ECBM E4040
Neural Networks and Deep Learning

Introduction to Deep Learning (DL)

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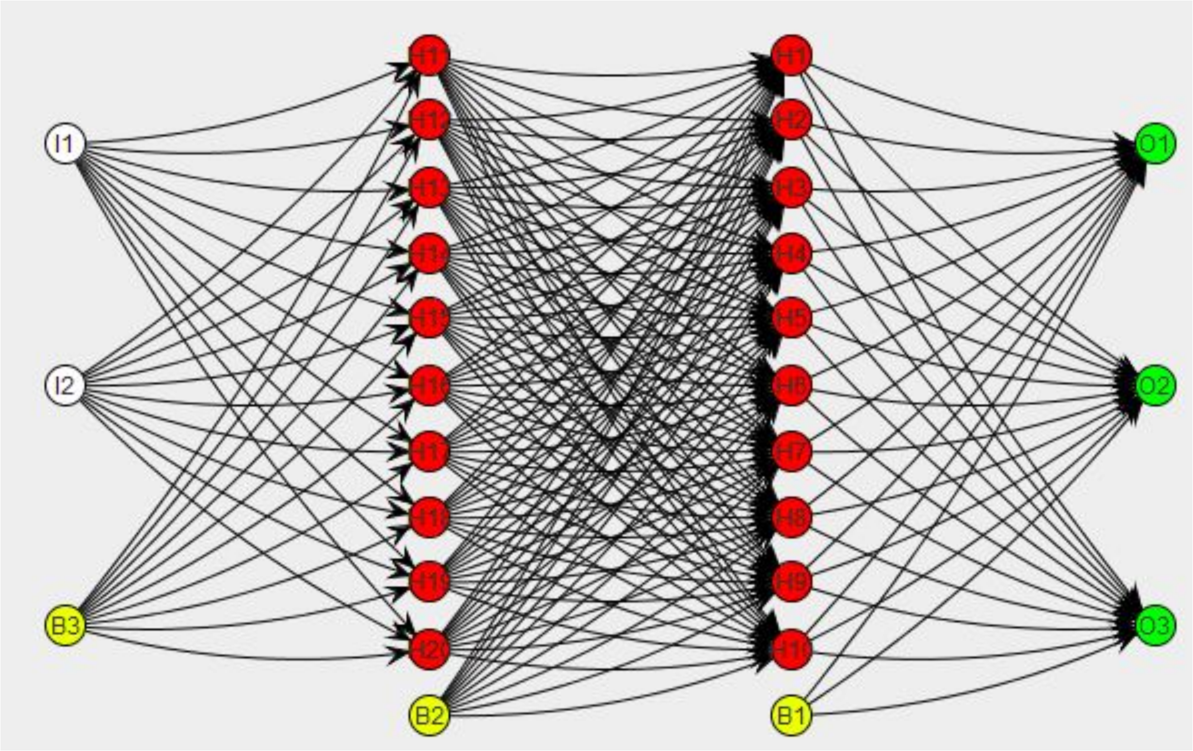
References and Acknowledgments

- **Lecture material by bionet group / Prof. Aurel Lazar (http://www.bionet.ee.columbia.edu/)**

Outline

- Artificial Neural Networks (ANNs) for Deep Learning
- What can deep learning do
- Biological Neural Networks
- What is Deep Learning / Artificial Neural Networks
- Historical Trends in DL

Artificial Neural Networks (ANN)



source https://www.codeproject.com/Articles/477689/JavaScript-Machine-Learning-and-Neural-Networks-wi

Artificial Neural Network Structure

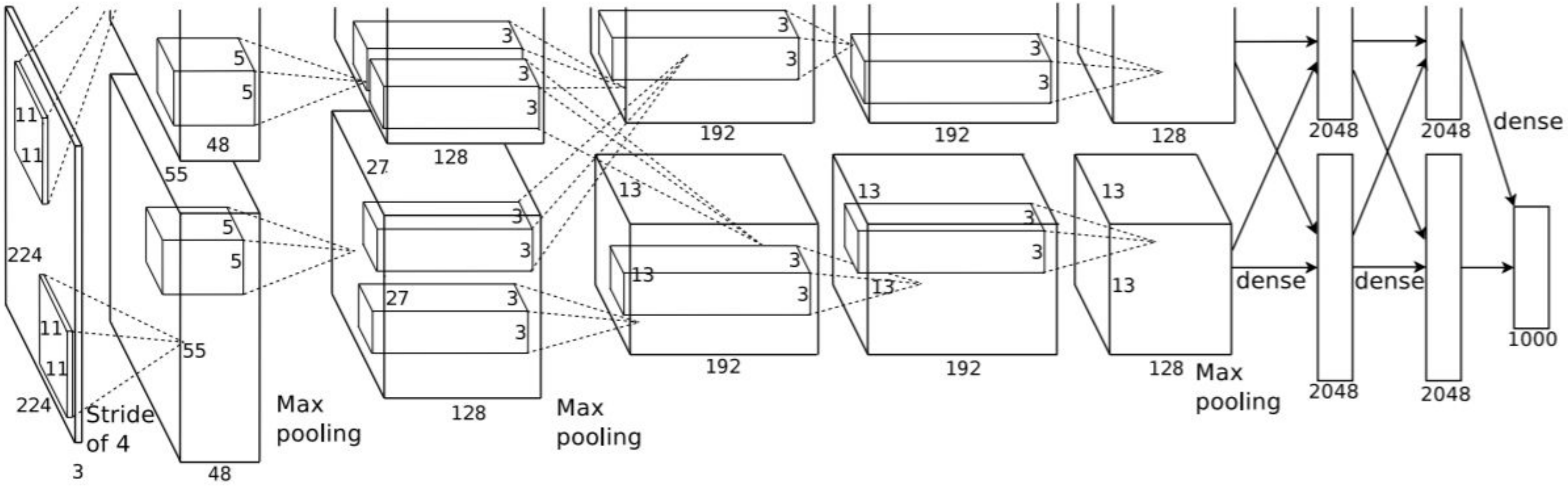


Figure 2: An illustration of the architecture of our CNN, explicitly showing the delineation of responsibilities between the two GPUs. One GPU runs the layer-parts at the top of the figure while the other runs the layer-parts at the bottom. The GPUs communicate only at certain layers. The network's input is 150,528-dimensional, and the number of neurons in the network's remaining layers is given by 253,440–186,624–64,896–64,896–43,264–4096–4096–1000.

http://papers.nips.cc/paper/4824-imagenet-classification-with-deep-convolutional-neural-networks.pdf

What do Neural Networks Do ?

In a nutshell:

- ANN can learn to **represent any function**

Artificial Neural Networks for Deep Learning

Deep learning uses architectures of

many-layer

artificial neural networks

Artificial Neural Networks

WHAT CAN DEEP LEARNING DO?

What can Deep Learning Do - Examples

Detect Objects in a Sample Image

from

Google research blog

https://research.googleblog.com/2017/06/supercharge-your-computer-vision-models.html

Original image: Mike Miley

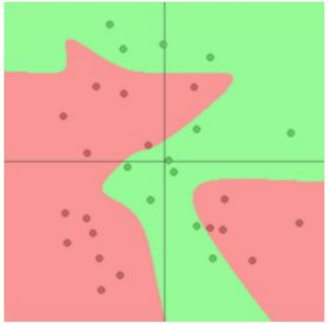
https://www.flickr.com/photos/mike_miley/

What can Deep Learning Do - Browser Demos

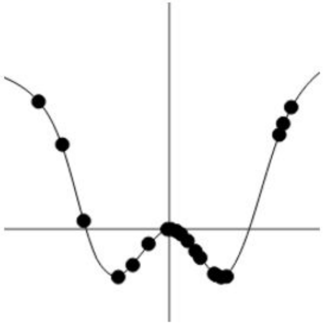
Classify **MNIST** digits with a Convolutional Neural Network

Classify **CIFAR-10** with Convolutional Neural Network

Interactively classify toy 2-D data with a Neural Network

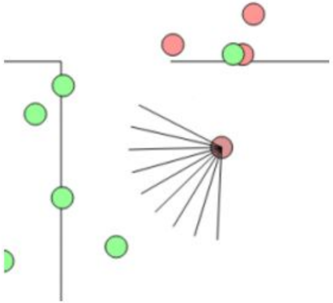


Interactively regress toy 1-D data



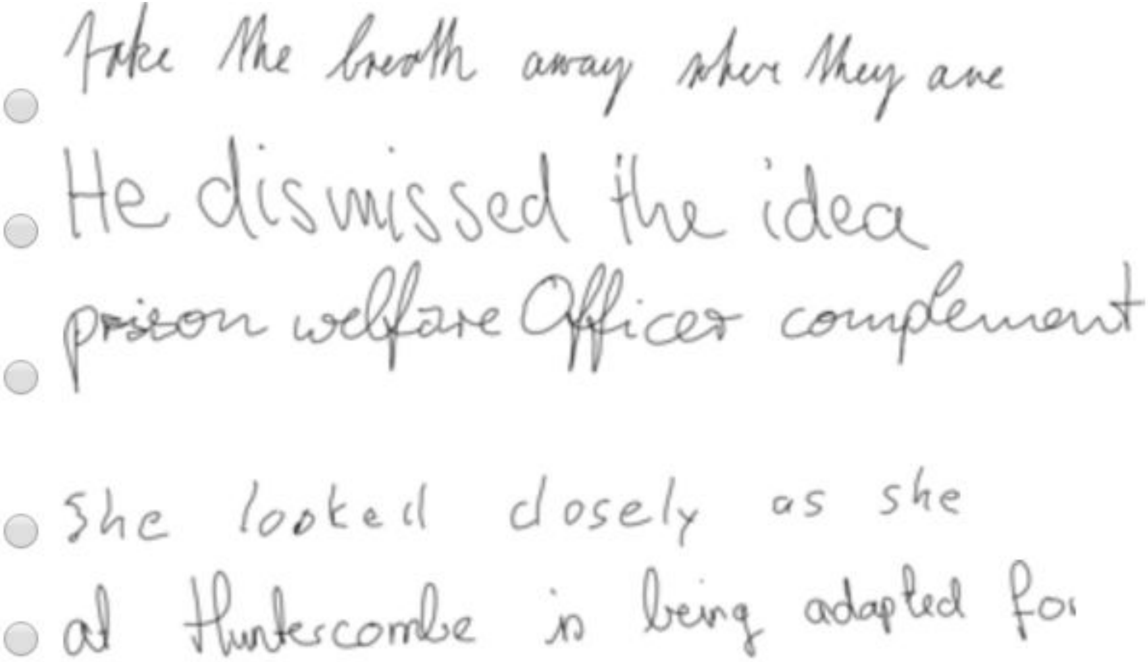
Train an MNIST digits Autoencoder

Reinforcement Learning with Deep Q Learning



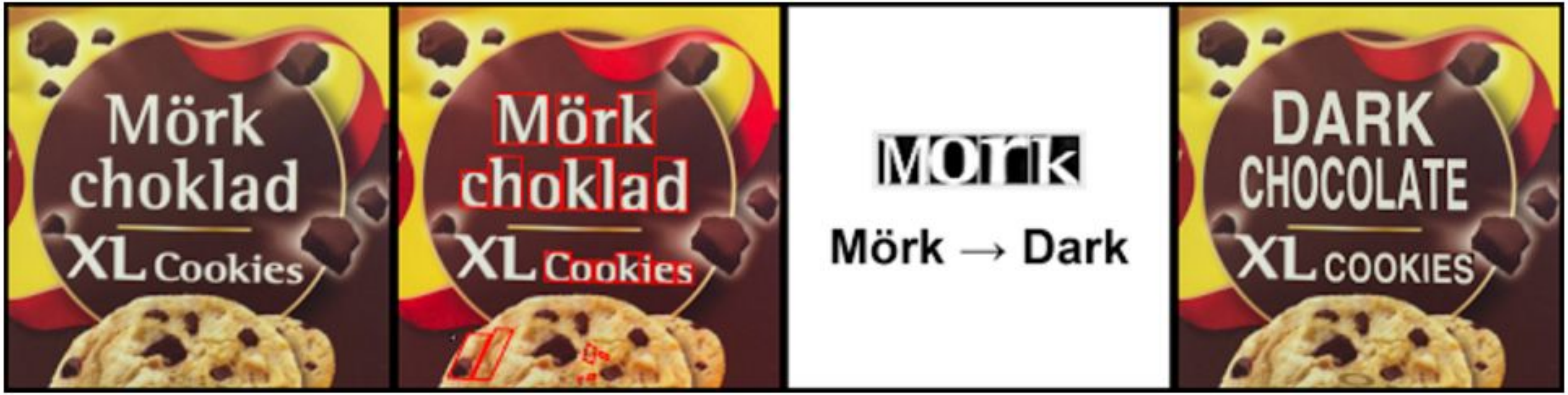
http://cs.stanford.edu/people/karpathy/convnetjs/

What can Deep Learning Do - Examples
Handwriting



http://www.cs.toronto.edu/~graves/handwriting.html

What can Deep Learning Do - Examples
Automatic Machine Translation



https://research.googleblog.com/2015/07/how-google-translate-squeezes-deep.html

What can Deep Learning Do - Examples
Project COSMOS: Cloud Connected Vehicles

Prof. Kostic lab

https://cosmos-lab.org/

Videos:

https://youtu.be/SvXrQPRBkHE

https://www.dropbox.com/s/p69pg079a48ylv6/radarMap.190619.slowCompare.mp4?dl=0

What can Deep Learning Do

ImageNet - www.image-net.org

Image database organized according to the WordNet hierarchy (the nouns), in which each node of the hierarchy is depicted by hundreds and thousands of images.

22K categories and 14M images

- **Animals: Bird, Fish, Mammal, Invertebrate**
- **Plants: Tree, Flower**
- **Food**
- **Materials**
- **Artifact: Tools, Appliances, Structures**
- **Person**
- **Scenes: Indoor, Geological, Formations**
- **Sport Activities**

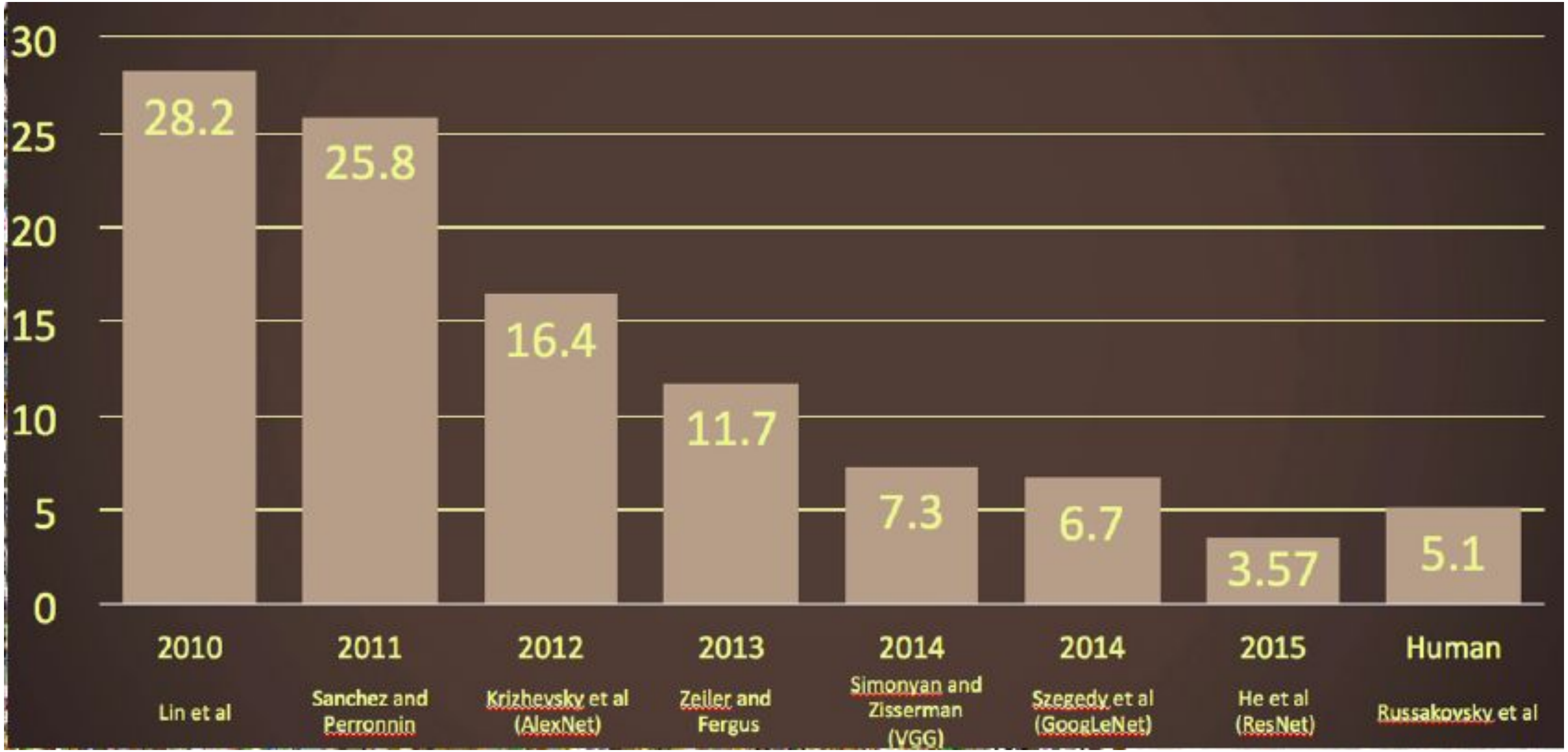
What can Deep Learning Do
ImageNet - Large Scale Visualization Challenge

Evaluates algorithms for object localization/detection from images/videos and scene classification/parsing at scale.

- **Object localization for 1000 categories.**
- **Object detection for 200 fully labeled categories.**
- **Object detection from video for 30 fully labeled categories.**
- **Scene classification for 365 scene categories (Joint with MIT Places team) on Places2 Database http://places2.csail.mit.edu.**
- **Scene parsing**

http://image-net.org/challenges/LSVRC/2016/index

What can Deep Learning Do
ImageNet - Image Classification

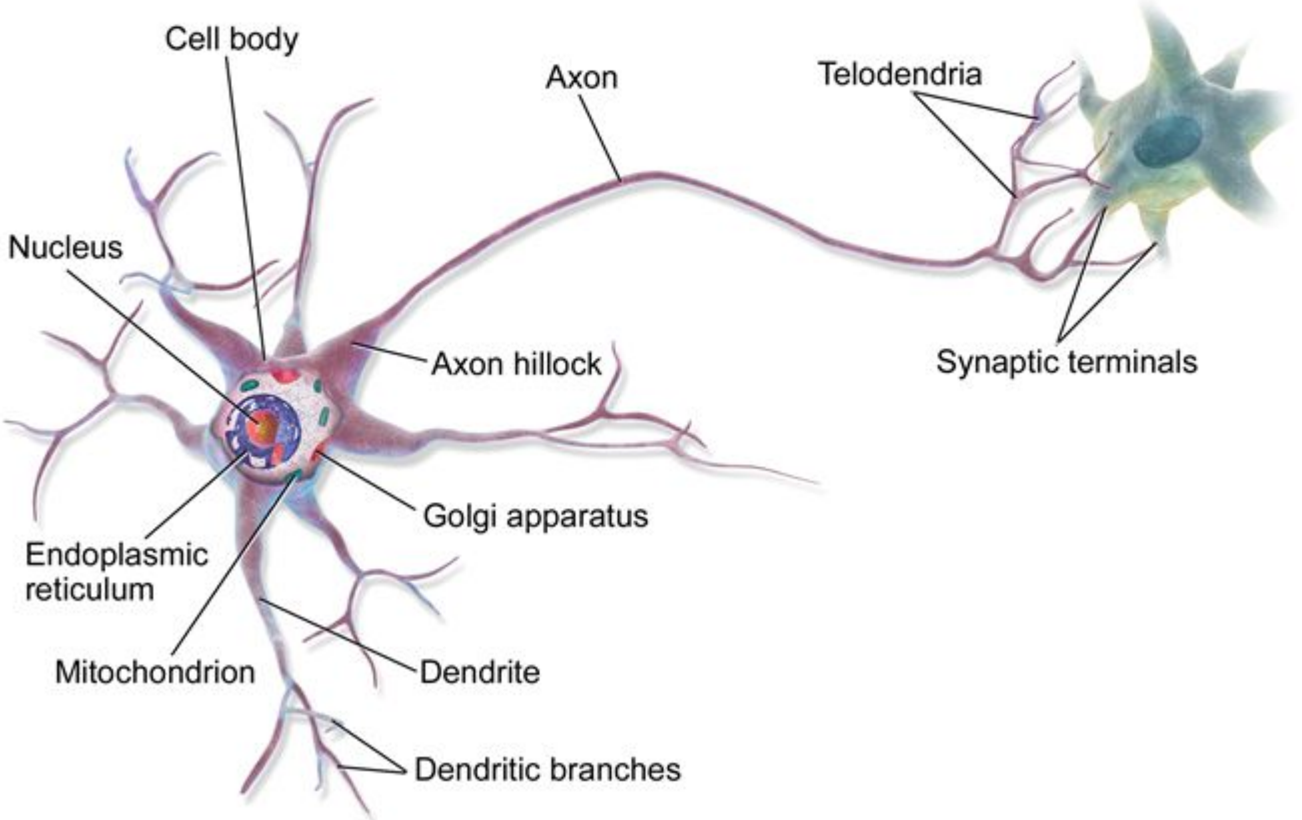


Russakovsky et al. arXiv, 2014

Biological Neural Networks

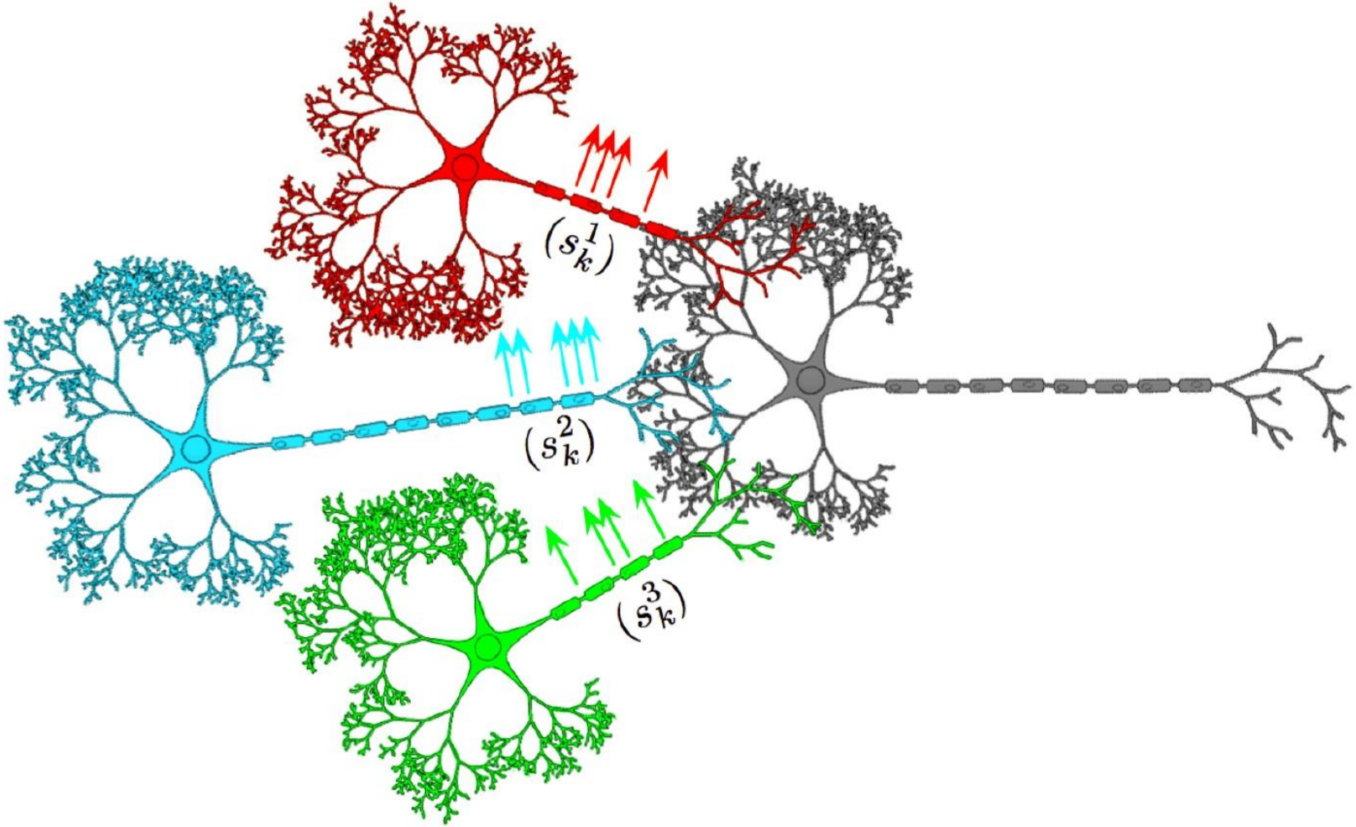
relationship to ANNs

Biological Neural Networks - Neurons



A neuron is an electrically excitable cell that processes and transmits information through electrical and chemical signals.

Biological Neural Networks - Inputs via Dendrites



Biological Neural Networks - Neurons

Dendrites receive electrochemical impulses from other neurons, and carry them inwards and towards the soma, while axons carry the impulses away from the soma.

Dendrites are short and heavily branched in appearance, while axons are much longer.

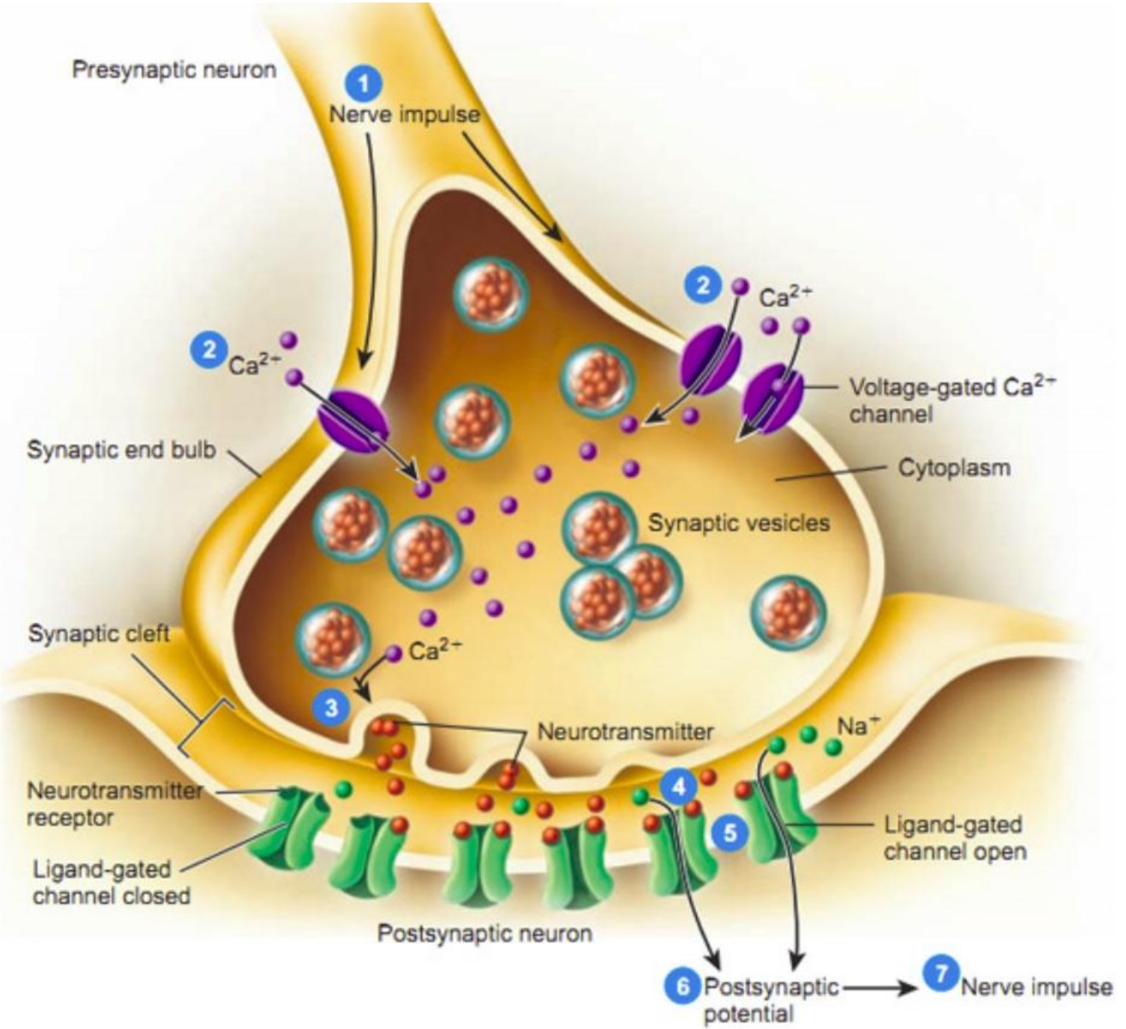
Generally, dendrites receive neuron signals, and axons transmit them.

Most neurons have a lot of dendrites and only have one axon.

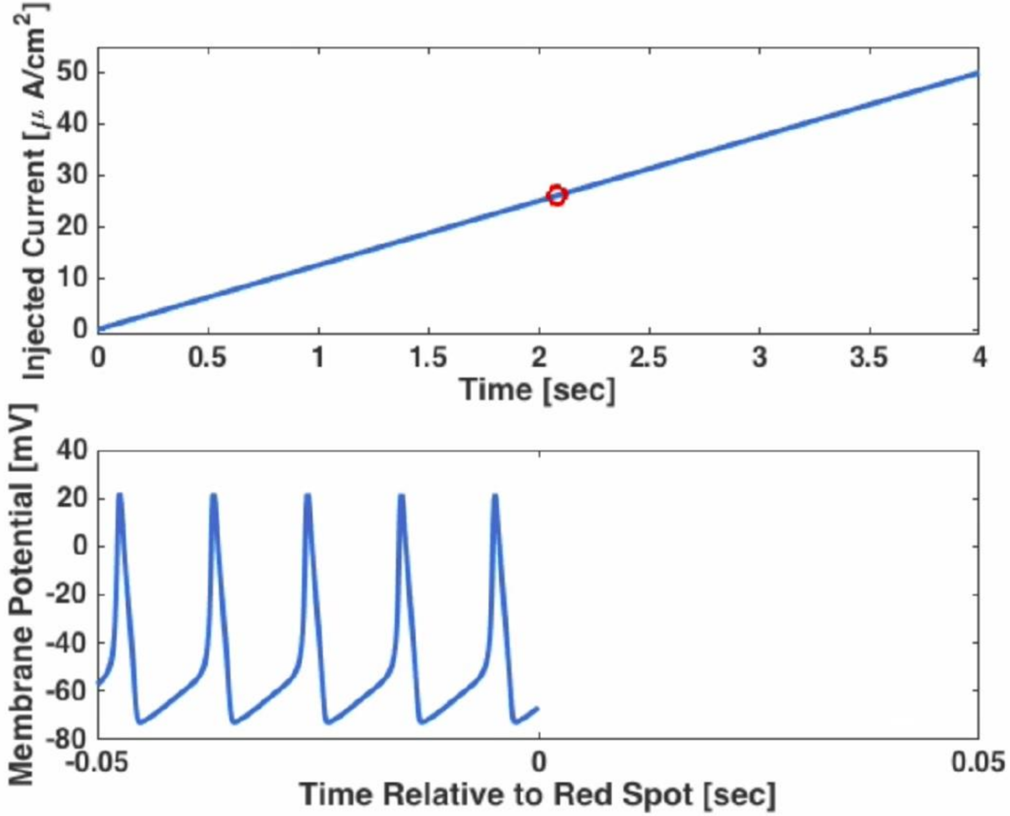
Dendrites’ radius tapers, while axons’ remain constant.

Biological Neural Networks

Signal transmission between neurons are through synapses.



Biological Neural Networks - Neurons Generate Action Potentials when Excited



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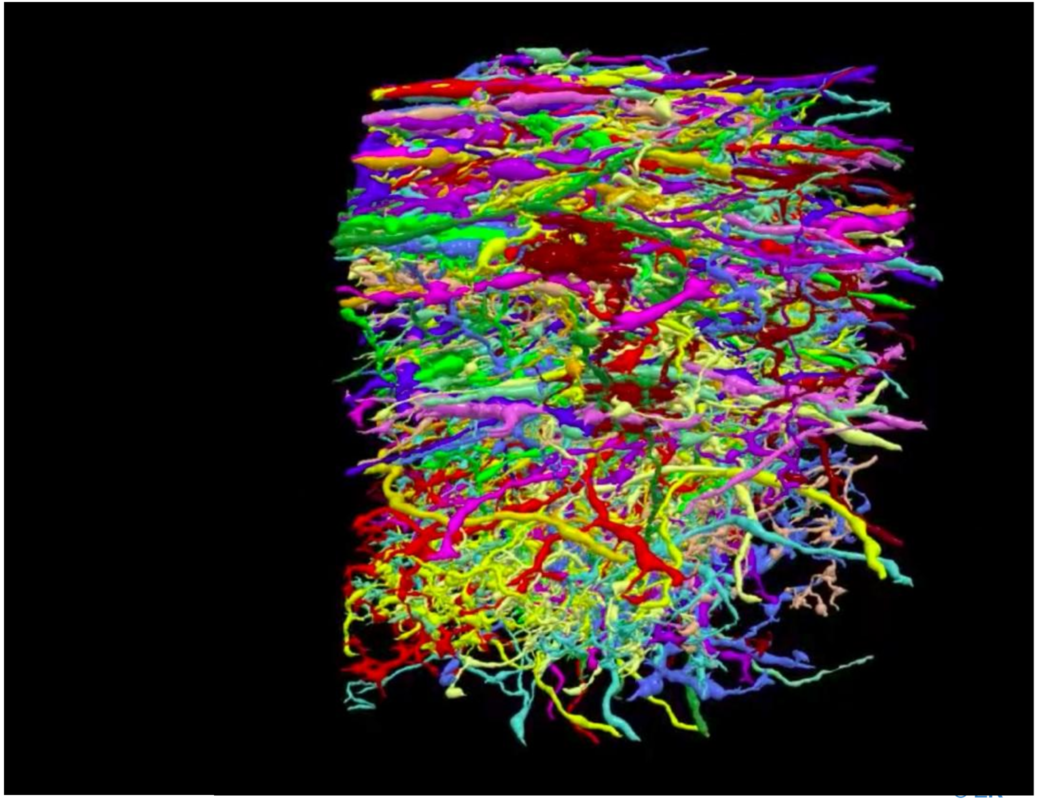
Biological Neural Networks - An Example of a Reconstructed Neural Network



What is Deep Learning

and artificial neural networks

What is Deep Learning? Starting with Standard Artificial Neural Networks (ANNs)

A standard ANN consists of

- **many simple, connected ``neurons"**
- **each neuron has an activation function**
- **input neurons get activated through sensors perceiving the environment**
- **other neurons are activated through weighted connections from previously activated neurons**

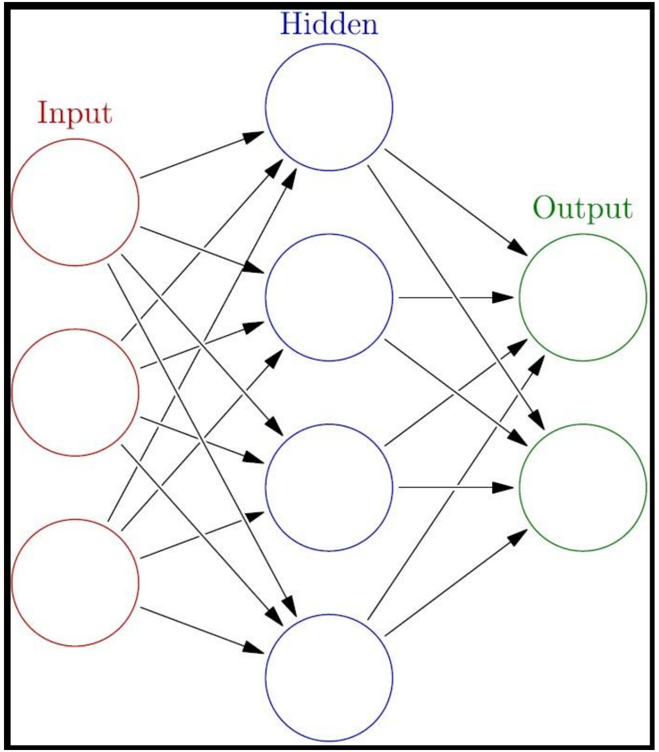
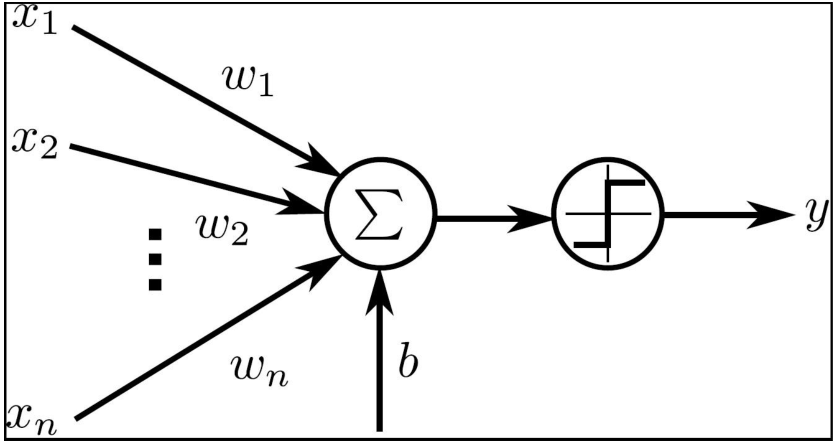


Figure: Glosser.ca Wikipedia

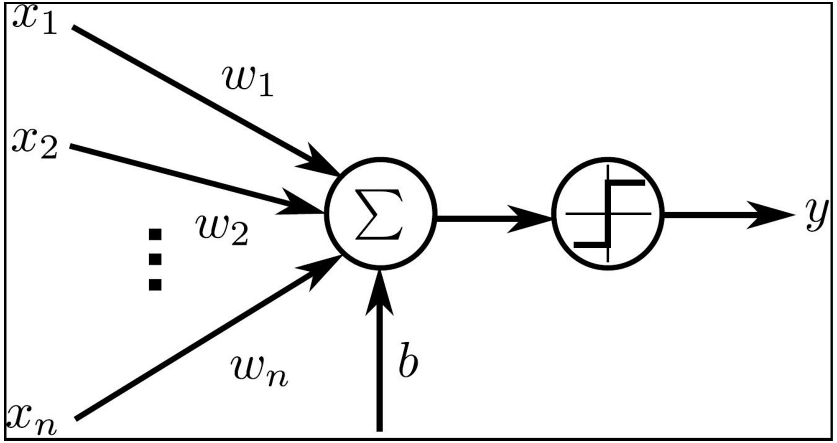
What is Deep Learning?
Perceptron



$$y(\boldsymbol{x}) = \begin{cases} 1, & if\, \boldsymbol{w}^T\boldsymbol{x} + b > 0 \\ -1, & otherwise \end{cases}$$

What is Deep Learning?

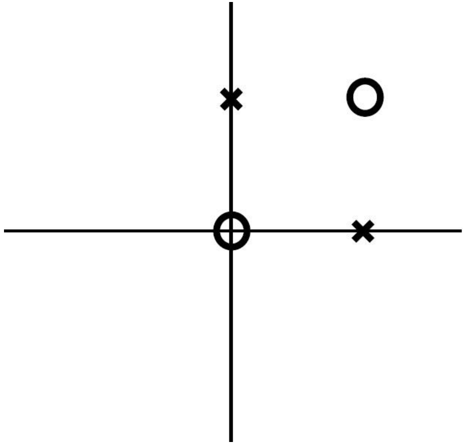
Perceptron



$$y(\boldsymbol{x}) = \begin{cases} 1, & if\, \boldsymbol{w}^T \boldsymbol{x} + b > 0 \\ -1, & otherwise \end{cases}$$

Linear classifier

Does not work on the following case (two classes are star and circle):



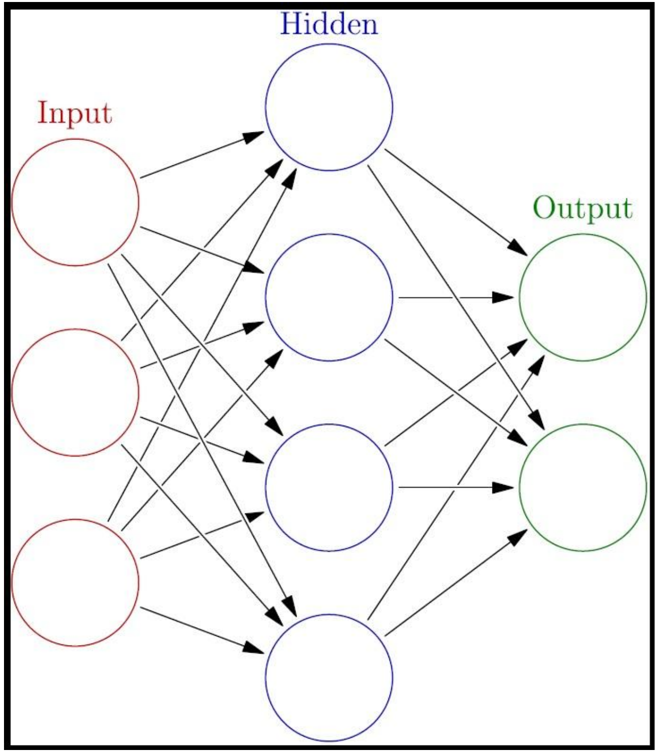
Deep Neural Networks
Multilayer Perceptron (MLP)

Universal approximation theorem:

A feed-forward network with a single hidden layer containing a finite number of neurons can approximate continuous functions on compact subsets of n.

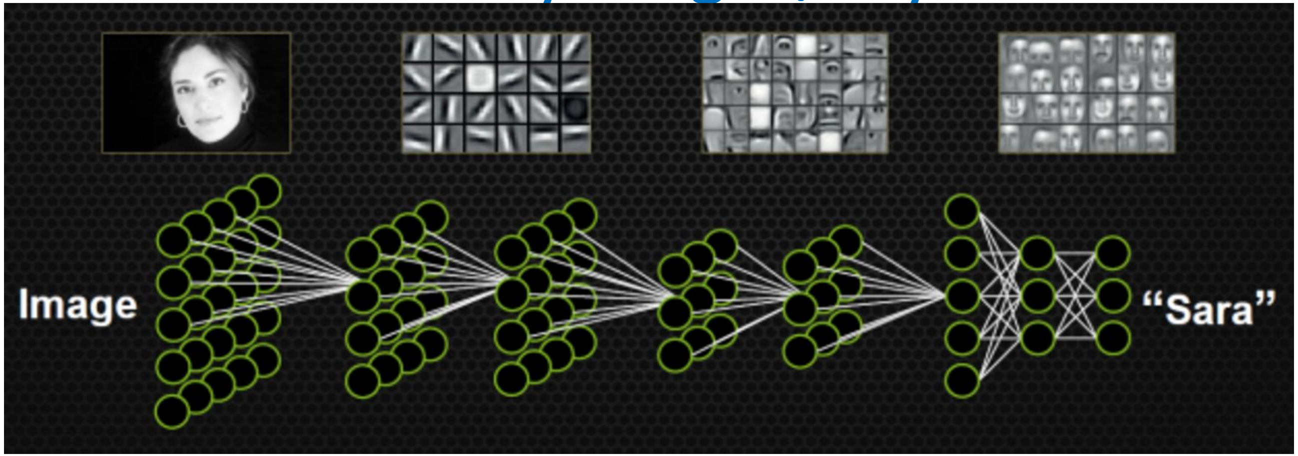
- **represents a simple/parallel structure that can be easily executed for prediction**
- **learning is much more time involved**

How to train a deep neural network becomes the central question.

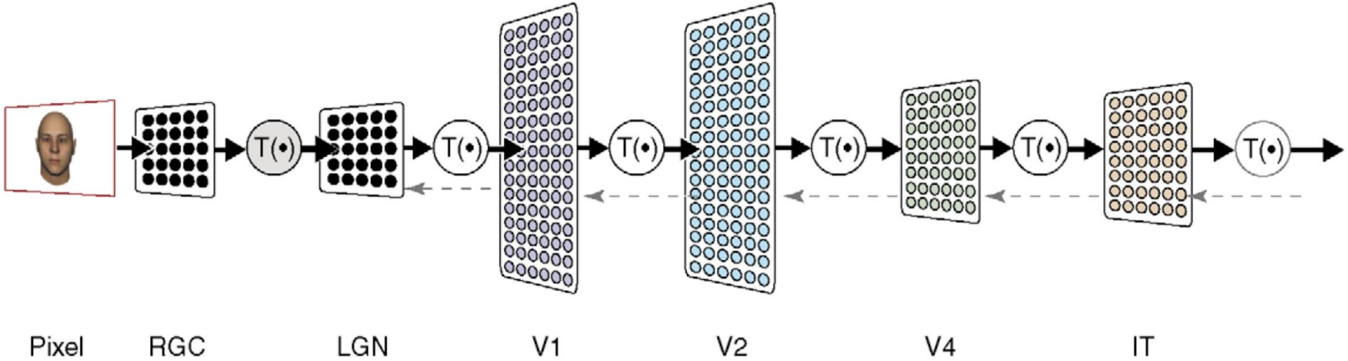


Deep Neural Networks
Neural Network with Many Stages/Layers

Deep Neural Network



Ventral Visual Processing System

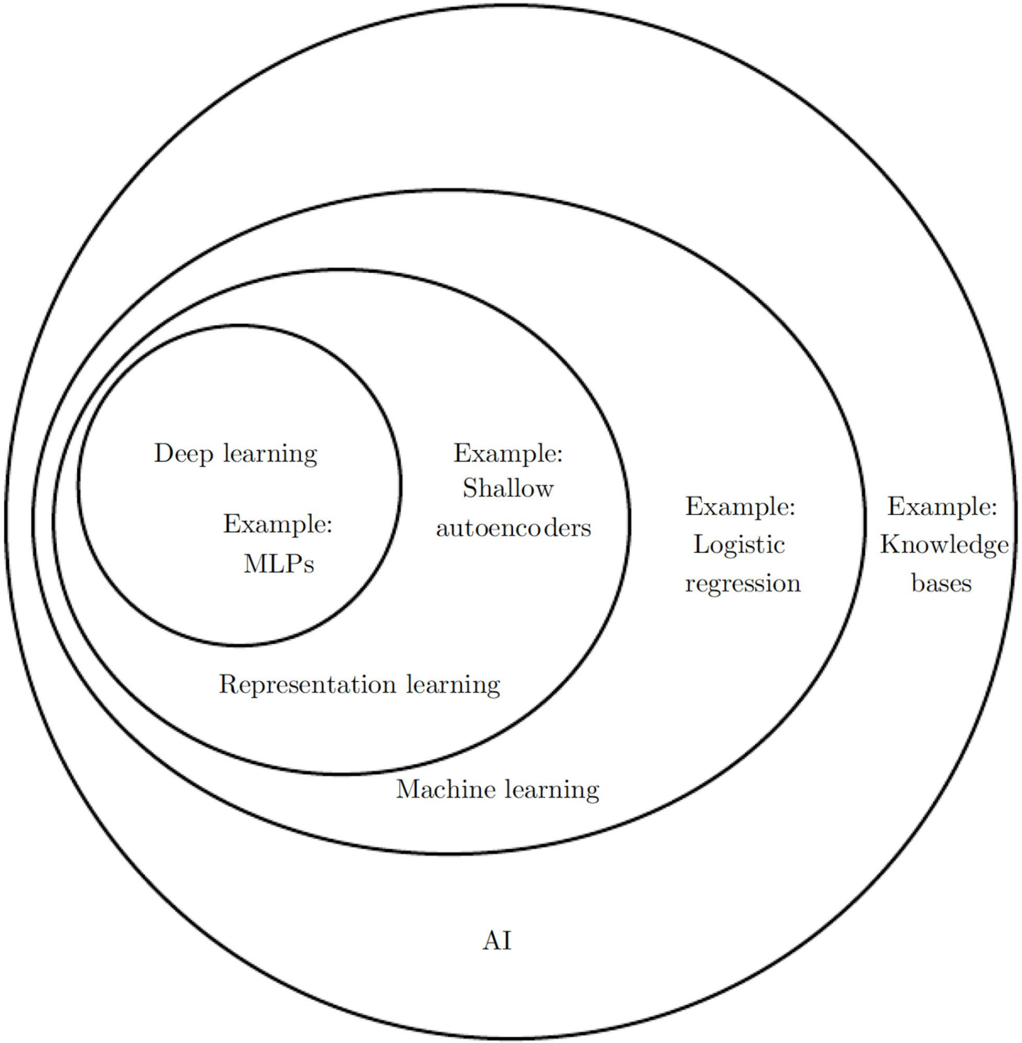


Disciplines of Artificial Intelligence Venn Diagram

Deep Learning

is only a subset of

AI



Features in Artificial Intelligence
How to Identify Them?

Conventional machine-learning techniques are limited in their ability to process natural data in their raw form. Therefore, features need to be extracted.

Feature identification:

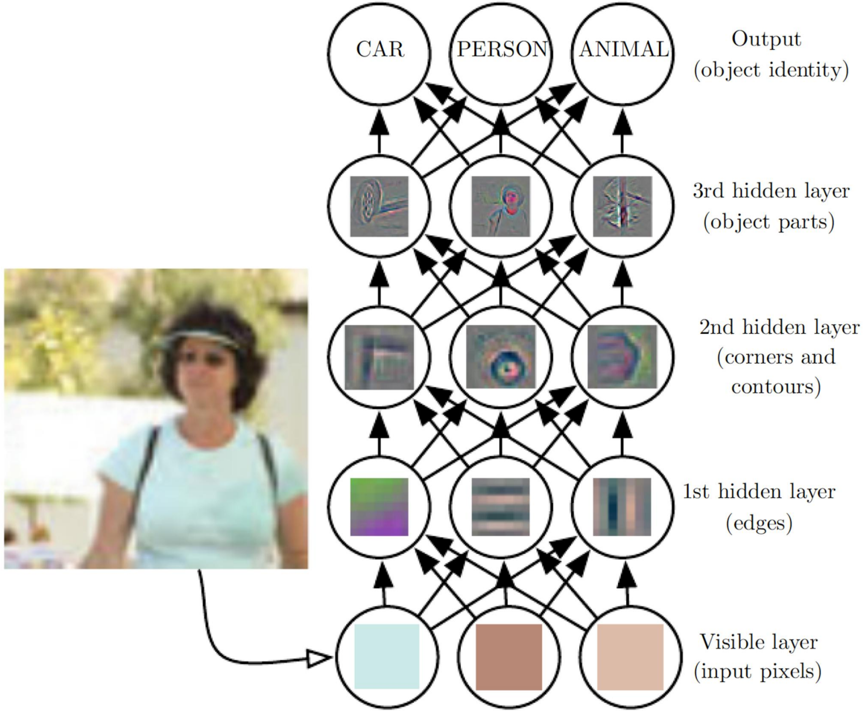
- **Requires careful engineering and considerable domain expertise to design a feature extractor which could transform raw data into a suitable internal representation or feature vector from which the learning subsystem (e.g. a classier) can detect or classify patterns in the input**

Features in Artificial Intelligence
How to Identify Them?

Obtaining a representation may be as difficult as solving the original problem.

Representation learning is a set of methods that allows a machine to be fed with raw data and to automatically discover the representation needed for detection or classification.

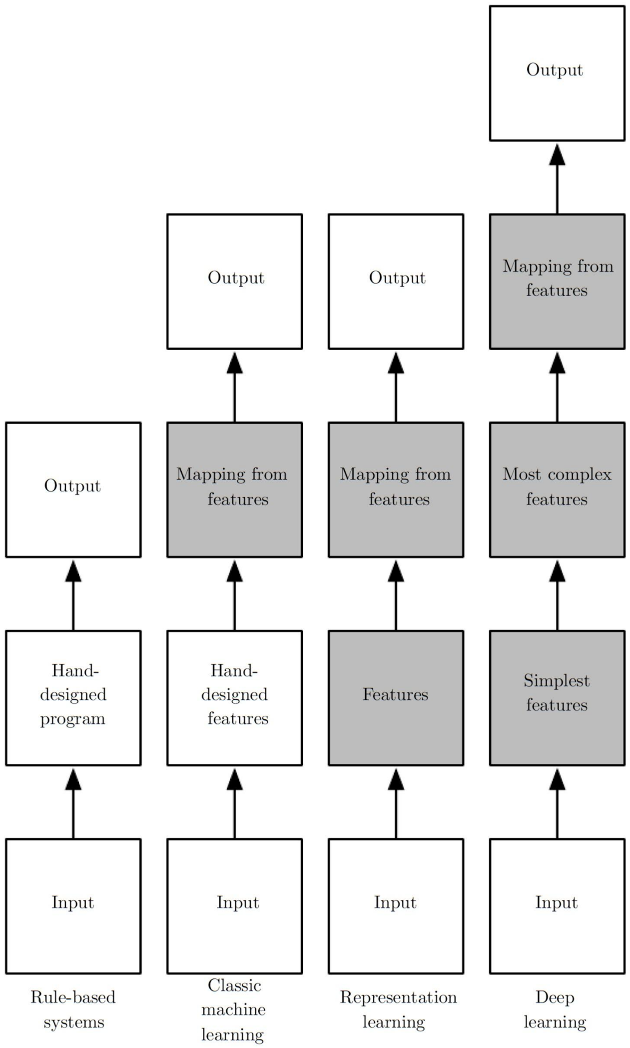
Features and Representation Learning Implemented by Deep Learning



Deep-learning methods are representation-learning methods with multiple levels of represen-tation, obtained by composing simple, but non-linear modules that each transform the representation at one level into a representation at a higher, slightly more abstract level.

Deep Learning

Comparison of Machine Learning Approaches



Deep Learning
History

- McCulloch-Pitts Neuron (1943), Perceptron (1960s)
- Back-propagation algorithm for training deep networks (1980s)
- Deeper networks than before can be trained and have record-breaking results (2006+), emphasizing the importance of depth.

Artificial Neural Networks (ANNs) and The Brain

ANNs are influenced by the structure of the mammalian visual system.

Rectified linear activation function.

One deep learning algorithm solves many different tasks.

But ANNs/deep learning is not the same as the brain:

- **It is not yet clear how**
  - **memory works in the brain**
  - **how values/functions are represented**
  - **what algorithms biological neural systems employ for learning.**

Deep Learning Adoption

Google

Microsoft

Facebook

IBM

NVIDIA

Netflix

Baidu

Car manufacturers
(Tesla, BMW, Volvo, Ford self-driving cars)

and many more

Deep Learning
Impact - Breaking Records

- MNIST (Hand-Written Digits)
- Traffic Sign Contest
- ImageNet (Visual Object Detection and Image Classification)

Deep Learning
Recent Upsurge

Why did deep learning become popular again in recent years?

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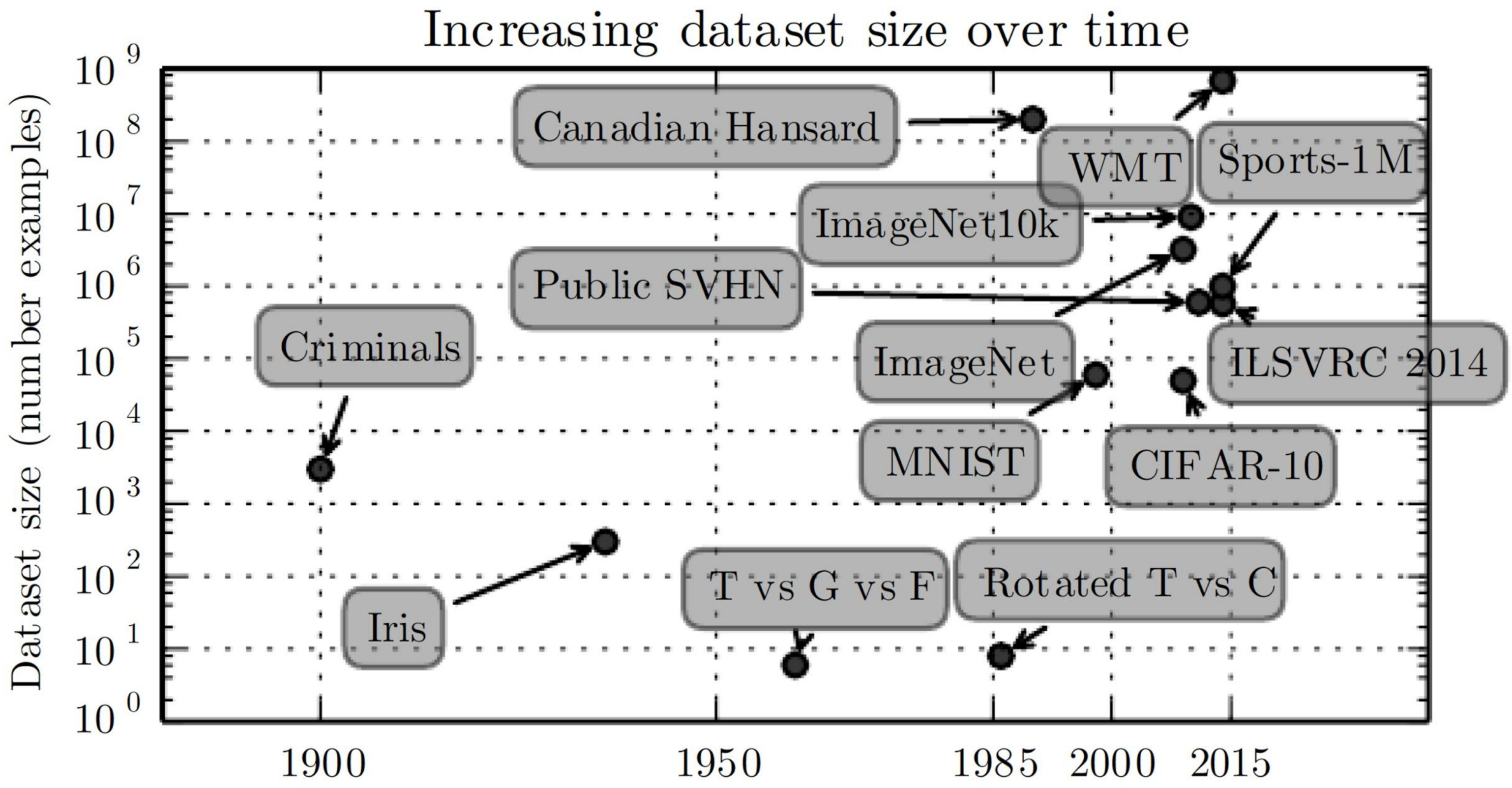
Deep Learning

Recent Upsurgence <- Data Abundance



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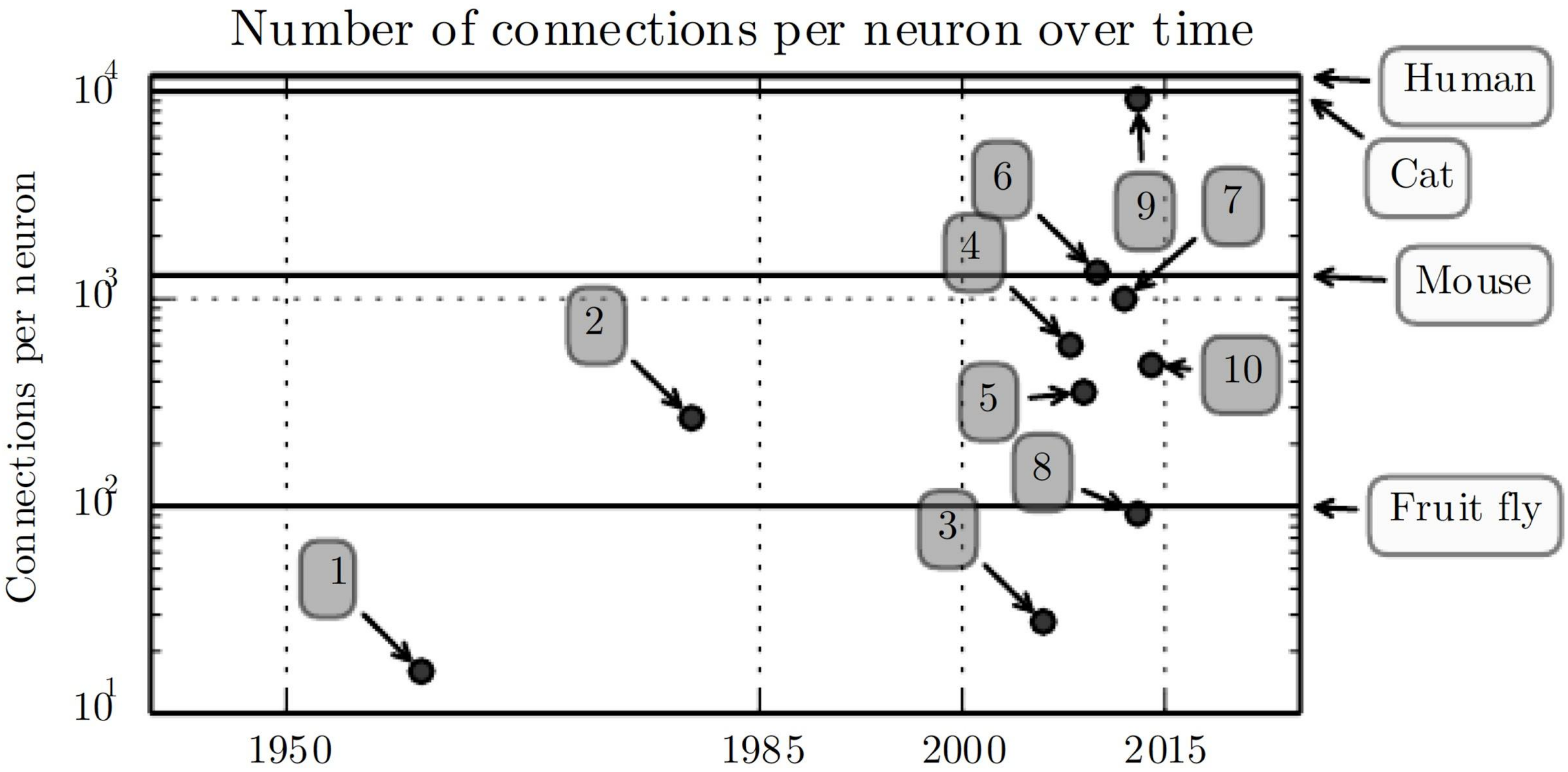
Deep Learning
Recent Upsurgence <- Computing Revolution

- Graphics processing unit (GPU)
- The Role of GPUs on Popularizing Deep Learning Algorithms
- 2010: a new MNIST record of 0.35% error rate. Made possible mainly through a GPU implementation of the Back Propagation algorithm that was up to 50 times faster than standard CPU versions.
- GPU based deep learning algorithms have won several pattern recognition competitions in the following years.
- Recent ImageNet records from Microsoft and Google are all GPU based.

Deep Learning: Larger and Faster Computers Support Increased ANN Model Size



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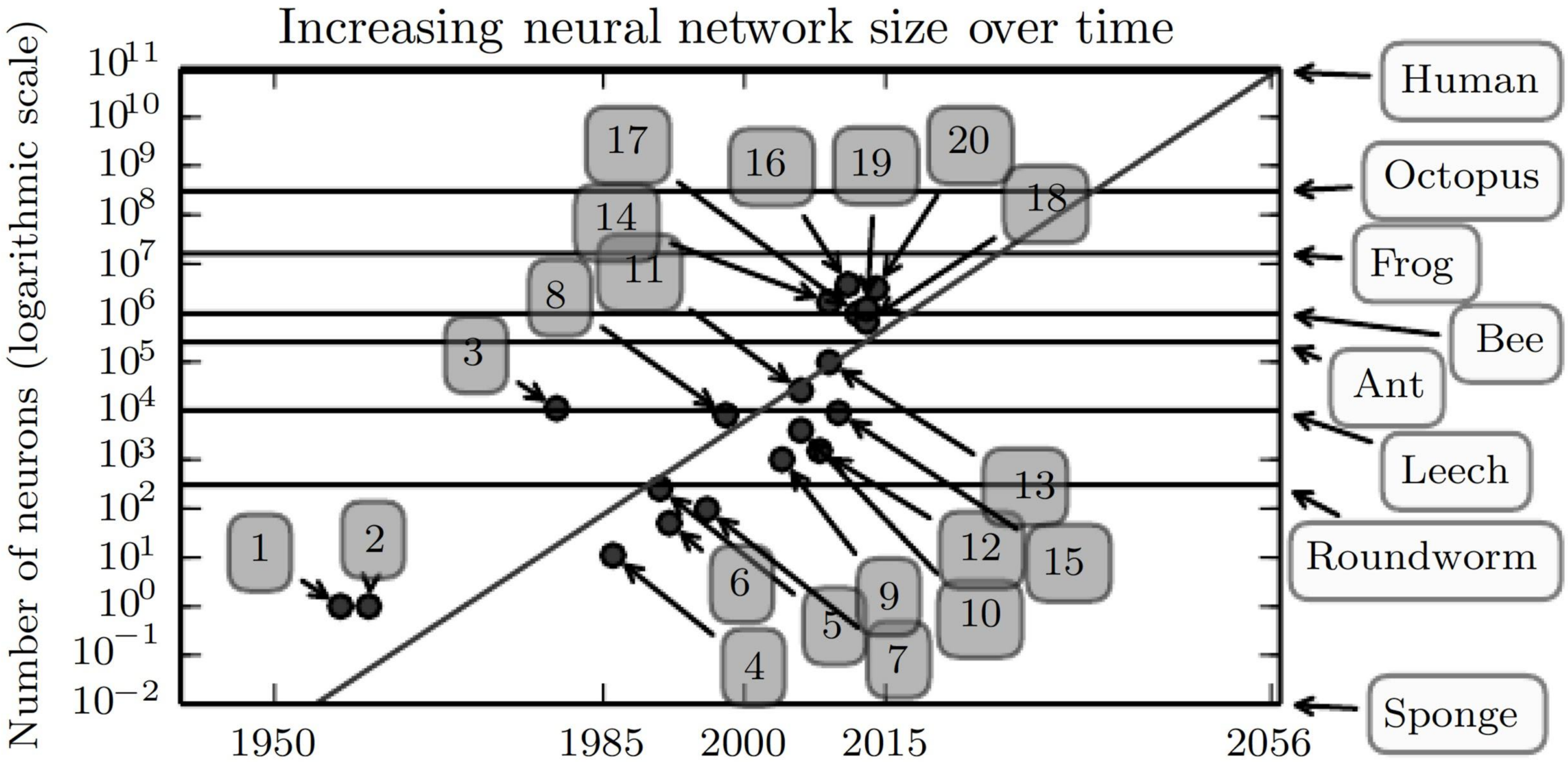
Deep Learning: Larger and Faster Computers Support Increased ANN Model Size



Deep Learning Enablers

- Data abundance
- GPUs

Deep Learning Applications in Science

Processing of massive amounts of data:

- Reconstructing neuron morphology from electron-microscopy raw data
- Analyzing particle accelerator data
- Predicting the activity of potential drug molecules
- Genetic research

Backup Slides

Various