Computational Neuroscience
&
Machine Learning

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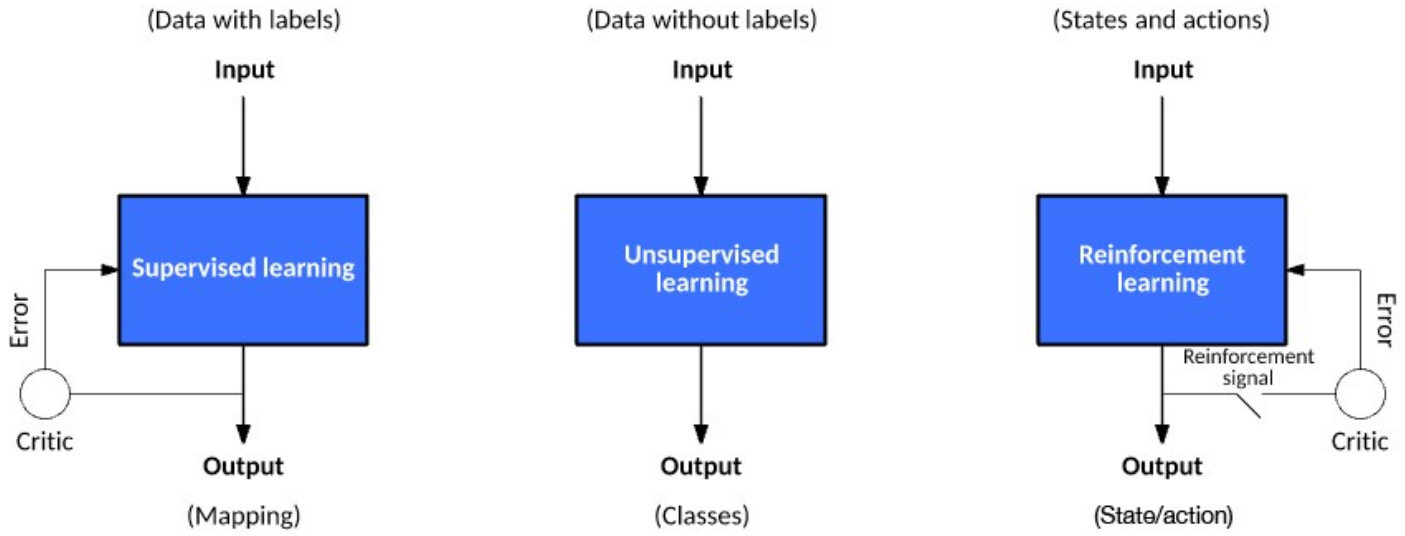
Machine Learning Definition

Machine learning is an application of artificial intelligence (AI) that provides systems (i.e. models) the ability to automatically learn and improve from experience without being explicitly programmed.



Is Computational Neuroscience a branch of Machine Learning or vice versa?

Answer!!

Computational neuroscience is the field of study in which:

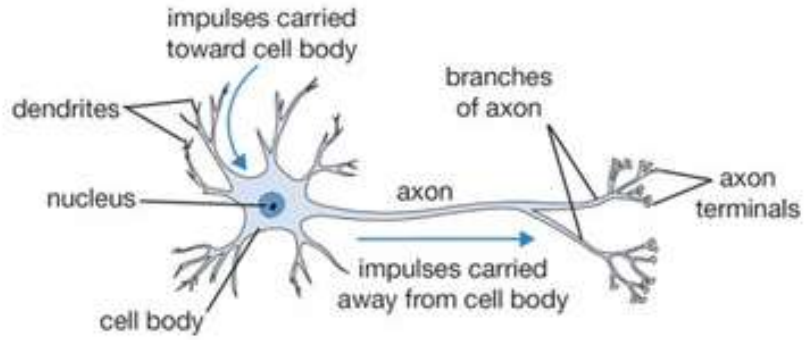
- **Mathematical tools and theories** are used to **investigate brain function**
- It can also incorporate diverse approaches from electrical engineering, **computer science** and physics in order to understand **how the nervous system processes information**

https://www.nature.com/subjects/computational-neuroscience

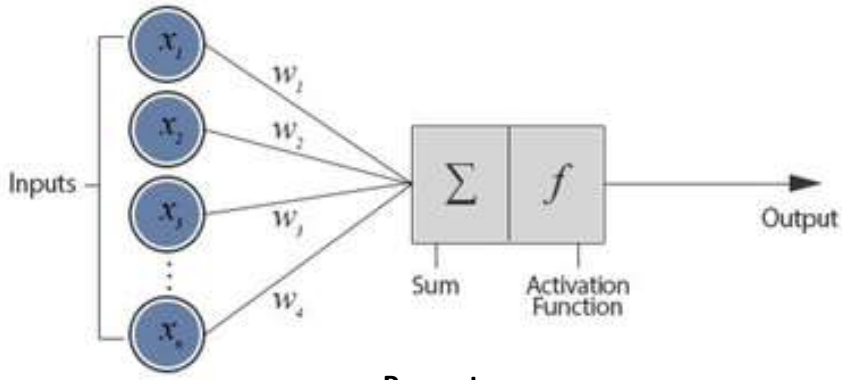
How Computational Neuroscience (i.e. neuroscience) contributes to Machine Learning?

Artificial Neural Networks (Perceptron)

$$output = f\left(\sum_{k=1}^{n} x_k \cdot w_k\right)$$



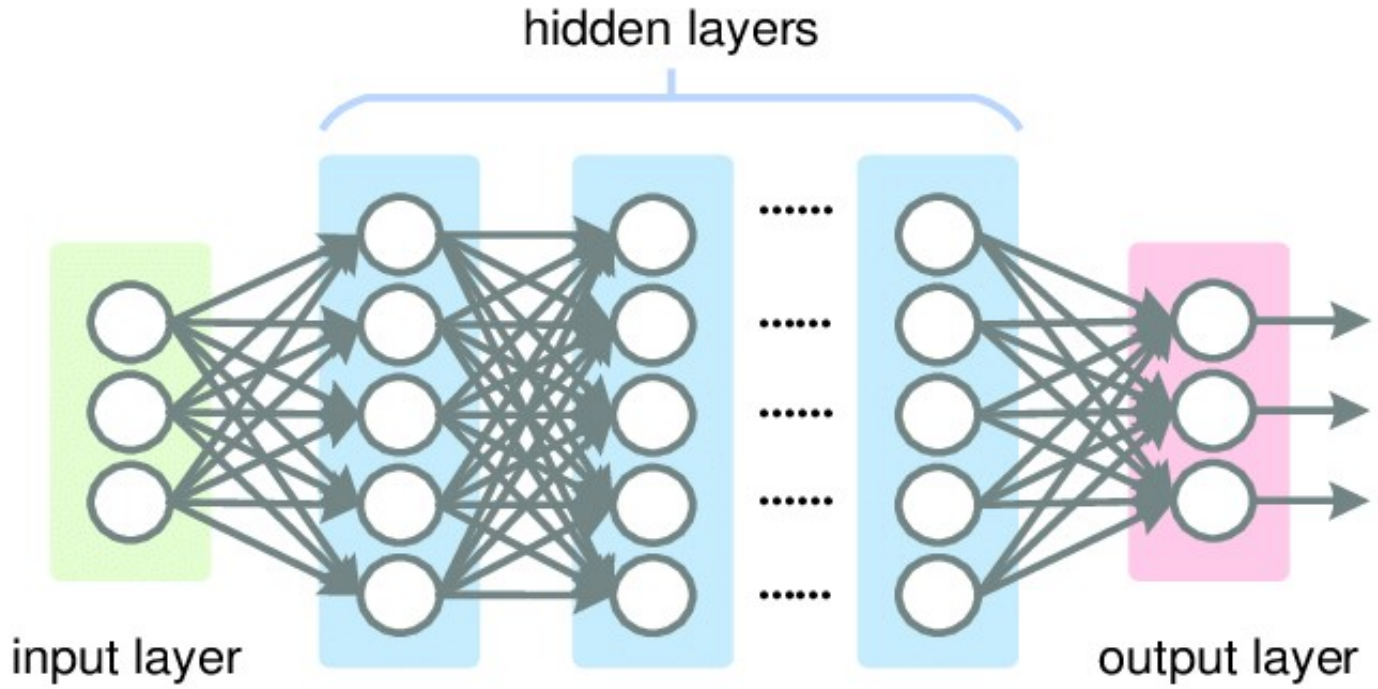
Real Neuron Structure



Perceptron

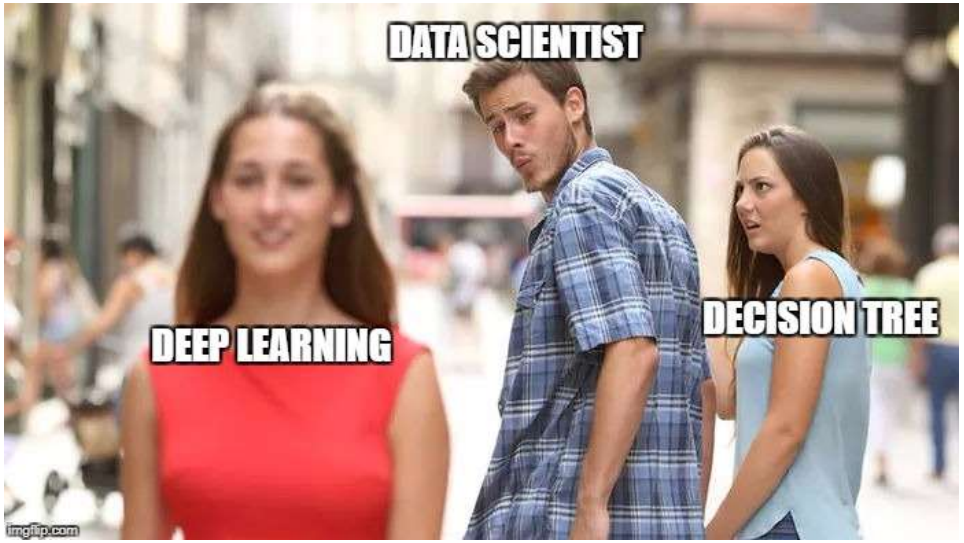
THE PERCEPTRON: A PROBABILISTIC MODEL FOR INFORMATION STORAGE AND ORGANIZATION IN THE BRAIN (Rosenblatt 1958)

Artificial Neural Networks (Multi perceptron)



Learning representations by back-propagating errors (Rumelhart et al., 1986)

Artificial Neural Networks (Deep Learning)



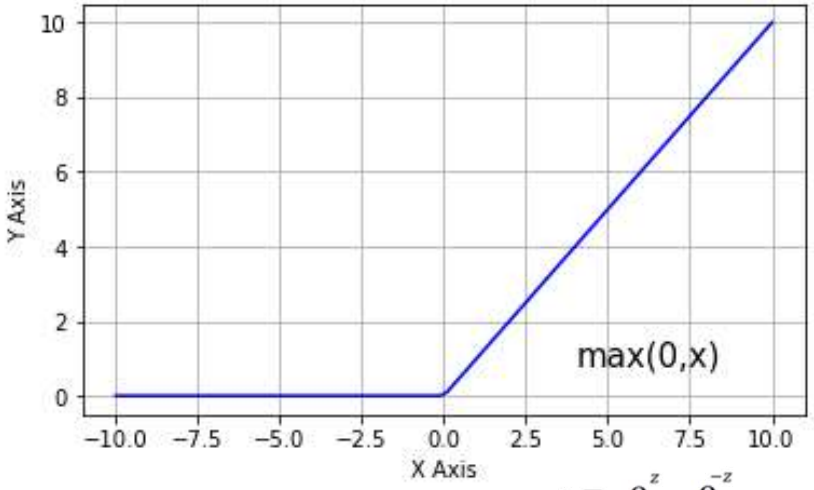
Artificial Neural Networks (Development of RELU function)

RELU Function

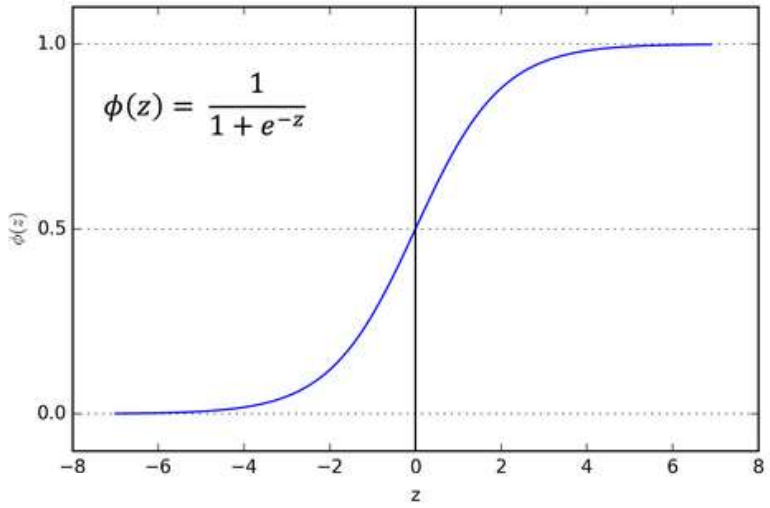
Sigmoid Function

Tanh Function

Artificial Neural Networks (Development of RELU function)

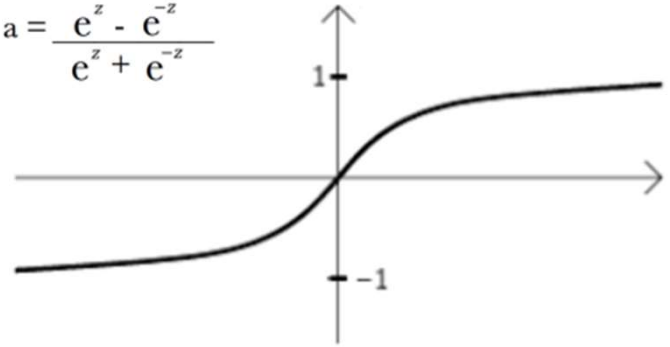


RELU Function



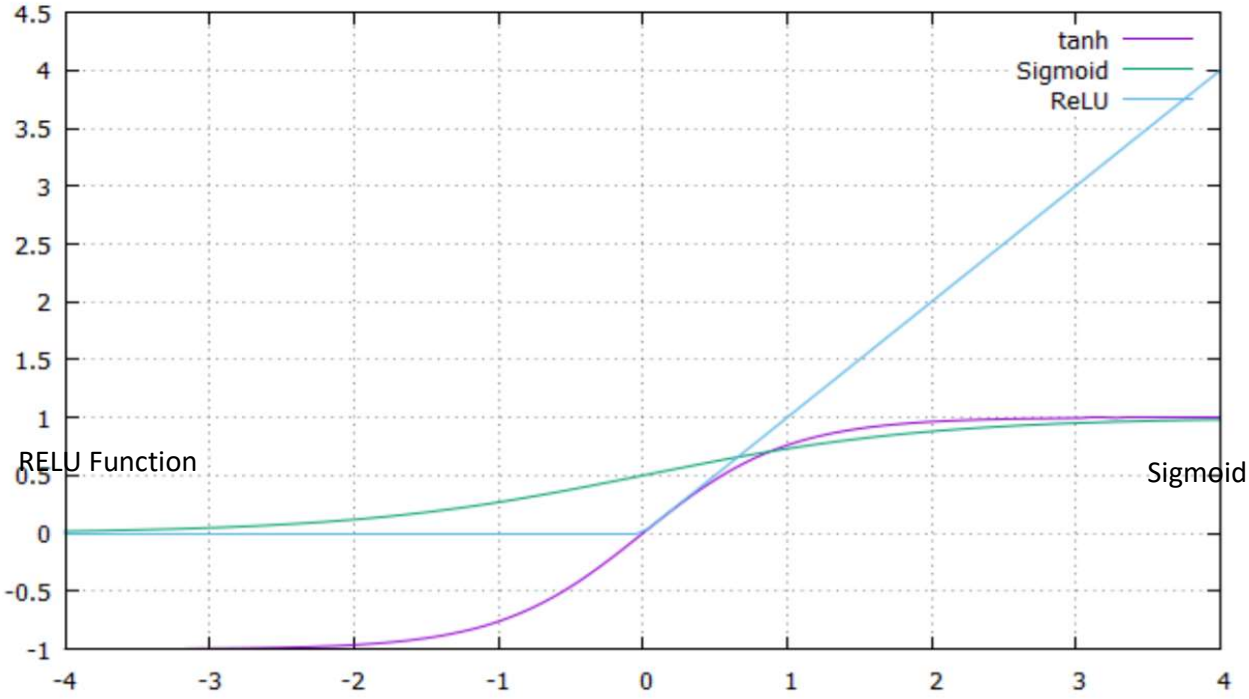
Sigmoid Function

$$a = \frac{e^{z} - e^{-z}}{e^{z} + e^{-z}}$$



Tanh Function

Artificial Neural Networks (Development of RELU function)

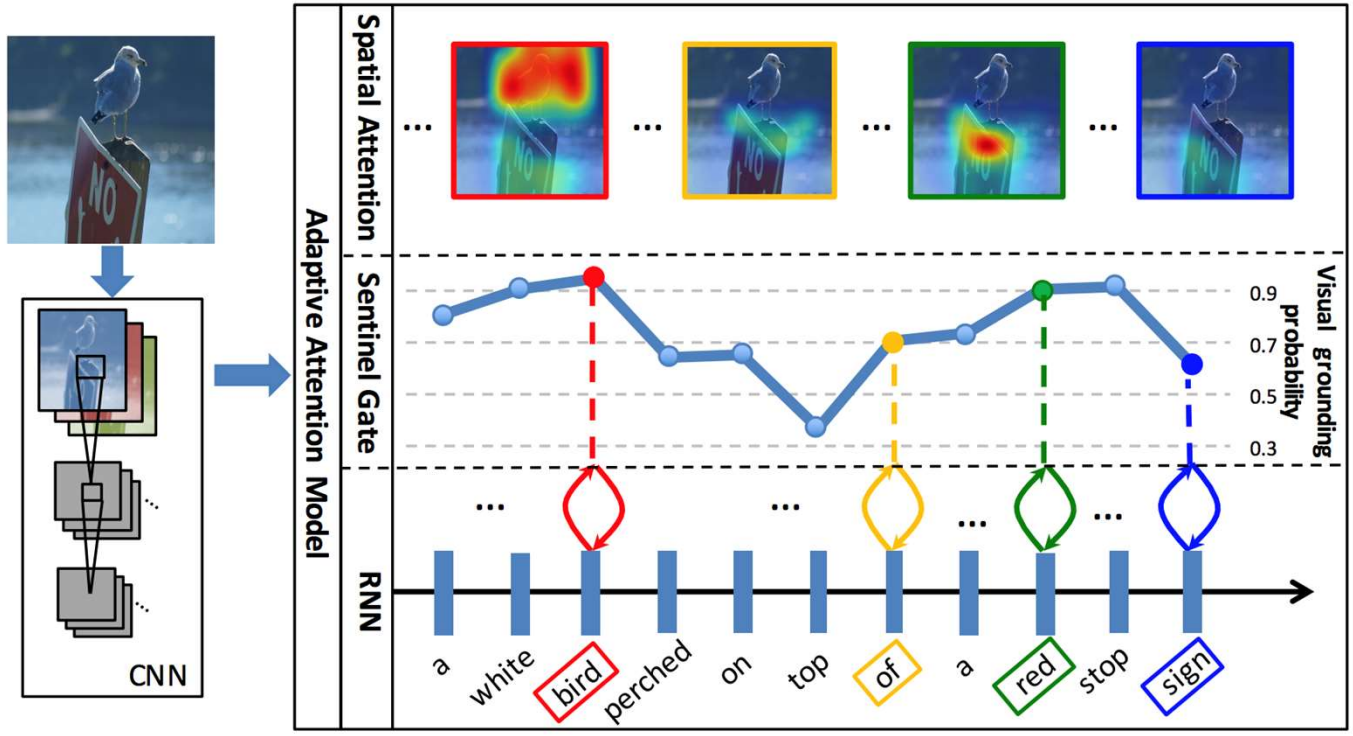


RELU Function

Sigmoid Function

Tanh Function

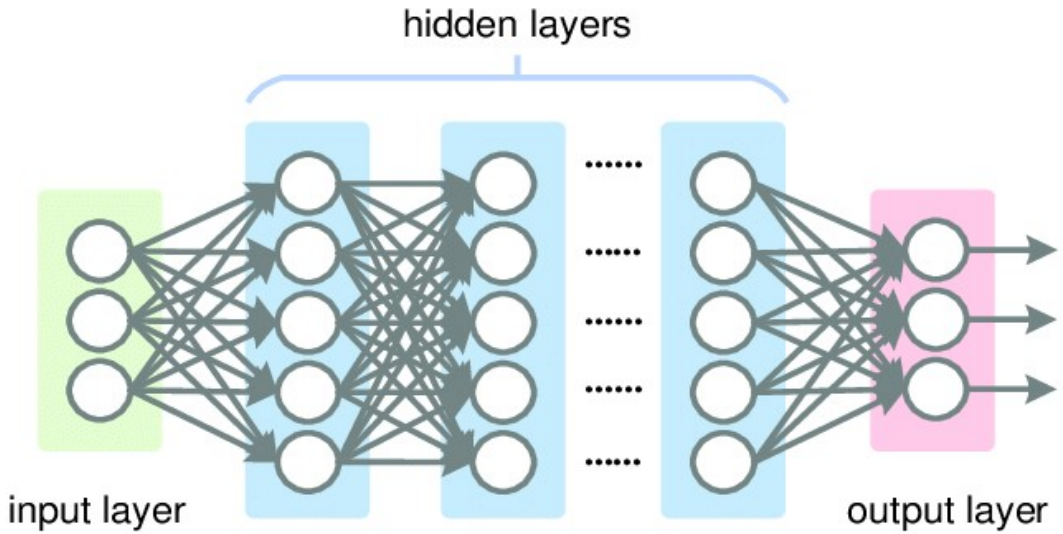
Artificial Neural Networks (Attention Mechanism)

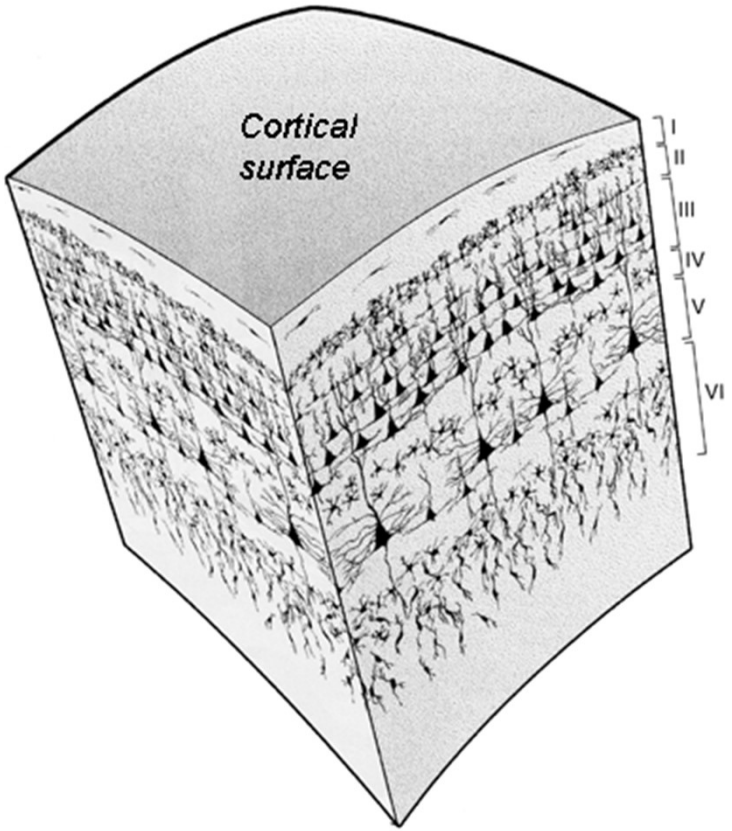


Orienting attention based on long-term memory experience (Summerfield et al., 2006)

Comparison of the real Brain and Deep Learning

- Number of layers

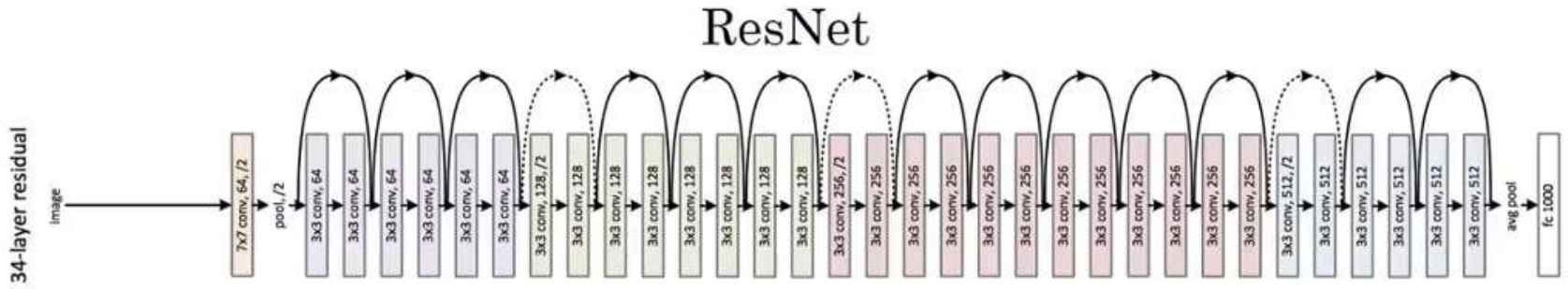




Deep Learning and Computational Neuroscience (Schutter, 2018)

Comparison of the real Brain and Deep Learning

- Number of layers
- Architectures (e.g. Residual Networks)



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Comparison of the real Brain and Deep Learning

- Number of layers
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Comparison of the real Brain and Deep Learning

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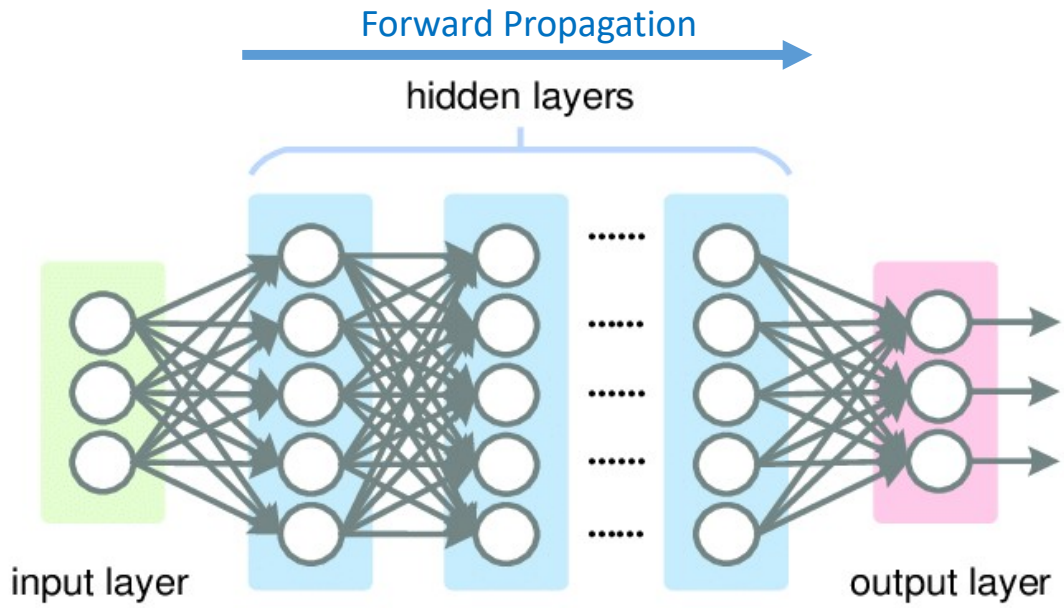
- Back-propagation



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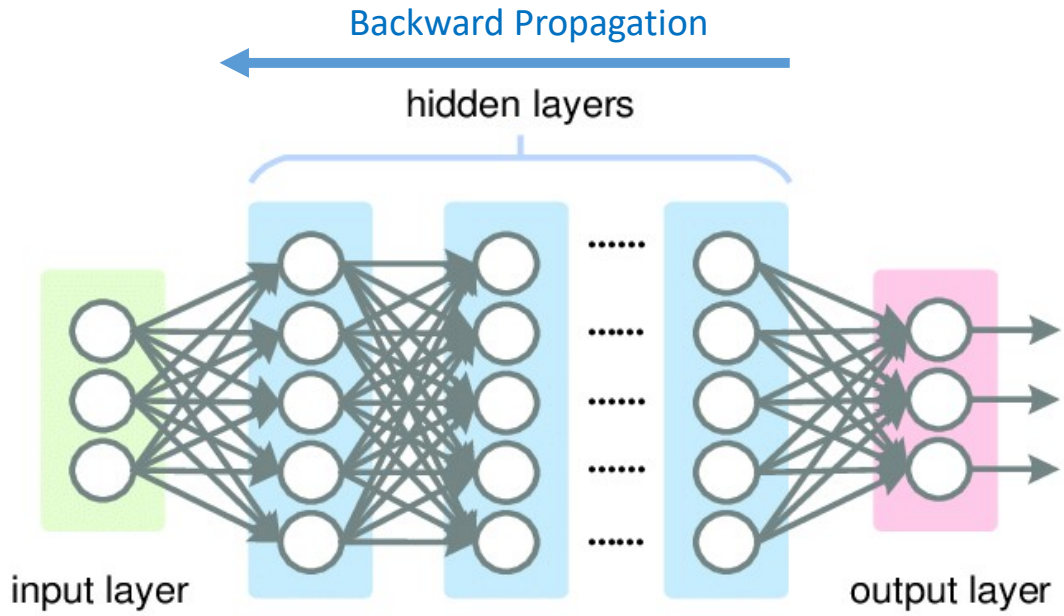
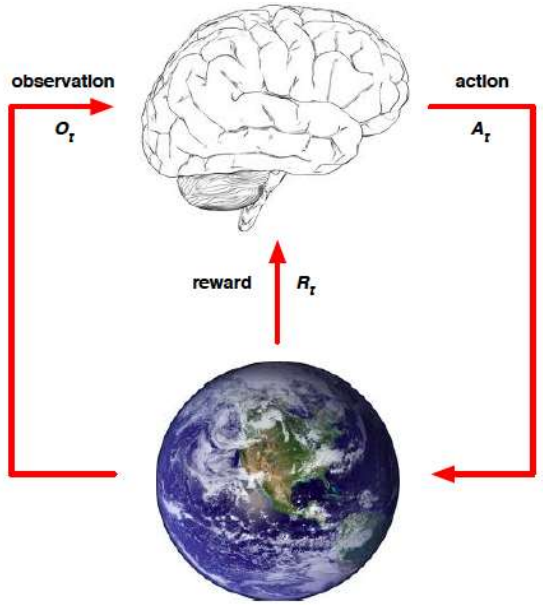


Deep Learning and Computational Neuroscience (Schutter, 2018)

Reinforcement Learning (Introduction)

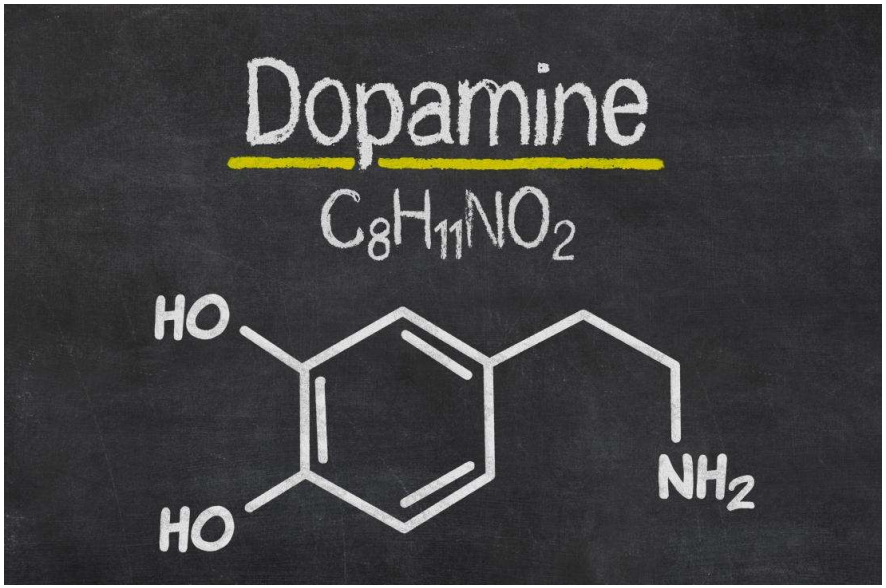
Reinforcement learning is learning what to do—how to map situations to actions—so as to maximize a numerical reward signal.



Reinforcement Learning: an Introduction (Sutton and Barto, 2018)

Reinforcement Learning (Dopamine)

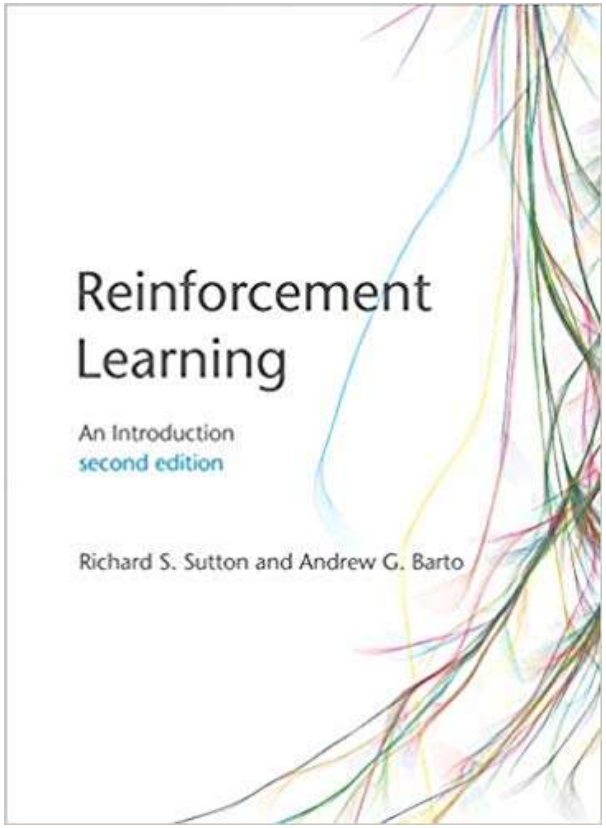
The theory that ***Dopamine = TD error*** is the most important interaction ever between AI and neuroscience.



$$V(s) \leftarrow V(s) + \alpha(\overbrace{r + \gamma V(s')}^{\text{The TD target}} - V(s))$$

Reinforcement Learning: an Introduction (Sutton and Barto, 2018)

Reinforcement Learning (Learning)

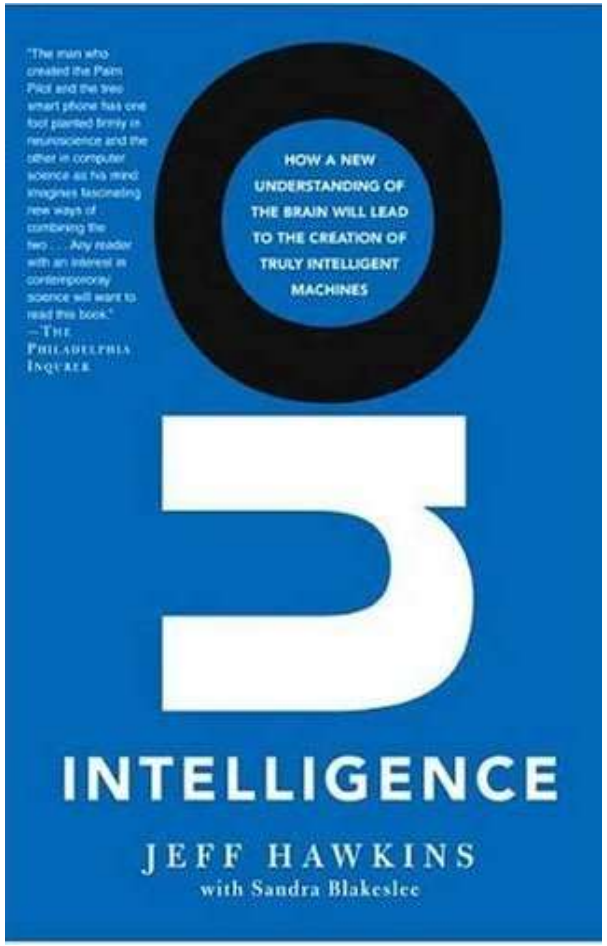


Reinforcement Learning: an Introduction (Sutton and Barto, 2018)

How brain actually works

Actual Reverse Engineering of the brain

Jeff Hawkins

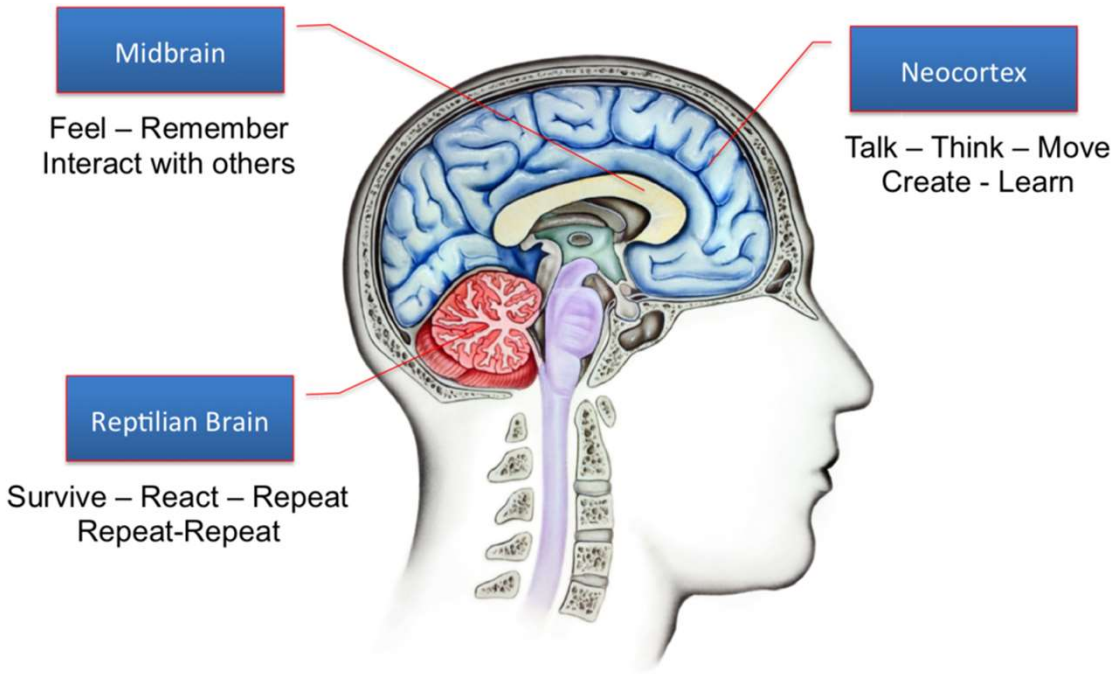


On intelligence (Hawkins, 2005)

How brain actually works (Neocortex)

Neocortex is the part of the mammalian brain involved in higher-order brain functions such as:

- Sensory perception
- Cognition
- Generation of motor commands
- Spatial reasoning
- Language



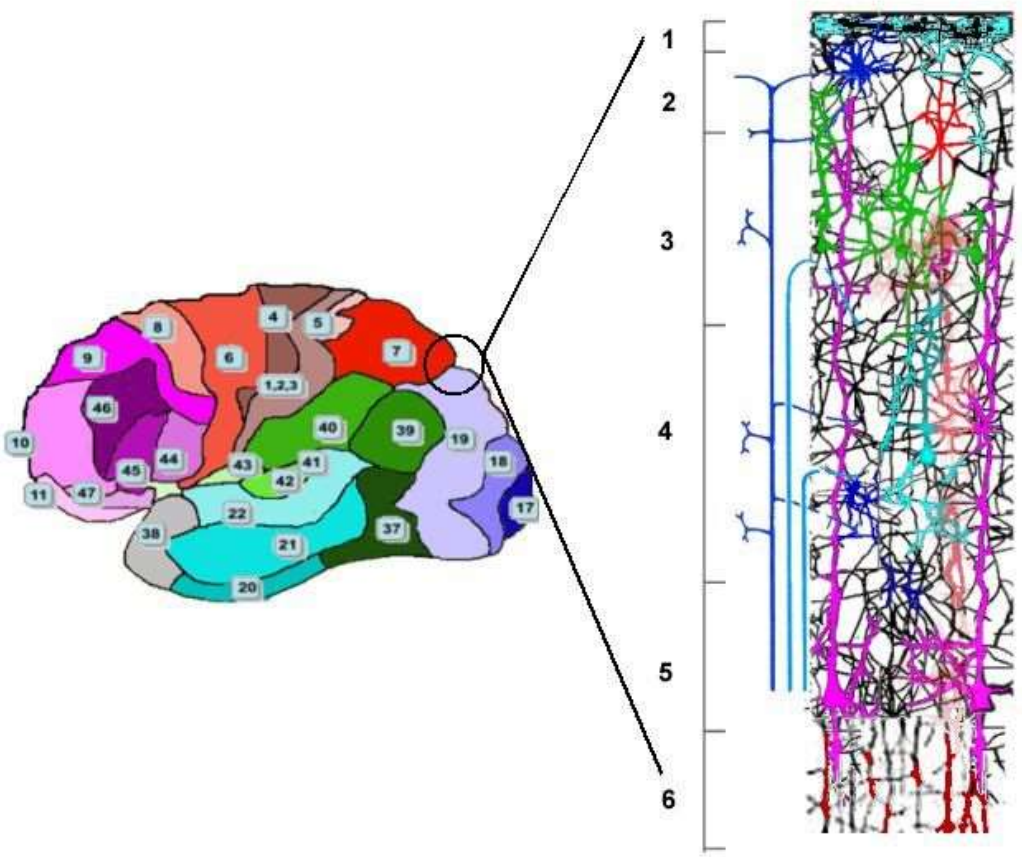
On intelligence (Hawkins, 2005)

How brain actually works (Cortical Column)

Cortical Column:

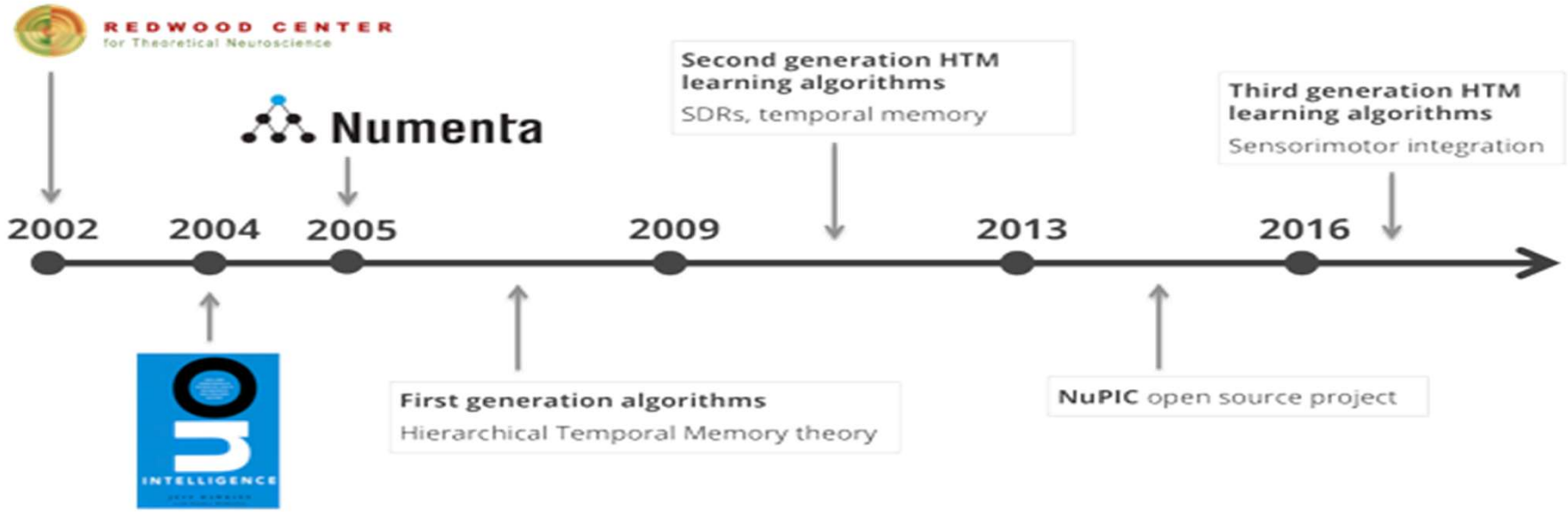
- An slice of neocortex
- Consisted of six layers (is it?)
- All of them have almost identical structure no matter what area of the neocortex

So, is the same algorithm running in the whole neocortex?



On intelligence (Hawkins, 2005)

How brain actually works (Numenta)



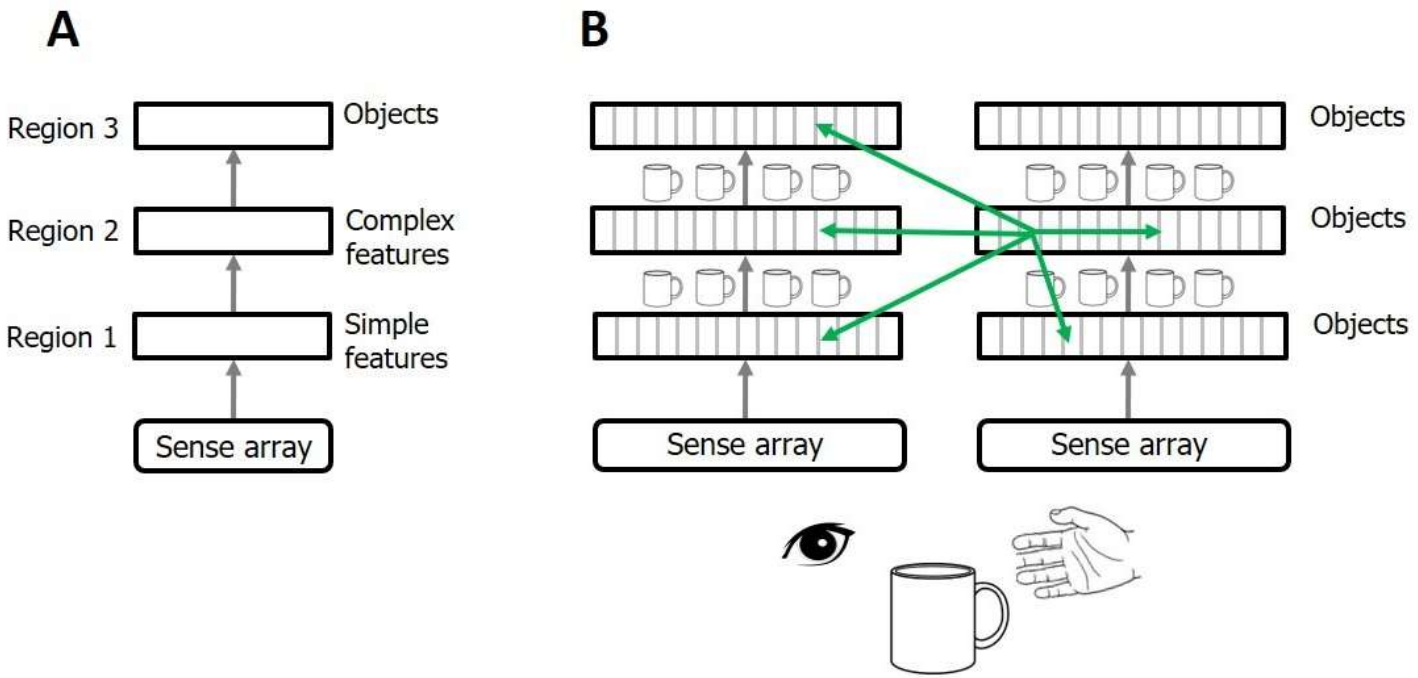
How brain actually works (HTM)

- Seed of Intelligence is neocortex
- Online Learning
- An evolving theory not a complete one
- ANNs are inspired but HTM is a direct reverse engineering of the brain
- ANNs needs a lot of examples, HTMs needs less

An overview of Hierarchical Temporal Memory: A new neocortex algorithm (Chen et. al, 2012)

How brain actually works (The Thousand Brains Theory of Intelligence)

A theory for how the neocortex works



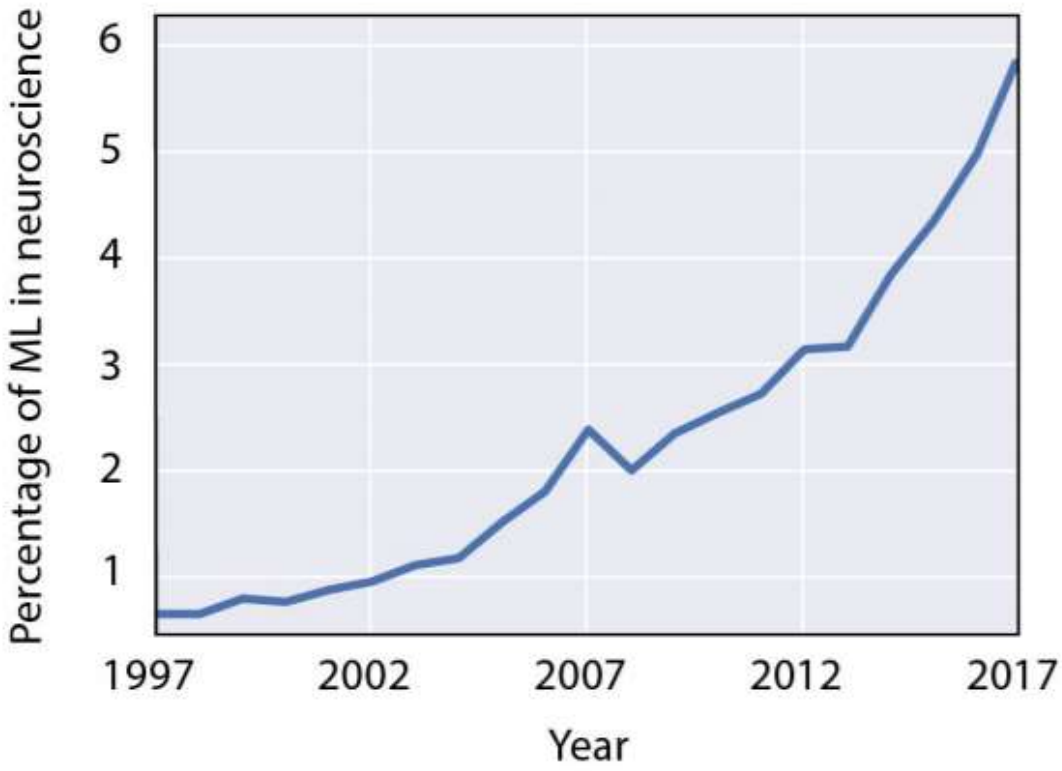
A Framework for Intelligence and Cortical Function Based on Grid Cells in the Neocortex (Hawkins et. Al, 2019)

How Machine Learning contributes to Computational Neuroscience (i.e. Neuroscience)?

Short Answer!

Computational Neuroscience use Machine Learning algorithms as a mathematical tool to analyze neural/behavioral data.

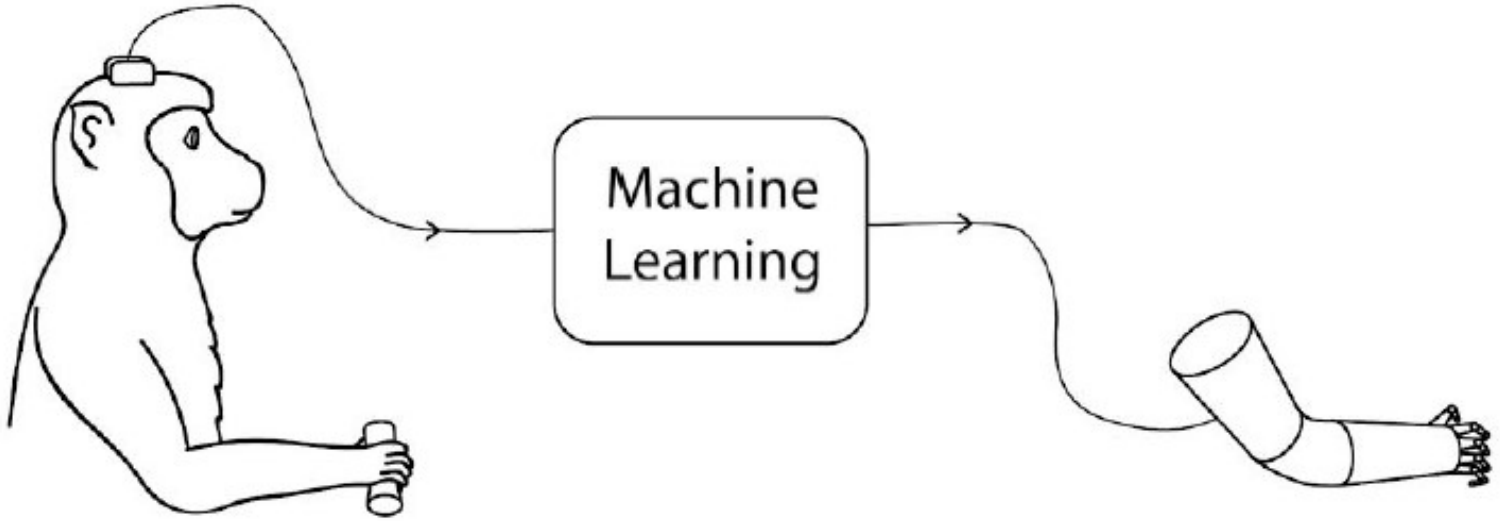
ML in Neuroscience over last 2 decades



The Roles of Supervised Machine Learning in Systems Neuroscience (Glaser et al. 2019)

Solving Engineering Problems

Mapping measurements *(X)* variables to some quantity of interest *(Y)*

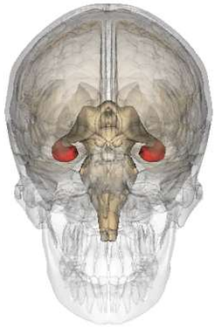


Mapping neural activities to movement of prosthetic limb

The Roles of Supervised Machine Learning in Systems Neuroscience (Glaser et al. 2019)

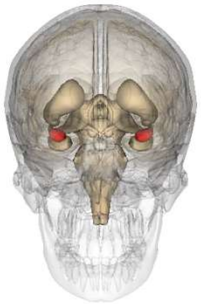
Identifying Predictive Variables

Motor Cortex

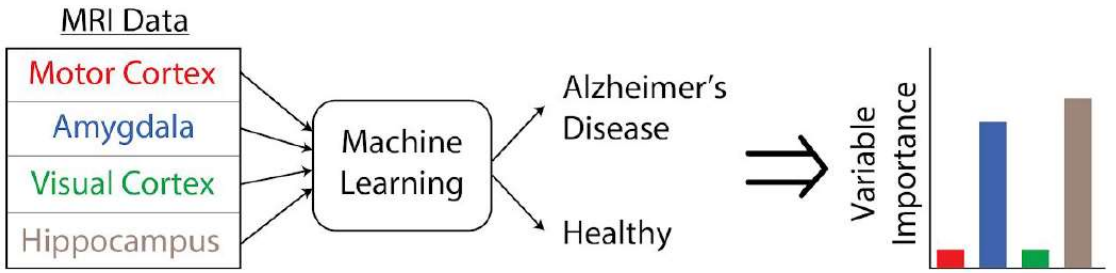


Hippocampus

Visual Cortex



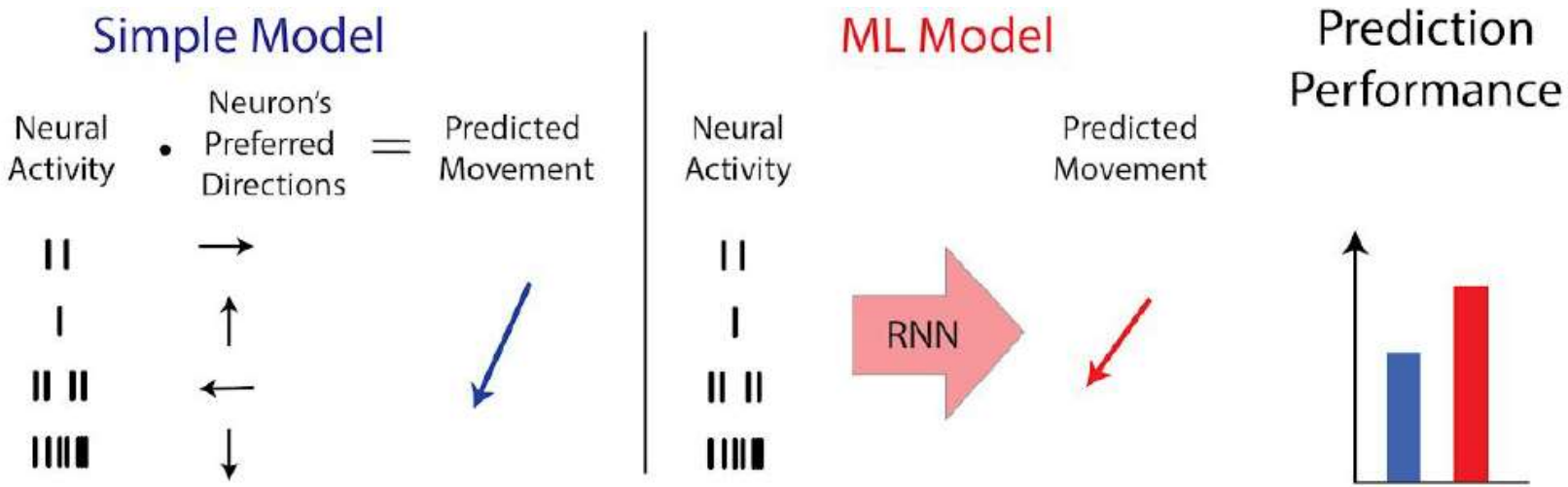
Amygdala



Using MRI data to identify which brain regions are most predictive for diagnosing Alzheimer's disease

The Roles of Supervised Machine Learning in Systems Neuroscience (Glaser et al. 2019)

Benchmarking Simple Models



Comparing the predictive performance of the simple "population vector" model of how neural activity relates to movement to a ML benchmark

The Roles of Supervised Machine Learning in Systems Neuroscience (Glaser et al. 2019)

The End