Neural Networks and Deep Learning – Summer Term 2019

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Exercise sheet 1

Exercise 1 (Structure of a neuron):

Basic elements of a biological neuron in a neural network are:

- Dendrites,
- Cell body with the nucleus,
- Axon with the myelin sheath,
- Synapses

Those elements have the following functionality:

Dendrites: Receiving and processing operations for incoming information, generally take place in the dendrites and cell body. It receives impulses from other neurons and leads to postsynaptic potentials (PSP) at the Cell body. Incoming signals can be either **excitatory** or **inhibitory.** Neurons receive a lot of input signals throughout their dendritic trees. A single neuron may have more than one set of dendrites, and may receive many thousands of input signals.

Cell body with the nucleus: The cell body is responsible for spatiotemporal integration of incoming impulses (PSPs) of all dendrites. The cell body also produces the proteins so that the other parts of the neuron, including the dendrites, axons, and synapses are able to function properly.

Axon with the myelin sheath: The axon is the elongated fiber that extends from the cell body to the terminal endings and transmits the neural signal. The larger the diameter of the axon, the faster it transmits information. Some axons are covered with a fatty substance called **myelin** that acts as an insulator. These myelinated axons transmit information much faster than other neurons.

Synapses: Neuron-to-neuron connections are made onto the dendrites and cell bodies of other neurons. These connections, known as **synapses**, are the sites at which information is carried from the first neuron (**presynaptic neuron**) to the target neuron (**postsynaptic neuron**). The synapses allow electrical and chemical messages to be transmitted from the neuron to the other cells in the body.

Exercise 2 (Type of signal transmission in neuronal components):

1. **Transmission on Dendrites:** Dendrite propagates **electrical transmission** received from other neural cells to cell body. This transmission is defined as **analog**. Because postsynaptic potentials are measured by the amount of received neurotransmitter while electrical transmission to the cell body.

2. **Transmission on Axon:** Axon is responsible for **electrical transmission**. This transmission is defined as **Binary**. Because the strength of action potential does not depend on the size of postsynaptic potential, although the frequency of action potentials is influenced by PSP. However, action potential travels along Axon with constant amplitude.

3. **Transmission on Synapses:** Synapses are responsible for **chemical transmission** from one neuron to another. This transmission is defined as an **analog**. The neuron where the signal is initiated is called presynaptic neuron, while the neuron that receive the signal is called postsynaptic neuron. In the presynaptic neuron the chemical signals are packaged into small sacs called vesicles. Each vesicle can contain thousands of neurotransmitter molecules. When presynaptic neuron is excited by an electrical signal called an action potential, this causes the neuron to release signals into synaptic cleft. The transmission of chemical signals mostly depends on the strength of action potential. That's why the transmission on synapses is analog.

Exercise 3 (Neural codes):

- Basic neural "event" of a neuron to "communicate" with other neurons is: **action potential**.
- There are three basic neural codes to represent “meaningful information”:
    1. **Rate coding:** information represented in the average number of spikes per unit time. Temporal structure of a spike train ignored.

    2. **Temporal coding:** precise spike timing, timing fluctuations carry information.

    3. **Population coding:** information represented in averaging over a number of neurons. It also reflects stimulus changes nearly instantaneously.

Exercise 4 (Neuron models and neuron properties):

- The neuron models in the order of descending model complexity:
    i. Hodgkin-Huxley model
    ii. Integrate-and-fire model
    iii. Renewal neuron
    iv. Threshold element / perceptron

- Explanation of the following terms characterizing the behavior of a neuron:
    i. **Absolute refractory period:** Is the period of time during which a second action potential absolutely cannot be initiated, no matter how large the applied stimulus is.
    ii. **Relative refractory period:** Is the interval immediately following the Absolute Refractory Period during which initiation of a second action potential is inhibited, but not impossible. As voltage-gated potassium channels open to terminate the action potential by repolarizing the membrane, the potassium conductance of the membrane increases and the K+ ions move out of the cell and bring the membrane potential closer to the equilibrium potential for potassium and this can lead to membrane hyperpolarization.
    iii. **Gain function:** Relation between the frequency of action potentials emitted by a neuron to the input to the neuron.
    iv. **Interspike interval distribution:** Distribution (histogram) of the time between two consecutive action potentials of a neuron