Week 3 – part 3: Dendrite as a Cable

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 3: Dendrite as a Cable

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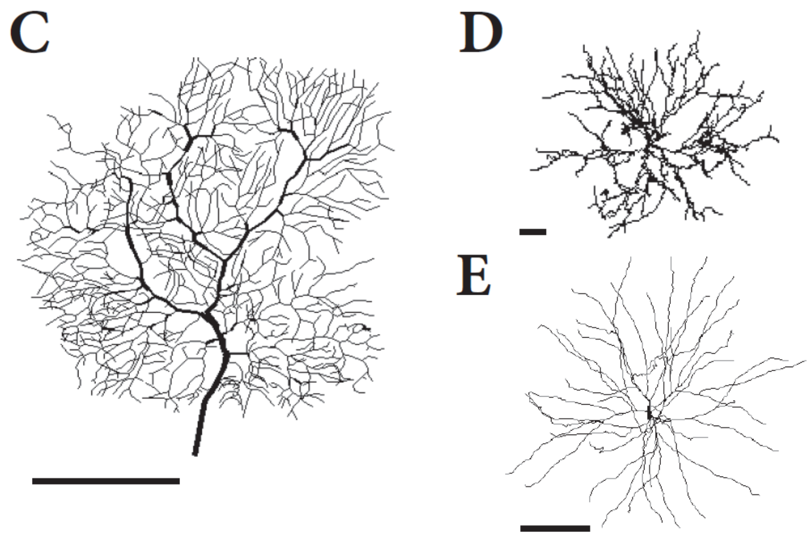
Neuronal Dynamics – 3.3 Dendrites



Neuronal Dynamics – 3.3 Dendrites

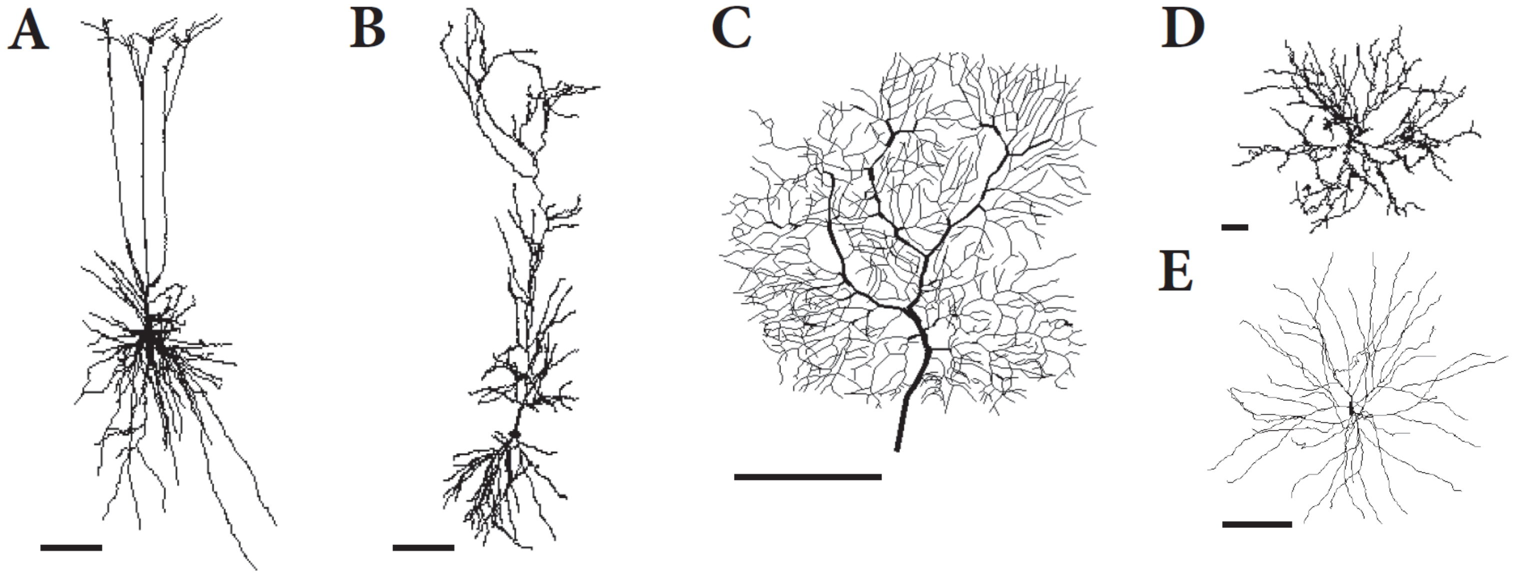


Fig. 3.4: Reconstructed morphology of various types of neurons. **A**. Pyramidal neuron from a deep cortical layer(Contreras et al., 1997). **B**. Pyramidal neuron from the CA1 of the hippocampus (Golding et al., 2005). **C**. Purkinje cell from the cerebellum (Rapp et al., 1994). **D**. Motoneuron from the spinal cord (Cullheim et al., 1987). **E**. Stellate neuron from the neocortex (Mainen and Sejnowski, 1996). Reconstructed morphologies can be downloaded from http://NeuroMorpho.Org. Scale bars represents 100 μm.

Neuronal Dynamics – Review: Biophysics of neurons

Cell surrounded by membrane

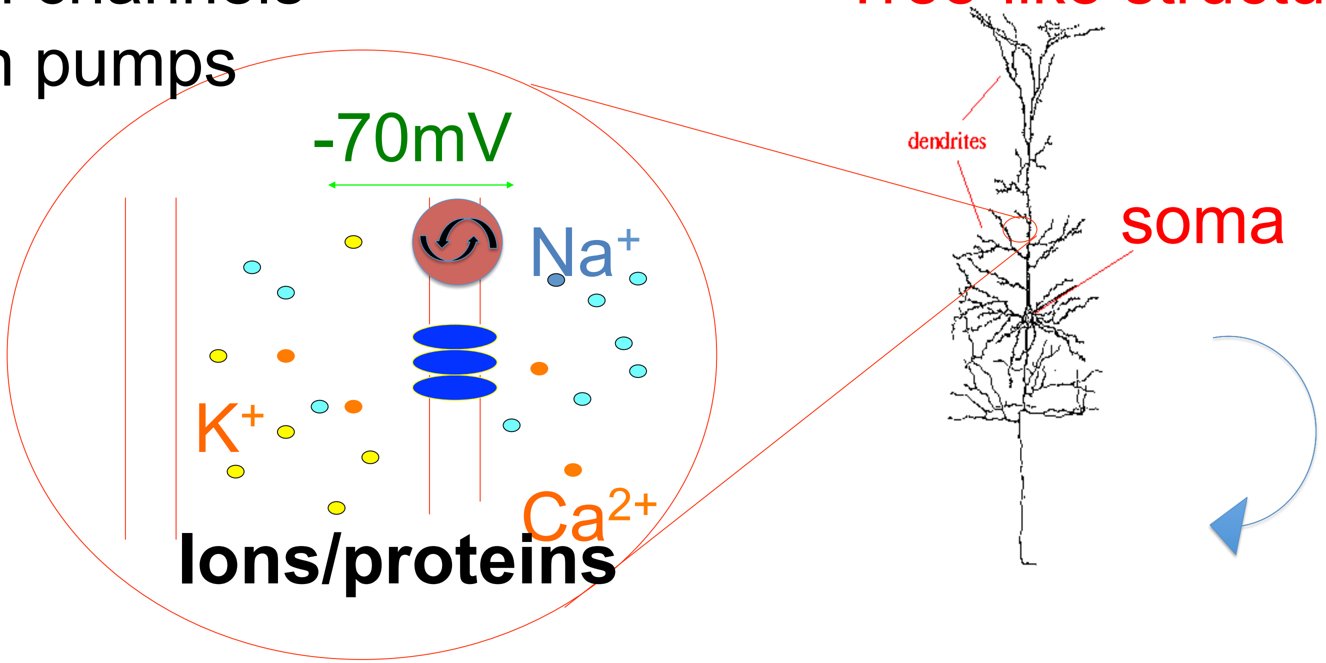
Membrane contains

- ion channels
- ion pumps

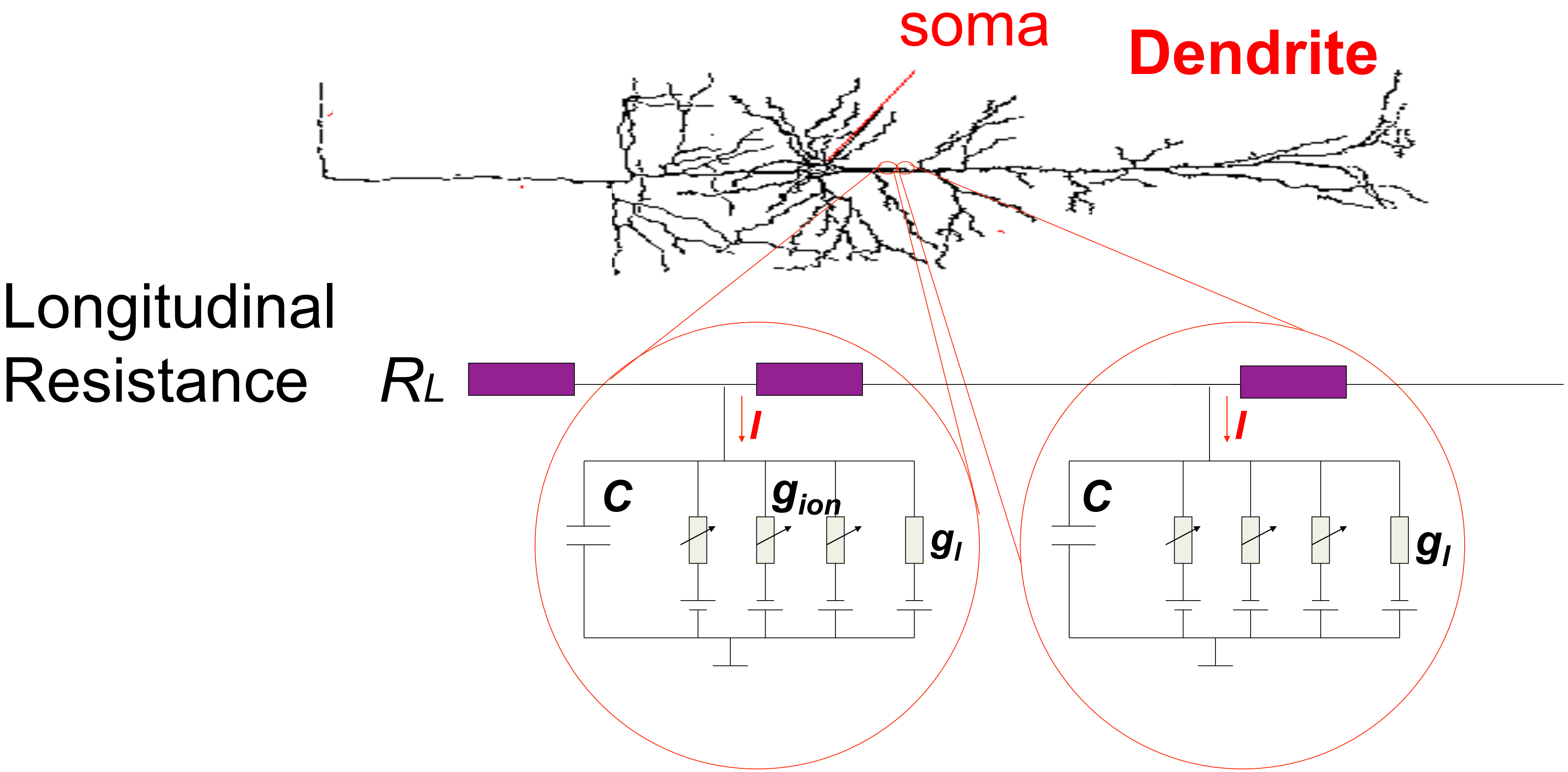
Dendrite and axon:

Cable-like extensions

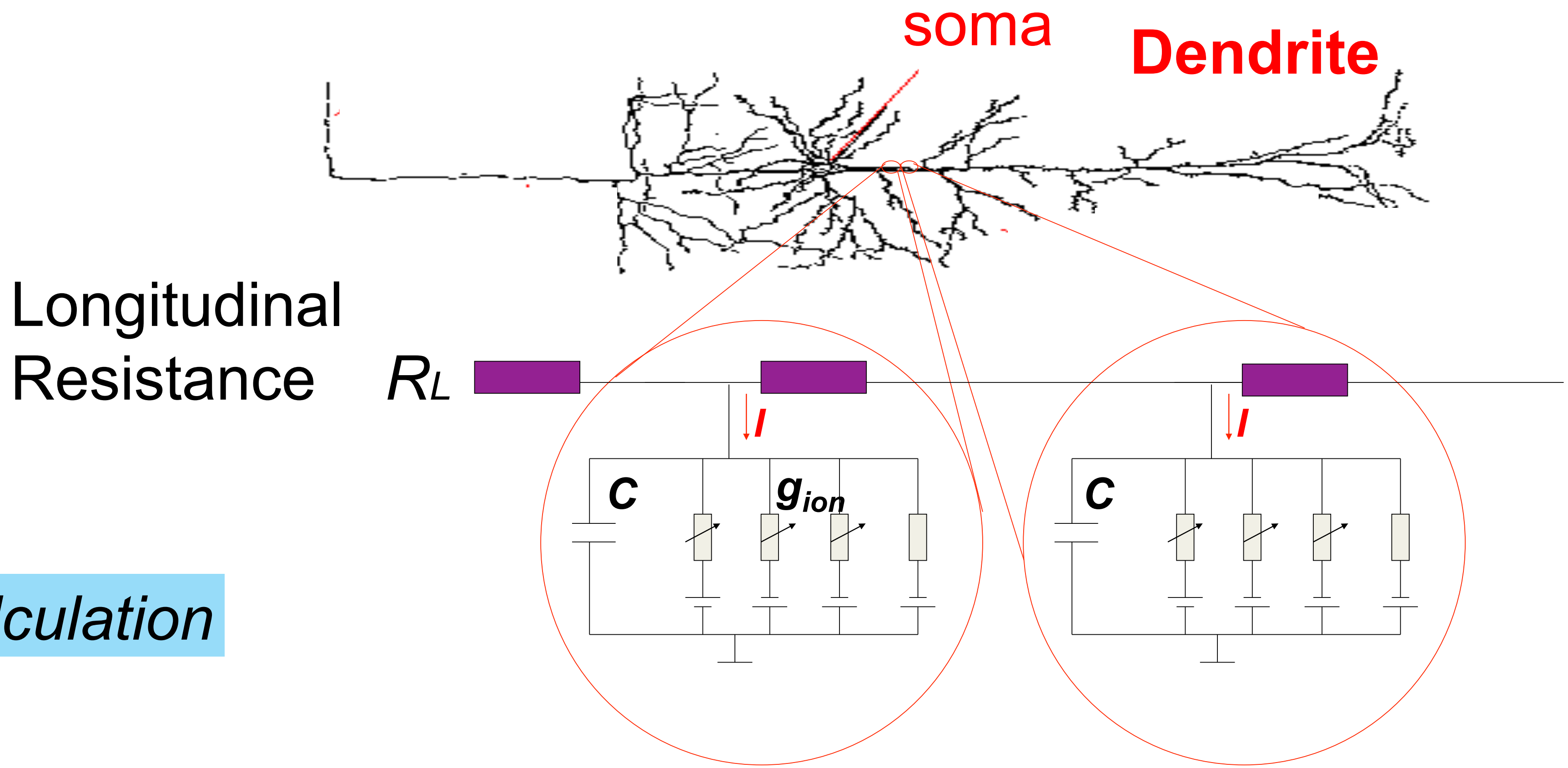
Tree-like structure



Neuronal Dynamics – Modeling the Dendrite

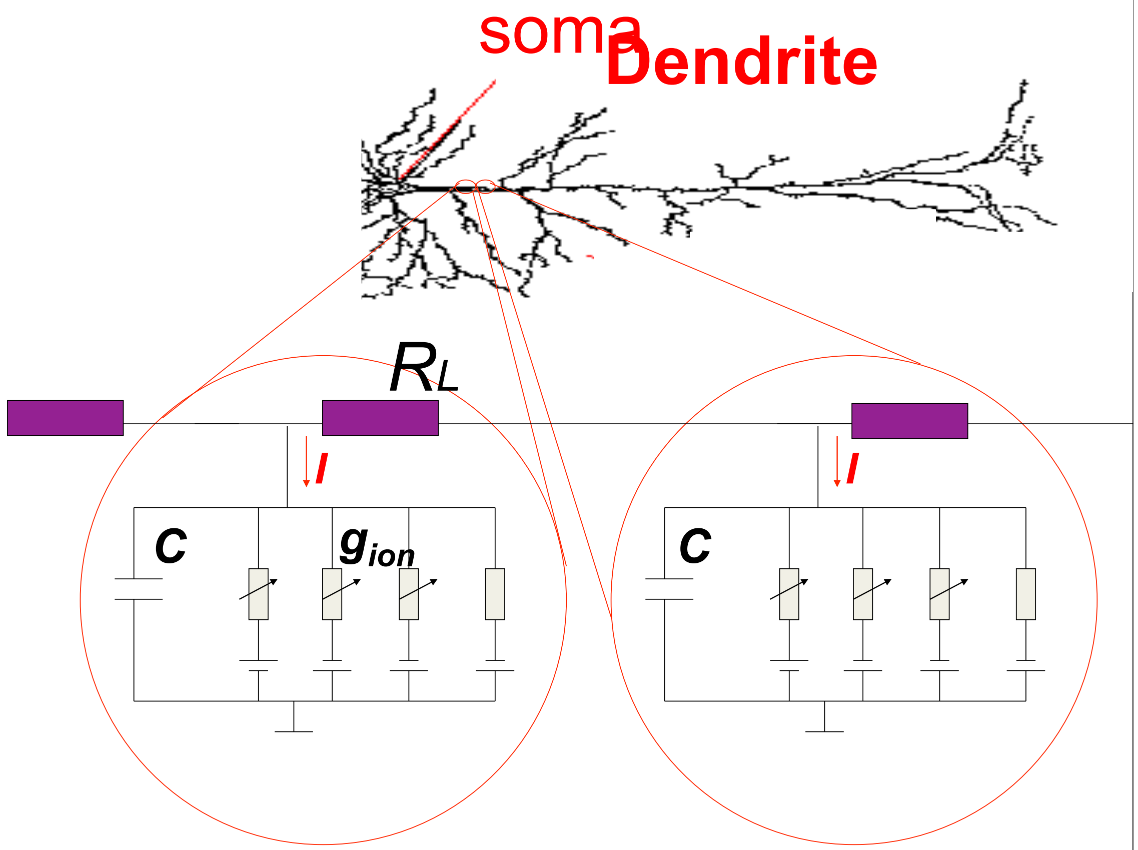


Neuronal Dynamics – Modeling the Dendrite



Calculation

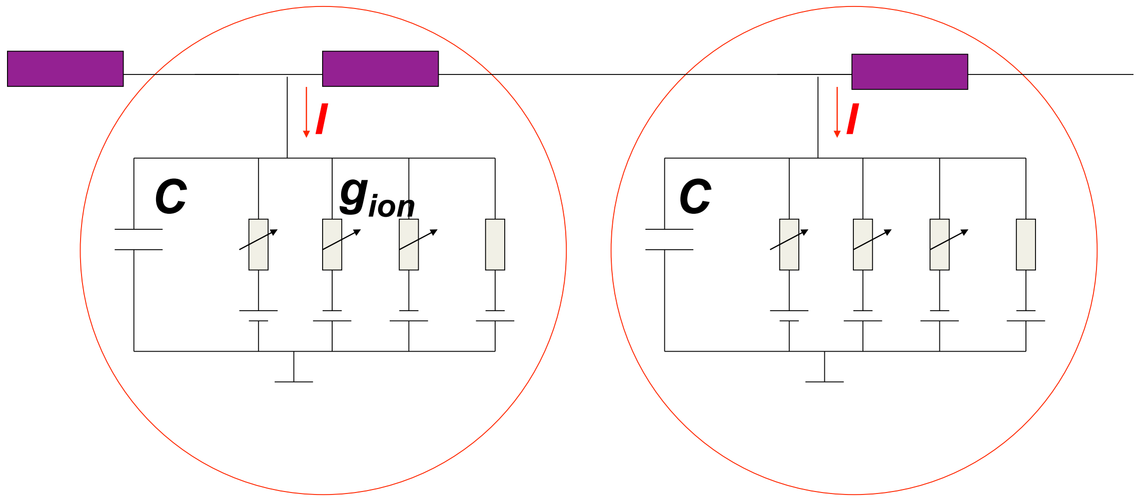
Neuronal Dynamics – Conservation of current



Neuronal Dynamics – 3.3 Equation-Coupled compartments

$$\frac{u(t,x-dx)-2u(t,x)+u(t,x+dx)}{R_L} = C\frac{d}{dt}u(t,x)+\sum_{ion} I_{ion}(t,x)-I^{ext}(t,x)$$

Basis for
- Cable equation
  lecture 3.4
- Compartmental models
  lecture 3.5



Week 3 – part 3B: Derivation of the Cable Equation

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√ 3.1 **Synapses**

√ 3.2 **Short-term plasticity**

3.3 **Dendrite as a Cable**

$\boxed{\text{Derivation of cable equation}}$

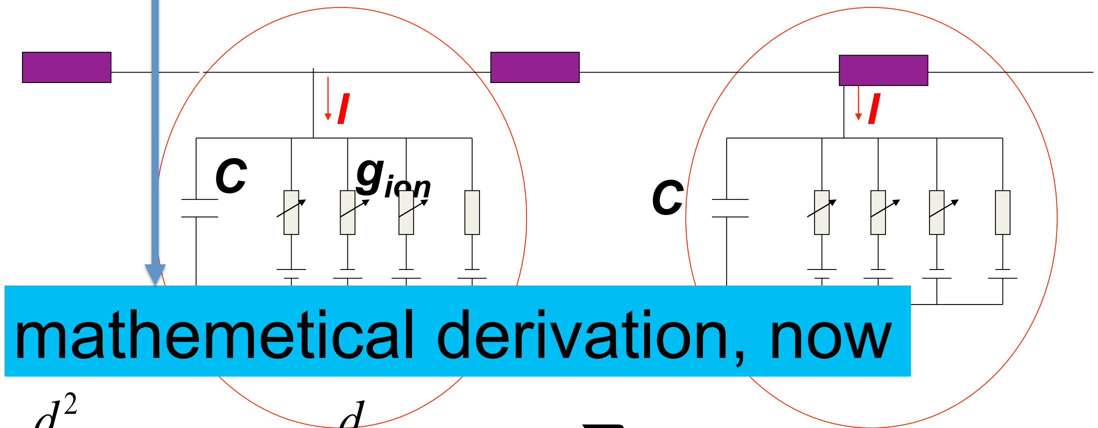
3.4 **Cable equation**

3.5 **Compartmental Models**

- active dendrites

Neuronal Dynamics – 3.3b Derivation of Cable Equation

$$\frac{u(t,x-dx) - 2u(t,x) + u(t,x+dx)}{R_L} = C\frac{d}{dt}u(t,x) + \sum_{ion} I_{ion}(t,x) - I^{ext}(t,x)$$



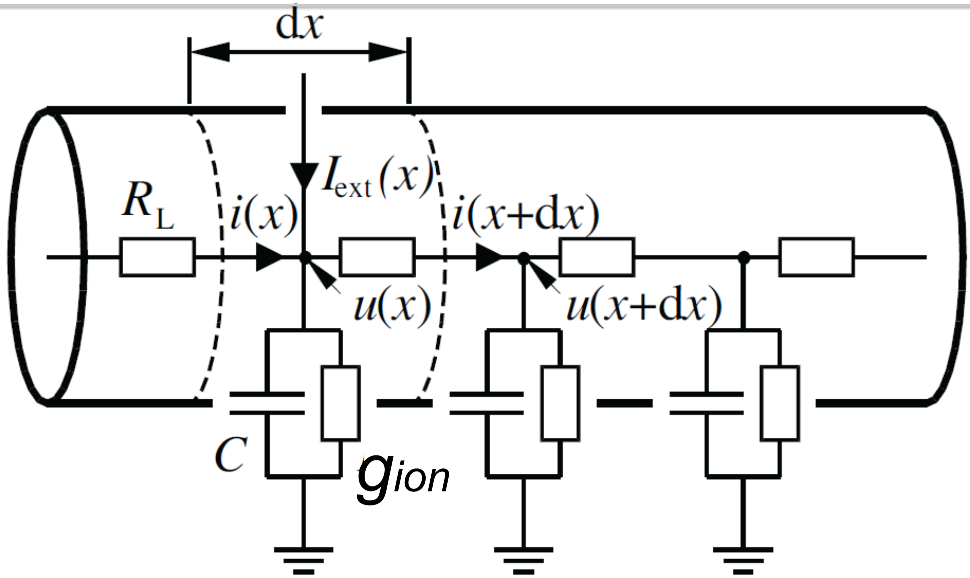
mathemetical derivation, now

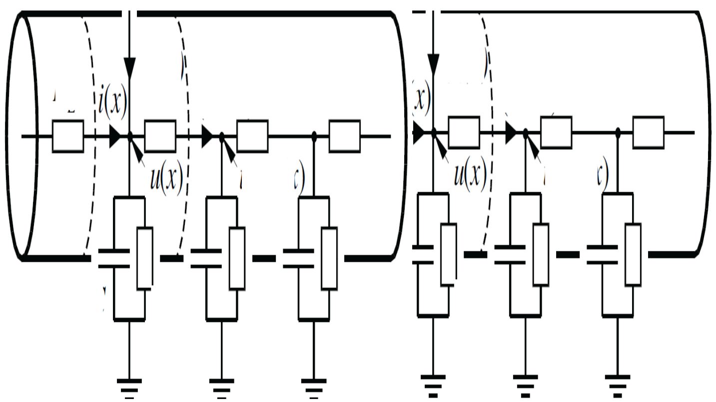
$$\frac{d^2}{dx^2}u(t,x) = cr_L\frac{d}{dt}u(t,x) + r_L\sum_{ion} i_{ion}(t,x) - r_L i^{ext}(t,x)$$

Neuronal Dynamics – 3.3 Modeling the Dendrite

$$R_L = r_L dx$$

$$C = c\,dx$$





$$I_{ion} = i_{ion} dx$$

$$I^{ext} = i^{ext}\, dx$$

Neuronal Dynamics – 3.3 Derivation of cable equation

$$\frac{u(t,x-dx)-2u(t,x)+u(t,x+dx)}{R_L} = C\frac{d}{dt}u(t,x)+\sum_{ion} I_{ion}(t,x) - I^{ext}(t,x)$$

$$R_L = r_L dx$$
$$C = c\, dx$$

$$I_{ion} = i_{ion} dx$$
$$I^{ext} = i^{ext}\, dx$$

$$\frac{d^2}{dx^2}u(t,x) = cr_L\frac{d}{dt}u(t,x) + r_L\sum_{ion} i_{ion}(t,x) - r_L i^{ext}(t,x)$$

Neuronal Dynamics – 3.3 Dendrite as a cable

$$\frac{d^2}{dx^2}u(t,x) = cr_L \frac{d}{dt}u(t,x) + r_L \sum_{ion} i_{ion}(t,x) - r_L i^{ext}(t,x)$$

$\sum_{ion} i_{ion}(t,x) = leak$ passive dendrite

$\sum_{ion} i_{ion}(t,x) = Ca, Na, \ldots$ active dendrite

$\sum_{ion} i_{ion}(t,x) = Na, K, \ldots$ axon

Neuronal Dynamics – Quiz 3.3

Multiple answers possible!

Scaling of parameters.

Suppose the ionic currents through the membrane are well approximated by a simple leak current. For a dendritic segment of size dx, the leak current is characterized by a membrane resistance R. If we change the size of the segment From dx to 2dx

[ ] the resistance R needs to be changed from R to 2R.
[ ] the resistance R needs to be changed from R to R/2.
[ ] R does not change.
[ ] the membrane conductance increases by a factor of 2.