS30017 Computational Neuroscience

Week 4: Synapses and Synaptic Plasticity

Video 2: COMPUTATIONAL MODELLING OF A SYNAPSE

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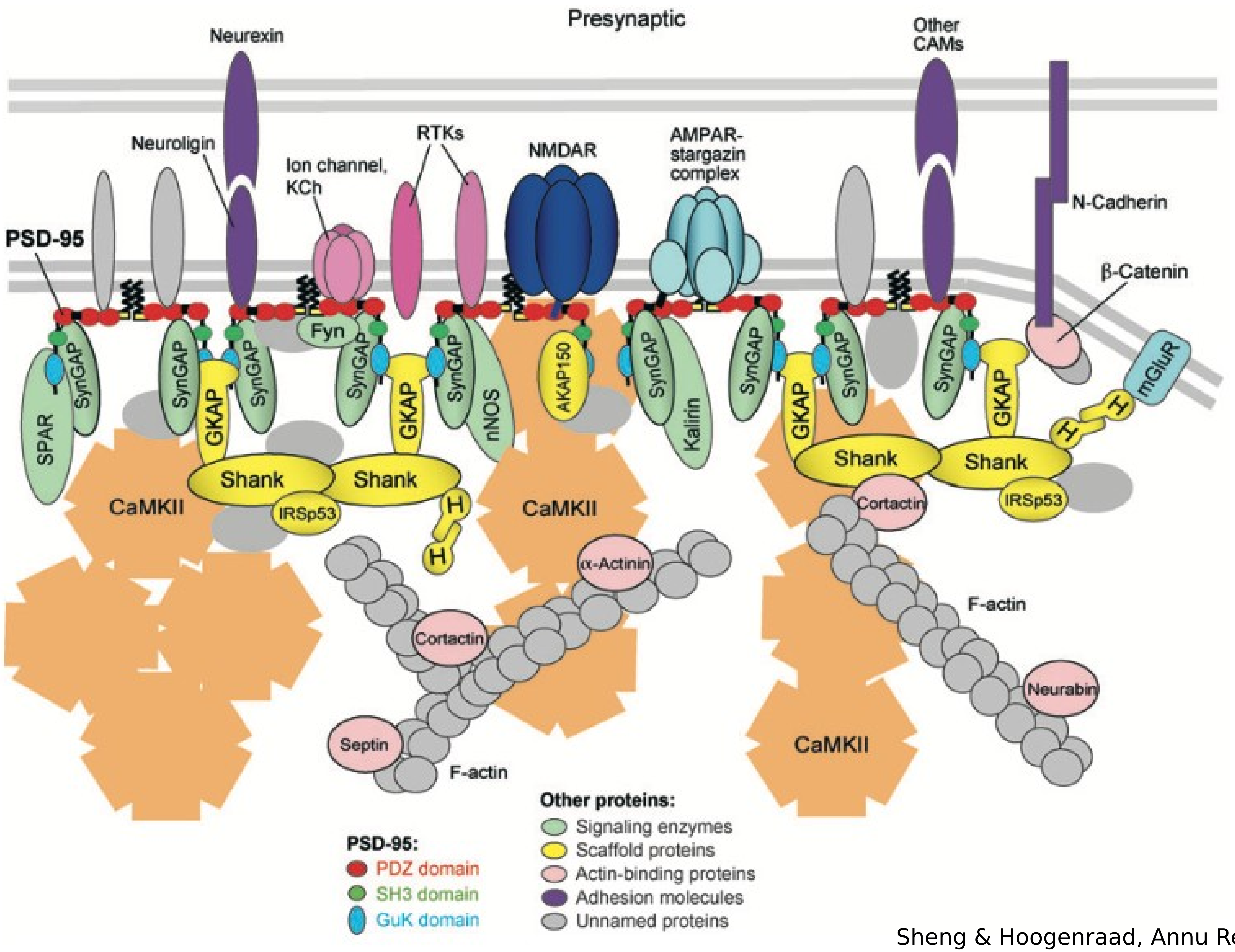
Intended learning outcomes

- Understand different abstract representations of synapses;
- Be able to write down a simple model for a synaptic input;

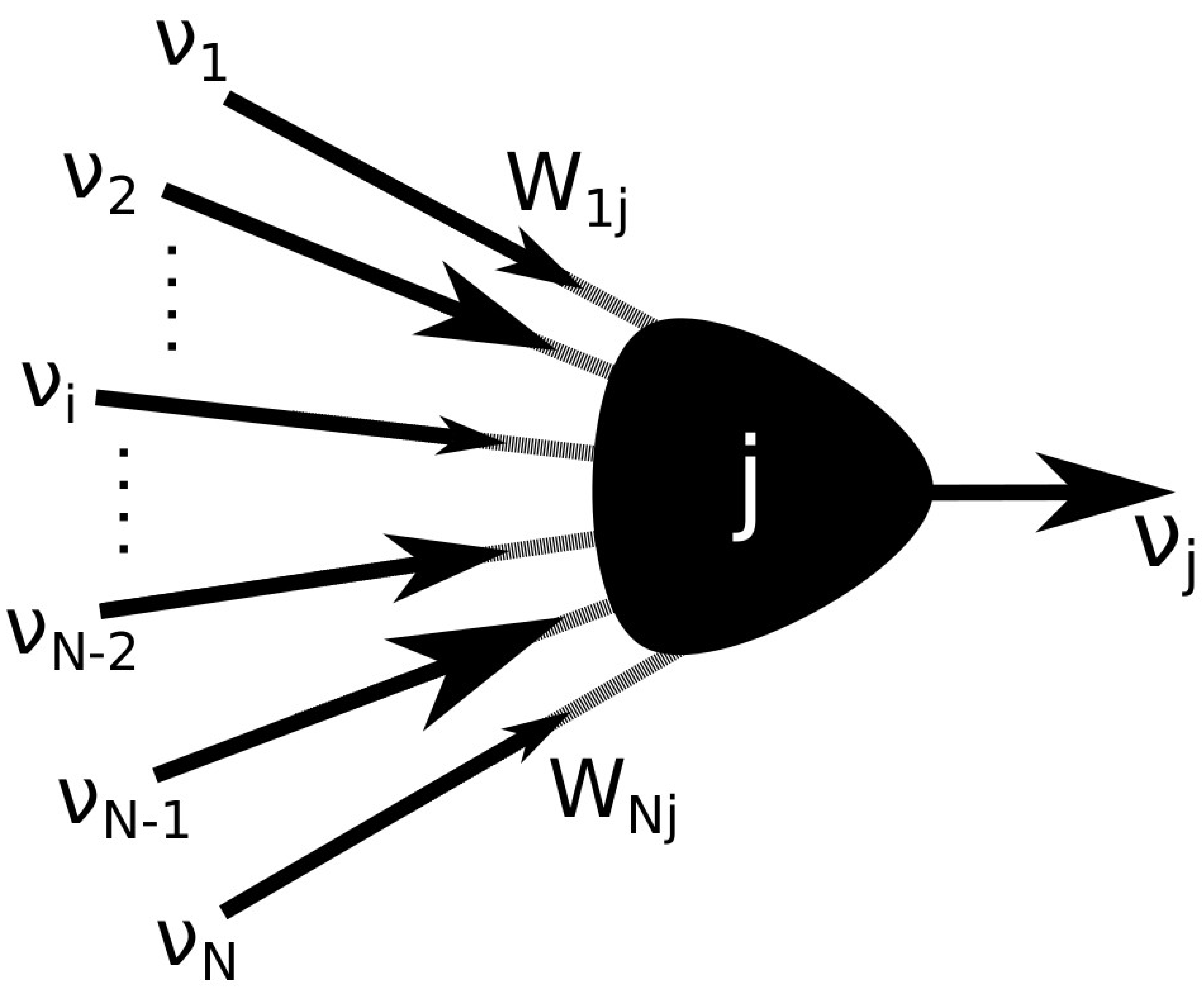
Synapses are complex



Sheng & Hoogenraad, Annu Rev Neurosci (2007)

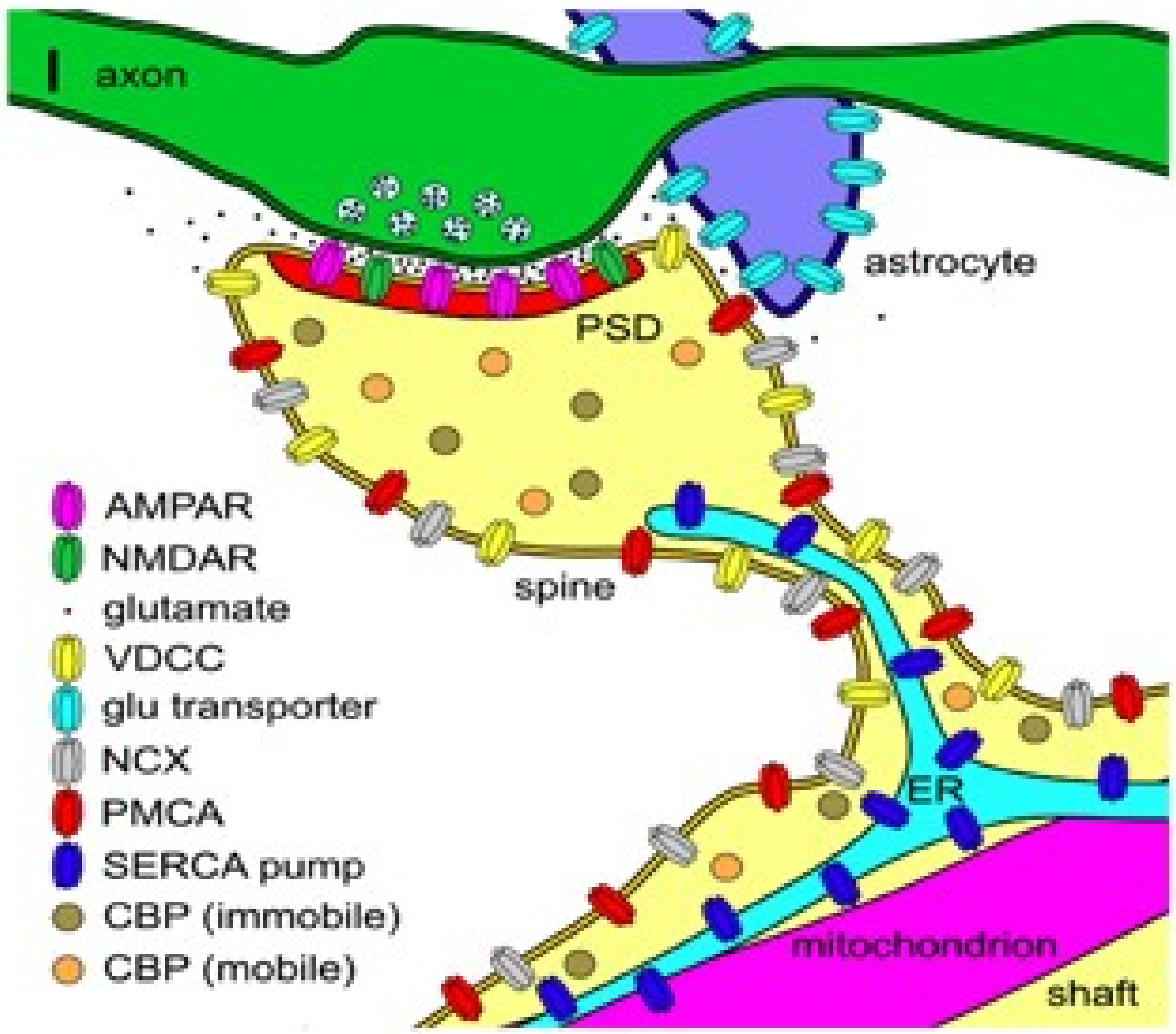
Computational model of a synapse

- Many possible levels of abstraction:

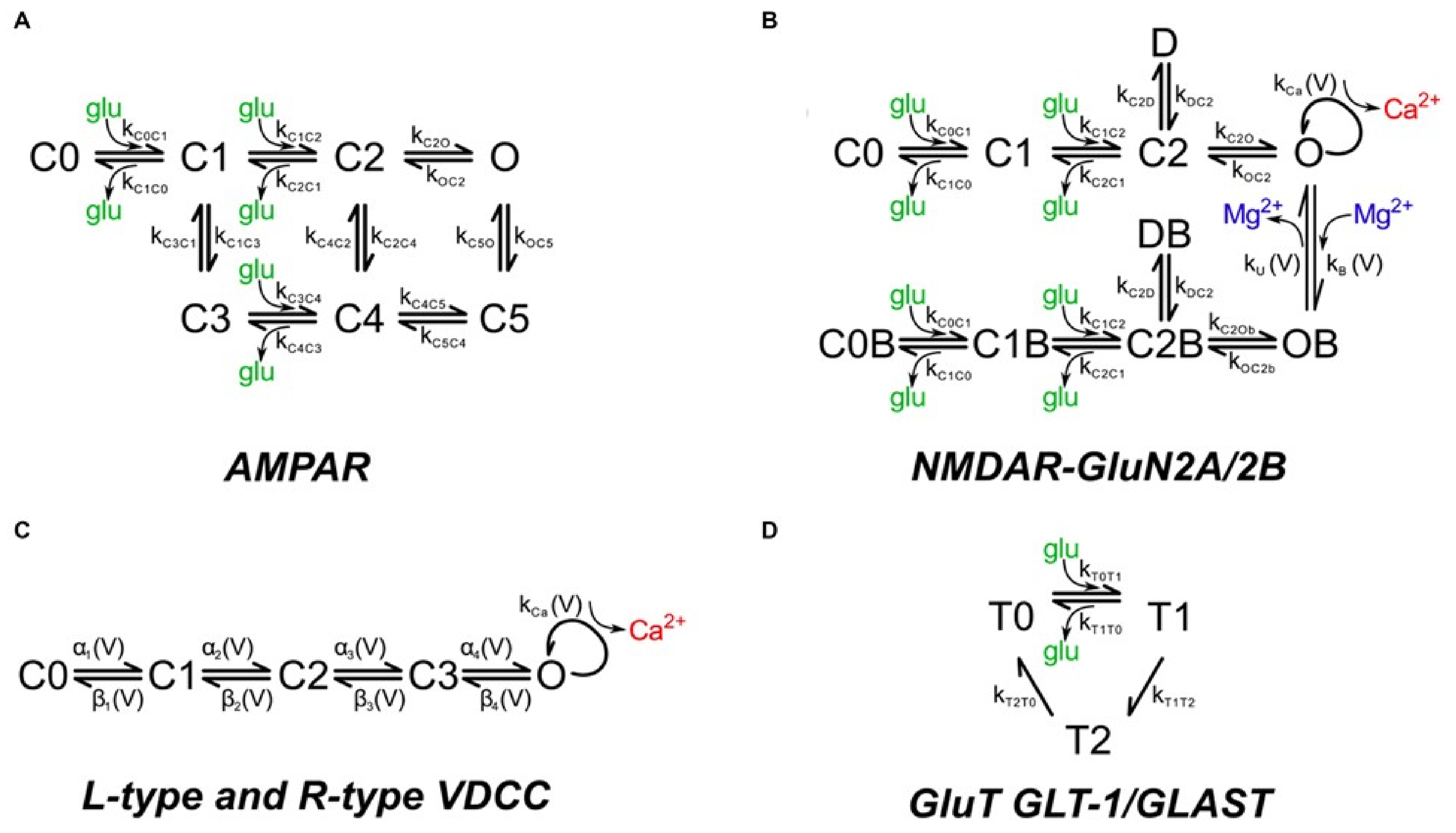


$$\nu_j = \sum_i W_i \nu_i$$

MCell simulation of synaptic release



Bartol et al, Frontiers Syn Neuro (2015)



Simulations at molecular level are possible: detailed but computationally expensive

Model of a synapse

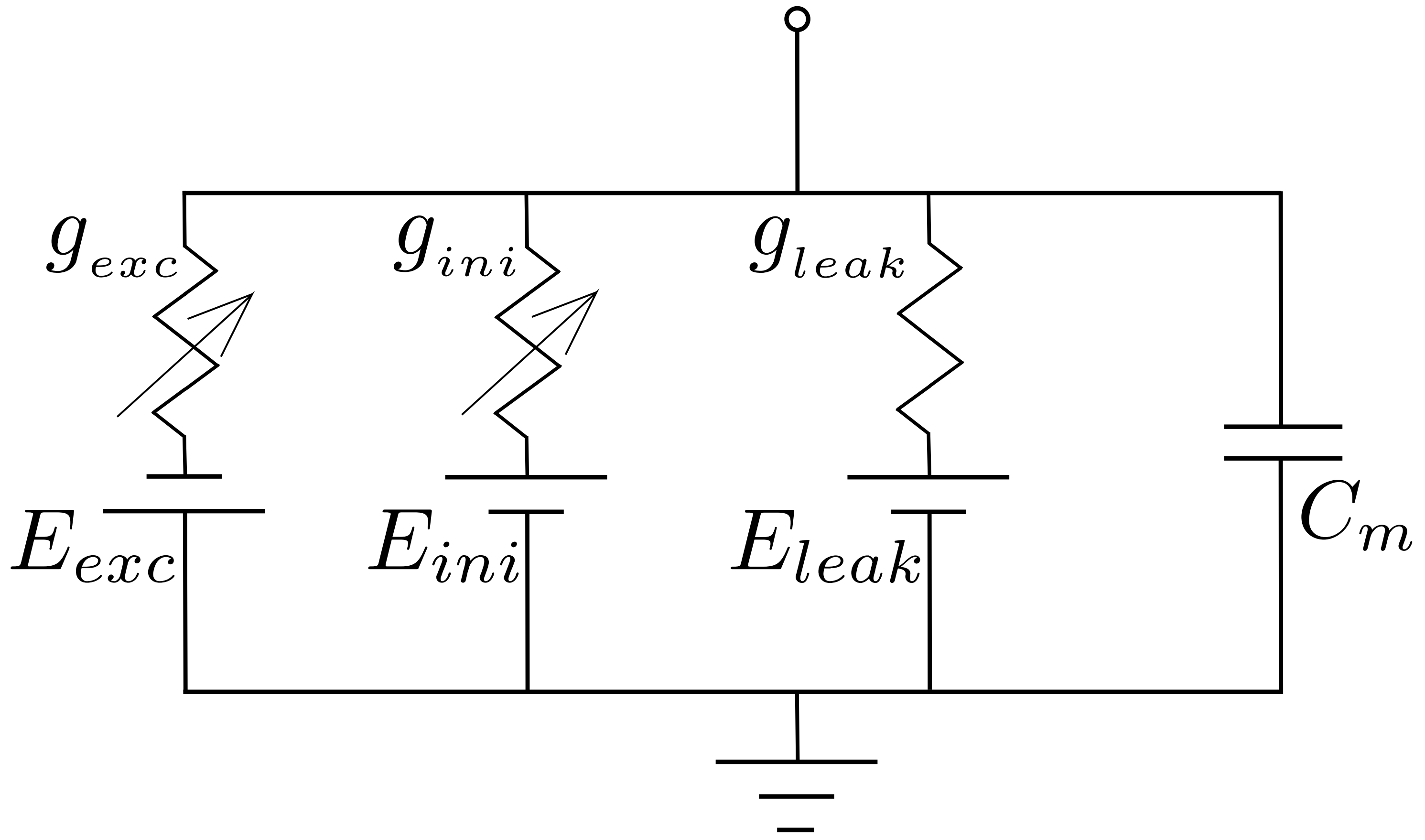
- We could simulate the dynamics of each molecule involved in the signalling process (like the MCell simulation).
- But since that is (very) computationally expensive, we might instead go for a reduced mass-action chemical-kinetics model.
- However for many purposes that is still too expensive and parameter heavy, so instead we use even simpler phenomenological models that black-box the synapse as a simple input-output system.

What goes is model of a synapse?

- Synapses are unreliable → transmission is probabilistic;
- Weighted transformation of input amplitudes, non-linear;
- Can be excitatory or inhibitory (depending on presynaptic neuron);

Simple model of a synapse

- The most common way to phenomenologically model a synapse is as a time-dependent conductor in series with a battery.



$$I_s(t) = \bar{g}_s s(t)[E_s - V(t)]$$

$s = exc, inh$

- The value of E_s determines whether the synapse is excitatory or inhibitory:
  - ➔for excitatory synapses E_s usually = 0 mV
  - ➔for inhibitory synapses E_s usually = V_{rest}

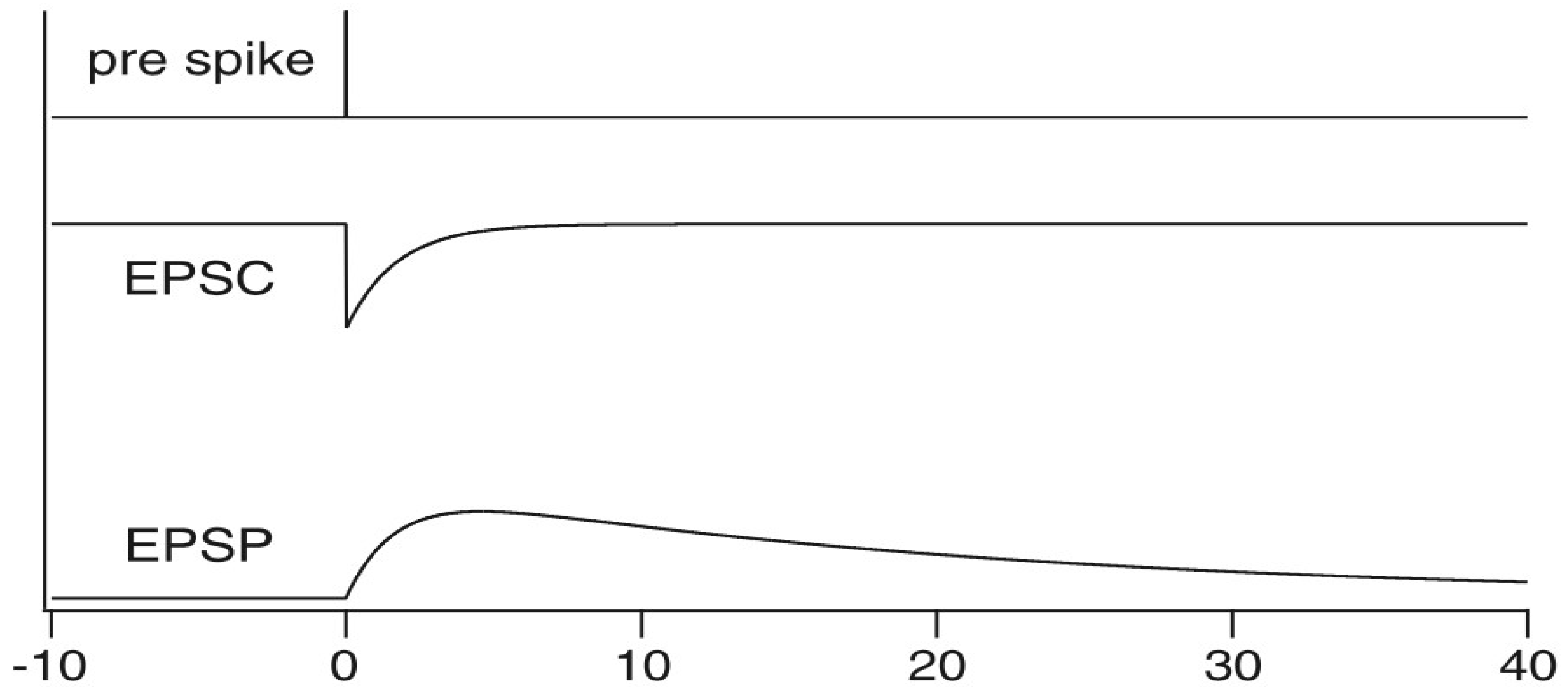
- But how should we model *s(t)*?

Simple model of a synapse

Single exponential

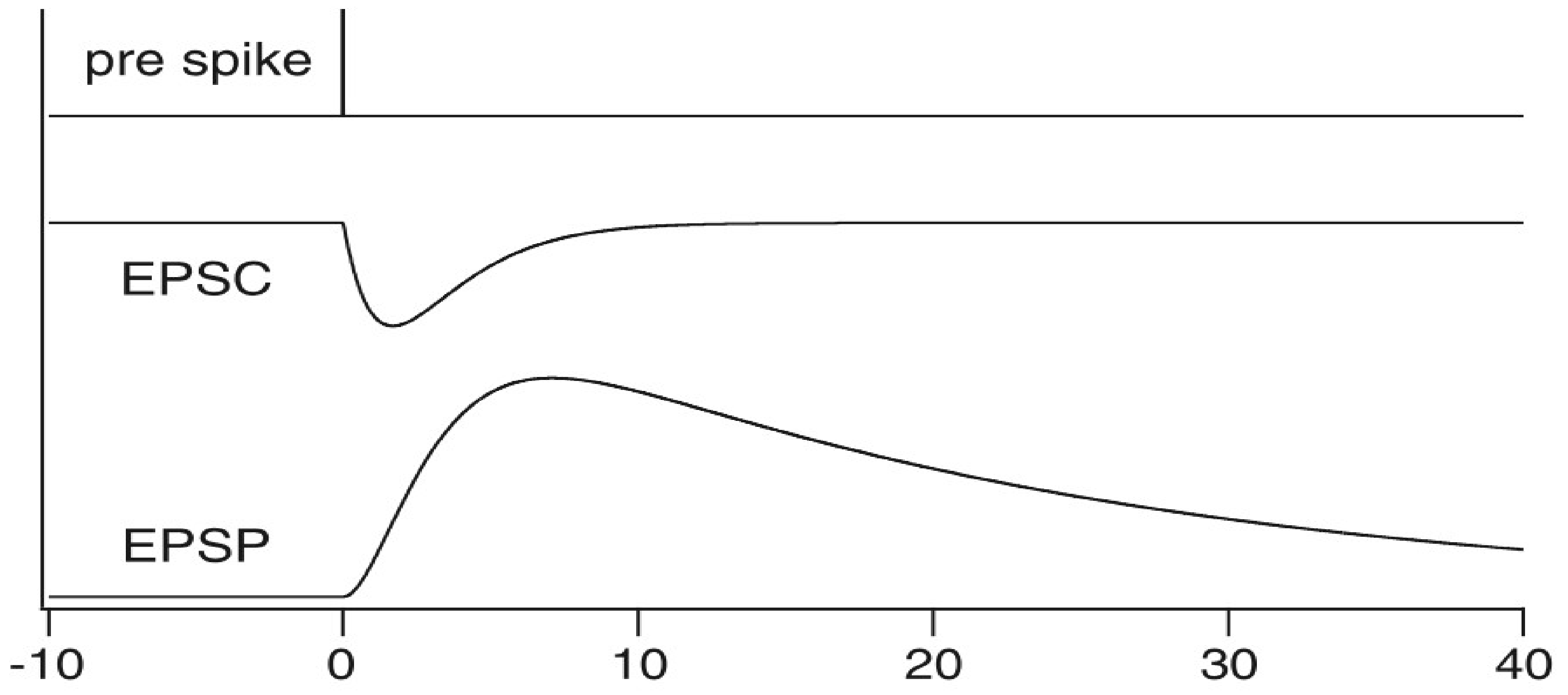
$$s(t) \rightarrow s(t) + 1$$

$$s(t) = e^{-t/\tau_s}$$



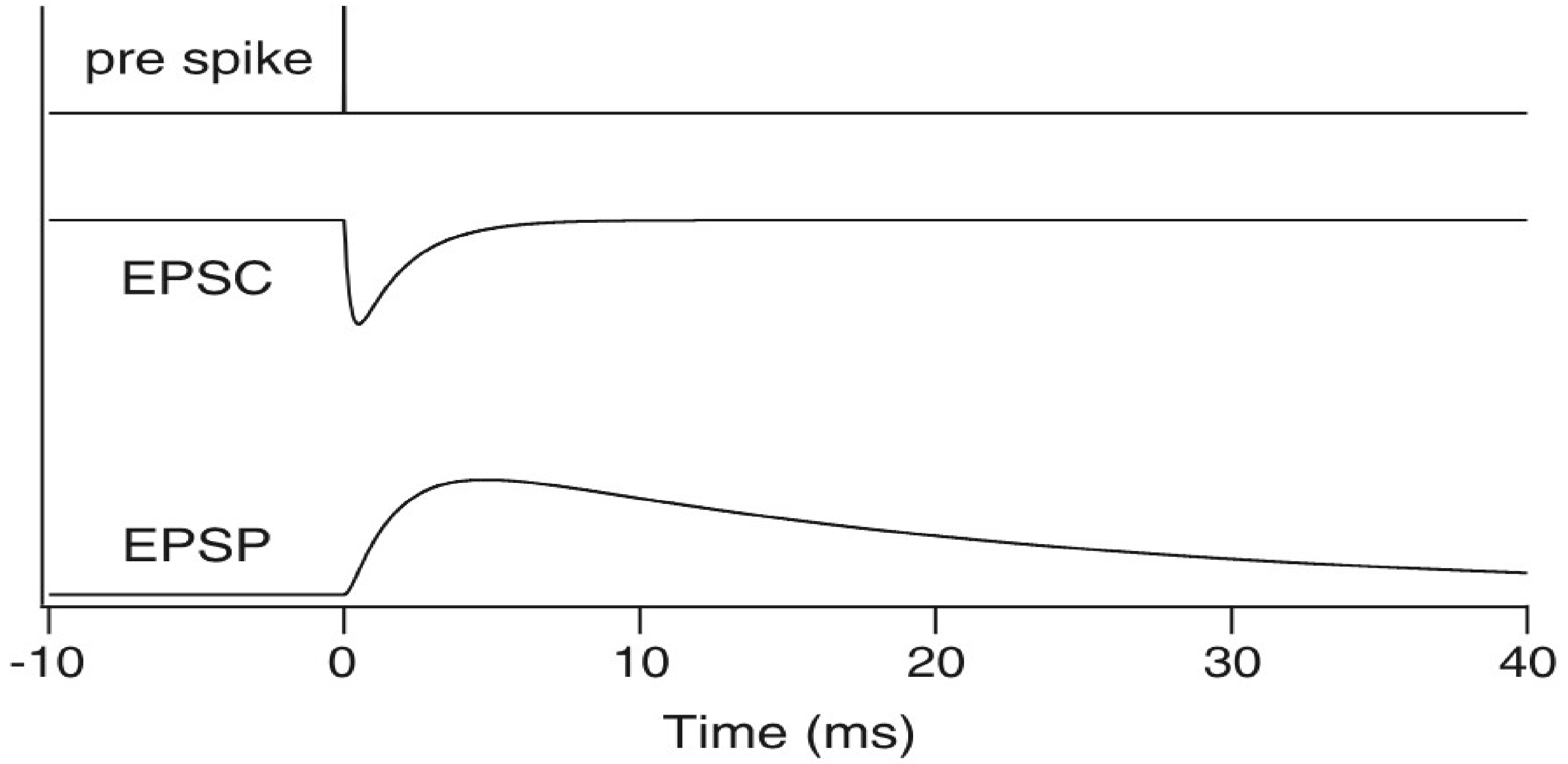
Alpha function

$$s(t) = te^{-t/\tau_s}$$



Difference of two exponentials

$$s(t) = e^{-t/\tau_{decay}} - e^{-t/\tau_{rise}}$$



Figures from Roth & van Rossum
https://www.researchgate.net/profile/Mark_Van_Rossum/publication/266712567_Modeling_Synapses/links/546389350cf2c0c6aec4e4fe.pdf

Summary

- Real synapses are complicated molecular machines.
- We can model them at multiple levels of granularity, as appropriate for the task at hand.
- A simple way of modelling a PSP on the postsynaptic membrane potential is with the addition of a single impulse to the current.