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Neural Networks and Deep Learning – Summer Term 2018

Exercise sheet 1

Submission due: Tuesday, April 24, 11:30 sharp

Exercise 1 (Structure of a neuron):

Name the basic elements of a biological neuron in a neural network and briefly summarize the functional role of each element.

Solution:

- Dendritic tree / dendrites:
    - receive incoming signals from other neurons and propagate these signals (postsynaptic potentials) to the cell body
    - Signal transmission described by *passive* cable theory

- Cell body (soma):
    - spatiotemporal integration of postsynaptic potentials originating from the dendritic tree
    - emission of an action potential if the postsynaptic potential exceeds threshold

- Axon:
    - Propagation of action potential to the synapses (*active* process!)

- Synapses:
    - (Chemical) transmission of incoming pre-synaptic action potential over synaptic cleft towards dendrites of postsynaptic neuron

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

Name the type of signal transmission (electrical, chemical, wireless, …) at the axon, the synapses and the dendrites. Indicate whether it is a binary or an analog event (why?).

Solution:

- Axon: *electrical* transmission, binary (all-or-none)
  - the strength of an action potential is independent of the size of the postsynaptic potential PSP (as long as the PSP is above threshold); the PSP influences the *frequency* of action potentials
  - Action potential travels along axon with constant amplitude (*active* process!)
  - Note that the action potential itself reflects a continuous change of the membrane potential (which is an analog signal); but since the shape and the amplitude of this signal is always nearly the same, the *information content* of the signal is binary (there is an action potential or no action potential at a given time point – the shape of the action potential does not carry information)

- Synapses: *chemical* transmission, analog
  - Amount of neurotransmitter arriving at the postsynaptic membrane depends on various factors (i.e. is not constant), so it's not a binary event

- Dendrites: *electrical* transmission, analog
  - Size of PSP at dendrite depends on amount of received neurotransmitter; upon signal transmission to the cell body (which is described by passive cable theory), the size of the PSP decreases due to electrical resistance, so it's not a binary event

Exercise 3 (Neural codes):

What is the basic neuronal "event" of a neuron to "communicate" to other neurons? What are the basic neural codes to represent "meaningful information"? Give a brief explanation of the neural codes.

Solution:

- Basic neuronal event: action potential
  - But: a single action potential (and the precise time of its emission) might not be indispensable for information processing in a neural network
  - Instead, there might be neural codes to represent the information in a neural network

- Rate coding:
  - Information is represented in the *average* number of action potentials per unit time, i.e. temporal structure of spike train is ignored (time average)

- Temporal coding:
  - Precise spike timing is relevant, timing fluctuations carry information

- Population coding:
  - Information is represented in the *average* of neuron outputs in a population of neurons (population average)

- Note: These are theoretical models to represent the information in a neural network. Biological neural networks might actually use any combination of these codes (depending on a given task, the network involved etc.) or even a totally different scheme!

Exercise 4 (Neuron models and neuron properties):

a) Name the neuron models mentioned in the lecture in the order of descending model complexity (from complex to simple).
Optional: Briefly summarize some of their characteristics.

Solution:

- Hodgkin-Huxley model
  - (differential equation for membrane potential, includes ion channels, models shape of action potential)
- Integrate-and-fire neuron
  - (differential equation for membrane potential, no ion channels, point-like action potentials)
- Renewal neuron
  - (simple equation for postsynaptic potential, memorizes time elapsed since emission of previous action potential, refractory function added to postsynaptic potential, point-like action potentials)
- Threshold element
  - (simple equation for postsynaptic potential, no refractory properties, no memory, no interpretation of active state as individual action potential)

b) Explain the following terms characterizing the behavior of a neuron:

- Absolute refractory period
- Relative refractory period
- Gain function
- Interspike interval distribution

Solution:

- Absolute refractory period
  - Time period after emission of an action potential in which the neuron absolutely cannot emit another action potential, no matter how large a stimulus is applied

- Relative refractory period
  - Time period after the absolute refractory period in which the neuron's threshold to emit another action potential is increased (i.e. the emission of another action potential is inhibited, but not impossible)

- Gain function
  - Relation between the frequency of action potentials emitted by a neuron to the (constant) input to the neuron

- Interspike interval distribution
  - Distribution (histogram) of the time between two consecutive action potentials of a neuron

Note: The gain function $\nu(I)$ can be determined from the mean $<\tau>$ of the interspike interval distribution $D(\tau)$ calculated at input I: $\nu(I) = 1/<\tau(I)>$