Artificial Neural Networks and Deep Learning

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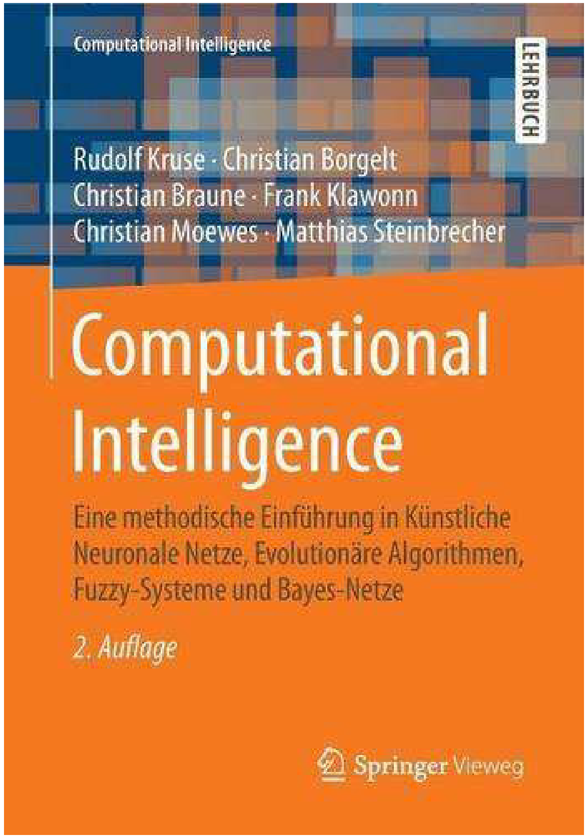
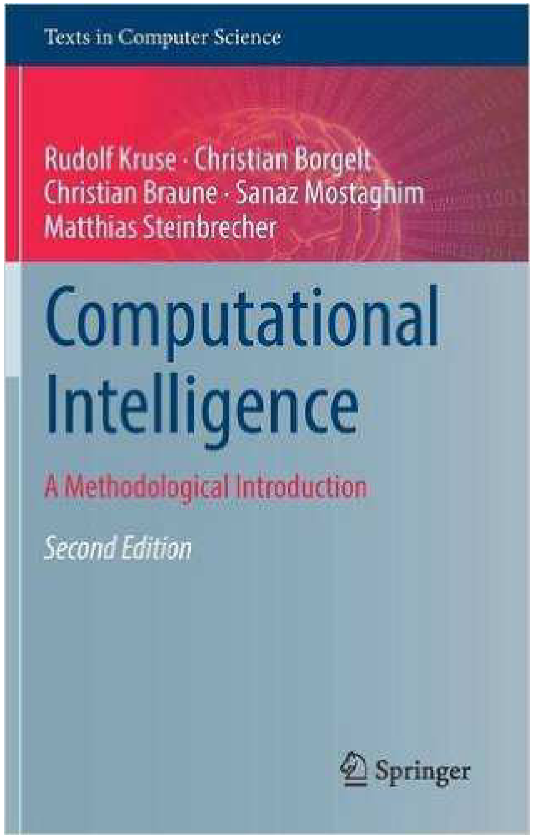
Textbooks



Textbook, 2nd ed.
Springer-Verlag
Heidelberg, DE 2015
(in German)



Textbook, 2nd ed.
Springer-Verlag
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(in English)

This lecture follows the first parts of these books fairly closely, which treat artificial neural networks.

Contents

Motivation: Why (Artificial) Neural Networks?

- **(Neuro-)Biology / (Neuro-)Physiology / Psychology:**
  - Exploit similarity to real (biological) neural networks.
  - Build models to understand nerve and brain operation by simulation.
- **Computer Science / Engineering / Economics**
  - Mimic certain cognitive capabilities of human beings.
  - Solve learning/adaptation, prediction, and optimization problems.
- **Physics / Chemistry**
  - Use neural network models to describe physical phenomena.
  - Special case: spin glasses (alloys of magnetic and non-magnetic metals).

Motivation: Why Neural Networks in AI?

Physical-Symbol System Hypothesis [Newell and Simon 1976]

A physical-symbol system has the necessary and sufficient means for general intelligent action.

Neural networks process simple signals, not symbols.

So why study neural networks in Artificial Intelligence?

- Symbol-based representations work well for inference tasks, but are fairly bad for perception tasks.
- Symbol-based expert systems tend to get slower with growing knowledge, human experts tend to get faster.
- Neural networks allow for highly parallel information processing.
- There are several successful applications in industry and finance.

Biological Background

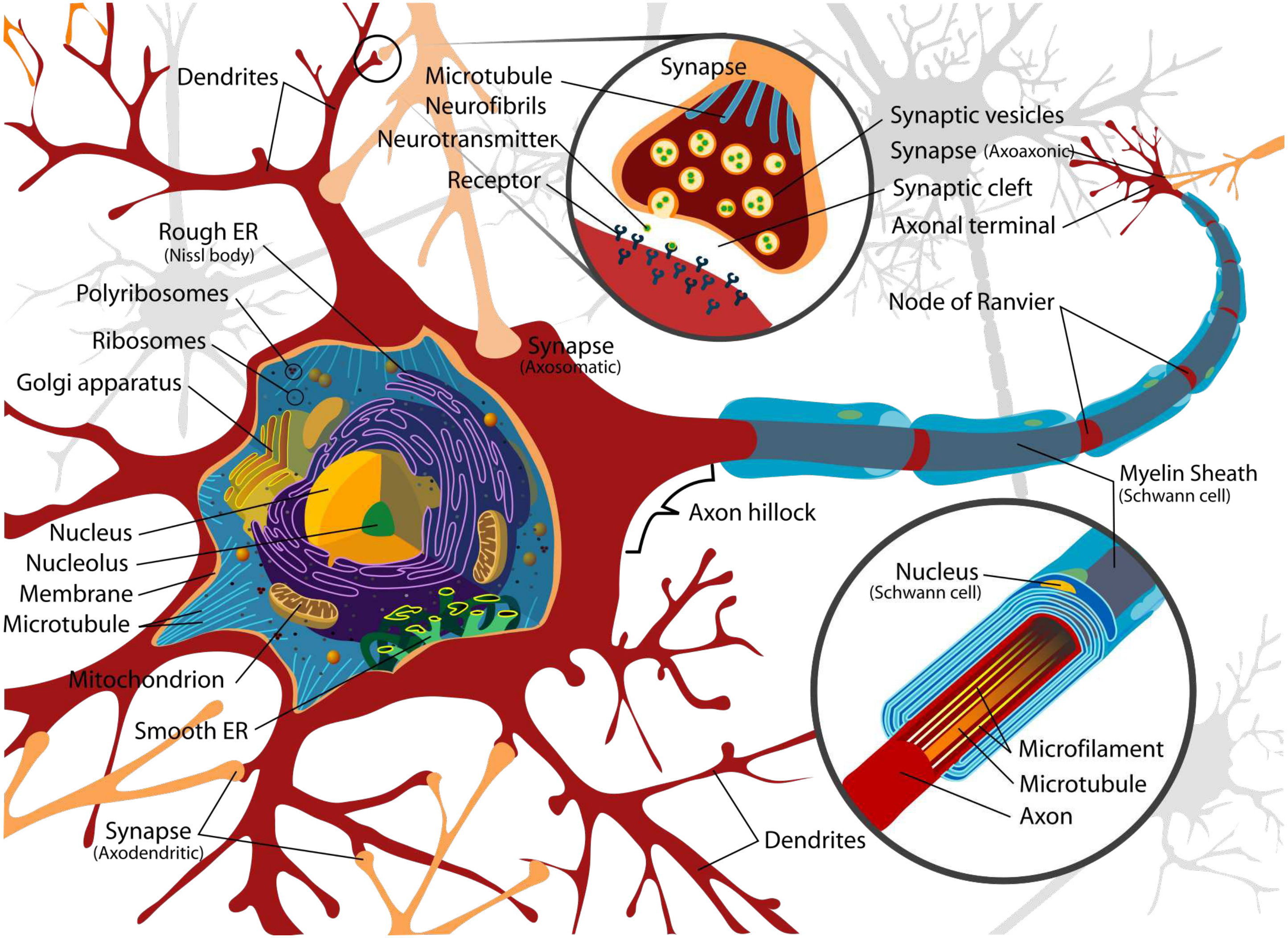
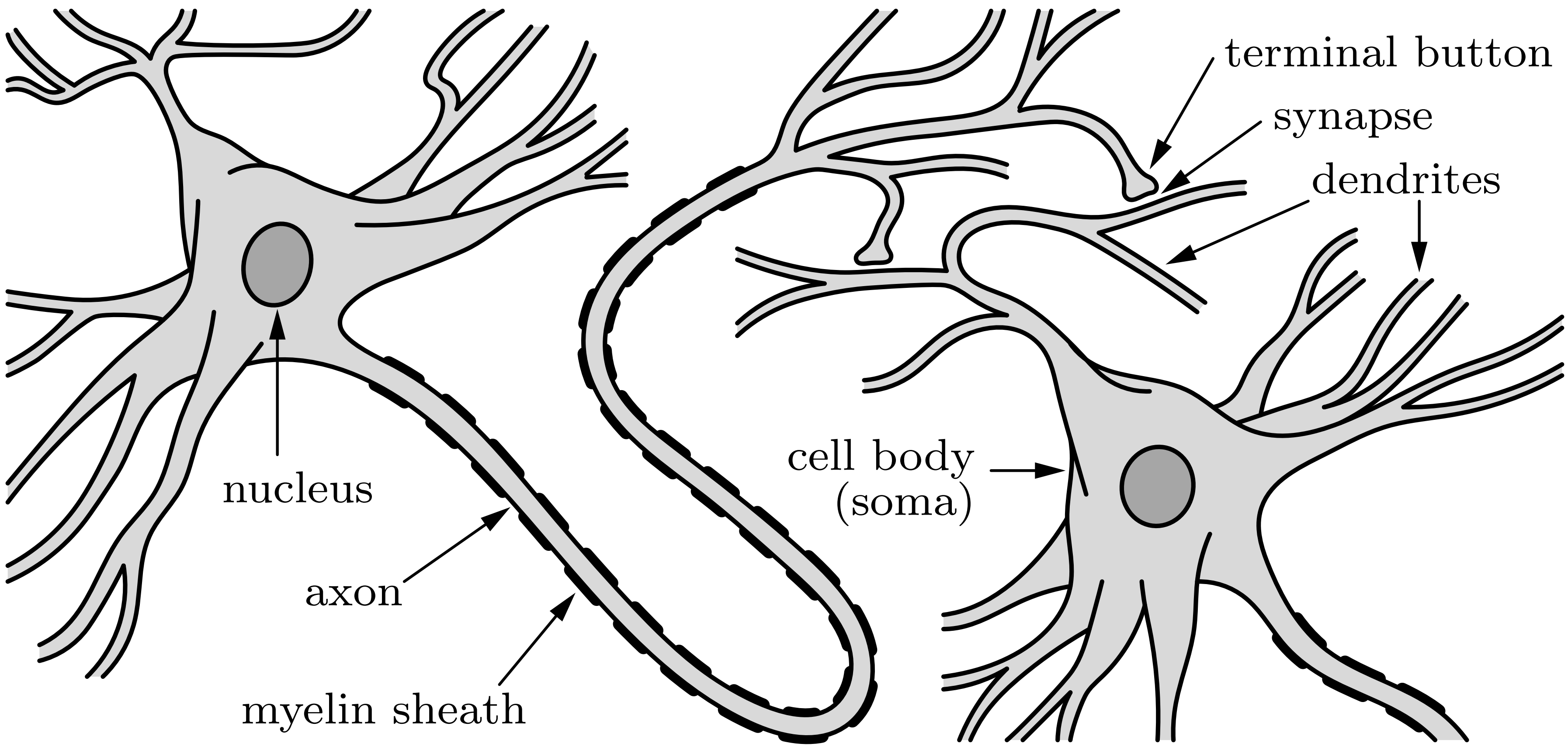


Diagram of a typical myelinated vertebrate motoneuron (source: Wikipedia, Ruiz-Villarreal 2007), showing the main parts involved in its signaling activity like the *dendrites*, the *axon*, and the *synapses*.

Structure of a prototypical biological neuron (simplified)



Biological Background

(Very) simplified description of neural information processing

- Axon terminal releases chemicals, called **neurotransmitters**.
- These act on the membrane of the receptor dendrite to change its polarization.
  (The inside is usually 70mV more negative than the outside.)
- Decrease in potential difference: **excitatory** synapse
  Increase in potential difference: **inhibitory** synapse
- If there is enough net excitatory input, the axon is depolarized.
- The resulting **action potential** travels along the axon.
  (Speed depends on the degree to which the axon is covered with myelin.)
- When the action potential reaches the terminal buttons,
  it triggers the release of neurotransmitters.

(Personal) Computers versus the Human Brain

	Personal Computer	**Human Brain**
processing units	1 CPU, 2–10 cores 10^{10} transistors 1–2 graphics cards/GPUs, 10^{3} cores/shaders 10^{10} transistors	10^{11} neurons
storage capacity	10^{10} bytes main memory (RAM) 10^{12} bytes external memory	10^{11} neurons 10^{14} synapses
processing speed	10^{-9} seconds 10^{9} operations per second	$> 10^{-3}$ seconds < 1000 per second
bandwidth	10^{12} bits/second	10^{14} bits/second
neural updates	10^{6} per second	10^{14} per second

(Personal) Computers versus the Human Brain

- The processing/switching time of a neuron is relatively large ($> 10^{-3}$ seconds), but updates are computed in parallel.
- A serial simulation on a computer takes several hundred clock cycles per update.

Advantages of Neural Networks:

- High processing speed due to massive parallelism.
- Fault Tolerance:
  Remain functional even if (larger) parts of a network get damaged.
- "Graceful Degradation":
  gradual degradation of performance if an increasing number of neurons fail.
- Well suited for inductive learning
  (learning from examples, generalization from instances).

It appears to be reasonable to try to mimic or to recreate these advantages by constructing **artificial neural networks**.