Week 3 – part 5: Compartmental Models

ÉCOLE POLYTECHNIQUE FÉDÉRALE DE LAUSANNE

Neuronal Dynamics:
Computational Neuroscience of Single Neurons

Week 3 – Adding Detail:
Dendrites and Synapses

Wulfram Gerstner

EPFL, Lausanne, Switzerland

- √ 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 5: Compartmental Models

ÉCOLE POLYTECHNIQUE
FÉDÉRALE DE LAUSANNE

√ 3.1 **Synapses**

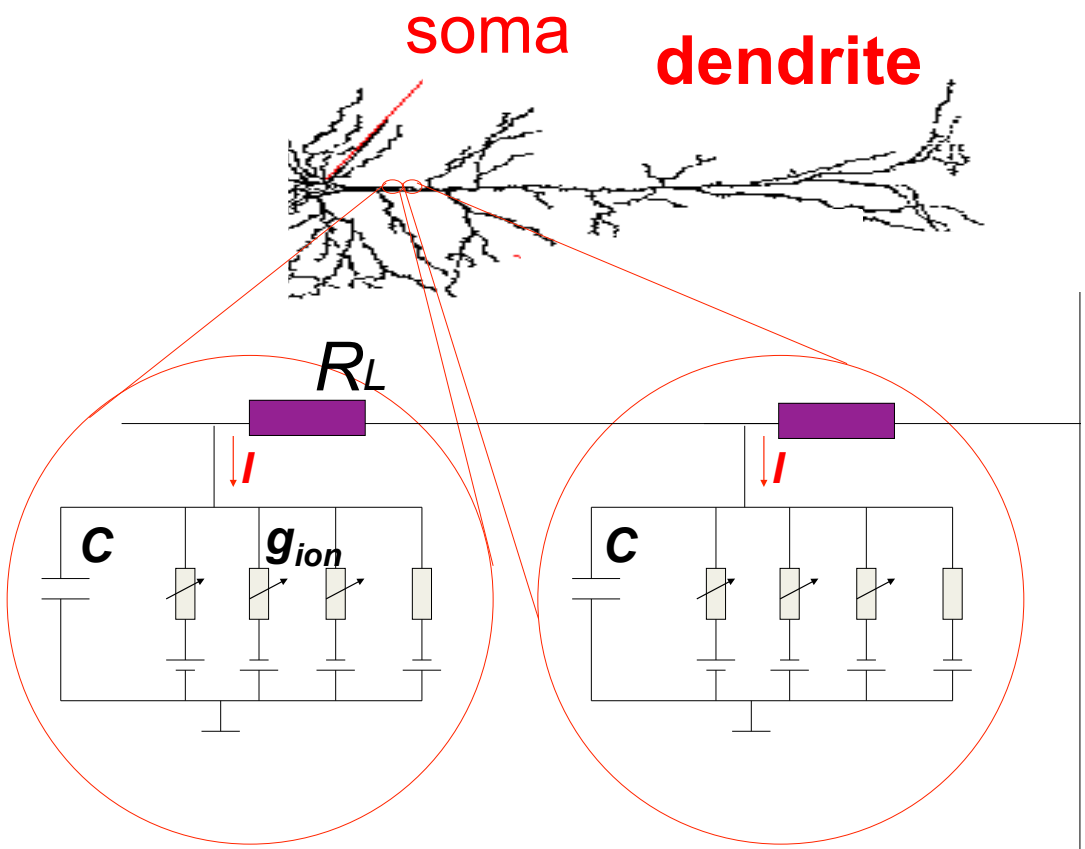
√ 3.2 **Short-term plasticity**

√ 3.3 **Dendrite as a Cable**

√ 3.4 **Cable equation**

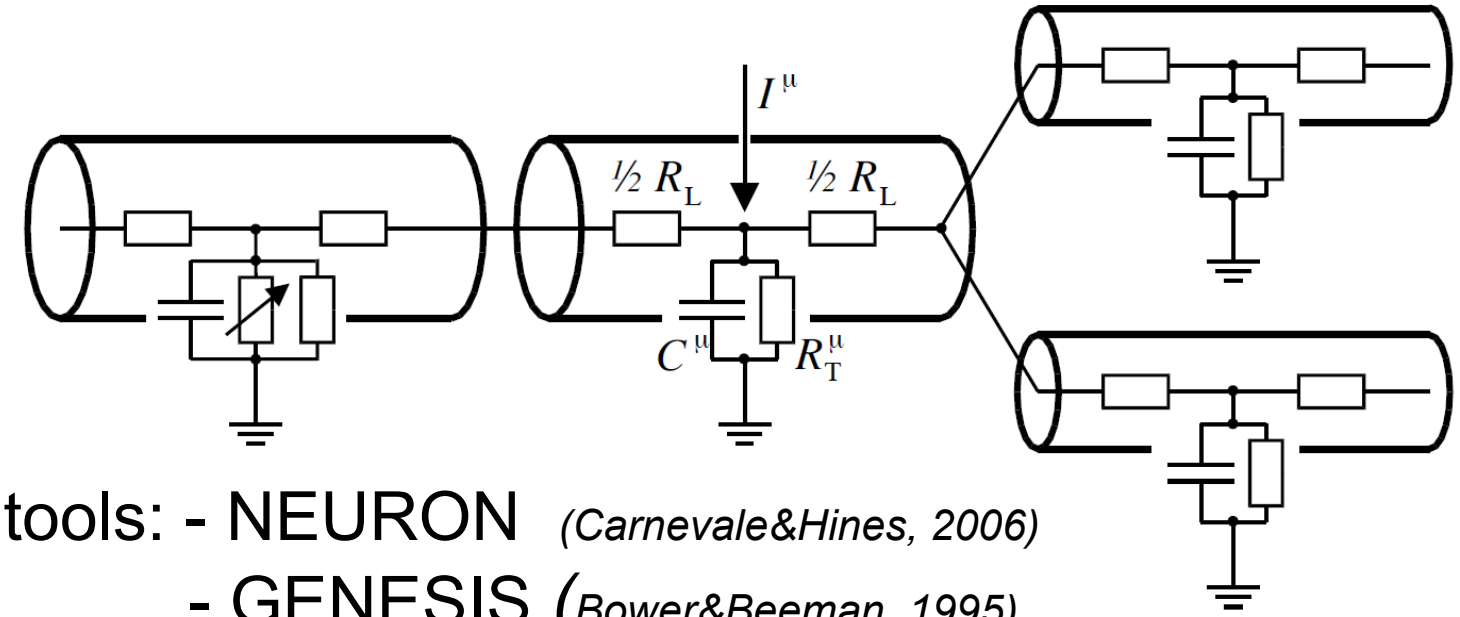
3.5 **Compartmental Models**
- active dendrites

Neuronal Dynamics – 3.5. Compartmental models



Neuronal Dynamics – 3.5. Compartmental models

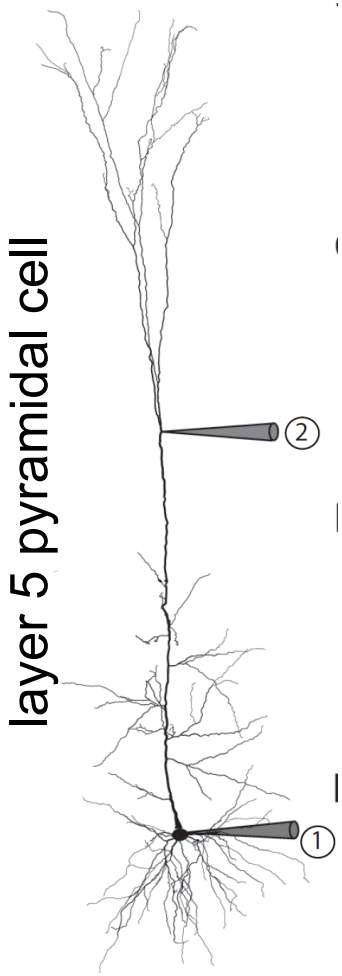
$$\frac{u(t,\mu-1)-u(t,\mu)}{0.5(R_L^{\mu}+R_L^{\mu-1})}-\frac{u(t,\mu)-u(t,\mu+1)}{0.5(R_L^{\mu}+R_L^{\mu+1})}=C^{\mu}\frac{d}{dt}u(t,\mu)+\sum_{ion}I_{ion}(t,\mu)-I^{\mu}(t)$$



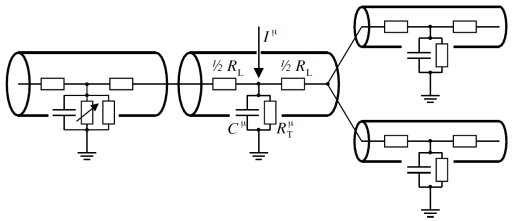
Software tools: - NEURON *(Carnevale&Hines, 2006)*

- GENESIS *(Bower&Beeman, 1995)*

Neuronal Dynamics – 3.5. Model of Hay et al. (2011)



Morphological reconstruction
-Branching points
-200 compartments $(\leq 20\mu m)$
-spatial distribution of ion currents



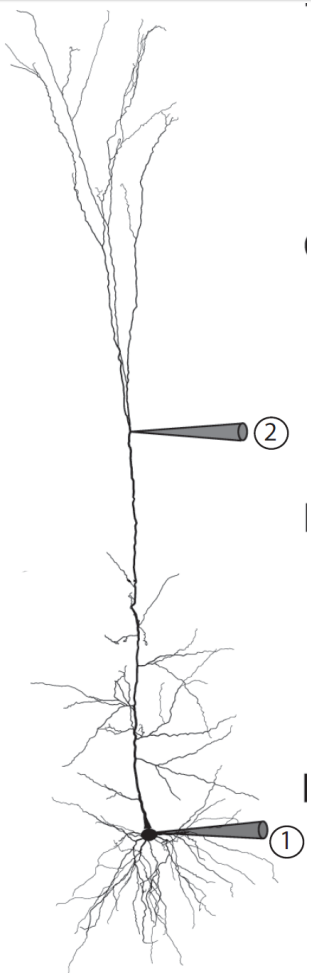
'hotspot'

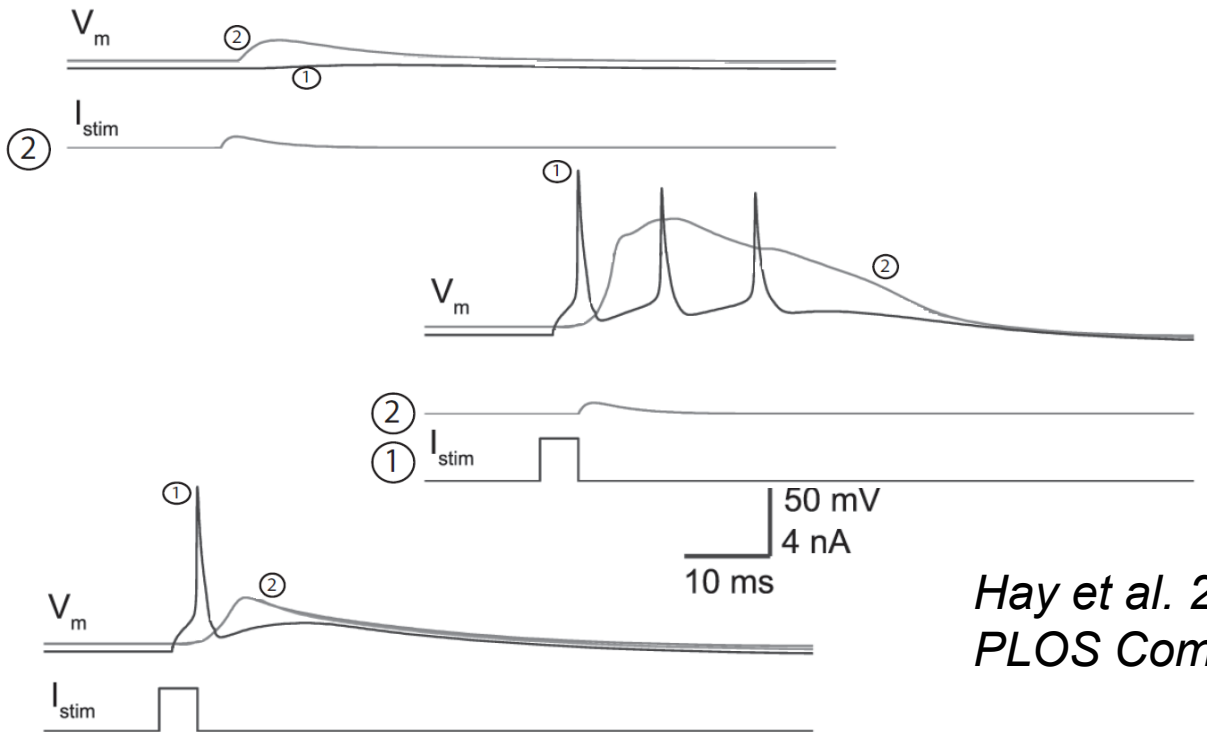
Ca currents

Sodium current (2 types)
- $I_{Na,transient}$ HH-type (inactivating)
- I_{NaP} persistent (non-inactivating)

Calcium current (2 types and calcium pump)
Potassium currents (3 types, includes I_M)
Unspecific current

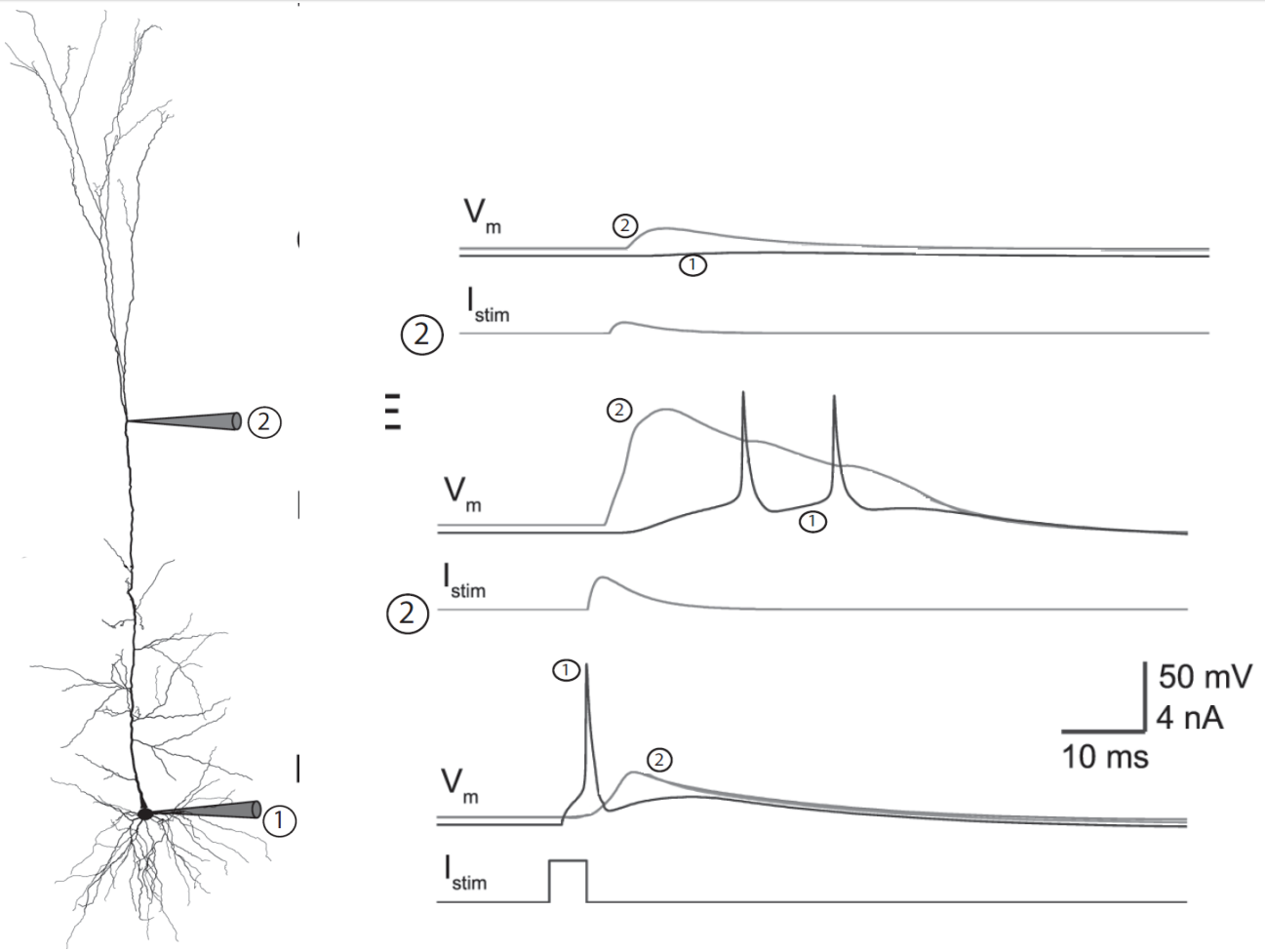
Neuronal Dynamics – 3.5. Active dendrites: Model





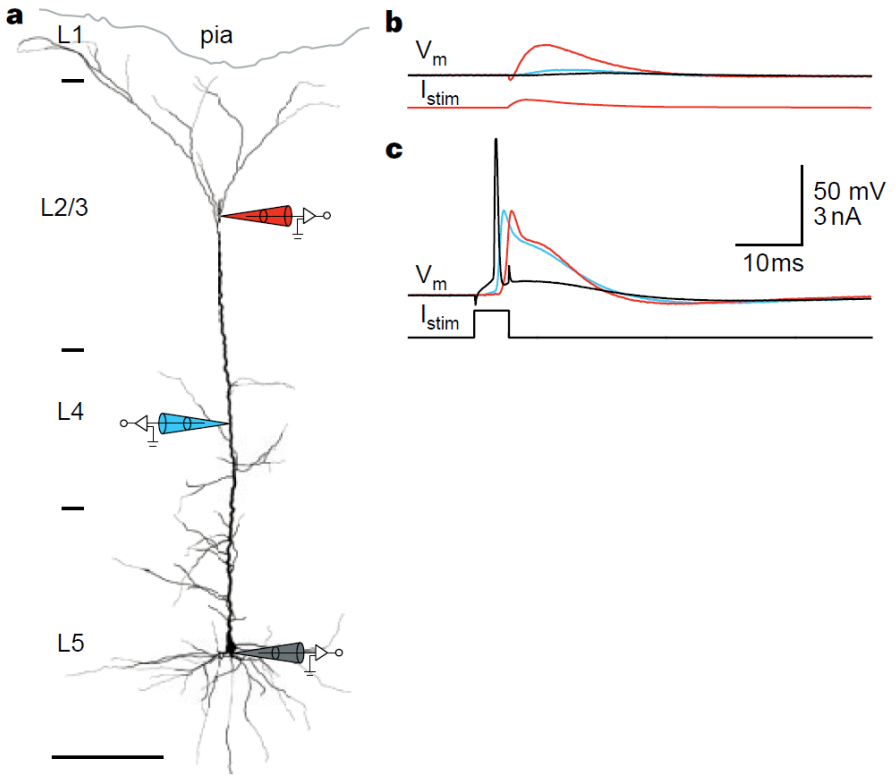
Hay et al. 2011,
PLOS Comput. Biol.

Neuronal Dynamics – 3.5. Active dendrites: Model



Hay et al. 2011,
PLOS Comput. Biol.

Neuronal Dynamics – 3.5. Active dendrites: Experiments



BPAP:

backpropagating action potential

Dendritic Ca spike:

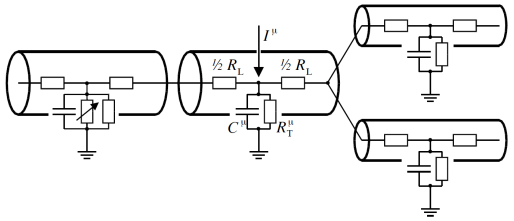
activation of Ca channels

Ping-Pong:

BPAP and Ca spike

Larkum, Zhu, Sakman
Nature 1999

Neuronal Dynamics – 3.5. Compartmental models



Dendrites are more than passive filters.

-Hotspots

-BPAPs

-Ca spikes

Compartmental models

- can include many ion channels
- spatially distributed
- morphologically reconstructed

BUT

- spatial distribution of ion channels difficult to tune

Neuronal Dynamics – Quiz 3.5

Multiple answers possible!

BPAP

[ ] is an acronym for BackPropagatingActionPotential
[ ] exists in a passive dendrite
[ ] travels from the dendritic hotspot to the soma
[ ] travels from the soma along the dendrite
[ ] has the same duration as the somatic action potential

Dendritic Calcium spikes

[ ] can be induced by weak dendritic stimulation
[ ] can be induced by strong dendritic stimulation
[ ] can be induced by weak dendritic stimulation combined with a BPAP
[ ] can only be induced be strong dendritic stimulation combined with a BPAP
[ ] travels from the dendritic hotspot to the soma
[ ] travels from the soma along the dendrite

Neuronal Dynamics – week 3 – Reading

Reading: W. Gerstner, W.M. Kistler, R. Naud and L. Paninski,
Neuronal Dynamics: from single neurons to networks and models of cognition. Chapter 3*: Dendrites and Synapses,* Cambridge Univ. Press, 2014
OR W. Gerstner and W. M. Kistler, *Spiking Neuron Models*, Chapter 2, Cambridge, 2002
OR P. Dayan and L. Abbott, *Theoretical Neuroscience*, Chapter 6, MIT Press 2001

References:

M. Larkum, J.J. Zhu, B. Sakmann (1999), *A new cellular mechanism for coupling inputs arriving at different cortical layers, Nature, 398:338-341*

E. Hay et al. (2011) *Models of Neocortical Layer 5b Pyramidal Cells Capturing a Wide Range of Dendritic and Perisomatic Active Properties, PLOS Comput. Biol. 7:7*

Carnevale, N. and Hines, M. (2006). *The Neuron Book*. Cambridge University Press.

Bower, J. M. and Beeman, D. (1995). *The book of Genesis*. Springer, New York.

Rall, W. (1989). *Cable theory for dendritic neurons*. In Koch, C. and Segev, I., editors, Methods in Neuronal Modeling, pages 9{62, Cambridge. MIT Press.

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

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