Week 3 – part 2: Synaptic short-term plasticity

ÉCOLE POLYTECHNIQUE
FÉDÉRALE DE LAUSANNE

Neuronal Dynamics:
Computational Neuroscience of Single Neurons

Week 3 – Adding Detail:
Dendrites and Synapses

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3.1 **Synapses**

3.2 **Short-term plasticity**

3.3 **Dendrite as a Cable**

3.4 **Cable equation**

3.5 **Compartmental Models**
- active dendrites

Week 3 – part 2: Synaptic Short-Term plasticity

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√ 3.1 **Synapses**

3.2 **Short-term plasticity**

3.3 **Dendrite as a Cable**

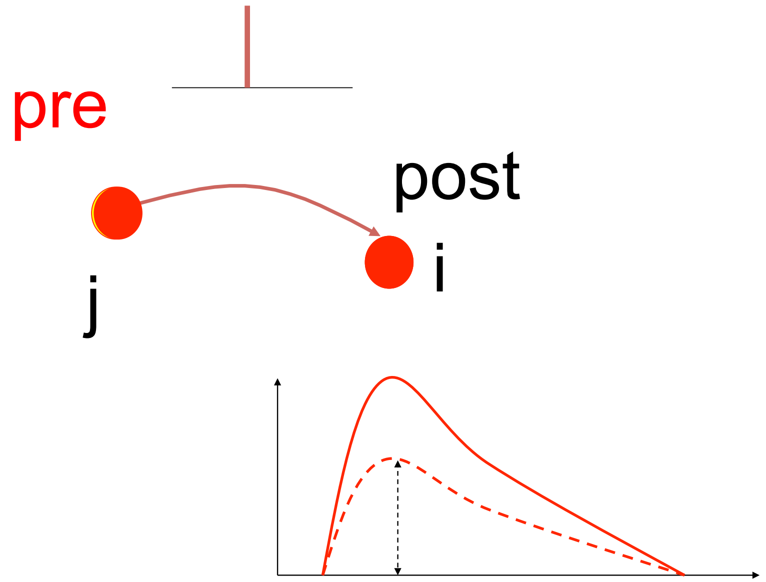
3.4 **Cable equation**

3.5 **Compartmental Models**
- active dendrites

Neuronal Dynamics – 3.2 Synaptic Short-Term Plasticity

$$I^{syn}(t) = g_{syn}(t)(u - E_{syn})$$

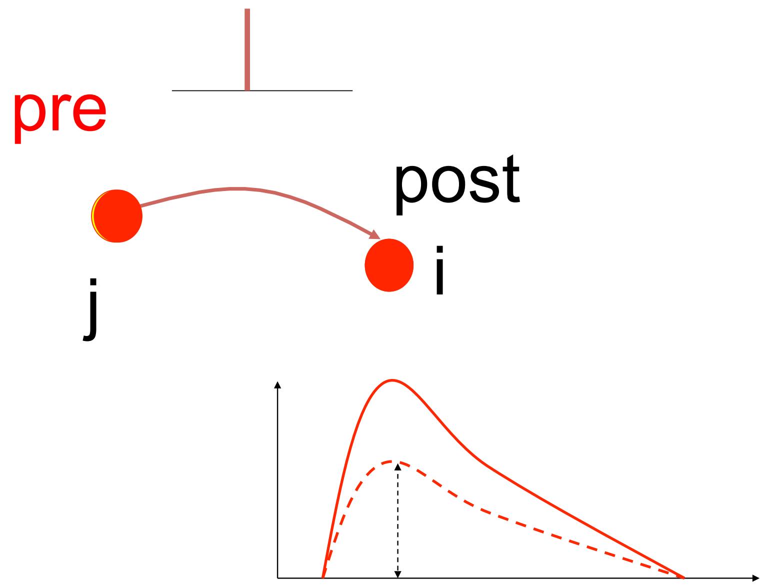
$$C\frac{du}{dt} = -g_l(u - u_{rest}) - I^{syn}(t)$$



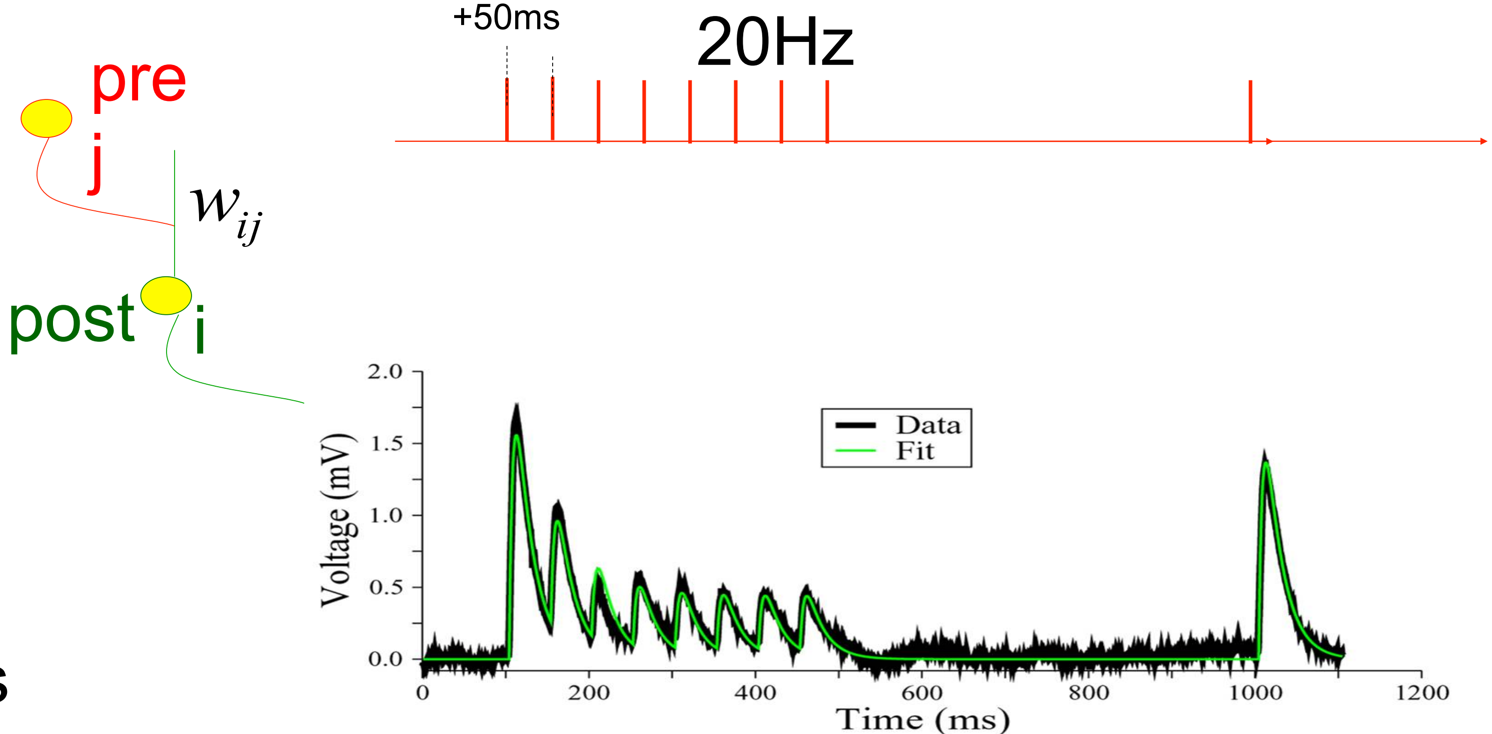
Neuronal Dynamics – 3.2 Synaptic Short-Term Plasticity

Short-term plasticity/ fast synaptic dynamics

Thomson et al. 1993
Markram et al 1998
Tsodyks and Markram 1997
Abbott et al. 1997



Neuronal Dynamics – 3.2 Synaptic Short-Term Plasticity



Changes

- induced over 0.5 sec
- recover over 1 sec

Courtesy M.J.E Richardson

Data: G. Silberberg, H.Markram

Fit: M.J.E. Richardson (Tsodyks-Pawelzik-Markram model)

Neuronal Dynamics – 3.2 Model of Short-Term Plasticity

Dayan and Abbott, 2001

Fraction of filled release sites

$$\frac{dP_{rel}}{dt} = -\frac{P_{rel} - P_0}{\tau_P} - f_D P_{rel} \sum_k \delta(t - t^k)$$

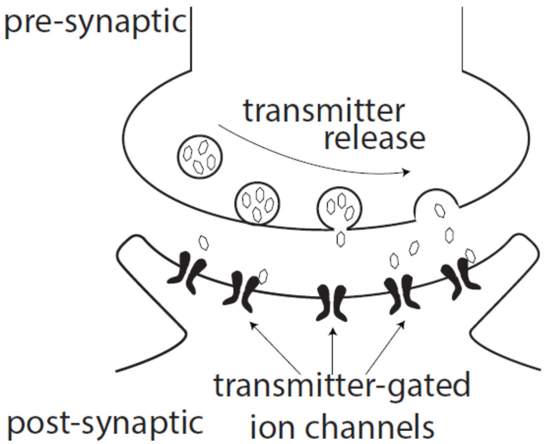


image: Neuronal Dynamics, Cambridge Univ. Press

Synaptic conductance

$$g_{syn}(t) = \bar{g}_{syn} e^{-(t-t_k)/\tau} \Theta(t - t_k)$$

Neuronal Dynamics – 3.2 Model of synaptic depression

4 + 1 pulses $\tau_P = 400ms$

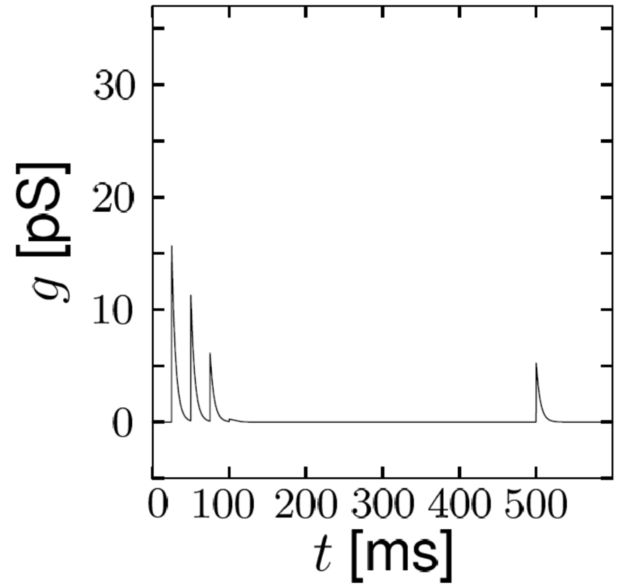


image: Neuronal Dynamics, Cambridge Univ. Press

Fraction of filled release sites

$$\frac{dP_{rel}}{dt} = -\frac{P_{rel} - P_0}{\tau_P} - f_D P_{rel} \sum_k \delta(t - t^k)$$

Synaptic conductance

$$\bar{g}_{syn} = c\, P_{rel}$$

$$g_{syn}(t) = \bar{g}_{syn} e^{-(t-t_k)/\tau} \Theta(t - t_k)$$

Dayan and Abbott, 2001

Neuronal Dynamics – 3.2 Model of synaptic facilitation

4 + 1 pulses $\tau_P = 200ms$

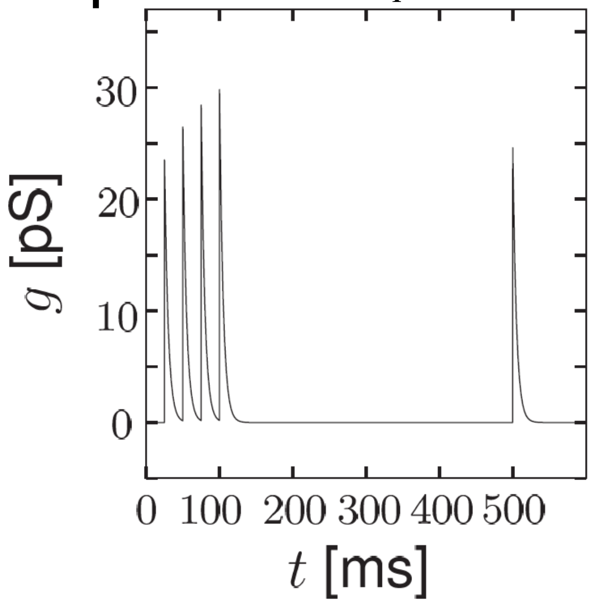


image: Neuronal Dynamics, Cambridge Univ. Press

Fraction of filled release sites

$$\frac{dP_{rel}}{dt} = -\frac{P_{rel} - P_0}{\tau_P} + f_F (1 - P_{rel}) \sum_k \delta(t - t^k)$$

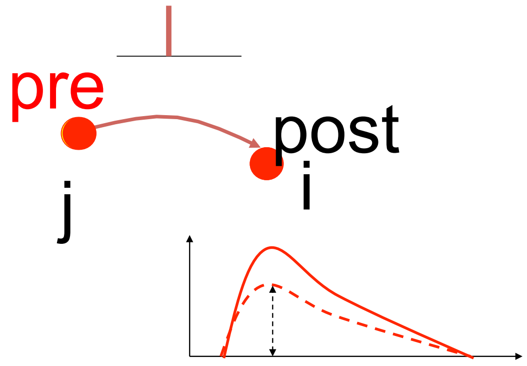
Synaptic conductance

$$\bar{g}_{syn} = c\, P_{rel}$$

$$g_{syn}(t) = \bar{g}_{syn} e^{-(t-t_k)/\tau} \Theta(t - t_k)$$

Dayan and Abbott, 2001

Neuronal Dynamics – 3.2 Summary



Synapses are not constant

-Depression

-Facilitation

Models are available

-Tsodyks-Pawelzik-Markram 1997

- Dayan-Abbott 2001

Neuronal Dynamics – Quiz 3.2

Multiple answers possible!

Time scales of Synaptic dynamics

[ ] The rise time of a synapse can be in the range of a few ms.
[ ] The decay time of a synapse can be in the range of few ms.
[ ] The decay time of a synapse can be in the range of few hundred ms.
[ ] The depression time of a synapse can be in the range of a few hundred ms.
[ ] The facilitation time of a synapse can be in the range of a few hundred ms.

Synaptic dynamics and membrane dynamics.

Consider the equation

$$(*) \qquad \frac{dx}{dt} = -\frac{x}{\tau} + c\sum_k \delta(t - t^k)$$

With a suitable interpretation of the variable *x* and the constant *c*

[ ] Eq. (*) describes a passive membrane voltage *u(t)* driven by spike arrivals.
[ ] Eq. (*) describes the conductance *g(t)* of a simple synapse model.
[ ] Eq. (*) describes the maximum conductance $\bar{g}_{syn}$ of a facilitating synapse

Neuronal Dynamics – 3.2 Literature/short-term plasticity

Dayan, P. and Abbott, L. F. (2001). Theoretical Neuroscience. MIT Press, Cambridge.

Abbott, L. F., Varela, J. A., Sen, K., and Nelson, S. B. (1997). Synaptic depression and cortical gain control. *Science* 275, 220–224.

Markram, H., and Tsodyks, M. (1996a). Redistribution of synaptic efficacy between neocortical pyramidal neurons. *Nature* 382, 807–810.

A.M. Thomson, Facilitation, augmentation and potentiation at central synapses, *Trends in Neurosciences,* 23: 305–312 ,2001

Tsodyks, M., Pawelzik, K., and Markram, H. (1998). Neural networks with dynamic synapses. *Neural. Comput.* 10, 821–835.