

ÉCOLE POLYTECHNIQUE
FÉDÉRALE DE LAUSANNE



EPFL

Week 3 – part 3: Dendrite as a Cable



√ 3.1 Synapses

√ 3.2 Short-term plasticity

3.3 Dendrite as a Cable

-Derivation of cable equation

3.4 Cable equation

3.5 Compartmental Models

- active dendrites

Welcome to the third part of week three. In the previous two parts, I've discussed synapses. Now, I would like to turn to dendrites.

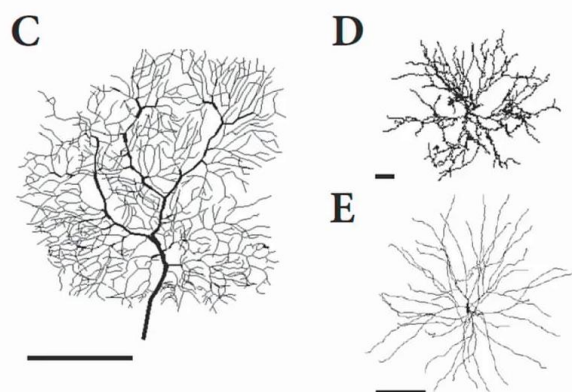
Notes

Summary



0m 04s

Neuronal Dynamics – 3.3 Dendrites



Indeed, dendrites are interesting. Neurons of different types have different dendrites. There are various shapes. And the question arises can we include the shape of dendrites into our modeling framework?

Notes

Summary



0m 16s

Neuronal Dynamics – 3.3 Dendrites

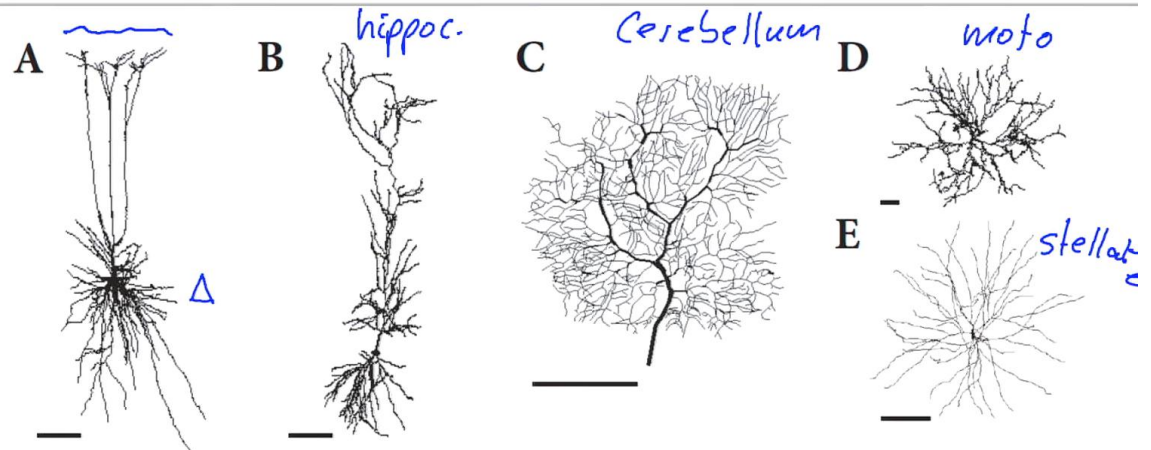


Fig. 3.4: Reconstructed morphology of various types of neurons. **A.** Pyramidal neuron from a deep cortical layer (Contreras et al., 1997). **B.** Pyramidal neuron from the CA1 of the hippocampus (Golding et al., 2005). **C.** Purkinje cell from the cerebellum (Rapp et al., 1994). **D.** Motoneuron 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 .

As I said, neurons come in different types, and different types have different shapes. Here's a first interesting example-- a pyramidal in neocortex. The surface of the cortex would be up here, and the cell body sits in one of the deeper layers. It's a pyramidal cell because the cell body is shaped like a pyramid. Here's another pyramidal cell in hippocampus. This is the shape of a Purkinje cell in cerebellum. These Purkinje cells are rather special, because nearly all the dendrites end in a very narrow plane. So it's a nearly two-dimensional shape-- a fan like extension. Here, we have a motoneuron. And here, we have a stellate cell in cortex. So we have all these different shapes. And the question is these shapes, this morphology of cell-- can we take that into account? Can we include that into our neuron models?

Notes

Summary



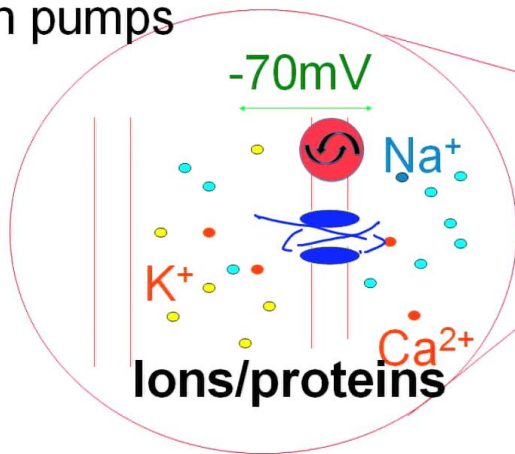
0m 32s

Neuronal Dynamics – Review: Biophysics of neurons

Cell surrounded by membrane

Membrane contains

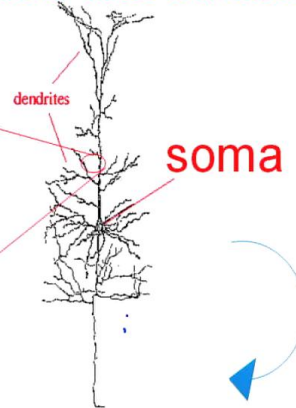
- ion channels
- ion pumps



Dendrite and axon:

Cable-like extensions

Tree-like structure



When I talked about biophysical models, when I talked about the Hodgkin-Huxley model, we focused on a piece of the cell membrane. And this piece of the cell membrane could be a piece of the dendrite. In the cell membrane of the dendrite embedded are ion channels. These ion channels can open and close. And if they are open, ions can flow in the cell or can flow out of the cell. So now, let's take this kind of picture. Let's take this kind of pyramidal cell, and let's rotate it by 90 degrees and stretch it out a little bit.

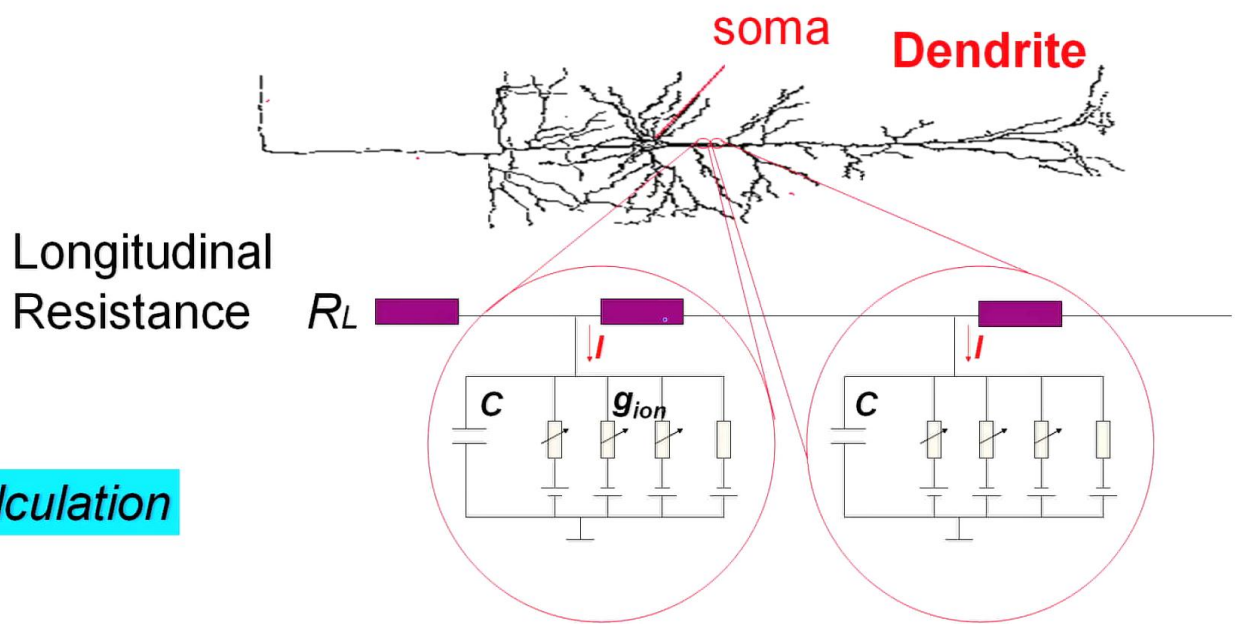
Notes

Summary



1m 48s

Neuronal Dynamics – Modeling the Dendrite



Calculation

So after we have turned the neuron, it looks like this. We have also stretched it out a little bit. And now, we focus on one segment of the dendrite. And just as in the Hodgkin-Huxley model, this segment of the dendrite will be described by some capacitance and different ion channels. Now, this is just a segment here. But of course, there's another segment sitting right next so the first one which will have a very similar circuit diagram. Now, these different segments are not isolated. They are connected. They talk to each other. And the longitudinal resistance reflects the effect that electric charge can flow along the dendrite. And this flow of electric charge corresponds to a longitudinal current. This longitudinal current cannot flow freely. The liquid in the dendrite and the composition of the membrane corresponds to a certain resistance for this longitudinal current. Now, with these elements, these different segments, is it now possible to write down a model for the dendrite as a whole? And I will lead you now through a few steps of calculation.

Notes

Summary

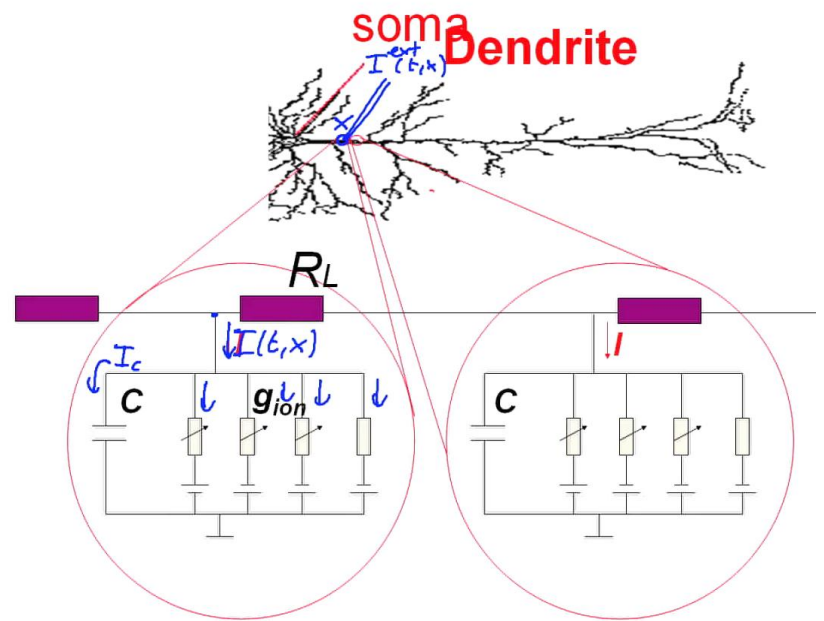


2m 26s

Neuronal Dynamics – Conservation of current

$$I(t, x) = I_c(t, x) + \sum_{ion} I_{ion}(t, x)$$

$$I(t, x) = C \cdot \frac{d}{dt} U(t, x) + \sum_{ion} I_{ion}(t, x)$$



So let's focus on the current onto this segment here. This is my current I . And because of conservation of current, this current has to split. Some of it goes as a capacitive current onto the capacitor. Others parts go through the different types of ion channel. So the total current is the capacity of current and the sum of all the different currents through the various ion channels. Now, this is just the current at one segment. This segment here is my segment at location x . So this would be the current at time t at location x . So I of t and x has a capacity of current at location x and all these ionic currents specific for this location x . We know from previous lectures that the capacity of current can be written as C , the capacitance, times d/dt of the voltage, u of t and x . And I'll copy the rest. So this would be the total current at this segment at location x . Now, what can I say about this total current? Well, this current here might arise from the fact and that an experimentalist injects a current at this location-- an external current. So a current could arise from current injection by an experimentalist.

Notes

Summary



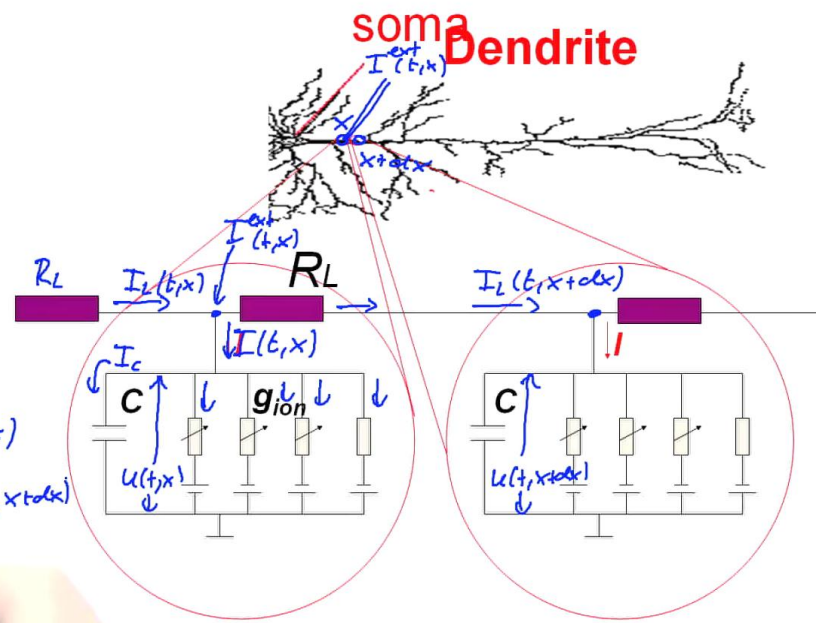
Neuronal Dynamics – Conservation of current

$$I(t, x) = I_c(t, x) + \sum_{ion} I_{ion}(t, x)$$

$$I(t, x) = C \cdot \frac{d}{dt} U(t, x) + \sum_{ion} I_{ion}(t, x)$$

$$I(t, x) = I_{ext}(t, x) + I_L(t, x) - I_L(t, x + dx)$$

$$U(t, x) - U(t, x + dx)$$



However, that's not the only contribution, because as I mentioned before, there's a longitudinal current through this longitudinal resistor. And this longitudinal current I will denote as I_L . And that's longitudinal current at my location x . But there is also a longitudinal current leaving my segment. And this is the longitudinal current in my next segment. The next segment is at location x plus dx . So this location here is x plus dx , the location on the dendrite. So the total current here will be this external current plus the longitudinal current minus the current that's leaving the segment, which is the longitudinal current at x plus dx . The longitudinal current has to pass through this resistor. So what can I say about this longitudinal current? Well, according to Ohm's law, the current is related to the resistance and the voltage. The voltage in this segment is u of t and x . The voltage in this segment is u of t and x plus dx . This voltage is also the voltage up here at these points. That means the voltage difference for this resistor, the voltage applied at this resistor, is u of tx minus u of tx plus dx . And the current is 1 over r . Well The same type of reasoning can be applied to this part here.

Notes

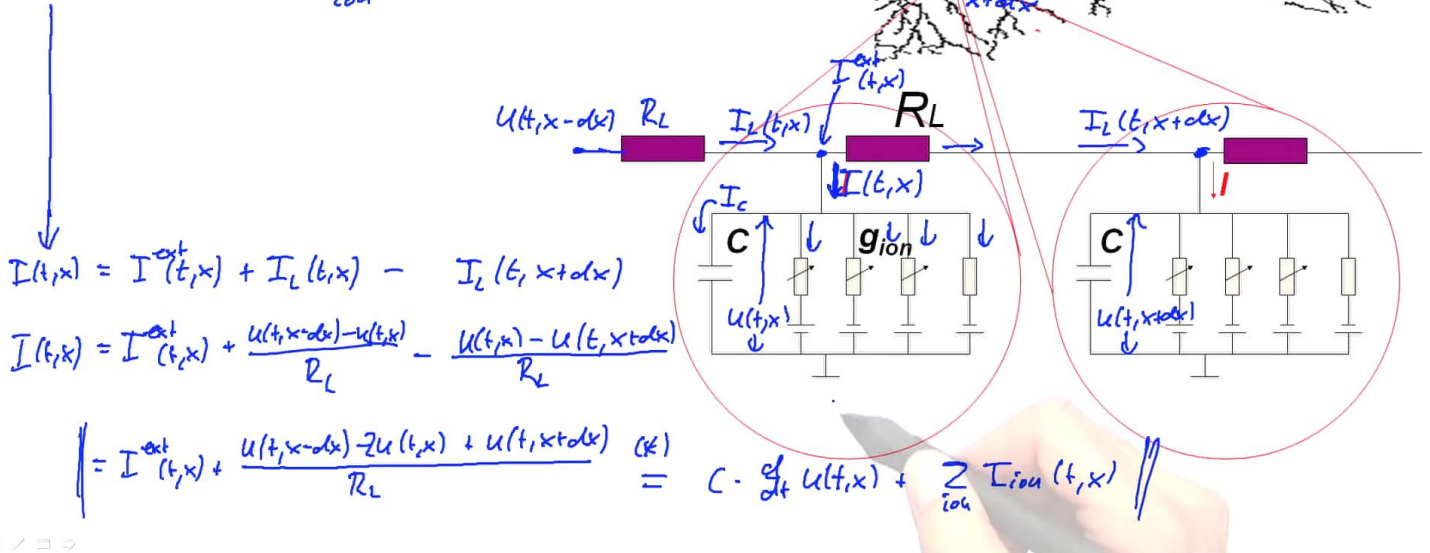
Summary



Neuronal Dynamics – Conservation of current

$$I(t, x) = I_c(t, x) + \sum_{ion} I_{ion}(t, x)$$

$$I(t, x) = C \cdot \frac{d}{dt} U(t, x) + \sum_{ion} I_{ion}(t, x) \quad (*)$$



$$I(t, x) = I_{ext}(t, x) + I_L(t, x) - I_L(t, x+dx)$$

$$I(t, x) = I_{ext}(t, x) + \frac{U(t, x-dx) - U(t, x)}{R_L} - \frac{U(t, x) - U(t, x+dx)}{R_L}$$

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

The voltage here would be the voltage at location x minus dx . And this current, therefore, is u of tx minus dx minus u of tx , again, divided by R_L . I add the external current, and then I have this total current. I can rewrite this by saying that the R_L , this resistance here, longitudinal resistance, is the same as this R_L here. So I have a single big denominator, R_L . Then I have here u of tx minus dx minus u of tx , another minus u of tx -- it's a factor of 2 here-- plus u of tx plus dx . So this is the total current. This is my expression of the total current flowing down here. But the same current is also described by this first equation up here. So I have an equality, and I can copy the start equation, c times d/dt u of t comma x plus the sum of all these ion channel currents, t and x . Now, this is the final equation which describes the current flow along the dendrite, between different segments of the dendrite, and the current flow through the membrane into the outer extracellular space.

Notes

Summary



8m 58s

Neuronal Dynamics – 3.3 Equation: Coupled compartments

we have found :

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

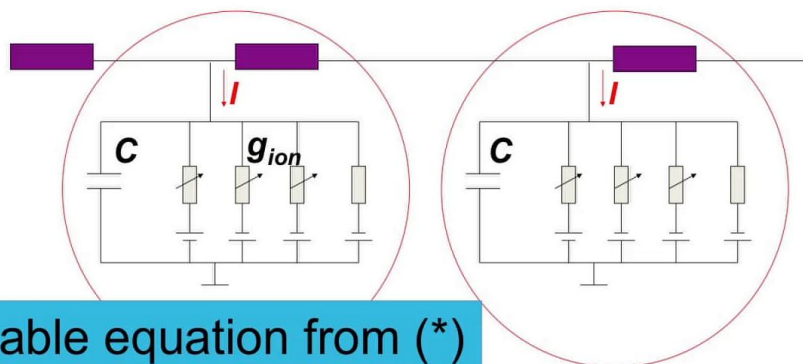
Eq. (*) is the basis for

-Cable equation

lecture 3.4

-Compartmental models

lecture 3.5



NEXT: Derivation of Cable equation from (*)

Notes

Summary

