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HEIDELBERG

# Spiking Neural Networks

Advanced Seminar

Computer Engineering

Eugen Rusakov

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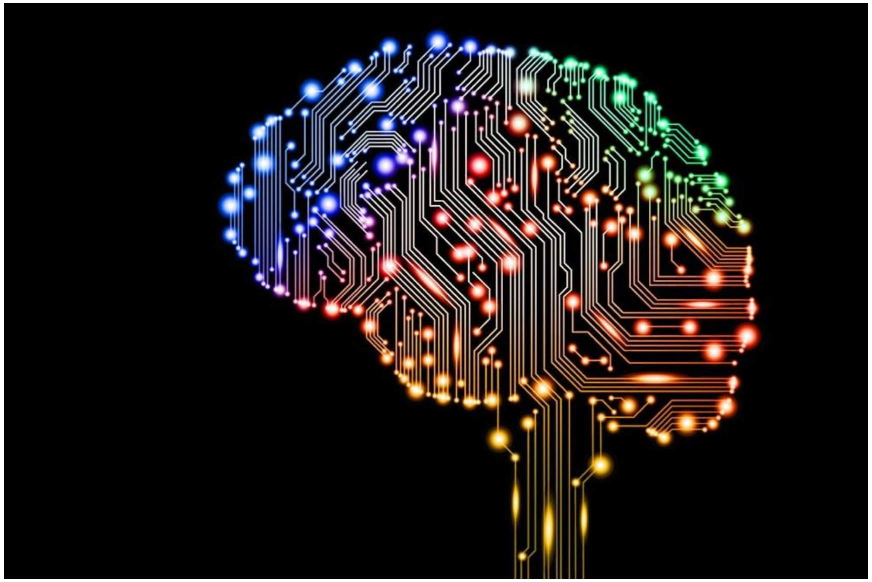
- Introduction & Motivation
- Human Brain Project
- Basics and Background
- Simulators
- Conclusion



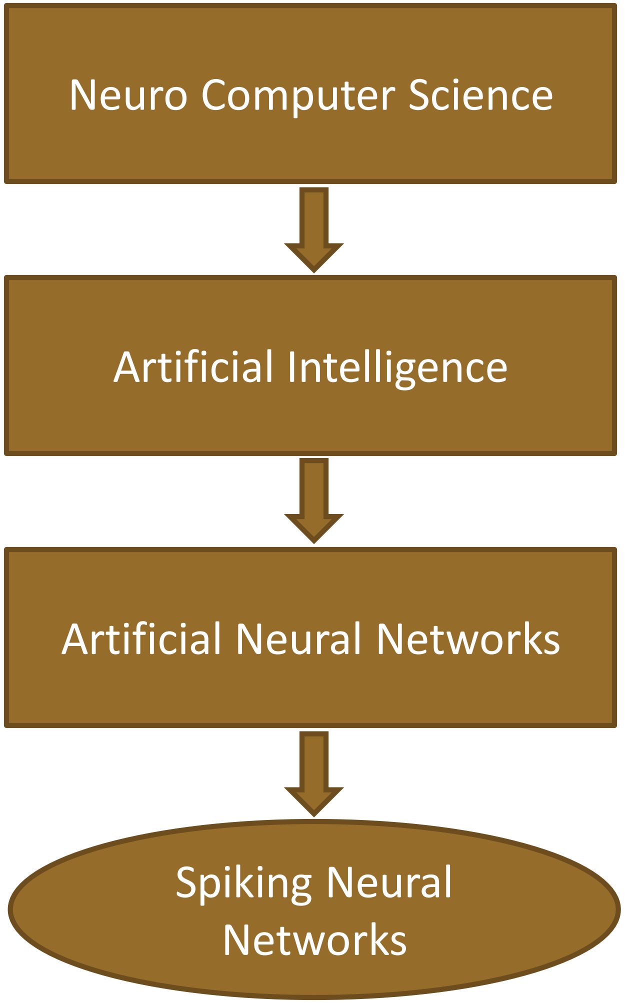
http://www.digitaltrends.com/computing/google-deepmind-artificial-intelligence/

Spiking Neural Networks

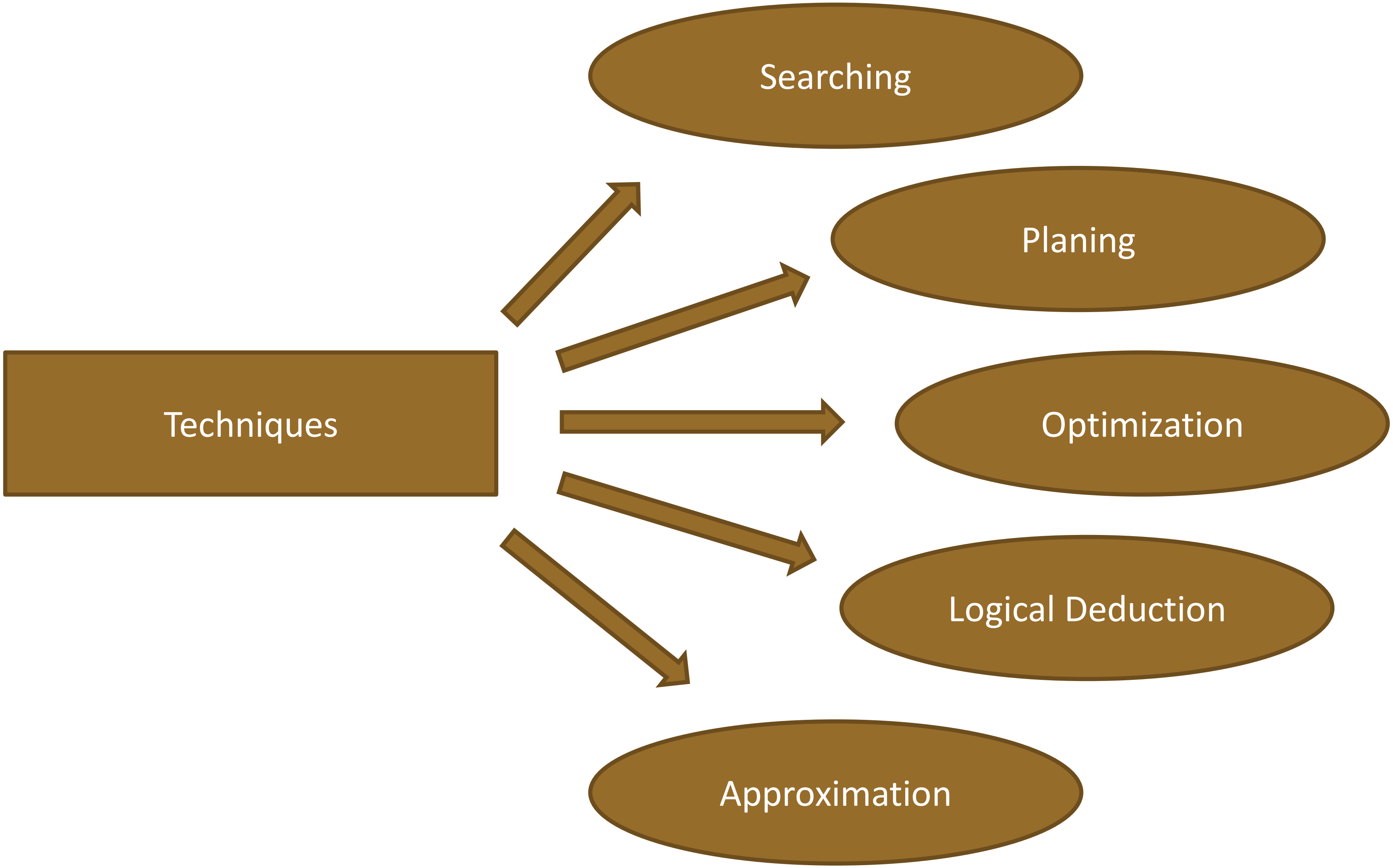
# Introduction & Motivation

# Introduction

- Artificial Intelligence (AI) is a research area from the neuro-informatics
- A interdisciplinary field, in which a number of sciences and professions converge
- Artificial Neural Networks (ANNs) are sub-area of AI, inspired by the neuro sciences



# Introduction

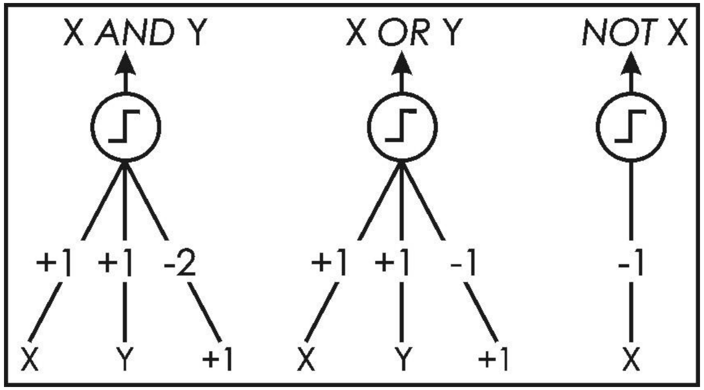


# Introduction

- Searching
  - Search for a specified solution of a given problem
- Planing
  - Plan and develop action sequences out of a problem decription which can be executed by agents a achieve a goal
- Optimization
  - Tasks often brings out optimization problems, which are attemped to solve by mathimatical programming
- Logical Deduction
  - Creating knowledge presentations for automized logic deduction (evidence systems or logical programming)
- Approximation
  - Deduce general rules from a given data size

# Introduction

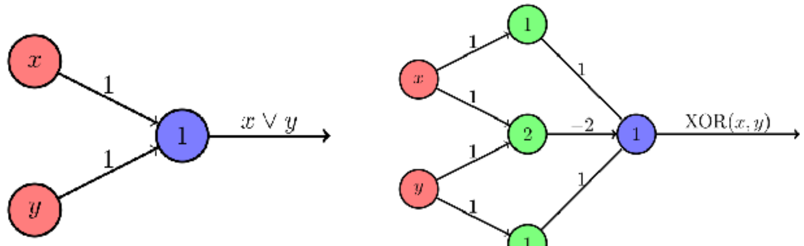
- First Generation
  - Introduced by Warren McCulloch and Walter Pitts in 1943
  - Logical and arithmetical function
  - Activation function was a Step-Function
  - Simple logic functions (a and b / a or b)
  - Generate binary values




http://www.webpages.ttu.edu/dleverin/neural_network/neural_networks.html

# Introduction

- **Second Generation**
  - Perceptron-Model introduced by Frank Rosenblatt in 1958
  - Activation functions are typically sigmoid or hyperbolic
  - Including new topologies
    - Further layer
    - More complex structures

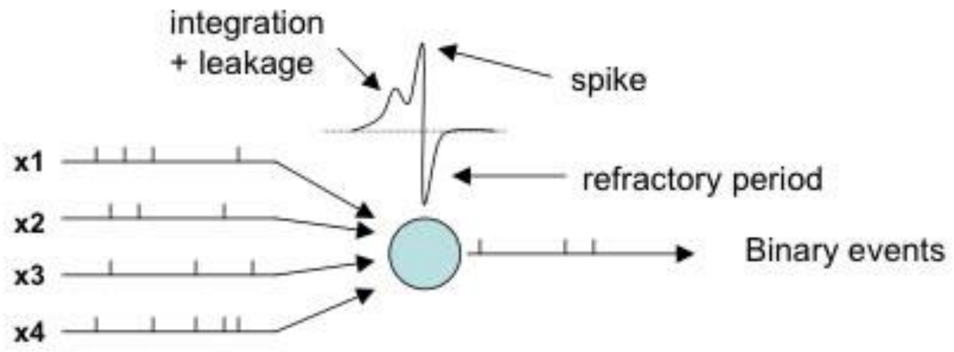



Single layer perceptron Multi layer perceptron

http://de.wikipedia.org/wiki/Perzeptron

## ▪ Third Generation

- Modulation of spike frequencies and timings
- Increasing amount of information transmitted per time unit
- Considering neurons as independent nodes instead as logic gates
  - Not firing at each propagation cycle
  - Synchronous or asynchronous information processing




http://lis2.epfl.ch/CompletedResearchProjects/EvolutionOfAdaptiveSpikingCircuits/

# Motivation

- Develop more realistic neural networks
  - Test and prove hypothesis of biological neural circuits
- Better learn behaviour
  - SNNs are high potential models for problems without or little explicit knowledge
  - A virtual insect seeking food without the prior knowledge of the environment

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# Human Brain Project

# Human Brain Project

- EU Flagship Initiative with nearly 500 researchers of 80 institutes from 20 countries. Dimensioned for 10 years with nearly 1.20 billion euros project budget.
- A collaboration to realise a new ICT-accelerated vision for brain research and its applications.
- A approach of a concerted international effort to integrate this data in a unified picture of the brain as a single multi-level system.

Human Brain Project

https://www.humanbrainproject.eu/de

# Human Brain Project

- Research Areas
  - Neuroscience
    - Achieve a unified, multi-level understanding of the human brain
    - Knowledge about healthy and diseased brain from genes to behaviour
  - Computing
    - Develop novel neuromorphic and –robotic technologies
    - Develop brain simulation, robot and autonomous systems control
  - Medicine
    - Develop biologically grounded map of neurological and psychiatric diseases based on clinical data
    - Understand the causes of brain diseases and develop new treatment

# Human Brain Project

- Vision and Expectations
  - The goal of the Human Brain Project is to translate these prospects into reality, catalysing a global collaborative effort to integrate neuroscience data from around the world, to understand the human brain and ist diseases, and ultimately to emulate its computational capabilities.

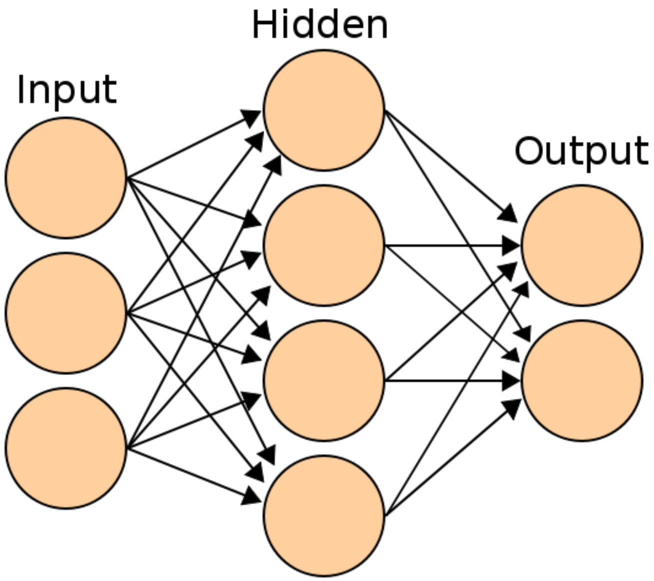

https://www.humanbrainproject.eu/de

Spiking Neural Networks

# Basics and Background

# Basics and Background

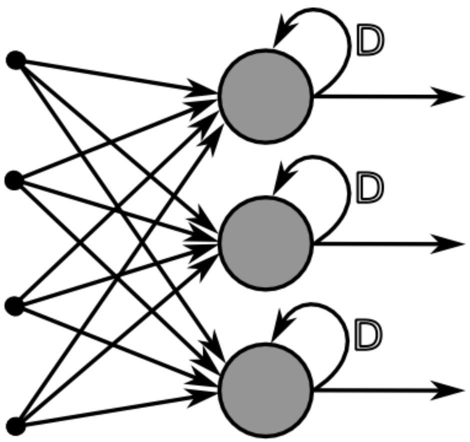
- Artificial Neural Networks
  - A model and abstraction of information processing
    - Not a replication of biological neural networks
  - Consists of neurons connected among themselves by synapses
  - Partitioned in three layers
    - Input, hidden and output layers
  - Different topologies



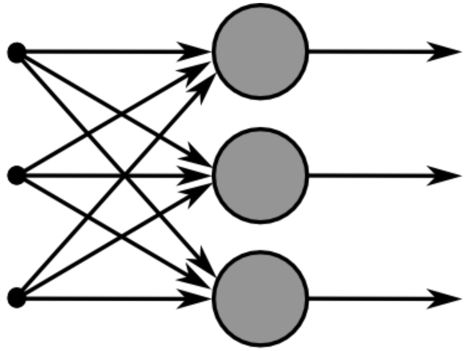

http://en.wikipedia.org/wiki/User:Mariam_Hovhannisyan

# Basics and Background

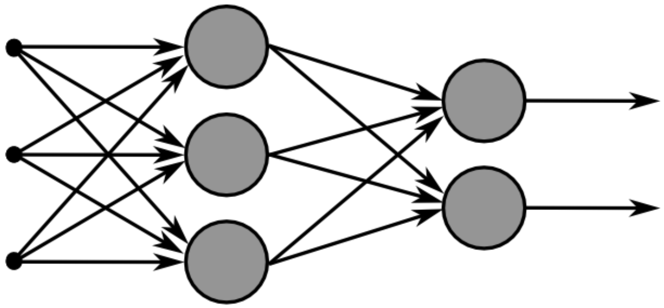
- Topologies




Recurrent Layer



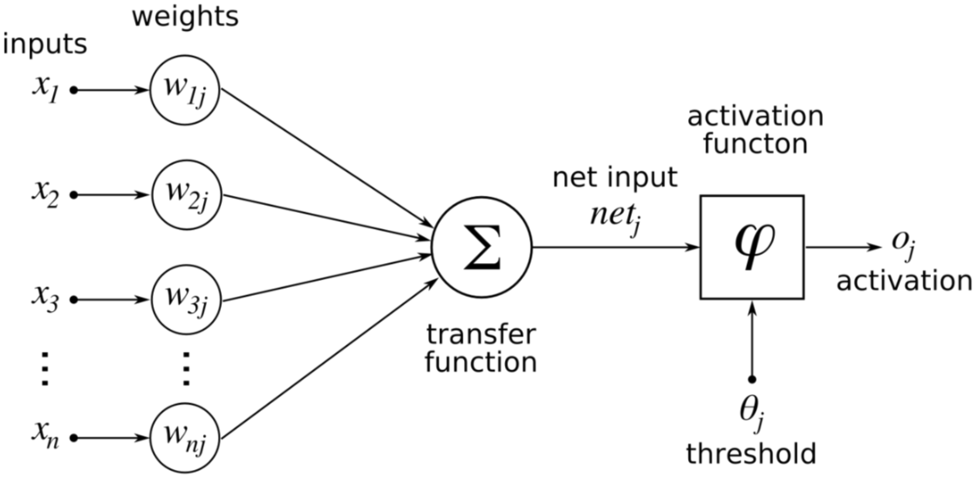
Single Layer



Multi Layer

http://de.wikipedia.org/wiki/K%C3%BCnstliches_neuronales_Netz

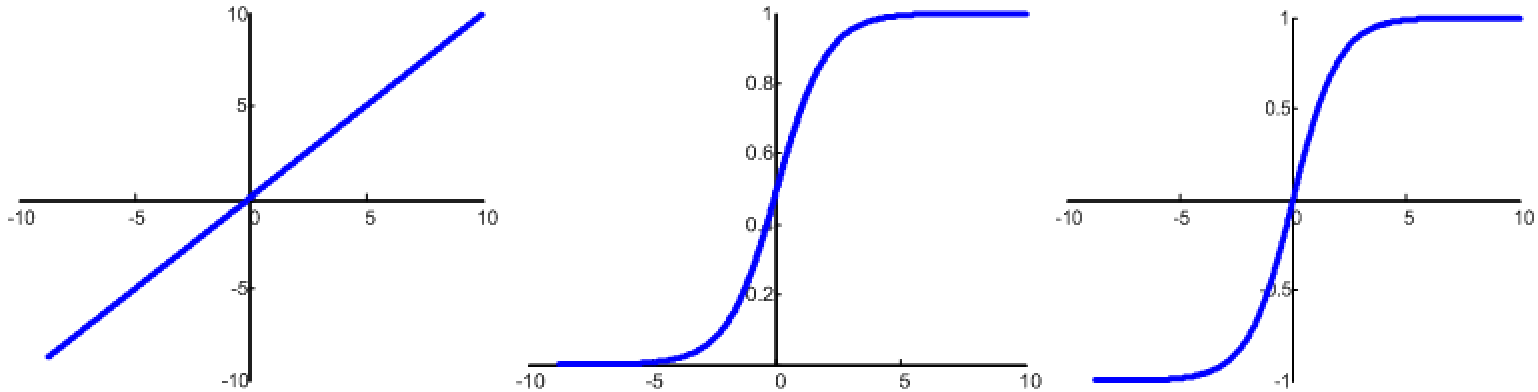
- Artificial Neurons
  - One or more Inputs
    - Each input can carry a different value
  - One or more Outputs
    - Each output carry the same value
  - Activation function with a threshold




http://de.wikipedia.org/wiki/K%C3%BCnstliches_neuronales_Netz

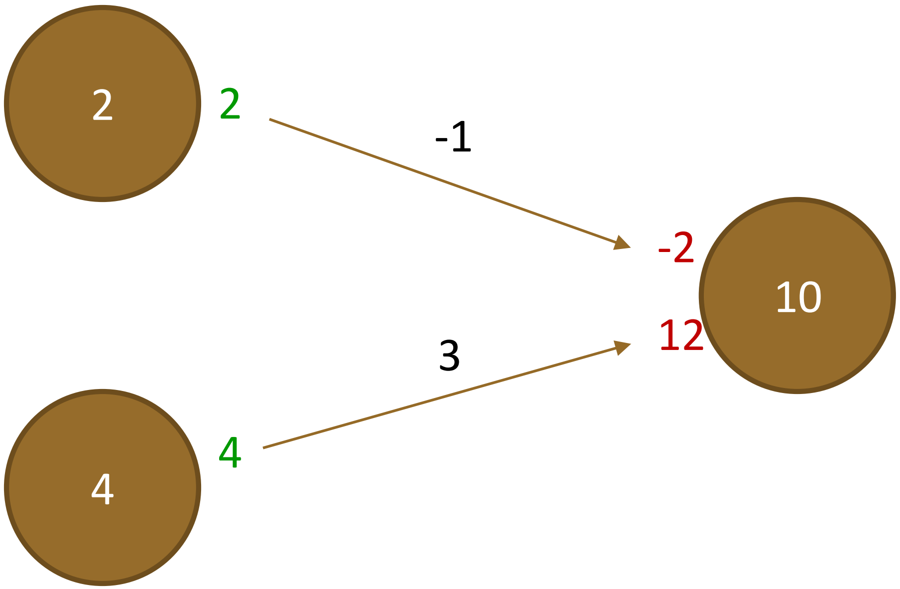
# Activation functions

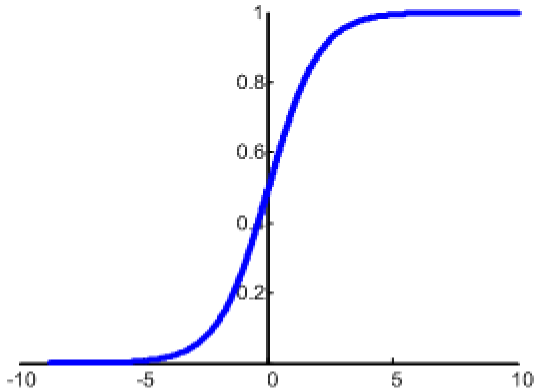
- Activation functions
  - This function gives the signals passing through the neuron a *weight* and decide if a signal can *pass or not*.



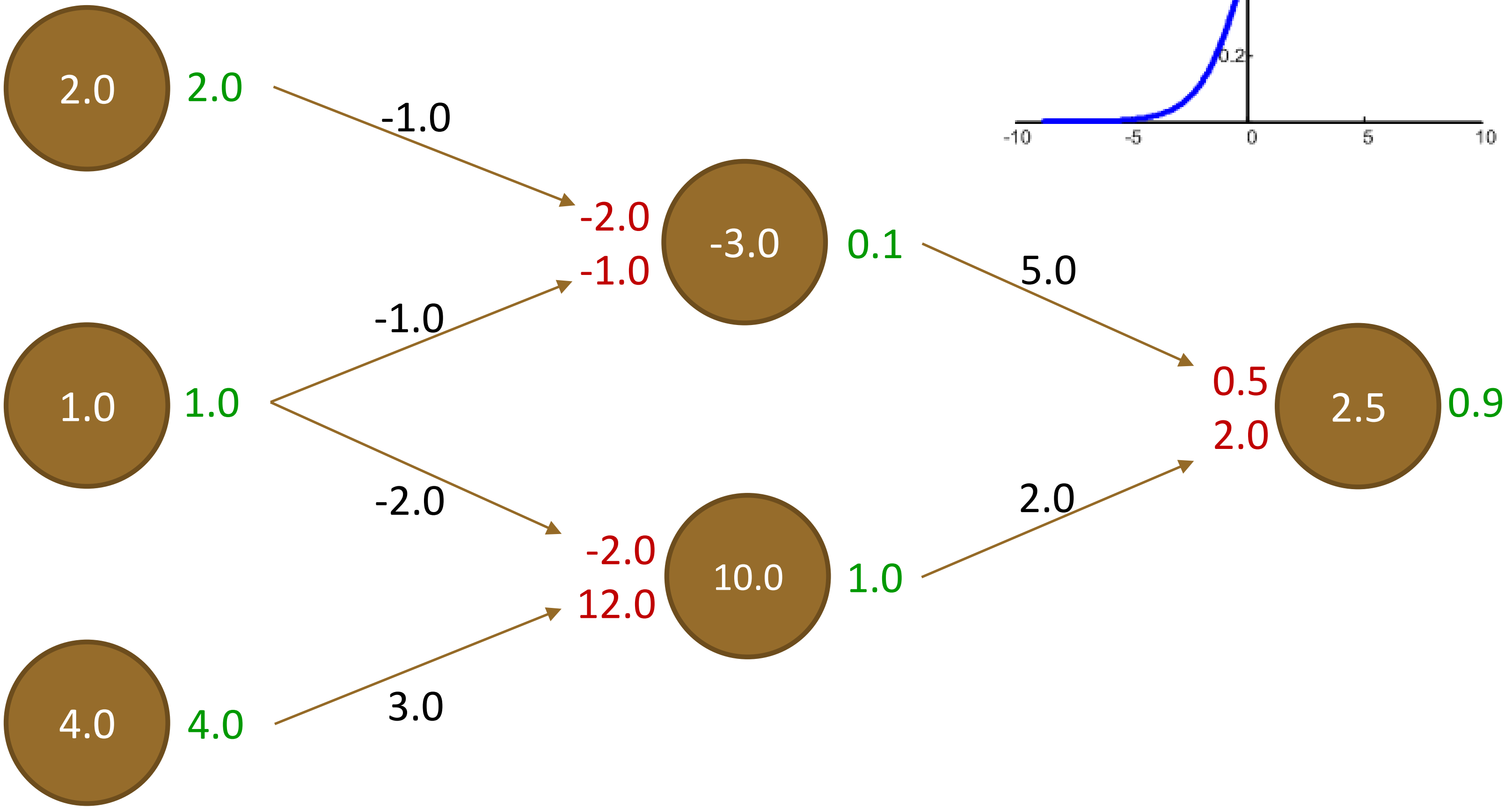

http://imgarcade.com/1/sigmoid-activation-function/

- Synapses
  - Connections between neurons, transmitting the information
  - Synapses have weights, which get multiplied with the signal passing through






- Example of signal passing



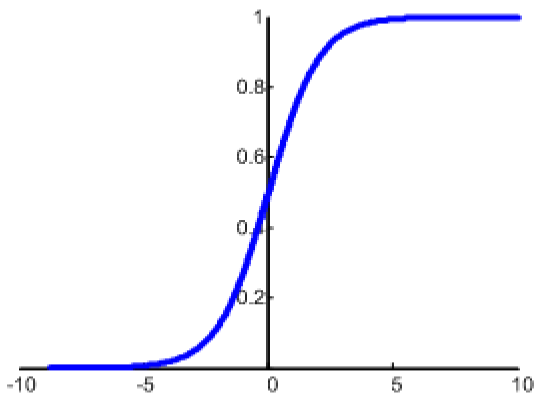
# Basics and Background

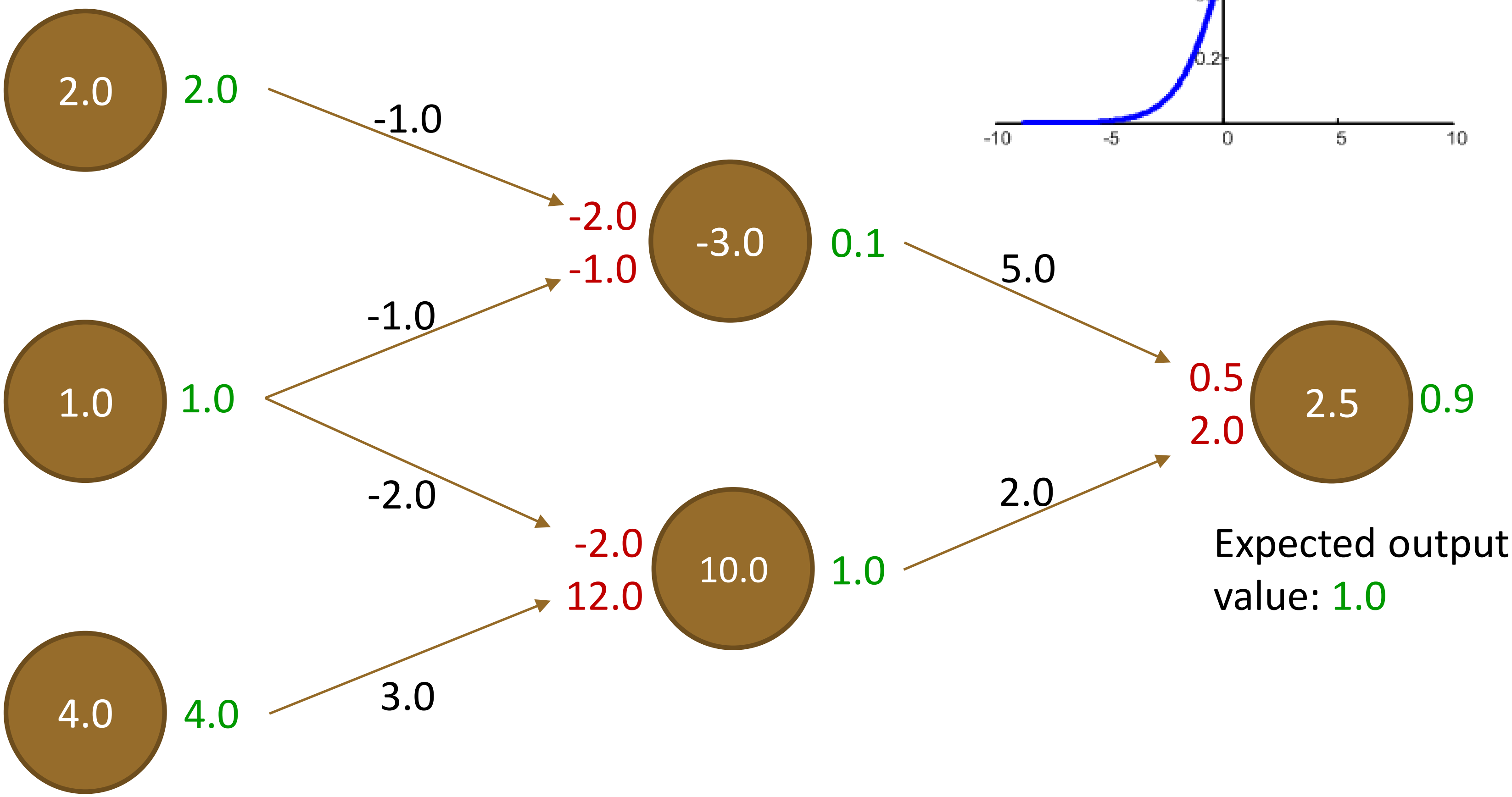
- Learn methods
  - Supervised
    - A set of example pairs are given and the aim is to find a correct function
  - Unsupervised
    - Some data is given and the cost function to be minimized
    - Try to create a solution without knowing the goal values
  - Reinforcement
    - Data are usually not given, but generated by an agent's interaction with the environment

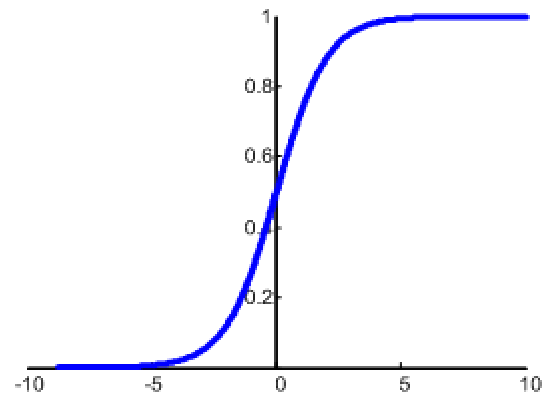
# Basics and Background

- Learning Behavior
  - Learning with neuron and synapses plasticity
    - Develop new connections
    - Delete existing connections
    - Modify weights of connections
    - Modify threshold values of neurons
    - Modify activation functions
    - Initiate new neurons
    - Eliminate existing neurons

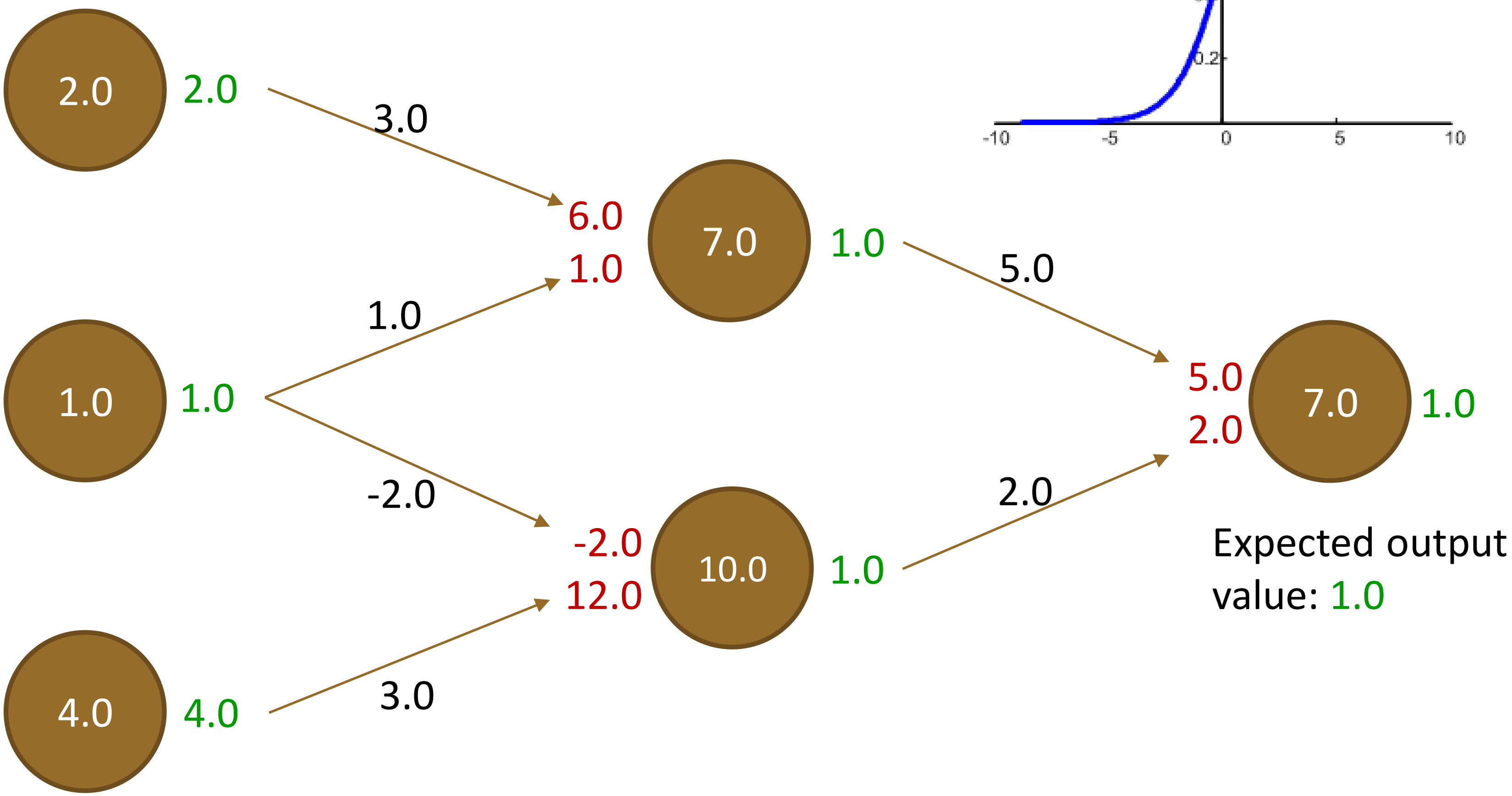
- Example for learning behavior



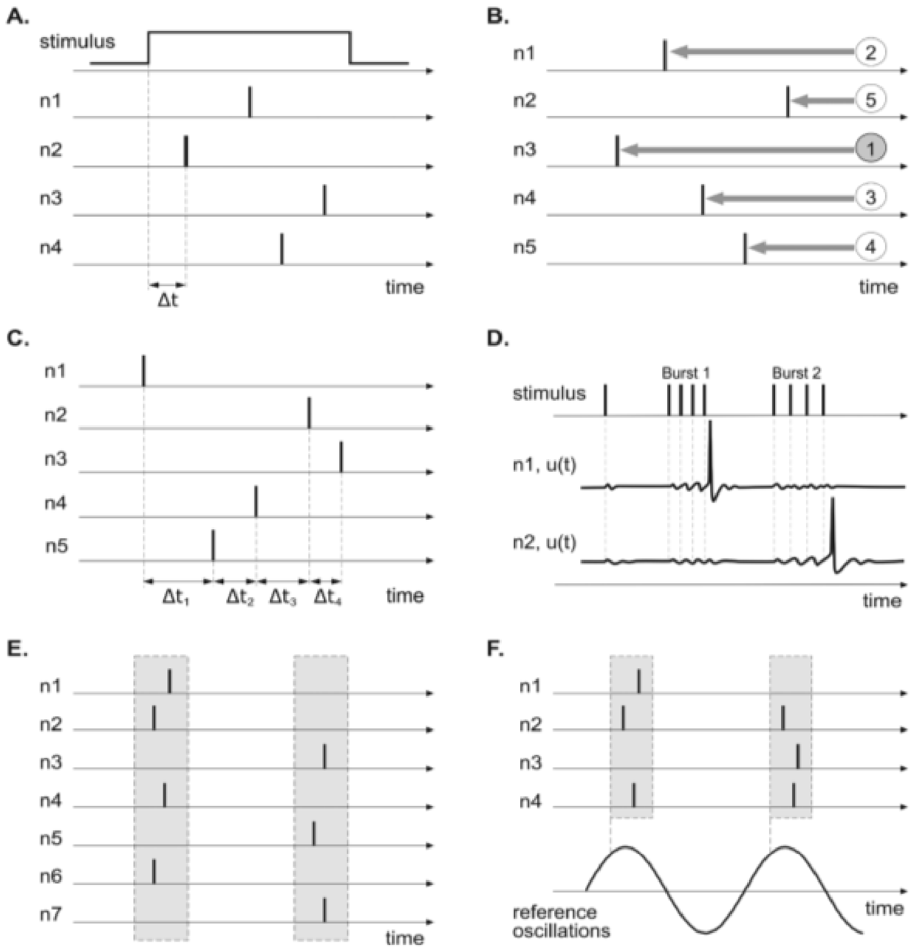






- Example for learning behavior

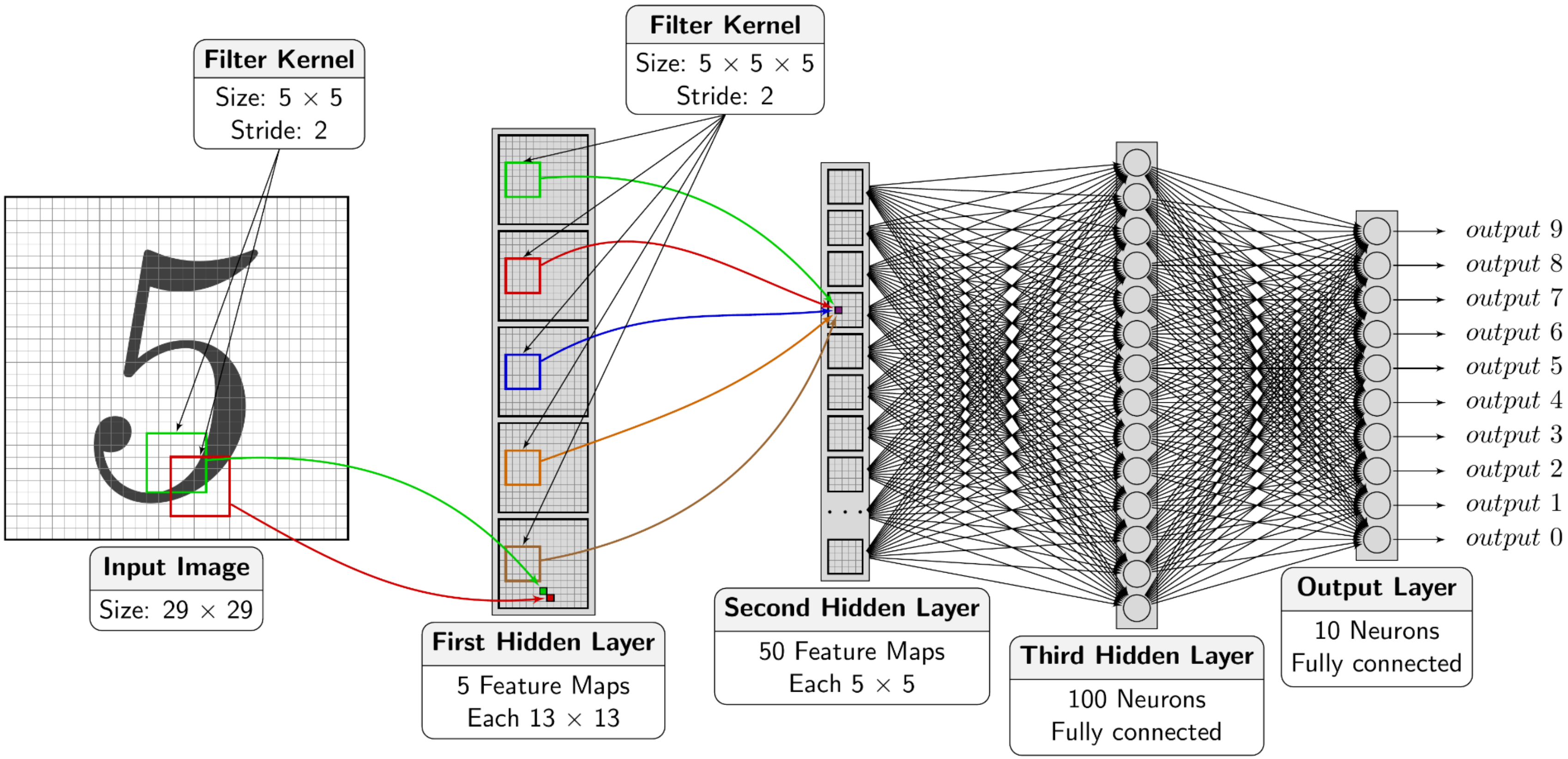


- Spiking Neural Networks
  - Increasing the information density due to spike modulation
  - Several different modulations for various brain areas




introduction to spiking neural networks: information processing, learning and applications (Filip Ponulak, Andrzej Kansinski)

# Basics and Background

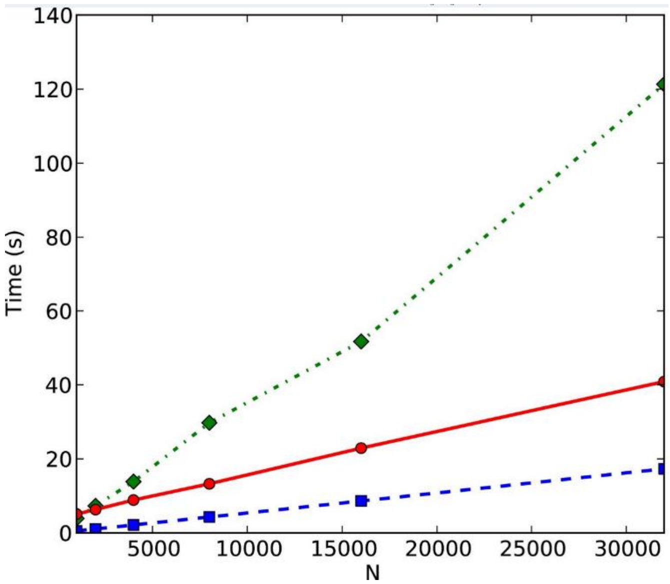



Deep Machine Learning on GPUs, Daniel Schlegel, Advanced Seminar

Spiking Neural Networks

# Simulators

- Brian Simulator
  - High flexible simulator for rapidly developing new models
  - Written in the programming language Python
    - Easy and intuitive syntax, attractive for teaching computational neuroscience
    - Especially valuable for working on non-standard neuron models
    - Disadvantage in performance due to interpreter language




CUBA network, using fixed 80 synapses per neuron, varying the number of neurons N

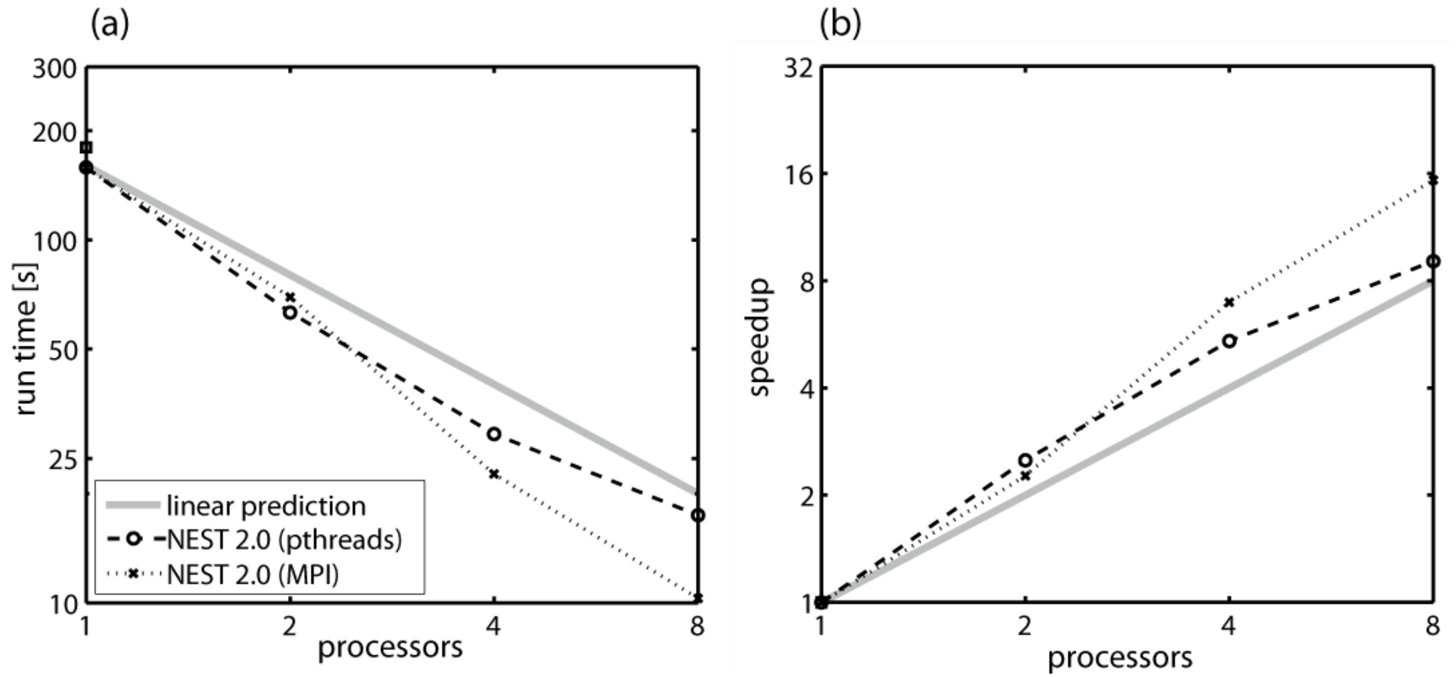
Goodman D and Brette R (2008) Brian: a simulator for spiking neural networks in Python. *Front. Neuroinform.* doi:10.3389/neuro.11.005.2008

# Simulators

- Neural Simulation Tool – NEST
  - Build to simulate large networks
  - Written object-oriented in C++
  - Consists of three main components
    - Nodes: neurons, devices are handled as nodes
    - Events: Spike-, Voltage- and Current-Events
    - Connections: Channels which exchange events

# Simulators

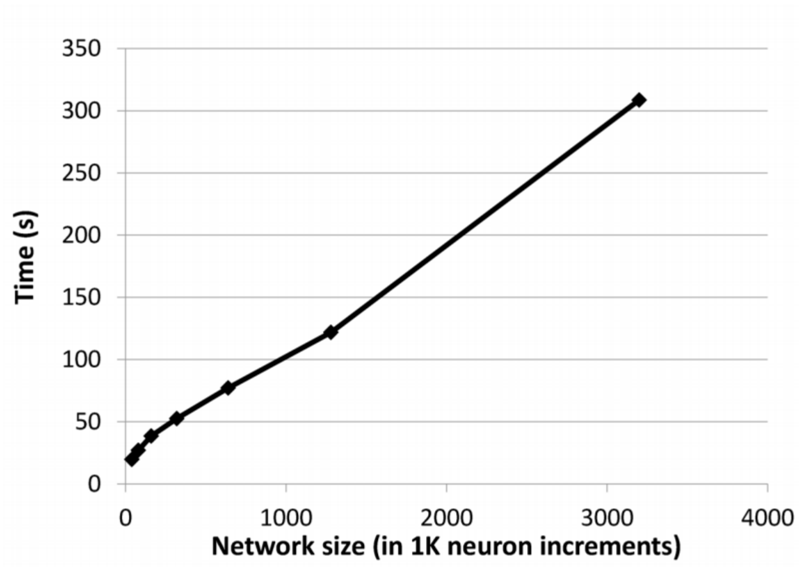
- Run-time of NEST for a large network



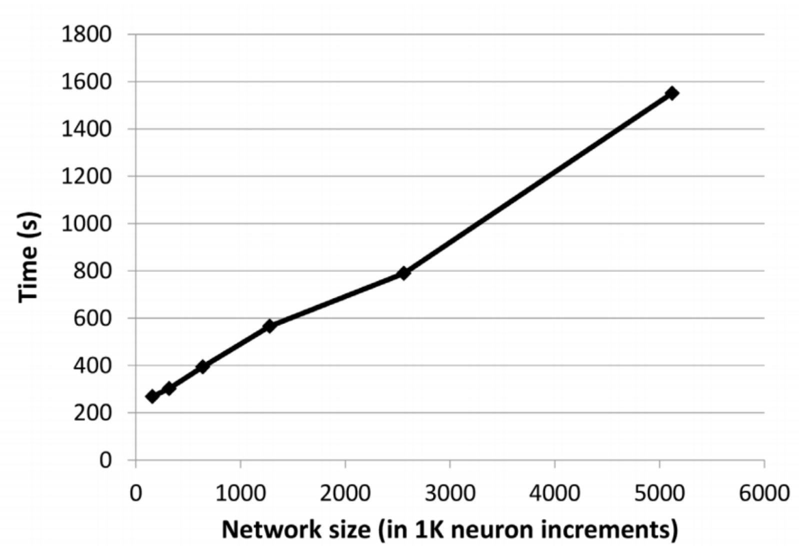

Network of **12500 neurons** (80% excitatory / 20% inhibitory)
Each neuron receiving **1250 inputs**
Total number of synapses **15.6 millions**

NEST by example: an introduction to the neural simulation tool NEST
(Marc-Oliver Gewaltig and Abigail Morrison and Hans Ekkehard Plesser)

- Comparison between CPU and GPU cluster




GPU: NVIDIA Tesla C1060 cluster of 64 nodes
Infiniband communication backend




CPU: Cluster of 128 nodes, Intel XEON E5520 2.27GHz
Infiniband communication backend
Master with 48 GB and Slaves with 12 GB memory

Kirill Minkovich, Corey M. Thibeault, 2014: HRLSim A High Performance Spiking Neural Network Simulator for GPGPU Clusters

Spiking Neural Networks

# Conclusion

# Conclusion

- Spiking Neural Networks are a high potential model for *realistic neural network behavior*.
- Modelling *higher intelligence* due to more complex neural networks with high performance computer systems like *Cluster* or *GPU computing*.
- A neural network model with a *short life* due to rapidly advances in neurosciences.
  - Assuredly there will be further generations of neural networks!

Questions?

# Spiking Neural Networks