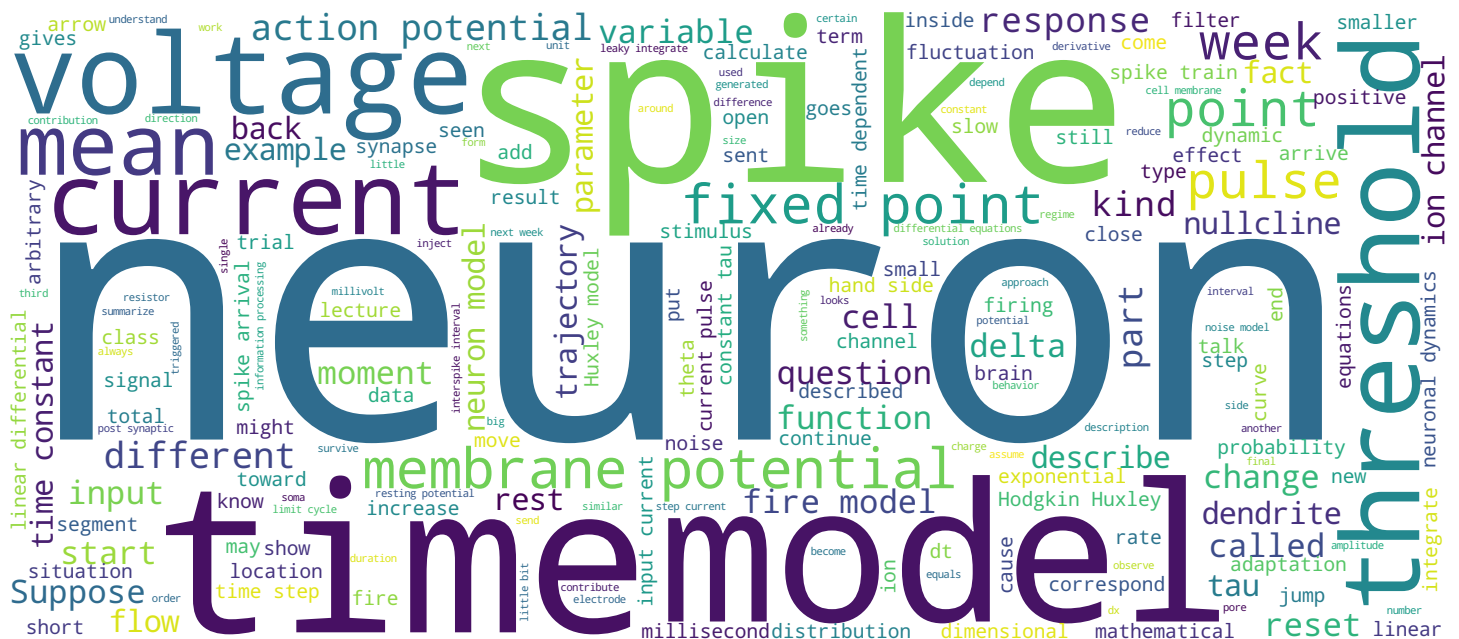


ÉCOLE POLYTECHNIQUE
FÉDÉRALE DE LAUSANNE

EPFL, Lausanne, Switzerland

1.5. Quality of Integrate-and-Fire Models



EPFL





1.1 Neurons and Synapses:

Overview

1.2 The Passive Membrane

- Linear circuit
- Dirac delta-function

1.3 Leaky Integrate-and-Fire Model

1.4 Generalized Integrate-and-Fire Model

1.5. Quality of Integrate-and-Fire Models

WULFRAM GERSTNER: Welcome to the class on neuronal dynamics. Neuronal dynamics is part of the larger field of computational neuroscience. Computational neuroscience works on a theoretical description of the brain.

Notes

Summary

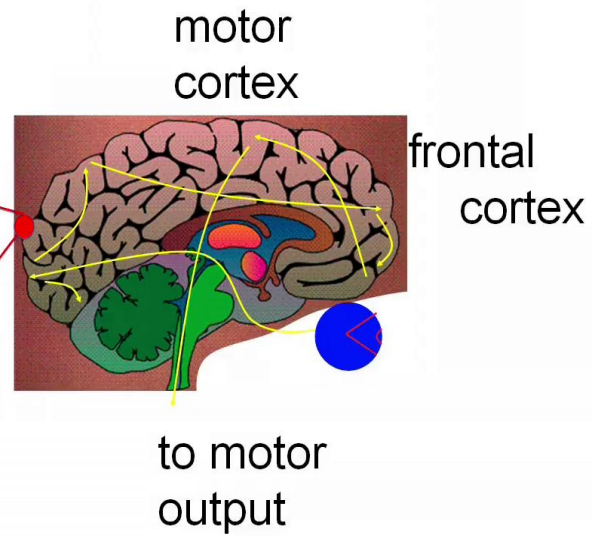
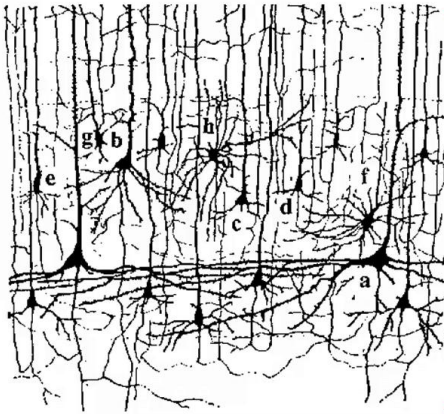


0m 05s

Neuronal Dynamics – 1.1. Neurons and Synapses/Overview



10 000 neurons
3 km wires



Our brain is organized in different areas. There's an area involved in visual information processing called the visual cortex. Imagine that you're riding a bicycle, and at a certain distance, you see a light switching from red to green. Information about the change of light color will enter through your eye and go to visual cortex. Now, you have to decide whether you want to speed up or whether you say, well, it's not worth doing it. I'm not going to make it. And you continue just as normal. While you make your decision, different areas of the brain are involved. Finally, you decide I want to speed up. Your motor cortex sends out a command, and your legs move faster. The description on the level of different brain areas is a rather coarse description. In this class, we will take a different approach. We will focus on one small cubic millimeter, say, of brain area. In this little area of a cubic millimeter, you'll find 10,000 cells or so. And these cells form an intricate network. The cells involved in information processing in the brain are called the neurons.

Notes

Summary



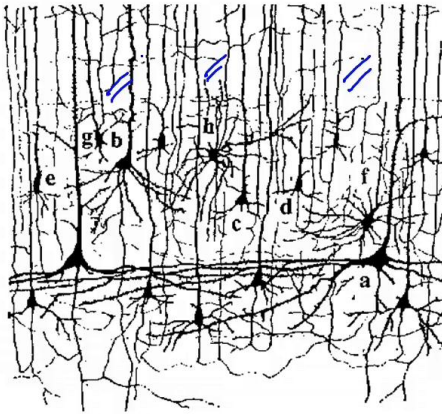
Neuronal Dynamics – 1.1. Neurons and Synapses/Overview



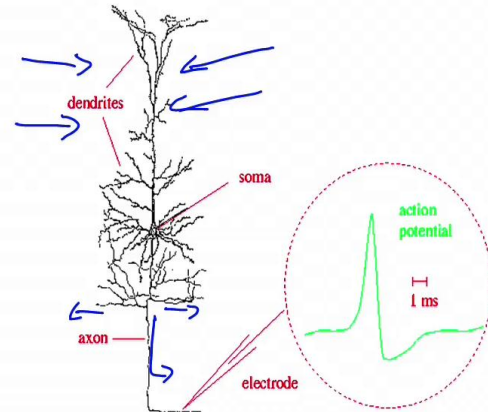
1mm

10 000 neurons

3 km wires



Ramon y Cajal



Neurons have different parts. There's a part called the dendrite. This is where information from other neurons will arrive. The soma is where the neuron decides whether it's going to send out a signal, or not. And then this signal travels along the axon to other neurons. Each neuron makes contact to thousands of other neurons. The contact points are called the synapses. So the axon will branch out and make different ramifications. And therefore, we have not just the cells with a cell body, but we have a lot of wire. In fact, in each small volume of one millimeter cubed, we will have about 10,000 neurons and several kilometers of wires. What you see here on the left hand side is a drawing of Ramon y Cajal, who did this drawing over 100 years ago. And this gives a glimpse of the intricate network that those neurons form. However, it's only a glimpse, and it's still a simplification, because wherever you see empty space here, in fact, there would be other cells, there would be other neurons, there would be more material. In the end, the brain consists of a fairly densely packed material. Neurons, synapses, wires is everywhere. Now, I mentioned already that these neurons send out signals.

Notes

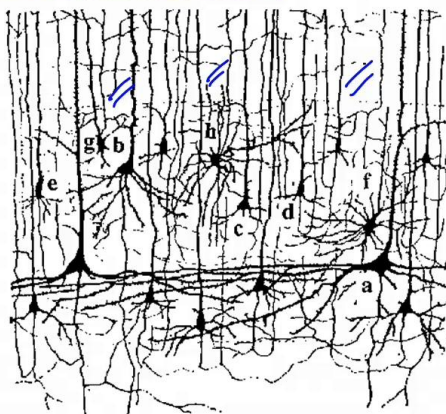
Summary



1m 42s

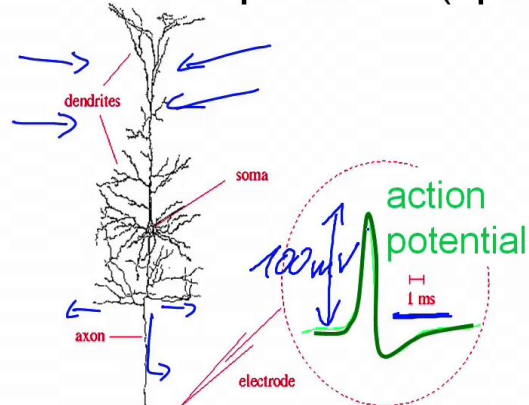
Neuronal Dynamics – 1.1. Neurons and Synapses/Overview

 10 000 neurons
1mm 3 km wires



Ramon y Cajal

Signal:
action potential (spike)



The signal consists of a short electrical pulse called an action potential or spike. An action potential has a duration of a few milliseconds. And it has an amplitude of about 100 millivolt. It's net electrical signal, it's an electrical pulse. I may ask the question, how this kind of pulse, how this kind of electrical signal is generated.

Notes

Summary

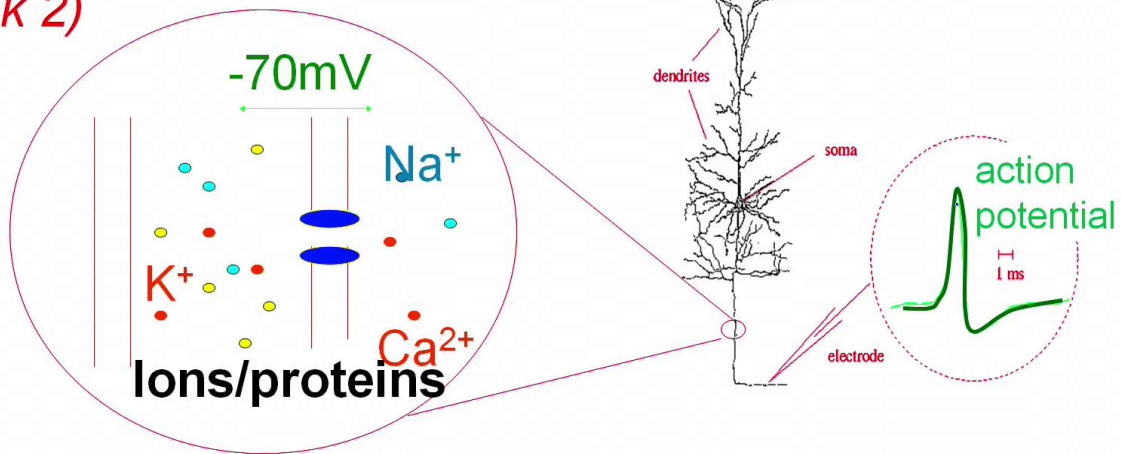


3m 31s

Neuronal Dynamics – 1.1. Neurons and Synapses/Overview

Hodgkin-Huxley type models: Biophysics, molecules, ions (week 2)

Signal:
action potential (spike)



Just as any other cell, neurons are surrounded by a cell membrane. In the cell membrane, you will find pores. These pores can open and close. And while the pores are open, ions can flow in and out of the cell. These ions carry an electrical charge and contribute to the generation of this electrical pulse of the action potential. Next week, we will develop models, we will talk about models of this biophysical interaction of ions, molecules. And these models are called Hodgkin-Huxley type models, or biophysical models, referring to Hodgkin-Huxley, who got a Nobel Prize for developing the first mathematical description on the level of molecules of the neuronal signals. These models are rather complicated. They describe the biophysics. In the week after week two, we will try to reduce the complexity of the description. And we'll talk about simplified model types.

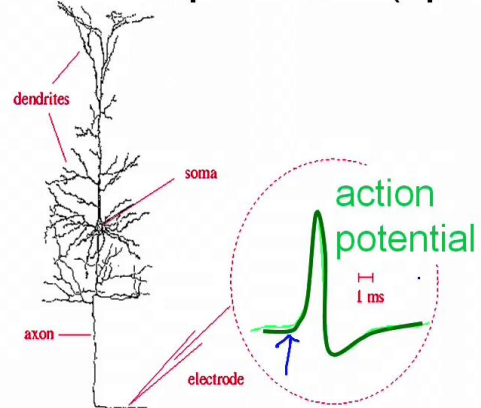
Notes

Summary



Neuronal Dynamics – 1.1. Neurons and Synapses/Overview

Signal:
action potential (spike)



Now, a particularly simple model is a model where we say, well, we don't really care about the biophysical mechanisms that contribute to the formation of an action potential. We just describe the action potential as a pulse, a standard pulse.

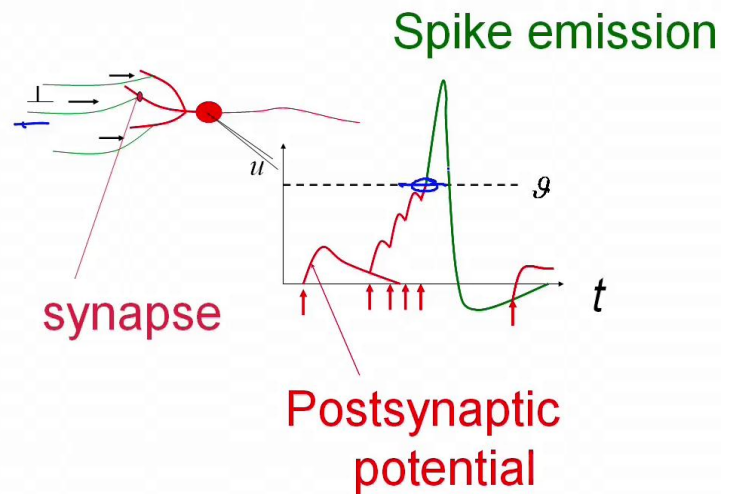
Notes

Summary



5m 15s

Neuronal Dynamics – 1.1. Neurons and Synapses/Overview



So suppose a pulse arise from a presynaptic neuron, from a sending neuron. It arrives, it goes over the synapse, and it causes a response on the postsynaptic side, on the side of the receiving neuron. The postsynaptic neuron is the neuron receiving the signal that goes across the conduct point across the synapse. So this input pulse here will cause this response over there. Now, this neuron will receive not just one input, but it will receive input pulses from many different neurons. Suppose many different pulses arrive. And the effects of all these different pulses will be added up. So this describes how different incoming pulses are transformed into a response of the receiving cell. This response is called the post-synaptic potential. But this does not yet tell us what makes this cell here decide if it will send out a signal itself, or not. The formation of a pulse is triggered in this model if this membrane potential, if this post-synaptic potential reaches a value θ , a threshold value. At this point, a spike is triggered, an action potential is sent out. And afterwards, we have some reset of the membrane potential to a lower value.

Notes

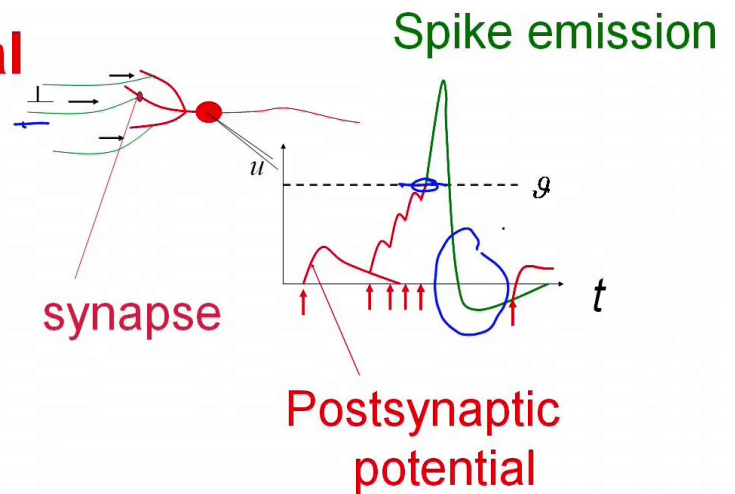
Summary



Neuronal Dynamics – 1.1. Neurons and Synapses/Overview

Integrate-and-fire models: Formal/phenomenological (week 1 and week 6+7)

- spikes are events
- triggered at threshold
- spike/reset/refractoriness



So in this kind of model, which I called integrate-and-fire model, in this kind of models, spikes are formal events. They are triggered at a moment when the membrane potential crosses the threshold. And then a spike is sent out. And after, the spike does some reset and refractoriness. A simple version of this model will be the topic for today. And then we'll come back to this model towards the end of this series of lectures. Suppose now we have this kind of model.

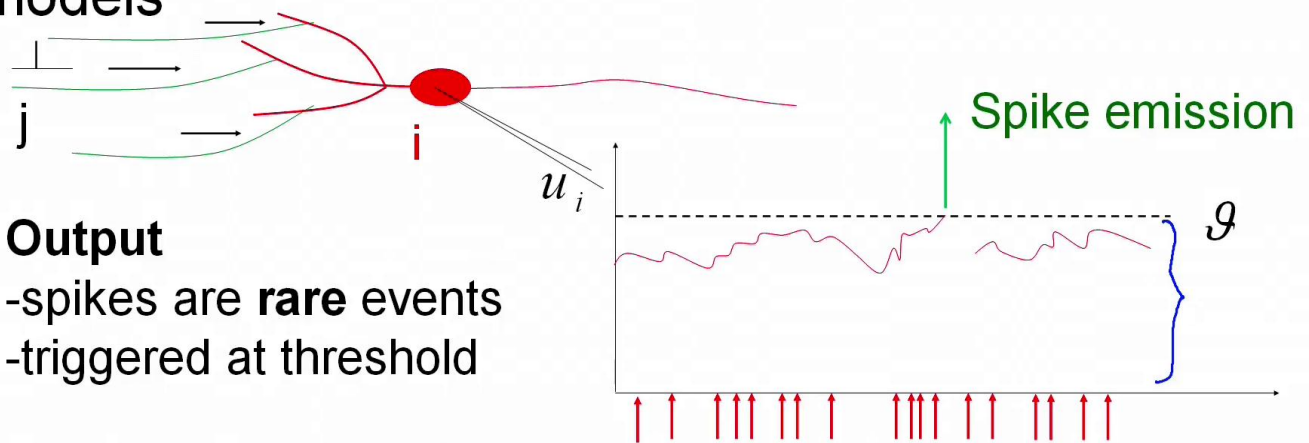
Notes

Summary



7m 06s

Noise and variability in integrate-and-fire models



Output

- spikes are **rare** events
- triggered at threshold

Subthreshold regime:

- trajectory of potential shows fluctuations

Random spike arrival

And our neuron receives many, many spikes from other neurons. To make things simple, we assume that spike arrival is random. As a result of this, the potential will fluctuate as a function of time. And only occasionally a spike is sent out. So spikes are rather rare events, triggered at a threshold. Below the threshold, in the regime which is called subthreshold regime, what we observe in the random spike arrival is a fluctuating membrane potential.

Notes

Summary



7m 40s

Neuronal Dynamics – membrane potential fluctuations

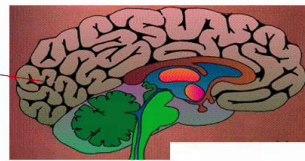
Spontaneous activity *in vivo*

What is noise?

What is the neural code?

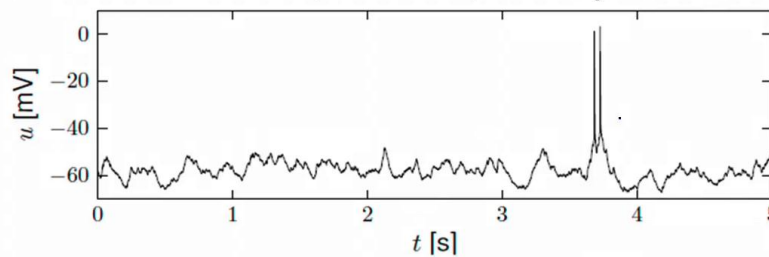
(week 5+6)

electrode



Brain

awake mouse, cortex, freely whisking,



Crochet et al., 2011

And this is reminiscent of what one finds if neuronal activity is recorded with an electrode in an awake mouse, for example. You see these fluctuations of the membrane potential. And spikes are rare events. From time to time, a spike is sent out. So in lectures in week five and six, we'll ask questions, what do these fluctuations mean? Is this noise? What's the meaning of these action potentials? What's the information transmitted by the neuron? What is the neural code?

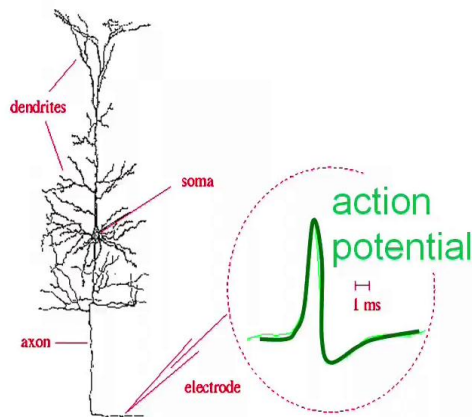
Notes

Summary



8m 20s

Neuronal Dynamics – 1.1. Neurons and Synapses/Overview



Week 1: A first simple neuron model/
neurons and mathematics

Week 2: Hodgkin-Huxley models and
biophysical modeling

Week 3: Two-dimensional models and
phase plane analysis

Week 4: Two-dimensional models
Dendrites

Week 5: Variability of spike trains and
the neural code

Week 6: Noise models, noisy neurons
and coding

Week 7: Estimating neuron models for
coding and decoding

So overall, I will present this week a first simplified model of a neuron. Then in the next week, it will go on to Hodgkin-Huxley models, which we then simplify and reduce to what's called a FitzHugh-Nagumo model.

Notes

Summary



Neuronal Dynamics – Exercises 1.1



Take 3 minutes NOW!

Multiple answers possible!

We'll talk about the dendrite. We'll talk about neural coding. We'll talk about the question of noise, about the question of what is the information processed and transmitted by a neuron. And in week seven, in a final lecture, I will put these different things together and show how to extract from neuronal data a model of a neuron which is able to describe neural information processing to describe to transform incoming signal into output spikes and therefore, shed light on the questions of coding and decoding. After this short introduction, I would now like you to do a first little exercise. Please take two or three minutes and answer the following questions. And then I will continue with a first model.

Notes

Summary



9m 18s

Neuronal Dynamics – Exercises 1.1

A cortical neuron sends out signals which are called:

- ☐ action potentials
- ☐ spikes
- ☐ postsynaptic potential

The dendrite is a part of the neuron

- ☐ where synapses are located
- ☐ which collects signals from other neurons
- ☐ along which spikes are sent to other neurons

In an integrate-and-fire model, when the voltage hits the threshold:

- ☐ the neuron fires a spike
- ☐ the neuron can enter a state of refractoriness
- ☐ the voltage is reset
- ☐ the neuron explodes

In vivo, a typical cortical neuron exhibits

- ☐ rare output spikes
- ☐ regular firing activity
- ☐ a fluctuating membrane potential

Multiple answers possible!

Notes

Summary



10m 09s