Exercise 1 for Computational Neuroscience

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Note: Most of the material in these exercises is covered in the lecture slides. Sometimes, however, textbook reading or internet search might be required, too.

These exercises are – of course – not mandatory but they should help you to understand the topic better and prepare for the exam.

Models of the Visual System

Fig. 1 (left) shows a schematic diagram of the structure of the human visual system. In the right panel different types of damages are shown (in black).

Please, cut correctly the optic nerve (NO), the optic track (TO) or the Optic Chiasm (CO) by using four strokes in total, so that these cuts correspond to the four different types of damages A-D. Note: B is the easiest case!

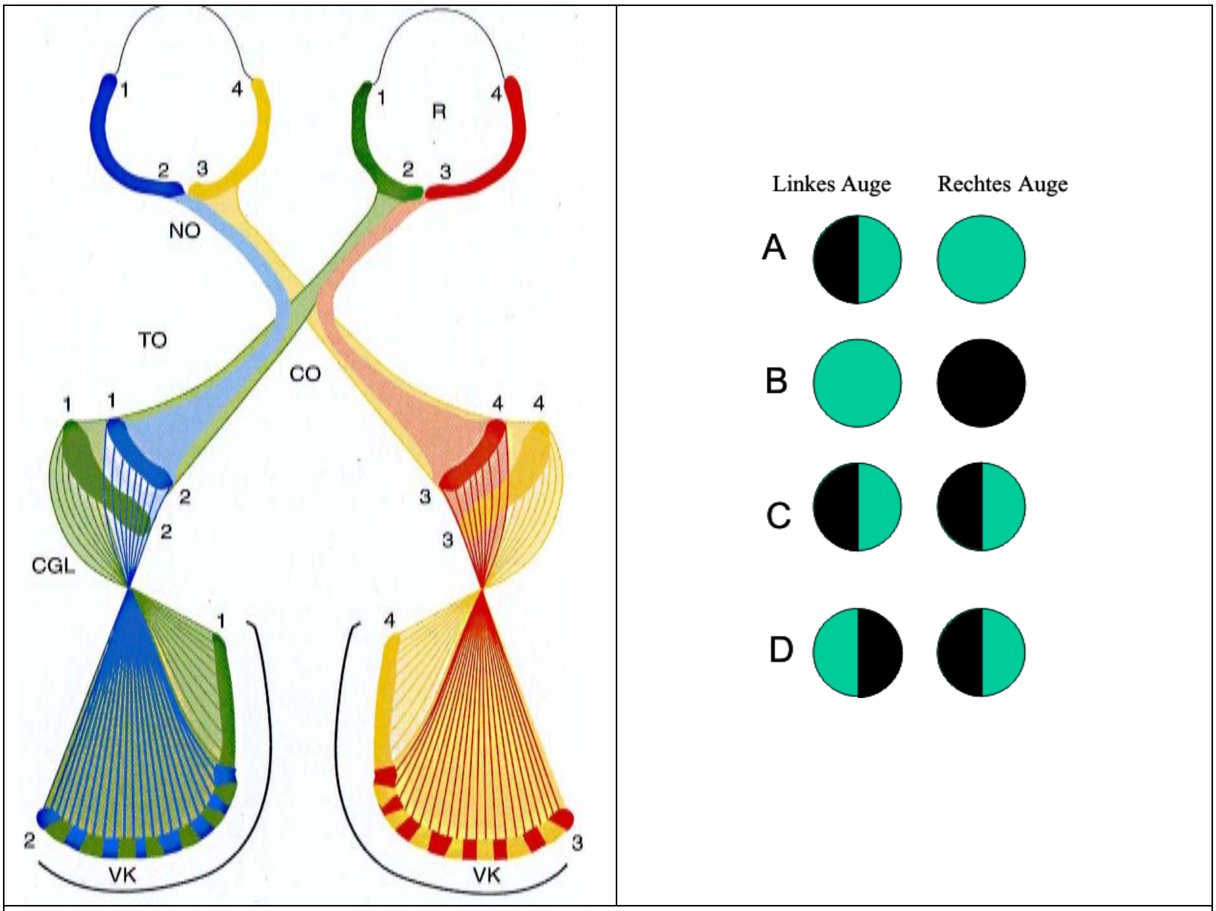

Fig 1) left, structure of the visual system. Right, different types of damages (in black) in left and right eye.

Receptive Fields

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A) What do we understand by a receptive field (choose skin or retina as an example)?
B) What do we understand by orientation selectivity in the visual cortex?
C) The diagram to the right shows a model of orientation selectivity. Please explain it in words.
D) The triangles and crosses denote projection neurons. In which brain structure are these located?
E) Name the projection neurons (triangles and crosses) with the correct term for their stimulus sensitivity. (Please note: There are 2 correct solutions.)
F) How many sub-fields are there in the receptive field in the diagram shown to the right?
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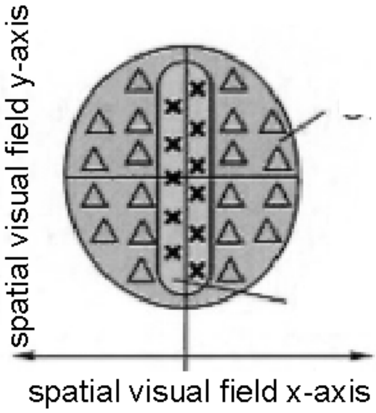

Fig. 1 Visual cortical receptive field
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Membrane Potential – Nernst Equation

Here, the simplified version of the Nernst equation for a fictional ion *X* can be found:	$V_x = -\frac{60}{z}\log\frac{[X]_i}{[X]_o}[mV]$

A) Will the potential become more negative or more positive if the concentration $[X]_i$ increases?

B) Given $[X]_i = [X]_o$: what will be the resulting potential? What could be a physiological explanation for this?

C) In a more realistic set-up the potential will be influenced by several ion types. For describing the resulting potential one uses another equation. What is the name of it? Even this equation does not hold for all situations. Name at least one condition for which this equation does not hold.

Membrane Potential - Goldman-Hodgkin-Katz Equation

The subsequent equation is the **Goldman-Hodgkin-Katz Equation** for univalent ions (z=1)**.**

$$V_m = \frac{RT}{F} \ln \frac{P_K[K^+]_o + P_{Na}[Na^+]_o + P_{Cl}[Cl^-]_i}{P_K[K^+]_i + P_{Na}[Na^+]_i + P_{Cl}[Cl^-]_o}$$

1) Please explain which relationship is expressed by this equation.
2) There are a lot of parameters and constants in this equation. Please explain shortly all parameters and constants listed below.

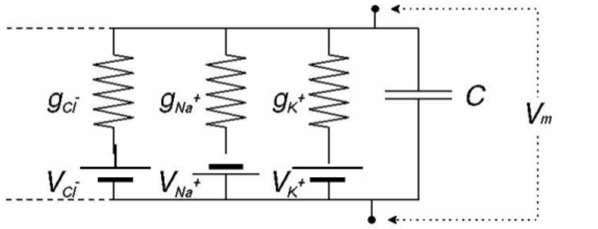
The simplification of this equation is called Nernst equation.

3) State the Nernst equation for the Sodium ion.
4) a) Assume that $[Na^+]_o$ / $[Na^+]_i$ = e holds in the Nernst equation.
   What is the value of V_m?
   b) Assume that $[Na^+]_o$ = 0 holds in the Nernst equation.
   What is the value of V_m?
   c) Assume that $[Na^+]_o$ = $[Na^+]_i$ holds in the Nernst equation.
   What is the value of V_m?

Membrane Potential

The following diagram shows an equivalent circuit for a membrane of a nerve cell.
We assume: V_{Cl-} = -70 mV, V_{K+}= -80 mV, V_{Na+}=+30mV.

Fig. 2) Electrical equivalence diagram of a neuronal membrane.



A) Which potential V_m do you obtain if you set g_{Na+}= "infinity" (which means the other conductivities are much lower and thus, in relative terms, close to zero)? Which physiological case does this approximately correspond to?

B) Which potential do you obtain if you set g_{Na+}=0 and at the same g_{K+}=g_{Cl-} (both of them non-zero)?

C) What approximately is the value of the membrane capacity?

D) The product τ=RC, where R is the total resistance of the membrane and C its capacity, is an important physiological constant. What is its name and its meaning? Remember what happens if you apply a voltage jump to the membrane. How does the response look like? (Draw it!) How does the response change for larger RC?

Membrane Potential and Calculating with Neurons

Question A) We consider two similar synapses (the same transmitter, the same ion currents), which are located at the soma of the post-synaptic neuron (see Fig. 2 below). Both synapses receive independent, excitatory input from different neurons. The maximal amplitudes of the obtained EPSPs are A and B, if EPSPs occur alone. Our measurement point is exactly in the middle between the two synapses, and we measure that there „summation“ occurs. We obtain a total EPSP with the maximal amplitude C, where $C = \lambda A + \mu B$. The factors λ and μ are always at least a bit smaller than one. Which of the following reasons can account for the fact that λ and/or μ are ***significantly*** smaller than one (incomplete summation)?

a) Synapses have larger spatial distance between each other.
b) Input signals (action potentials) at A and B have large temporal difference between each other.
c) B fires before A which leads to LTD and as a consequence to a reduction of synaptic weight λ.
d) The reversal potential of ion currents triggered by inputs A and B is close to the resting potential.
e) The reversal potential of ion currents triggered by inputs A and B is far away from the resting potential.

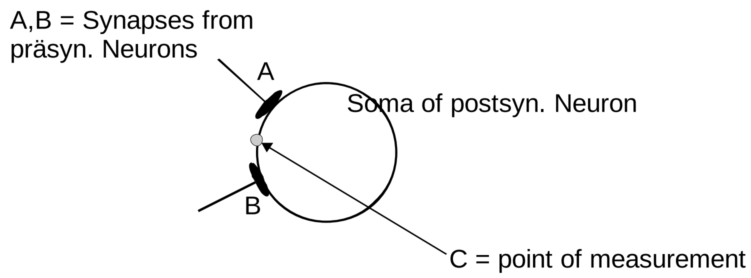


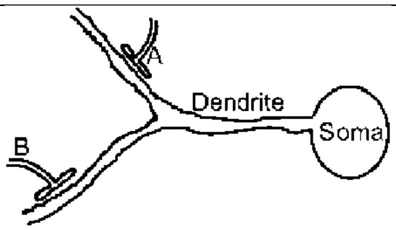
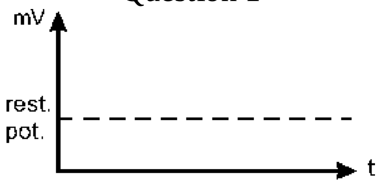
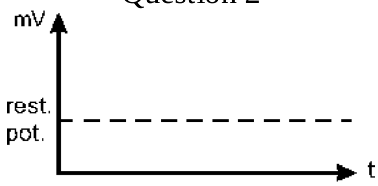
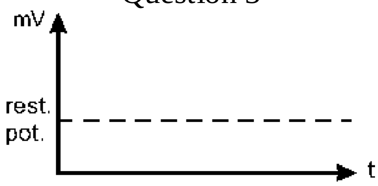
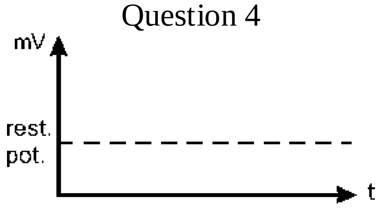
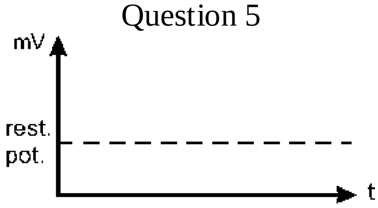
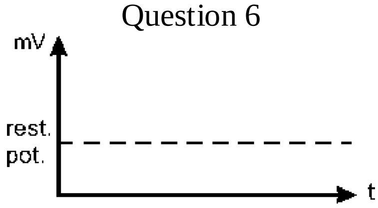
Fig.2) Summation at a neuron.

Question B) How does the integration at a neuron behave when the time constant is large?
Question C) What is a „coincidence detector neuron“?

Calculating with Neurons

The following diagram shows a schema of a possible synaptic wiring. We assume that directly at the synapse, all postsynaptic potentials have the same (absolute) amplitude. The neuron resides in its resting potential. Please draw the resulting potential at the soma for the following cases: (draw clearly and, where necessary, shortly explain what you mean!)

1) Synapses A and B are excitatory. They are excited simultaneously. Their equilibrium potential is far away from the resting potential.
2) Same as (1) but A is excited long before B.
3) Same as (1) but B is excited before A such that both EPSP arrive the summation point at the same point of time.
4) Same as (3) but the equilibrium potential of both synapses is only slightly above the resting potential.
5) Synapse A is excitatory, synapse B is inhibitory. They are excited simultaneously. The equilibrium potential is far away from the resting potential.
6) Same as (5) but the equilibrium potential of A is almost identical to the resting potential (Caution!).
7) And: In the wiring diagram, approximately indicate the summation point where both PSPs are summed up for the first time.

 *Fig 1) Schematic of a small neural circuit.*	Question 1 
Question 2 	Question 3 
Question 4 	Question 5 
Question 6 	Question 7: Please indicate directly in Fig. 1!