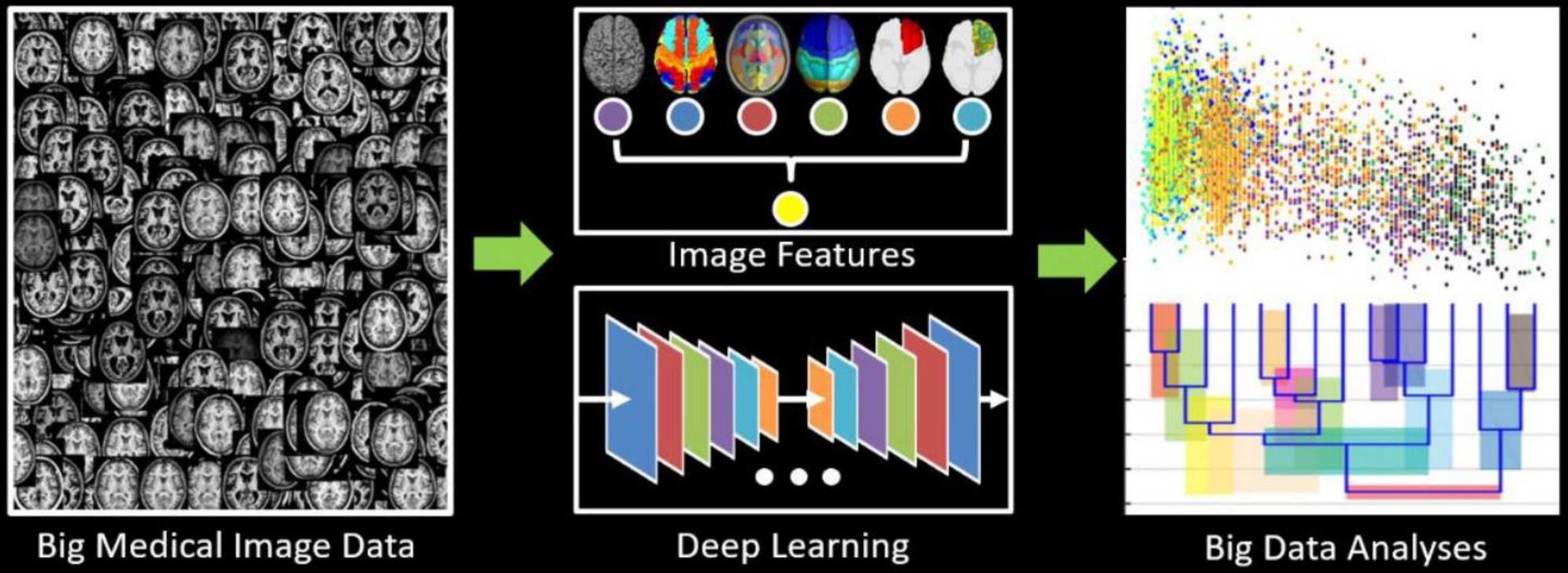


Neural Networks and Convolutional Neural Network

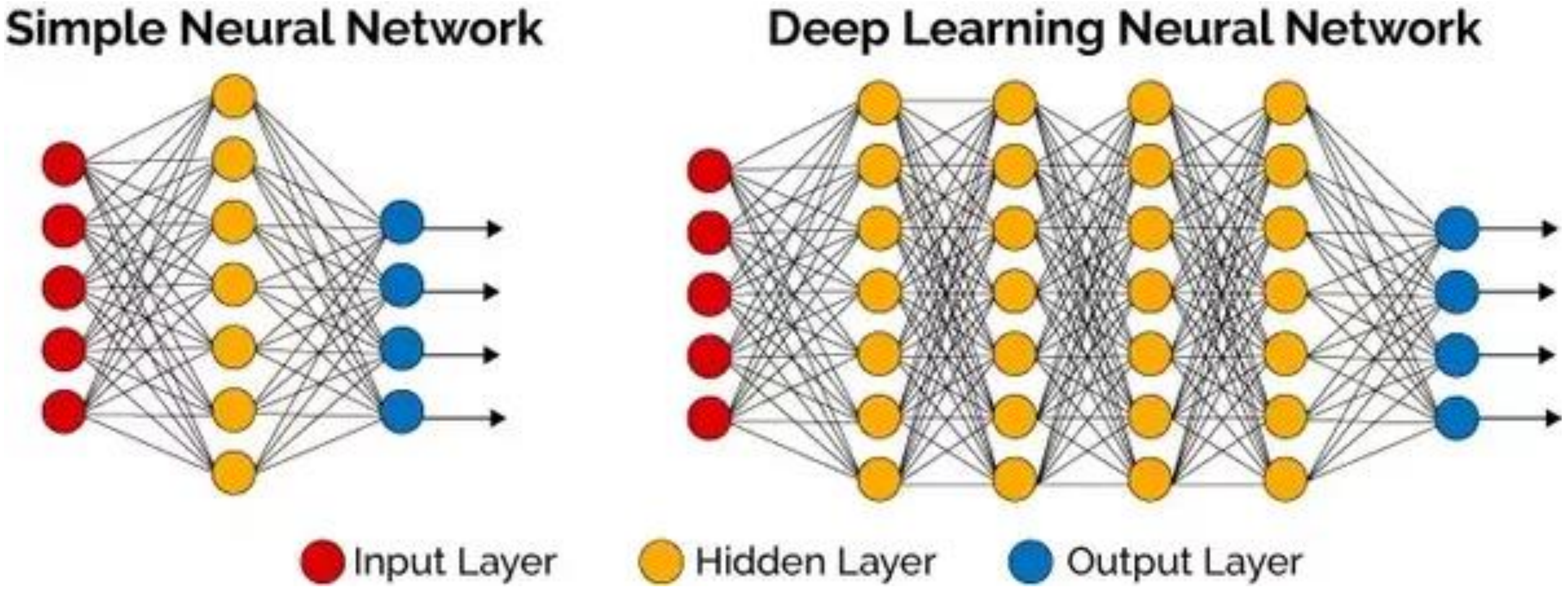
[Spring 2020 CS-8395-02 Deep Learning in Medical Image Computing]

Instructor: Yuankai Huo, Ph.D.
Department of Electrical Engineering and Computer Science
Vanderbilt University

Topics

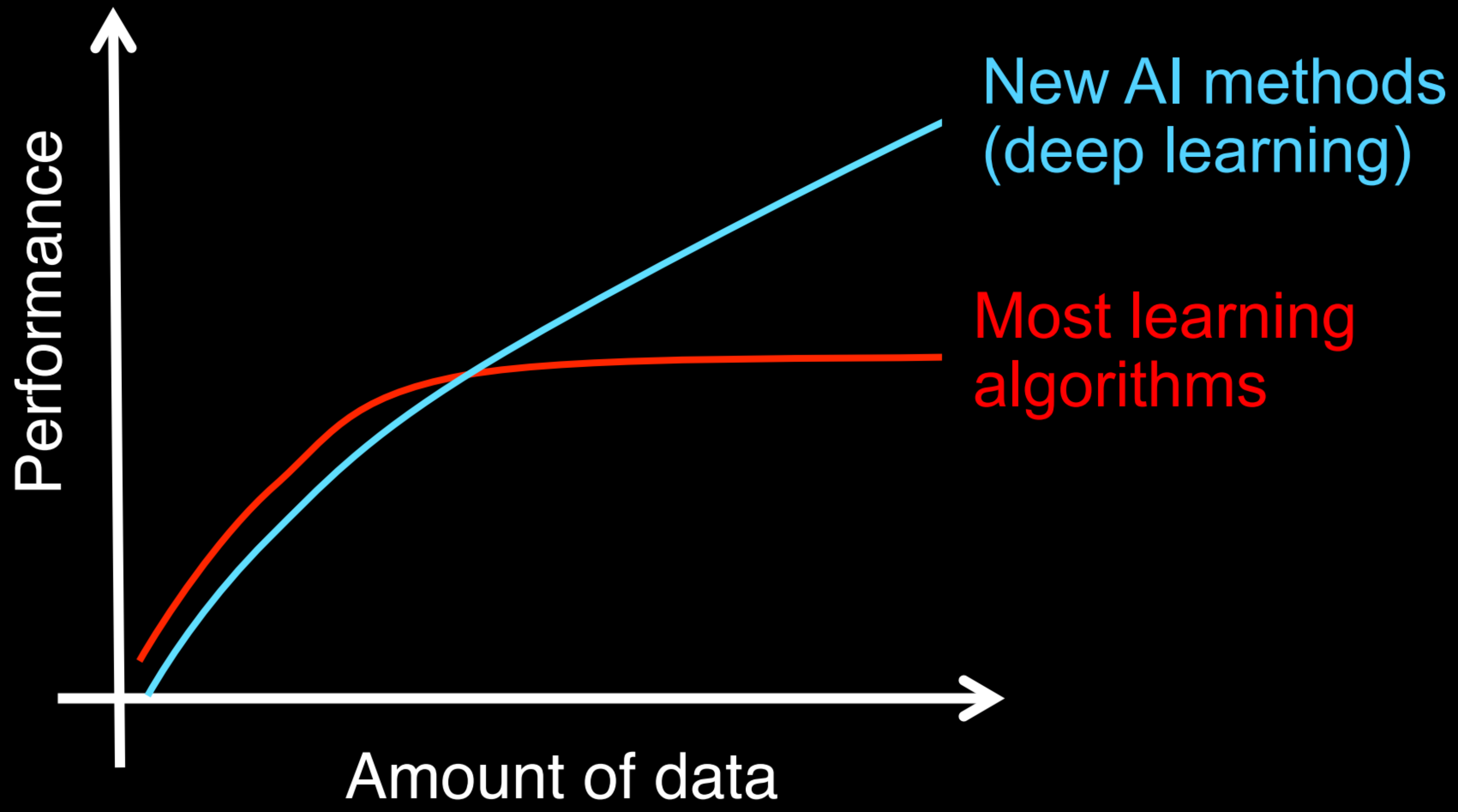
- Review
- Neural Network
- Convolutional Neural Network

Deep Learn = Deep Neural Network



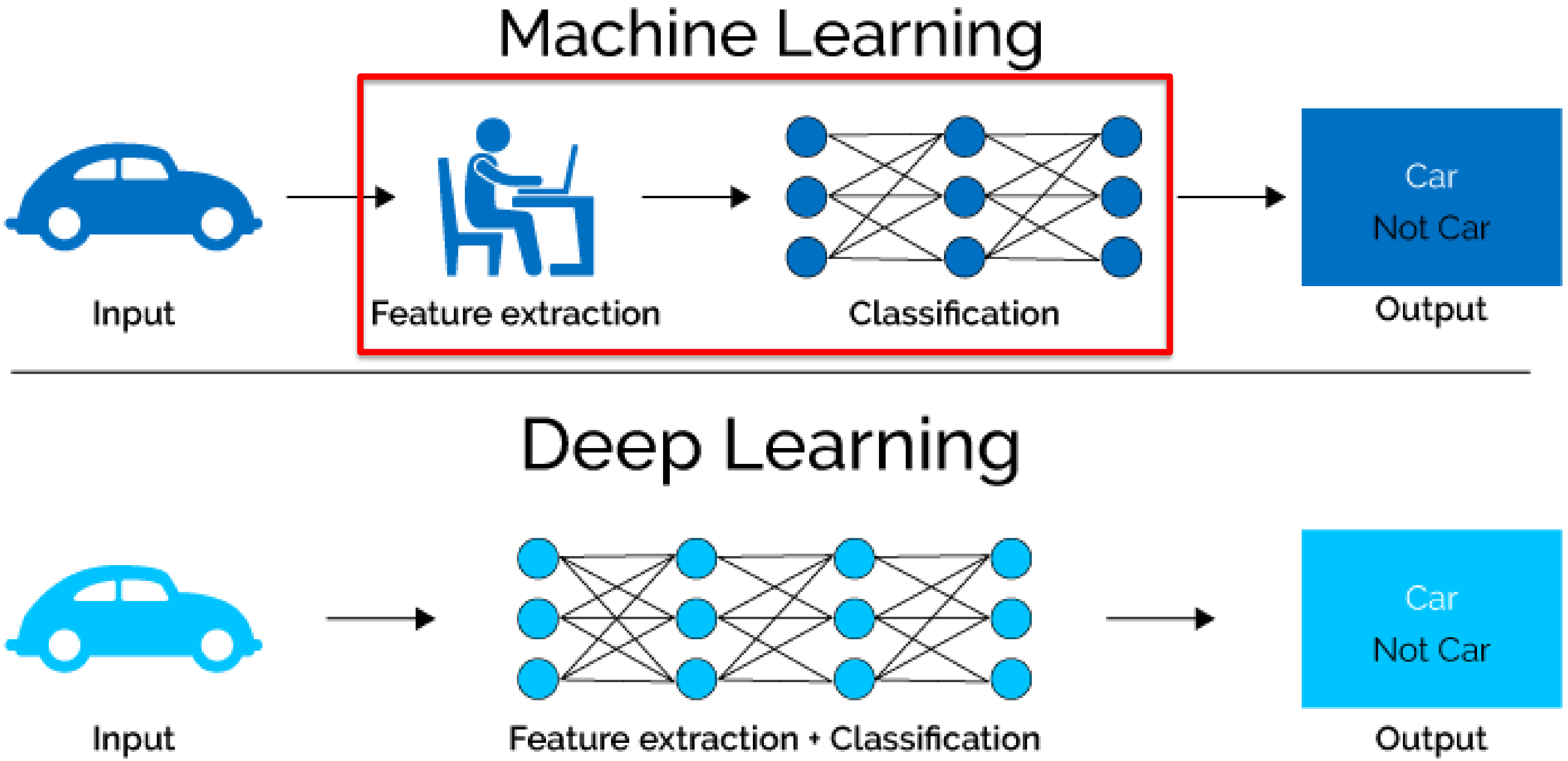
https://www.quora.com/What-is-the-difference-between-Neural-Networks-and-Deep-Learning

Advantages



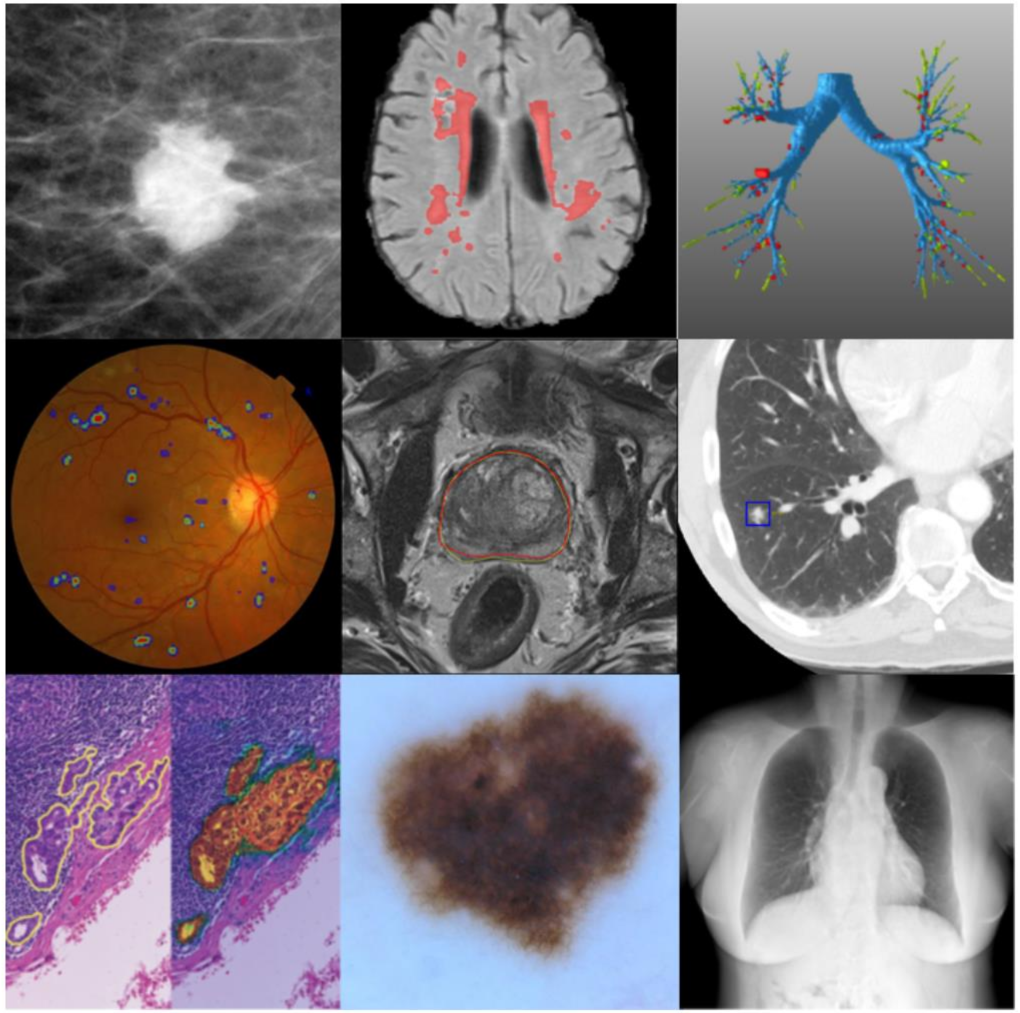
cs229.stanford.edu/materials/CS229-DeepLearning.pdf

Deep Learning vs. Machine Learning



https://www.quora.com/How-do-I-start-learning-machine-learning-and-deep-learning-using-C++

Applications



Some medical imaging applications in which deep learning has achieved state-of-the-art results. From top-left to bottom-right:

- mammographic mass classification (Kooi et al., 2016)
- segmentation of lesions in the brain (Ghafoorian et al. (2016b)
- leak detection in airway tree segmentation (Charbonnier et al., 2017)
- diabetic retinopathy classification (Kaggle challenge 2015
- image from van Grinsven et al. (2016)
- prostate segmentation (top rank in PROMISE12 challenge)
- nodule classification (top ranking in LUNA16 challenge)
- breast cancer metastases detection in lymph nodes (CAMELYON16)
- human expert performance in skin lesion classification (Esteva et al., 2017)
- state-of-the-art bone suppression in x-rays, image from Yang et al. (2016c).

https://arxiv.org/abs/1702.05747

Organization of Course

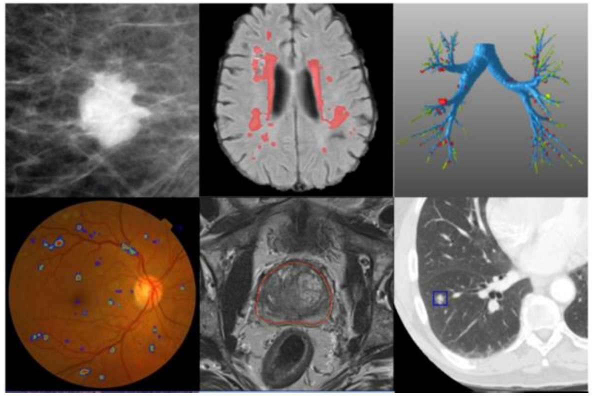
Overview

Overview of Deep Learning in Medical Image Computing
Neural Networks and CNN

Key Techs

Classification (Medical Image Diagnosis)
Detection (Landmark Localization and Detection)
Segmentation (Medical Image Segmentation)
GAN (Medical Image Synthesis)

Topics in Medical Image Computing



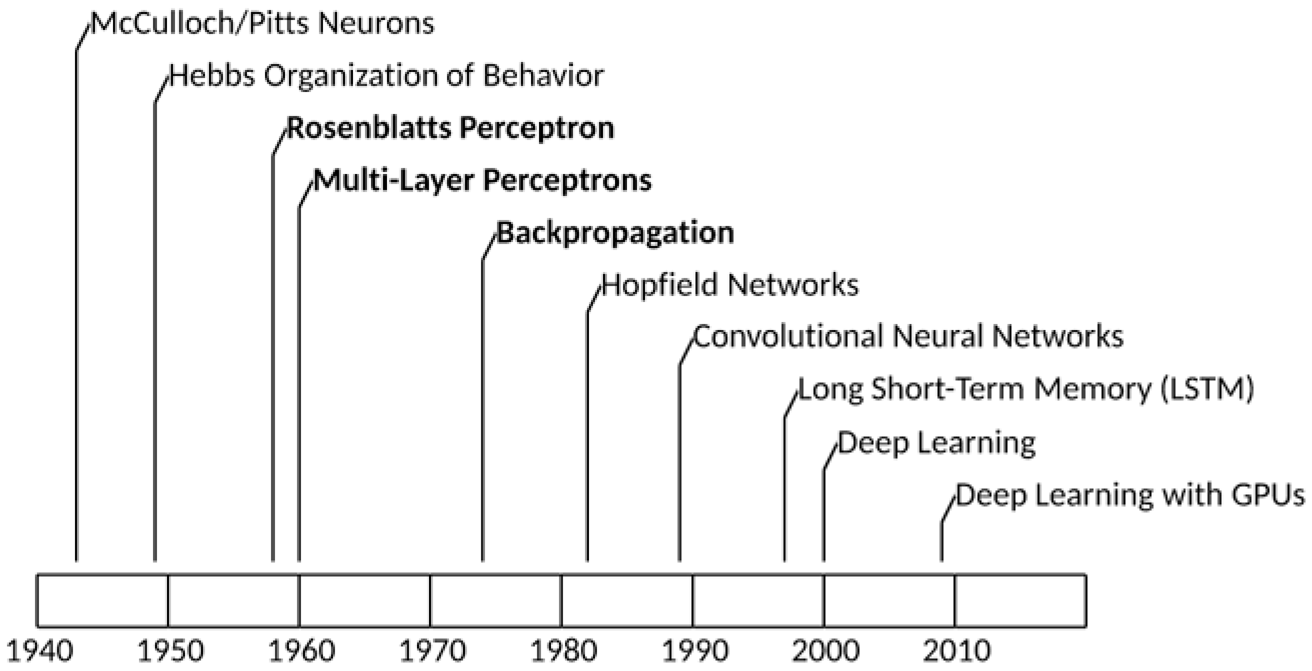
Definition

Artificial neural networks (ANN)：

computing systems vaguely inspired by the biological neural networks that constitute animal brains. Such systems "learn" to perform tasks by considering examples, generally without being programmed with any task-specific rules.

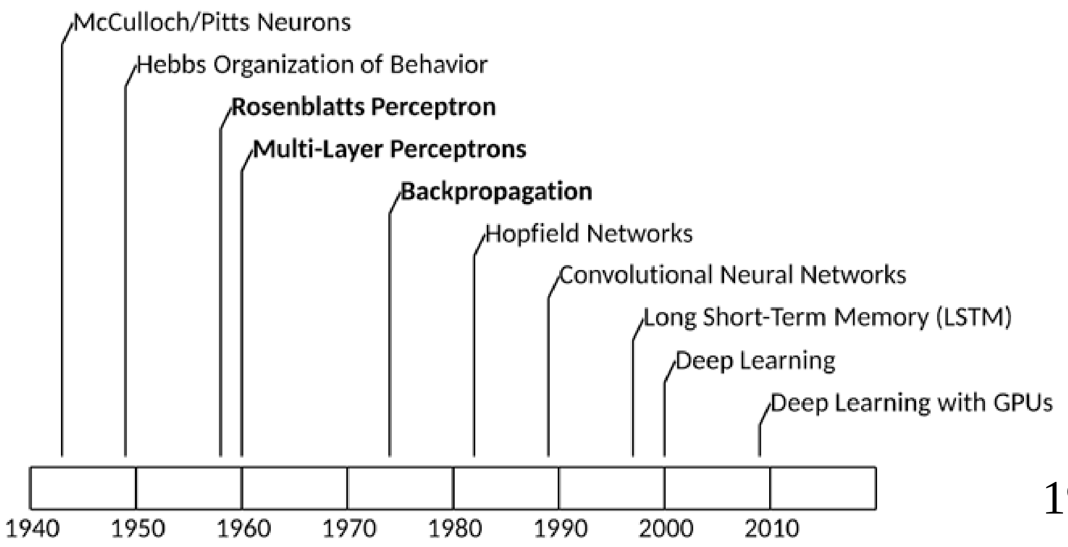
https://en.wikipedia.org/wiki/Artificial_neural_network

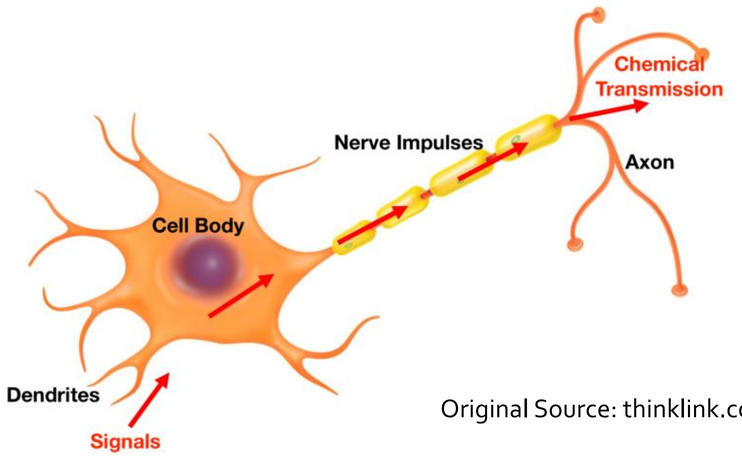
History



https://www.ibm.com/developerworks/library/cc-cognitive-neural-networks-deep-dive/index.html

McCulloch/Pitts Neurons

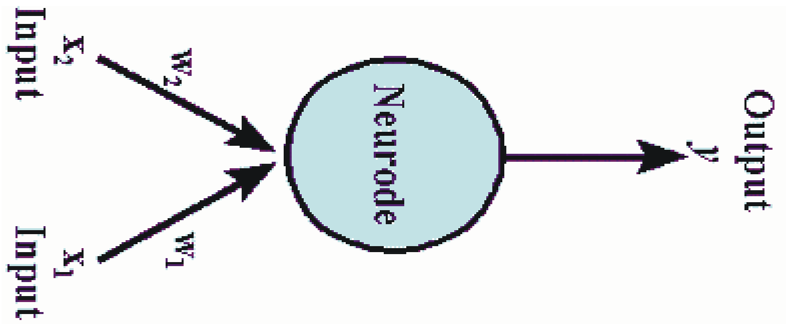




Original Source: thinklink.com

1943 paper, "A Logical Calculus of Ideas Immanent in Nervous Activity,"

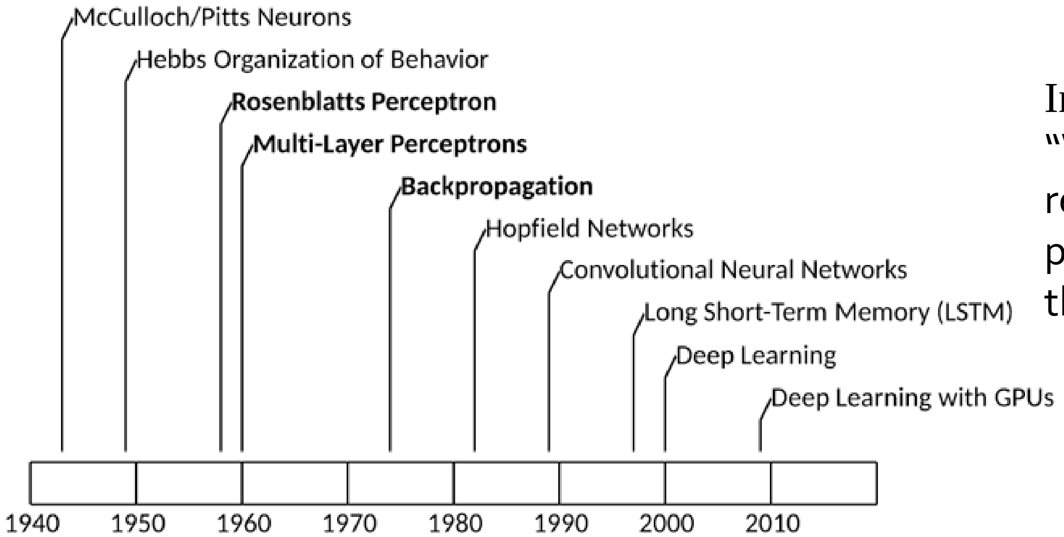
In the early 1940s, McCulloch and Pitts created a computational model for neural networks that spawned research not only into the brain but also its application to artificial intelligence.
One of the difficulties with the McCulloch-Pitts neuron was its simplicity. It only allowed for binary inputs and outputs, it only used the threshold step activation function and it did not incorporate weighting the different inputs.



https://www.ibm.com/developerworks/library/cc-cognitive-neural-networks-deep-dive/index.html

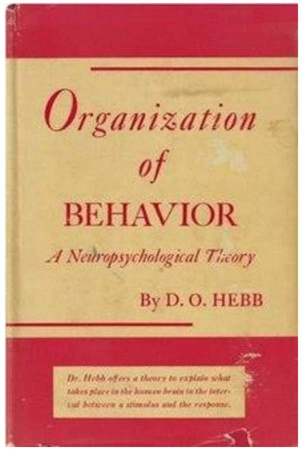
https://web.csulb.edu/~cwallis/artificialn/History.htm

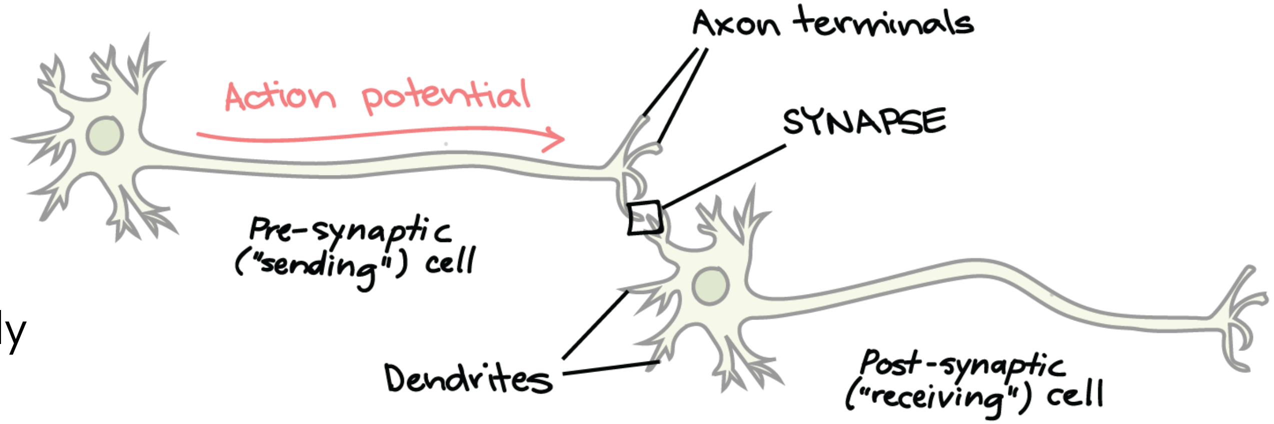
Hebb’s Organization of Behavior



In his book, *The Organization of Behavior*

“When an axon of cell A is near enough to excite a cell B and repeatedly or persistently takes part in firing it, some growth process or metabolic change takes place in one or both cells such that A’s efficiency, as one of the cells firing B, is increased.”



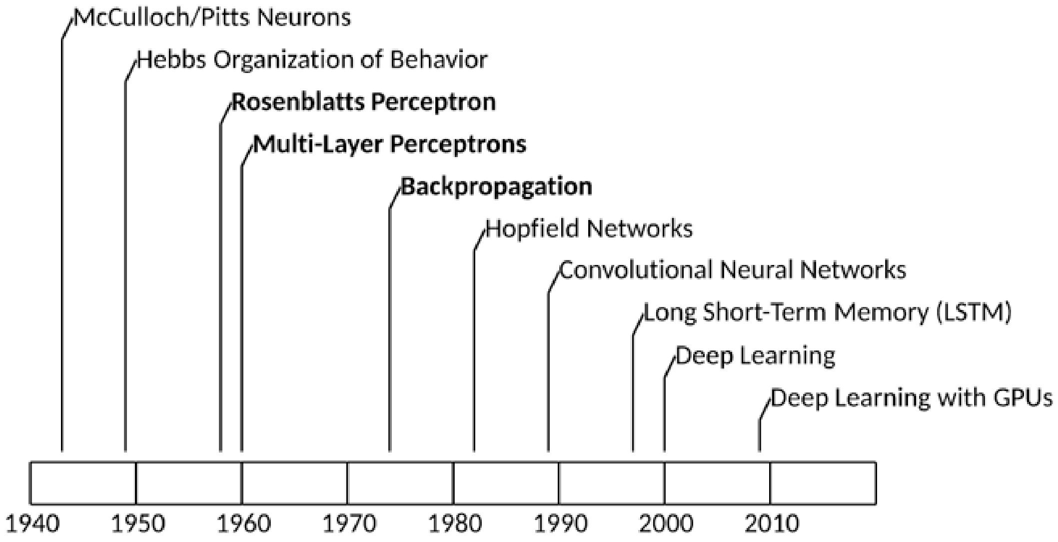


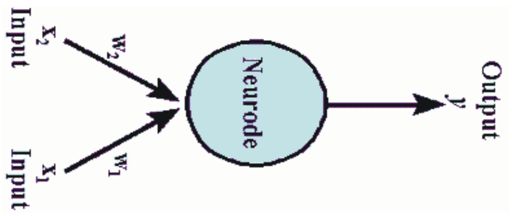
Later in this decade, Donald Hebb created *Hebbian learning*, which observed from biology that the synapse between two neurons is strengthened if the two neurons are simultaneously active.

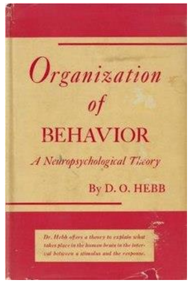
https://www.ibm.com/developerworks/library/cc-cognitive-neural-networks-deep-dive/index.html

https://www.khanacademy.org/science/biology/human-biology/neuron-nervous-system/a/the-synapse

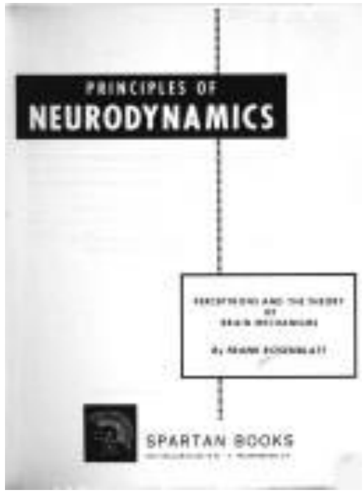
Rosenblatt's Perceptron

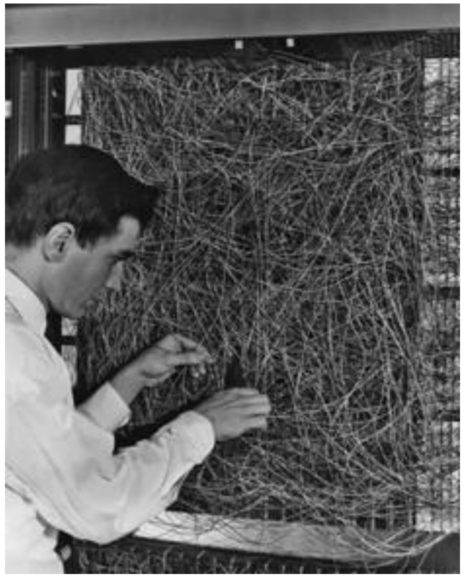






He discussed the perceptron in his 1962 book, *Principles of Neurodynamics*.



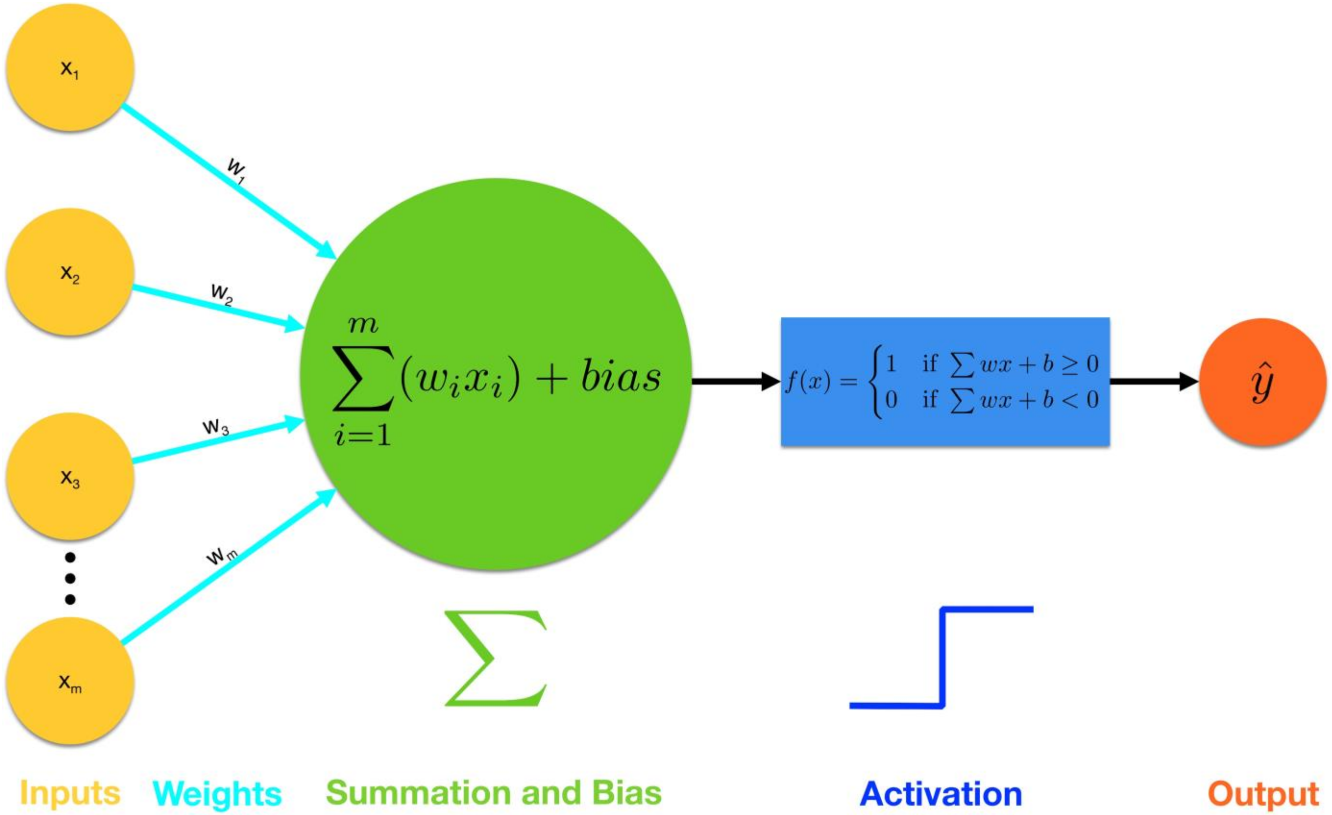


In 1958, Frank Rosenblatt created the perceptron, a simple neural model that could be used to classify data into two sets. However, this model suffered in that it could not correctly classify an exclusive-OR.

https://www.ibm.com/developerworks/library/cc-cognitive-neural-networks-deep-dive/index.html

https://web.csulb.edu/~cwallis/artificialn/History.htm
Rosenblatt and Perceptron, Source: The New Yorker
http://nahuakang.com/page3/

Perceptron



1. **Inputs** are fed into the perceptron
2. **Weights** are multiplied to each input
3. **Summation** and then add **bias**
4. **Activation function** is applied. Note that here we use a step function, but there are other more sophisticated activation functions like **sigmoid, hyperbolic tangent (tanh), rectifier (relu)** and more. No worries, we will cover many of them in the future!
5. **Output** is either triggered as 1, or not, as 0. Note we use $\hat{y}$ to label output produced by our perceptron model

http://nahuakang.com/page3/

Perceptron Example

You need to decide whether to study DL or not?

There are 3 factors that influence your decision:

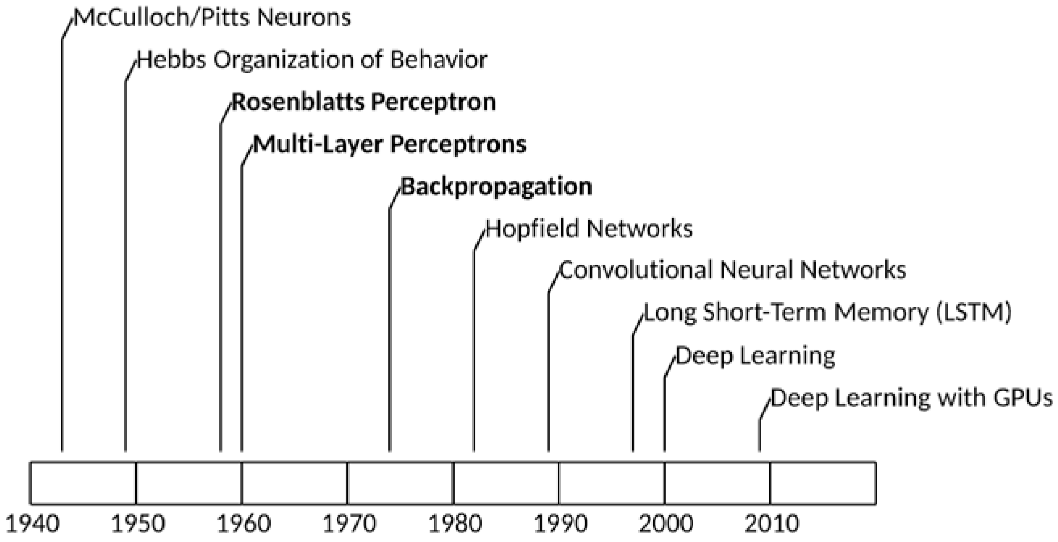
X_1 1. If you will earn more money after mastering DL (Yes: 1, No: 0)

X_2 2. Is the relevant mathematics and programming easy (Yes: 1, No: 0)

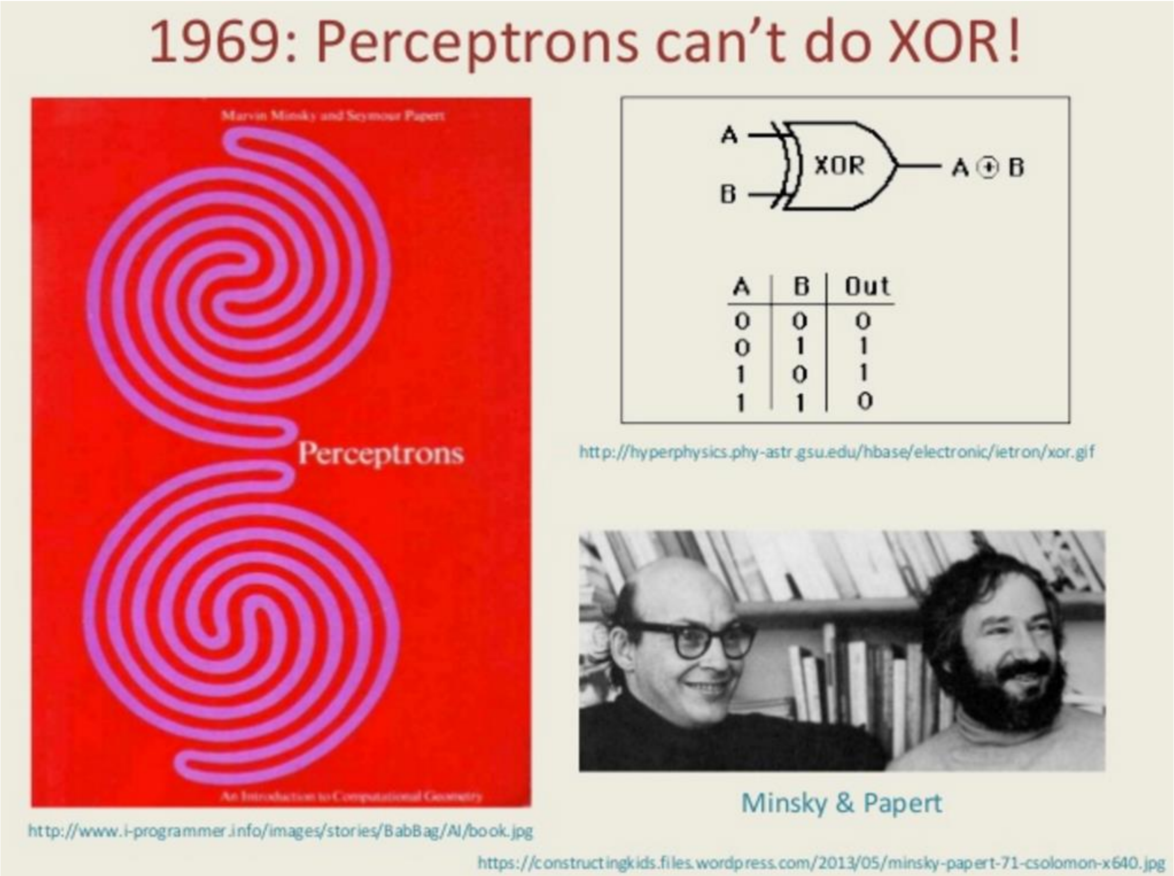
X_3 3. You can work on DL immediately without the need for an expensive GPU (Yes: 1, No: 0)

http://nahuakang.com/page3/

AI Winter

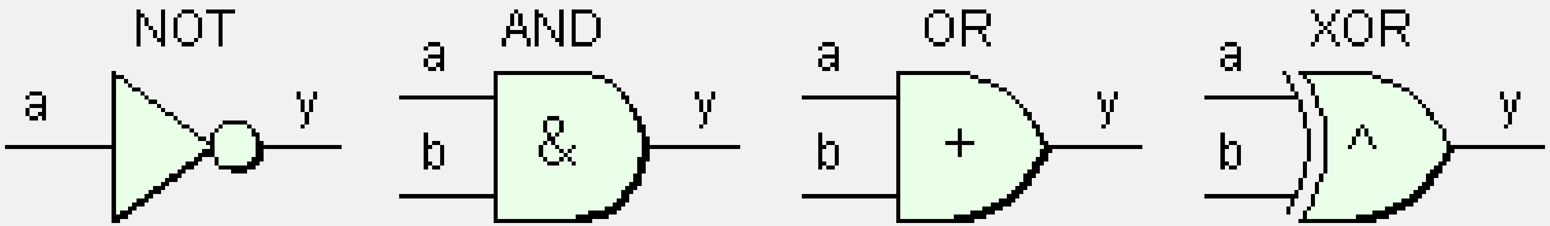


Marvin Minsky and Seymour Papert exploited this limitation in 1969 in their book Perceptrons in an attempt to return focus to symbolic methods for AI. The result was a decade-long decline in connectionist research funding. A



https://www.ibm.com/developerworks/library/cc-cognitive-neural-networks-deep-dive/index.html

Design XOR?



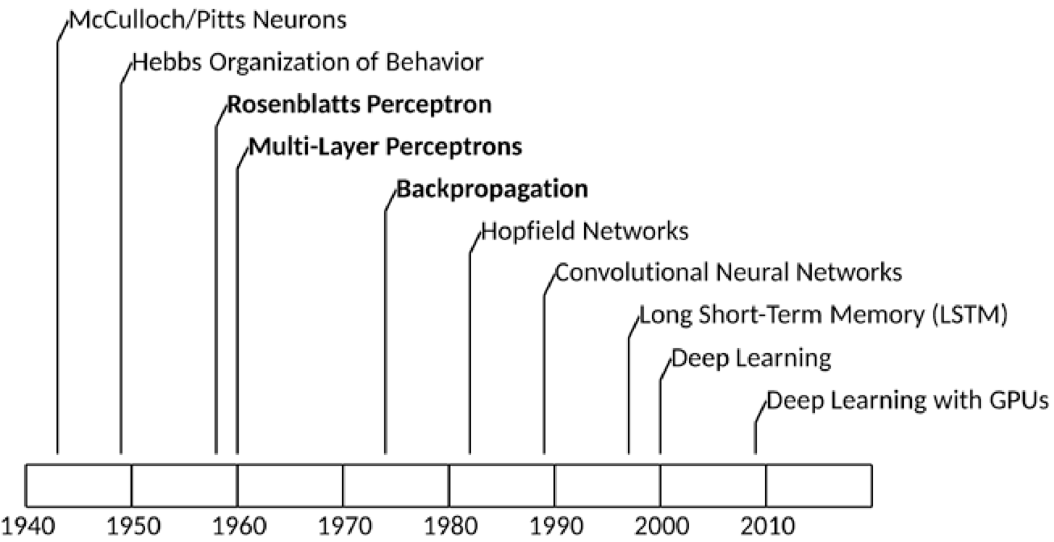
a	y
0	1
1	0

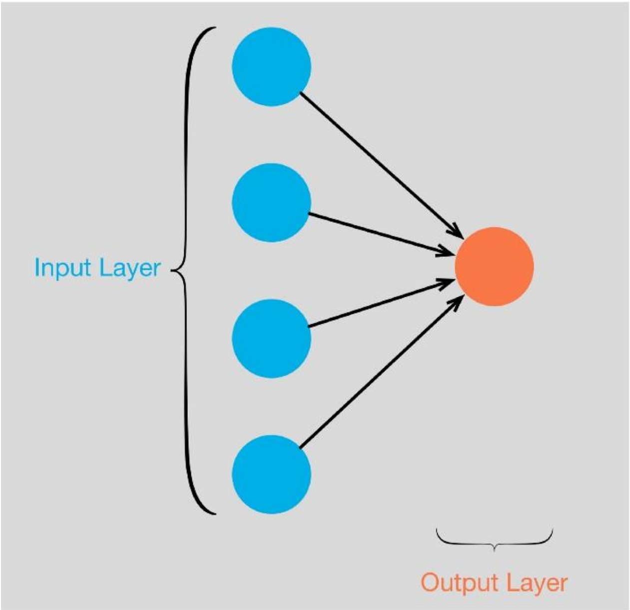
a	b	y
0	0	0
0	1	0
1	0	0
1	1	1

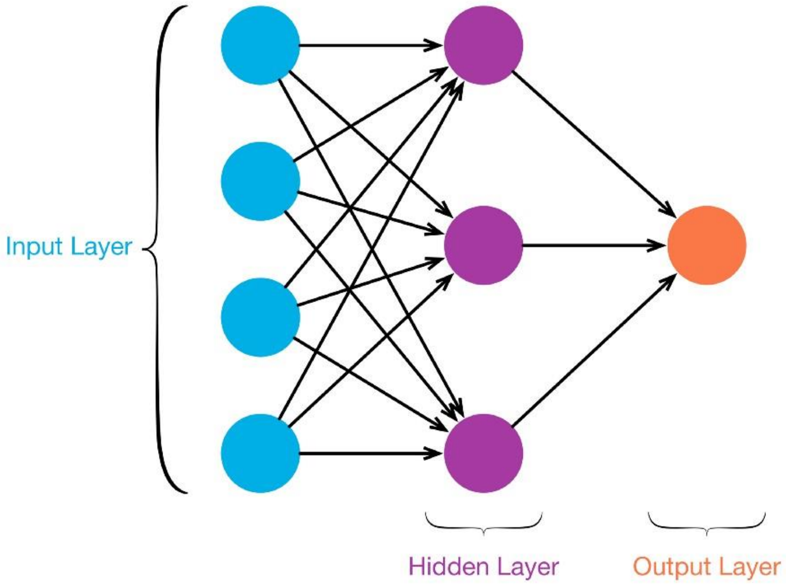
a	b	y
0	0	0
0	1	1
1	0	1
1	1	1

a	b	y
0	0	0
0	1	1
1	0	1
1	1	0

Multi-Layer Perceptrons





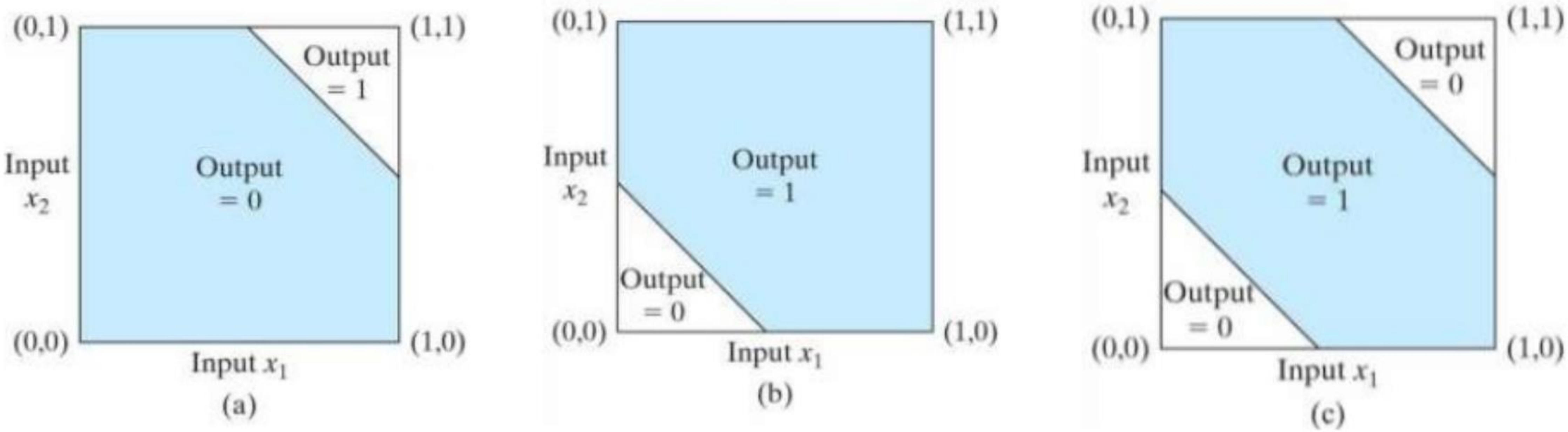


Idea is to add more layers

https://towardsdatascience.com/multi-layer-neural-networks-with-sigmoid-function-deep-learning-for-rookies-2-bf464f09eb7f

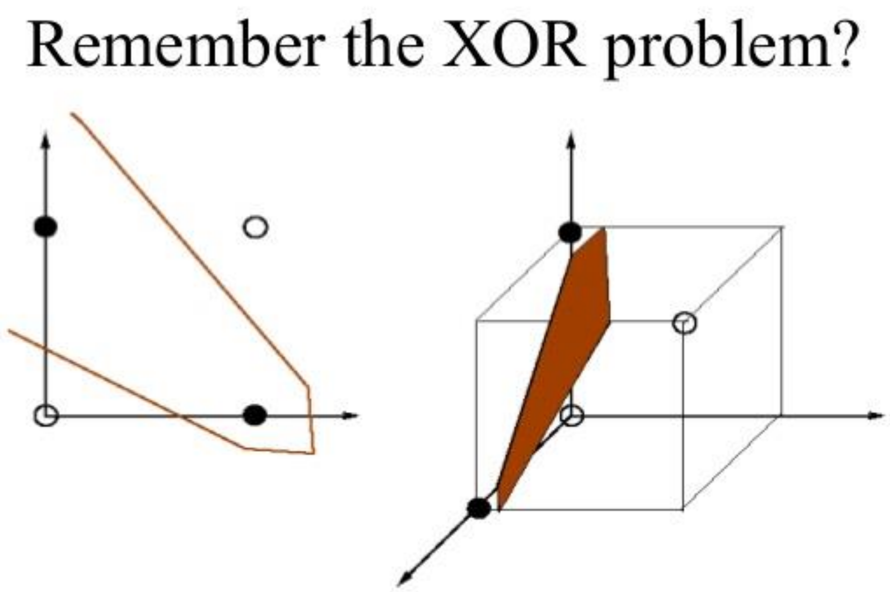
https://www.ibm.com/developerworks/library/cc-cognitive-neural-networks-deep-dive/index.html

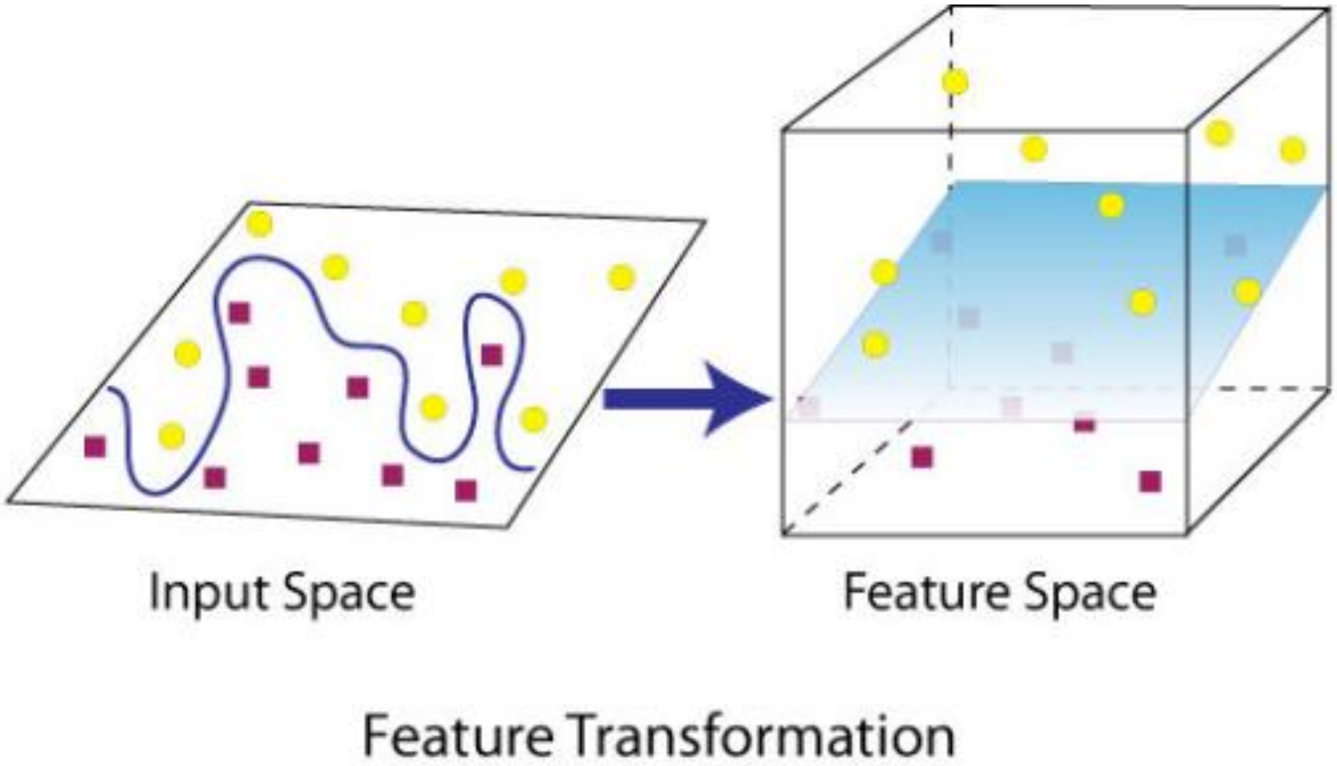
More Layers



https://www.slideshare.net/MostafaGMMostafa/neural-networks-multilayer-perceptron

Hyper Plane

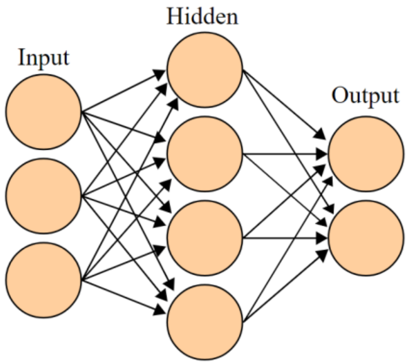




https://www.slideshare.net/nawalksharma/svm-and-kernel-machines

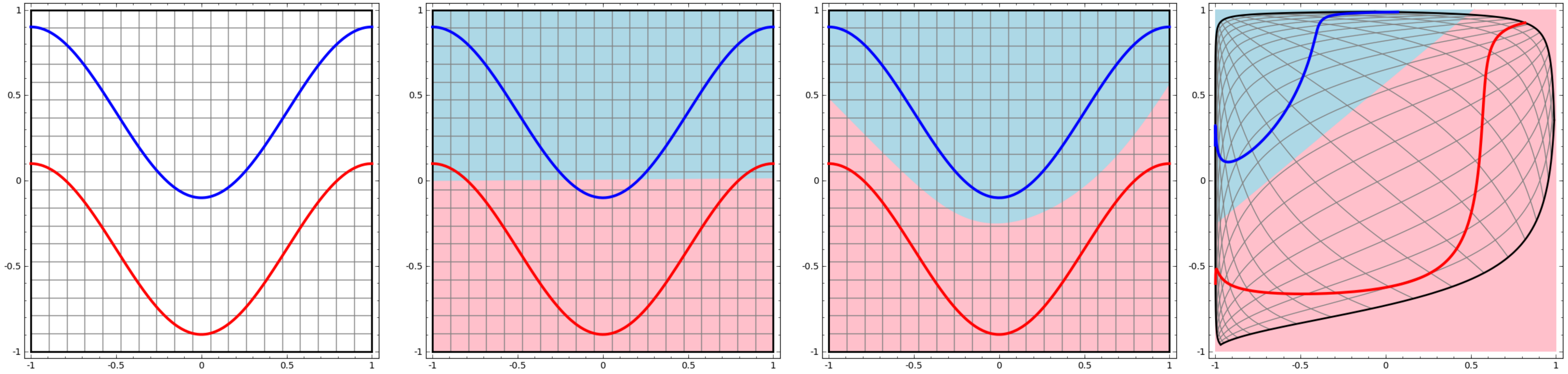
https://openi.nlm.nih.gov/detailedresult.php?img=PMC2850872_1472-6947-10-16-1&req=4

Intuitive Understanding

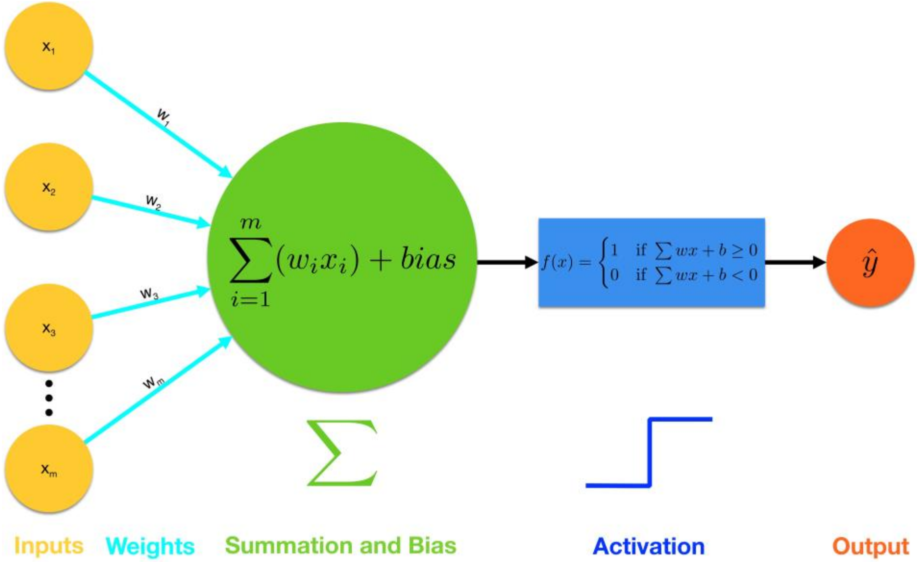


The hidden layer learns a representation so that the data is linearly separable

http://colah.github.io/posts/2014-03-NN-Manifolds-Topology/



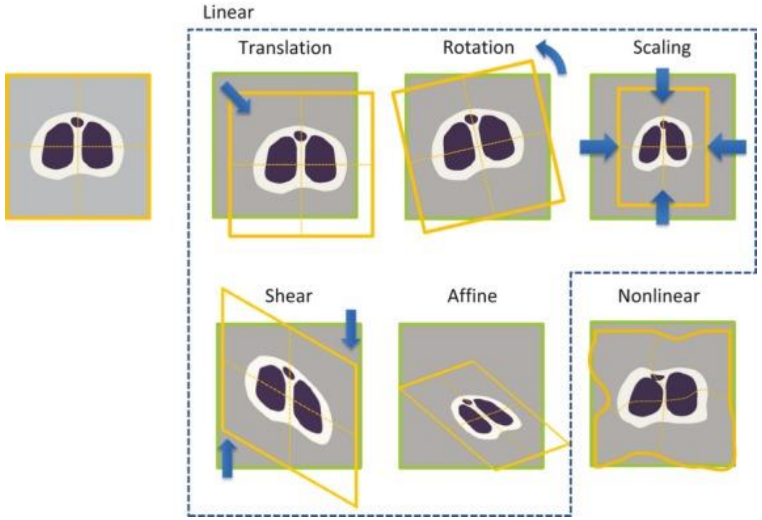
From Spatial Transform Point



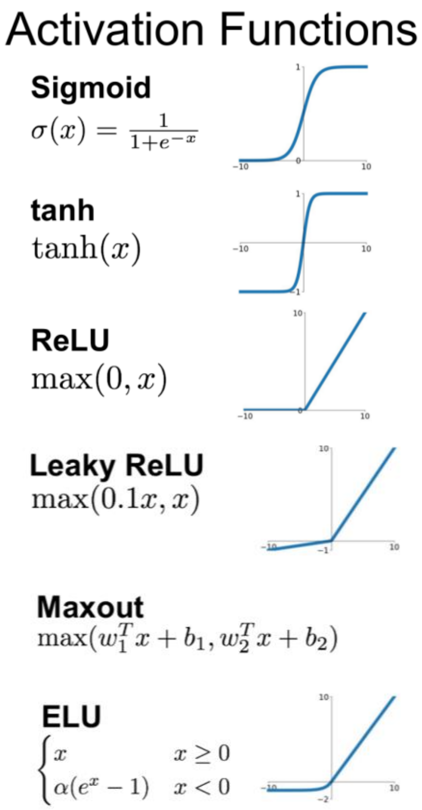
$$\hat{y} = \sigma\,(w^T x + b)$$

$$w^T x + b$$

linear transformation
(e.g. affine registration)

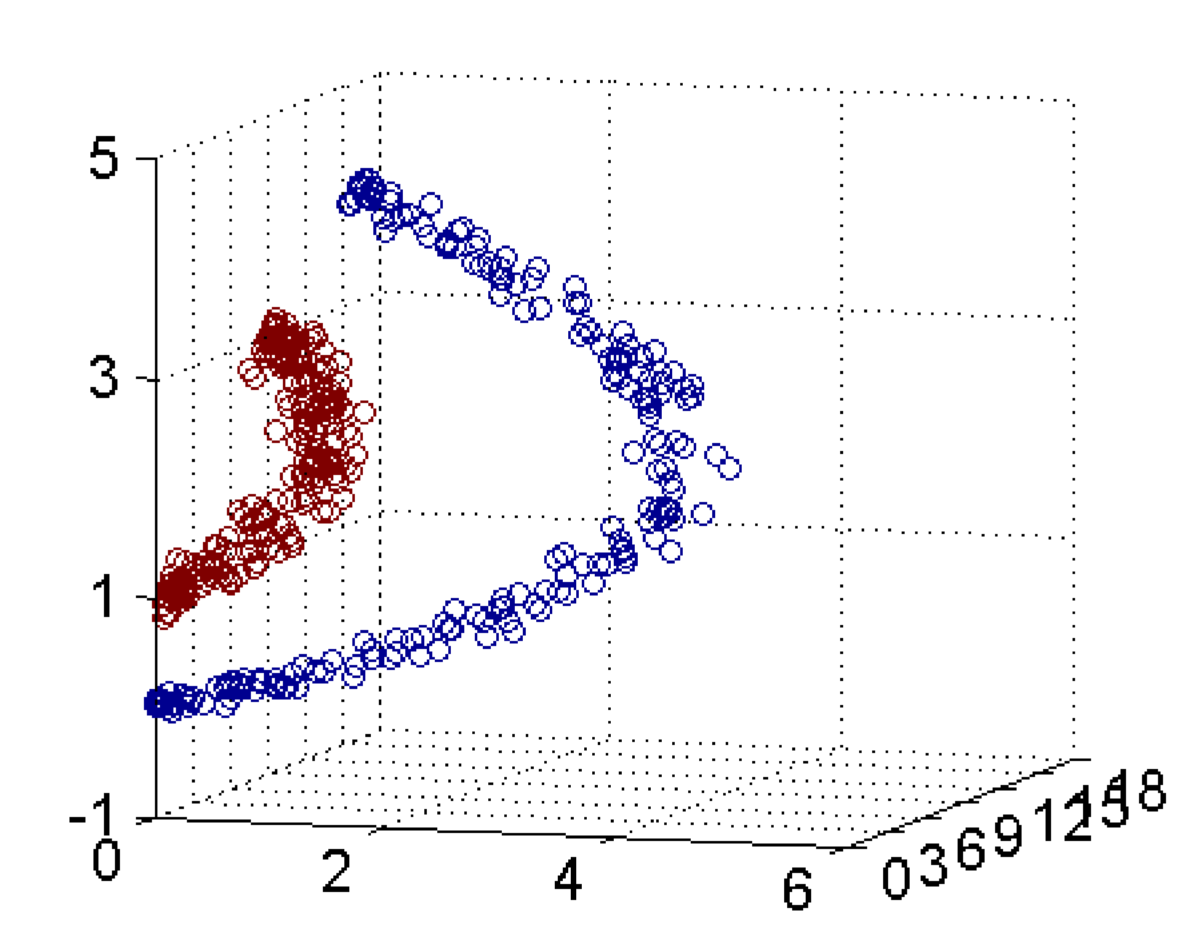


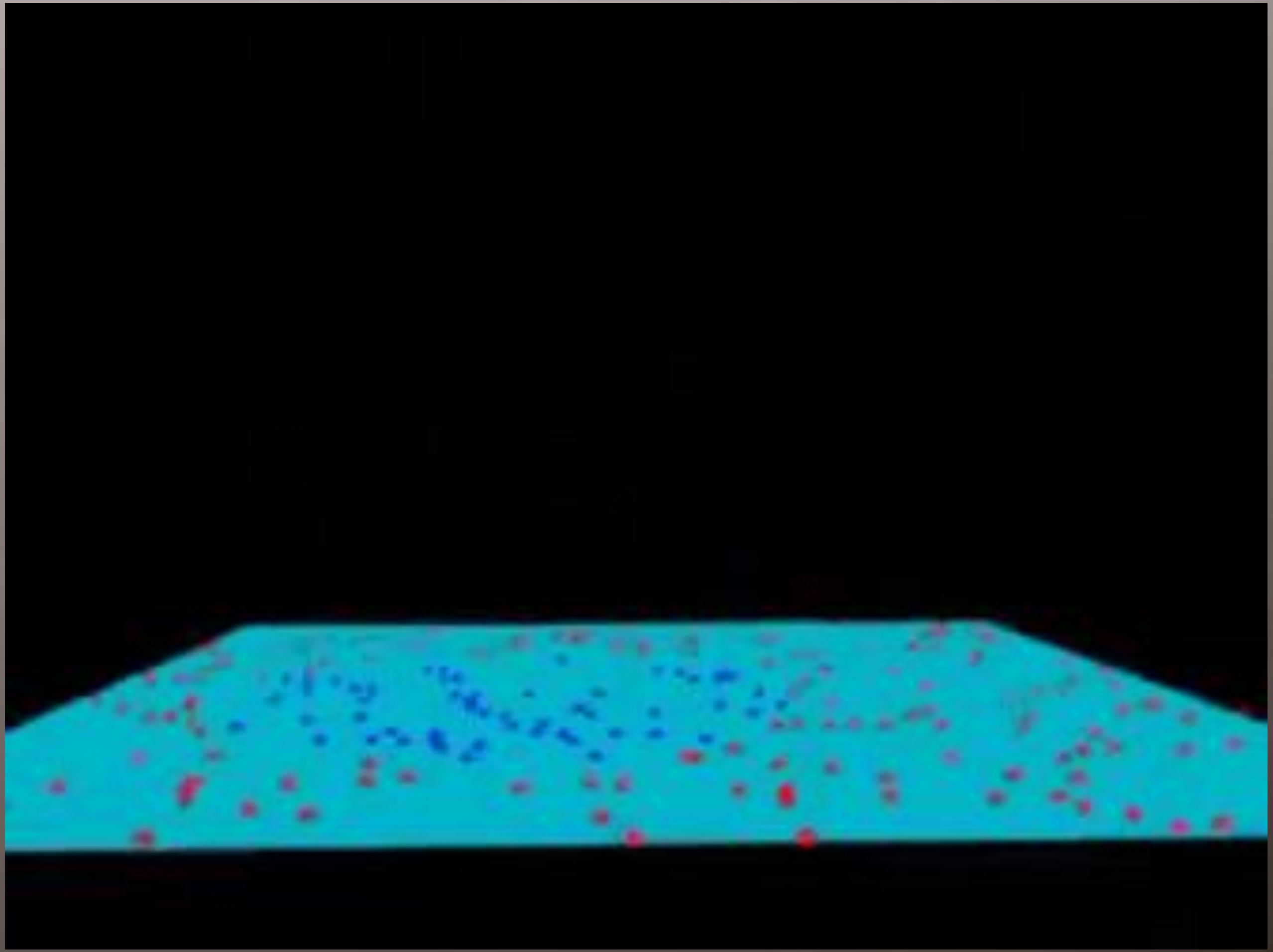
$$\sigma\,(\cdot)$$



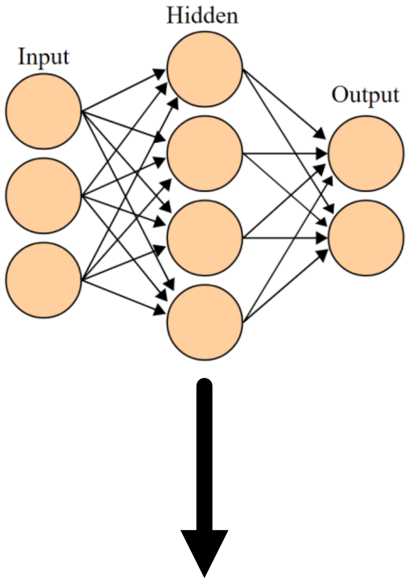
http://nahuakang.com/page3/

Hyper Plane

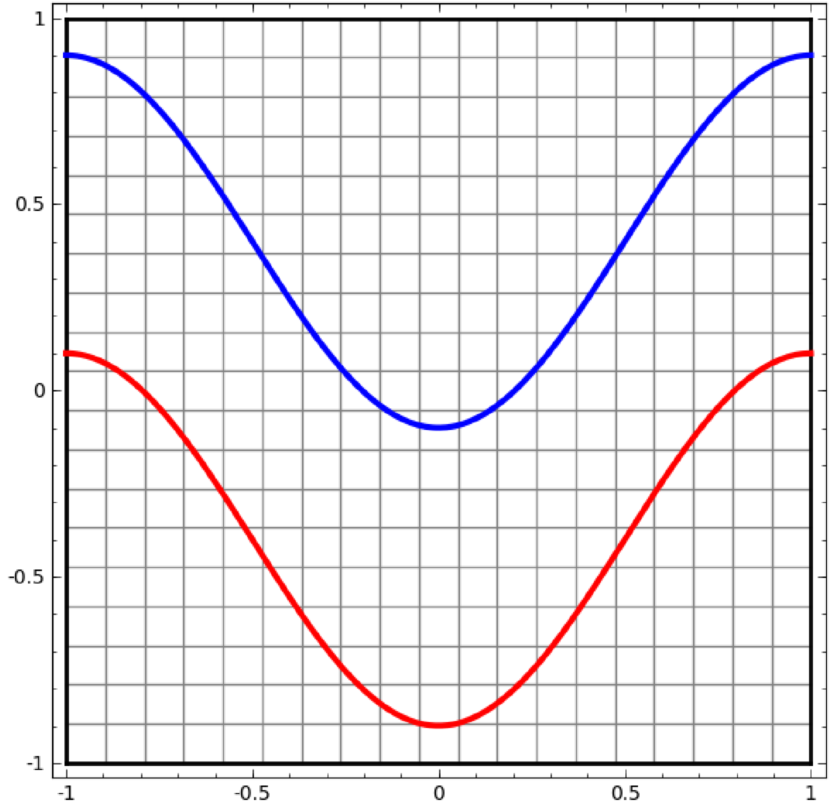


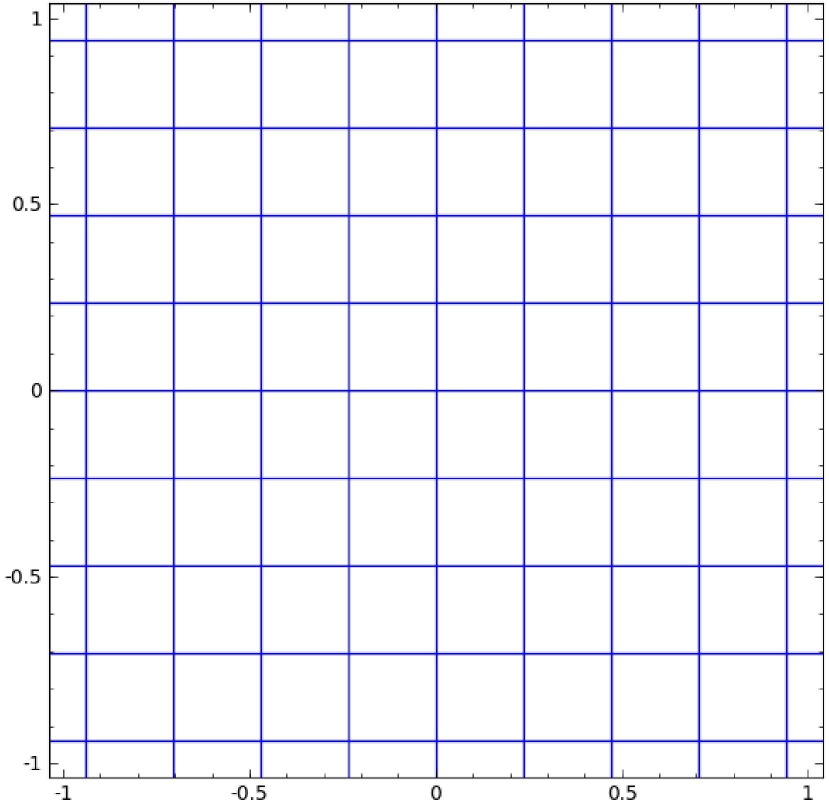


(Deep) Neural Network = Hyper Plan



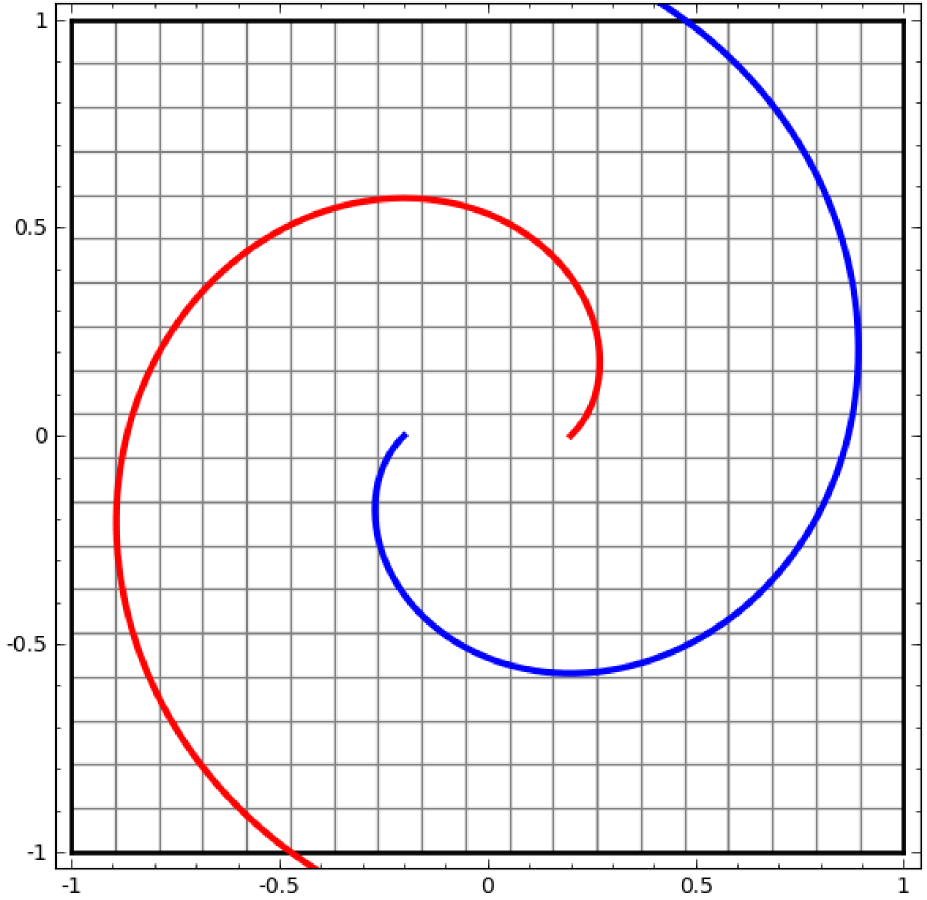
$$\tanh(Wx + b)$$

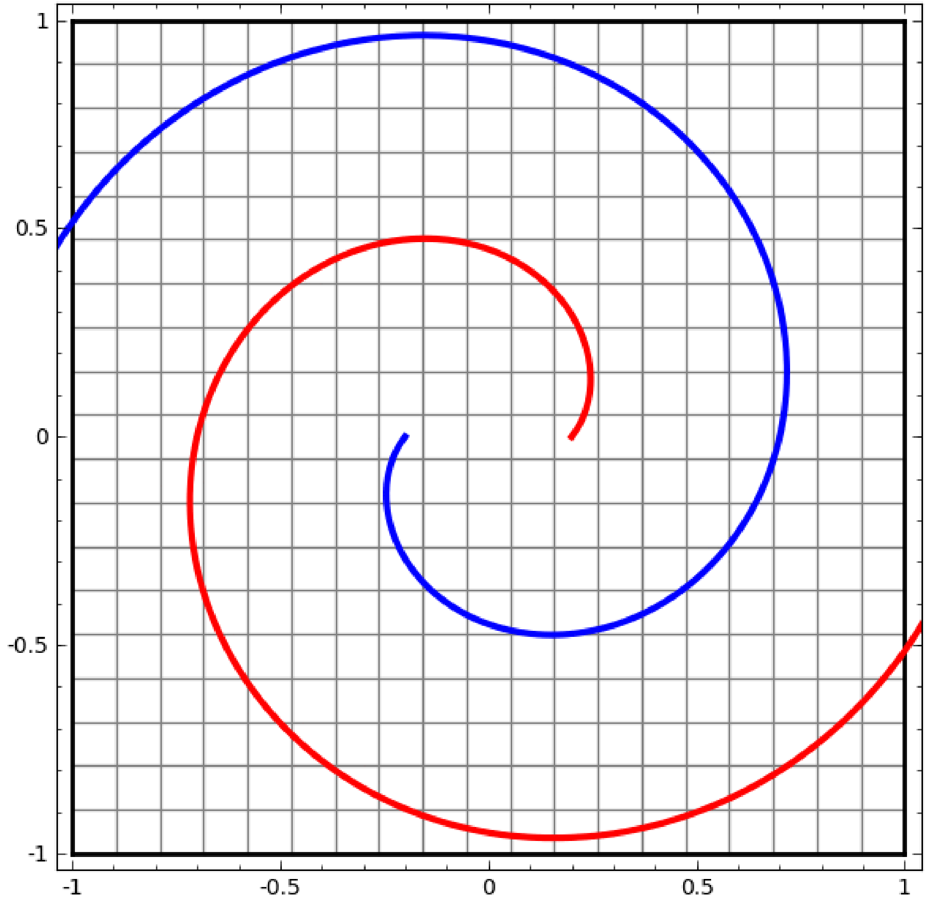




http://colah.github.io/posts/2014-03-NN-Manifolds-Topology/

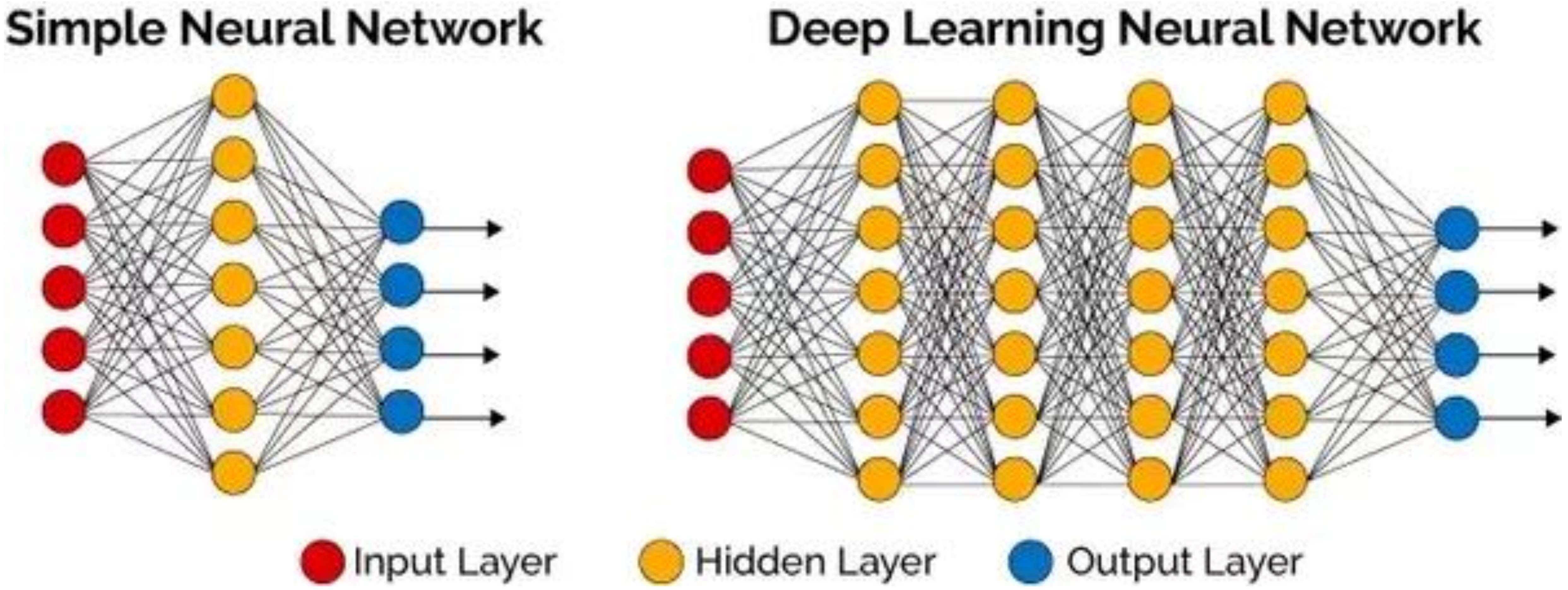
Need Good Training



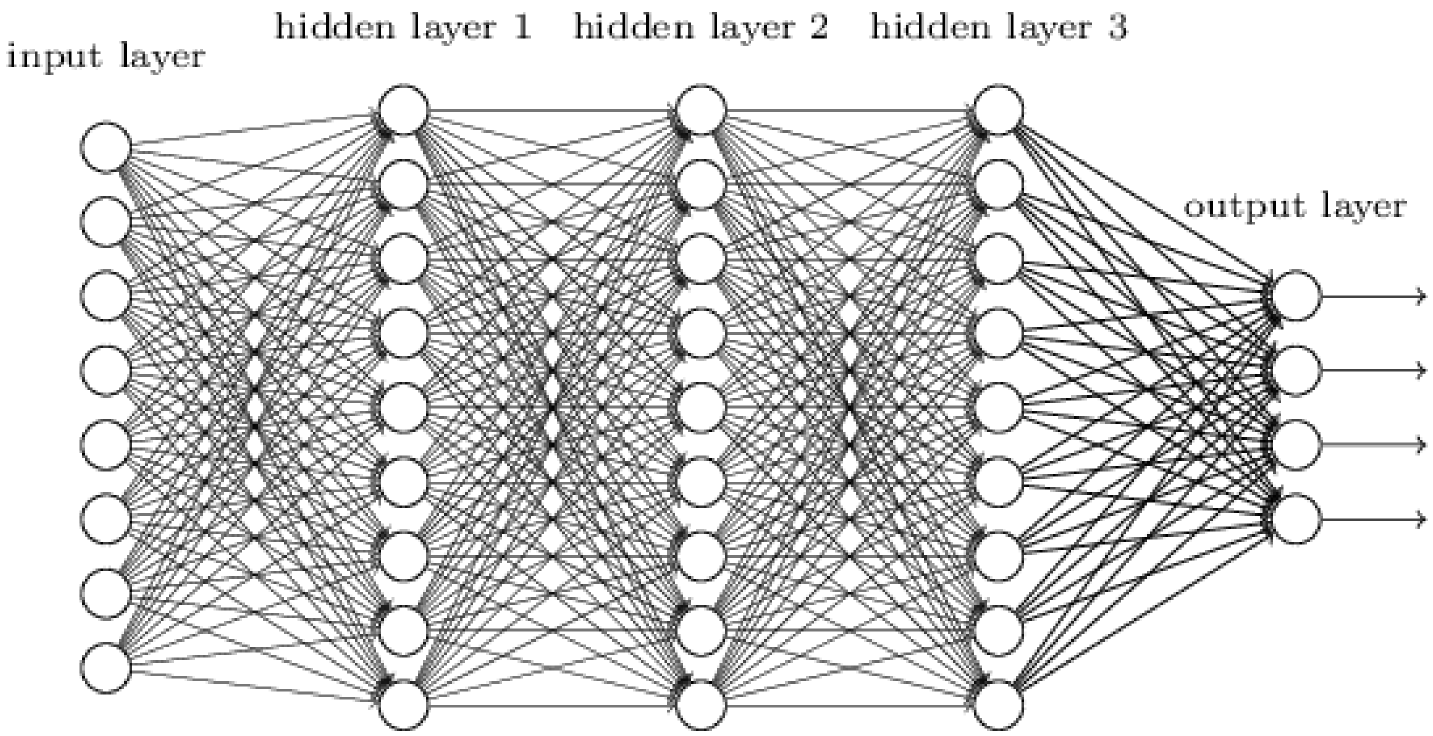


http://colah.github.io/posts/2014-03-NN-Manifolds-Topology/

Deep Neural Network



1D Data



Vanderbilt

UTK

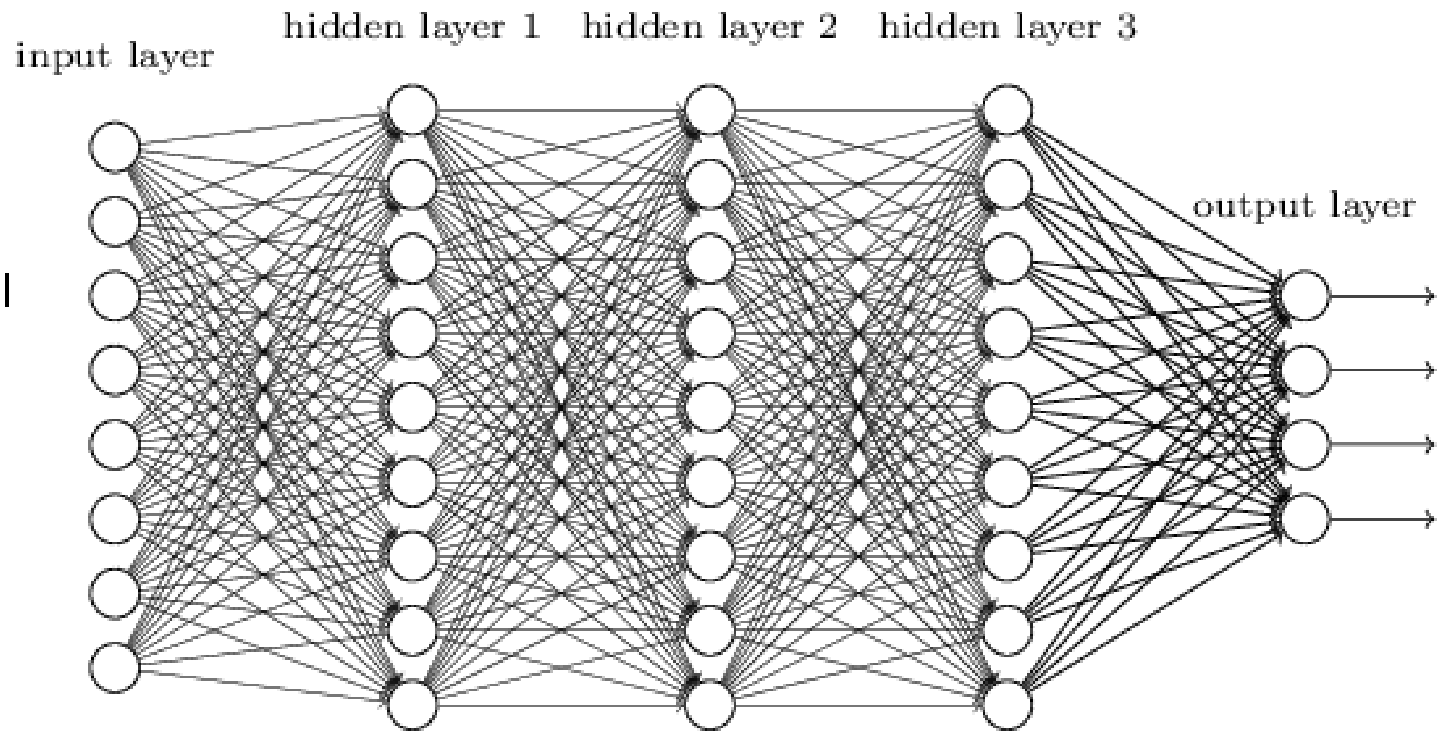
1D Data

GPA

SAT

Football

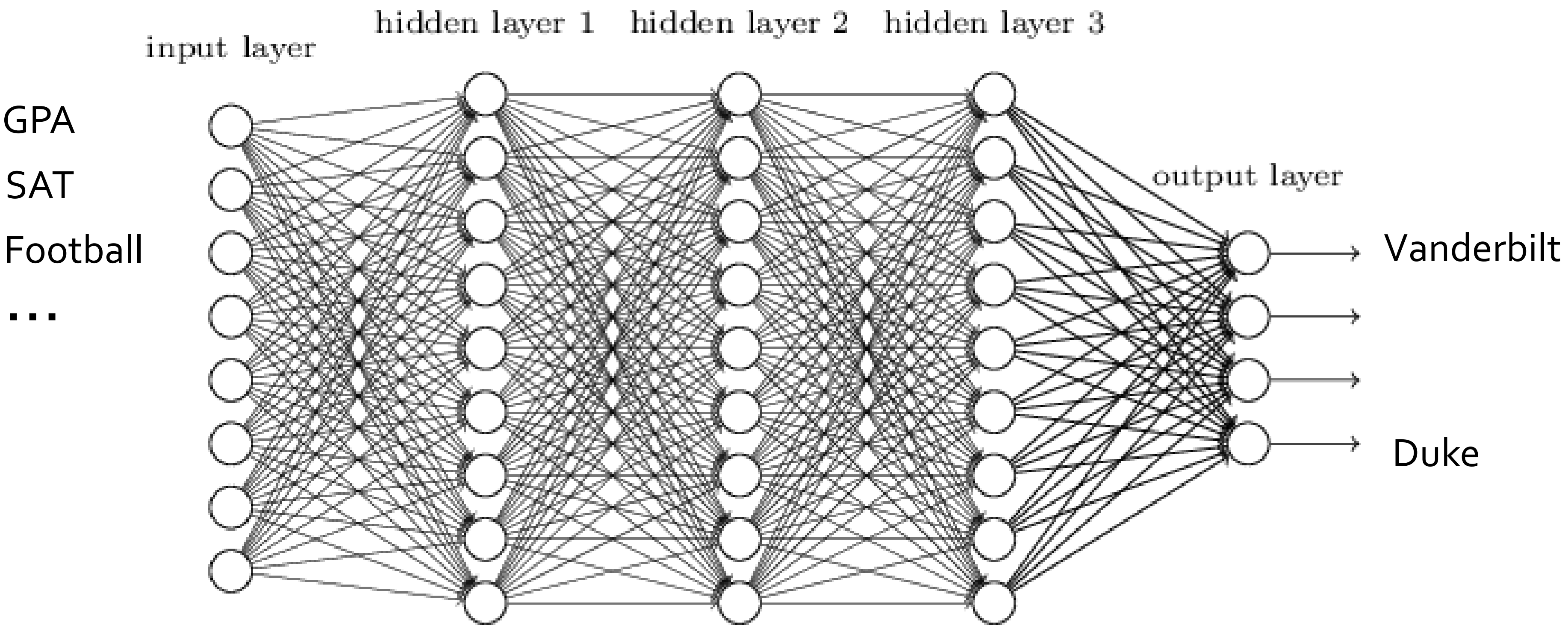
...



Vanderbilt

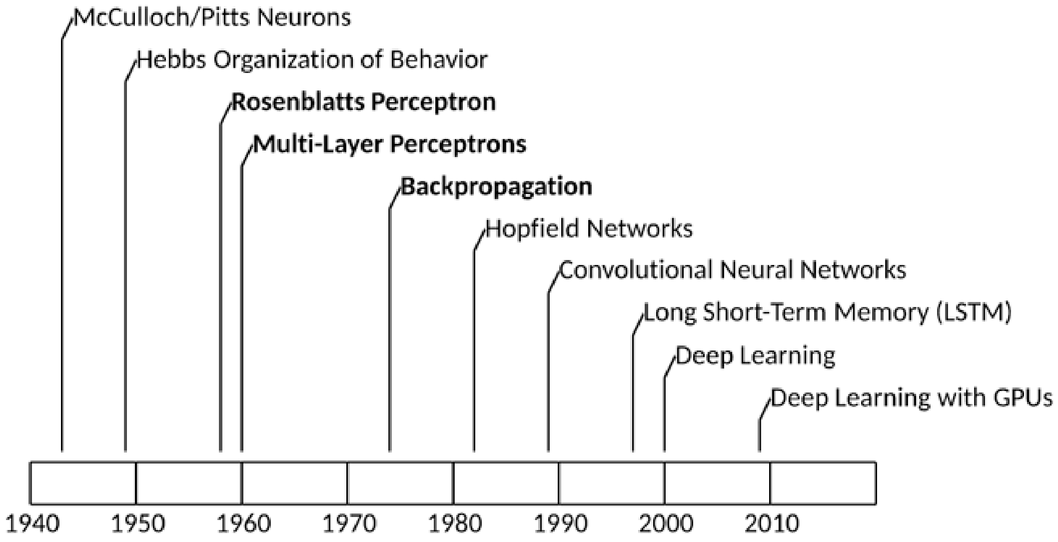
UTK

1D Data



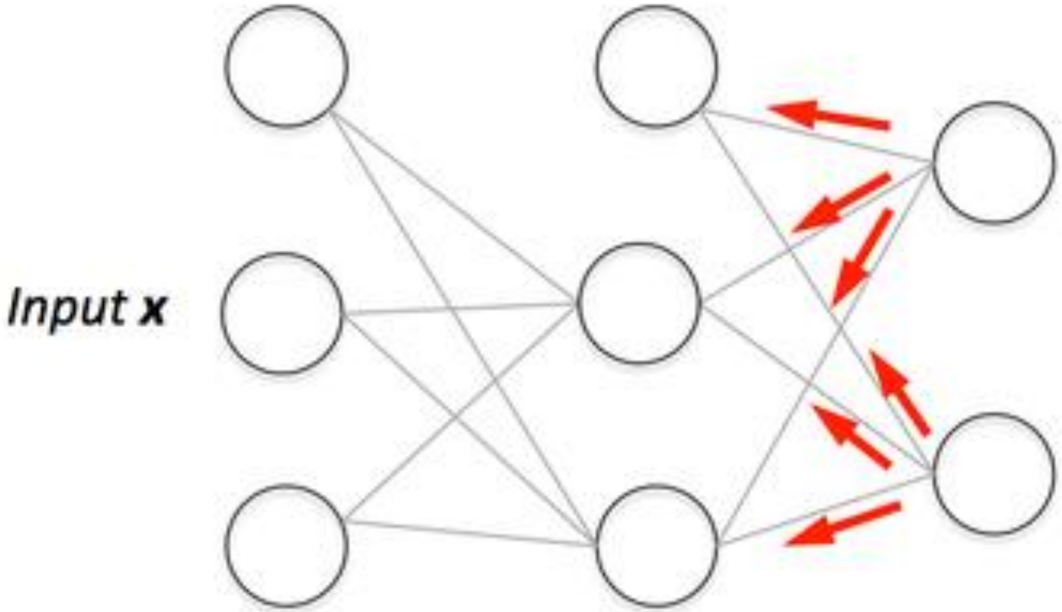
input layer
hidden layer 1
hidden layer 2
hidden layer 3
output layer
GPA
SAT
Football
...
Vanderbilt
Duke

Backpropagation



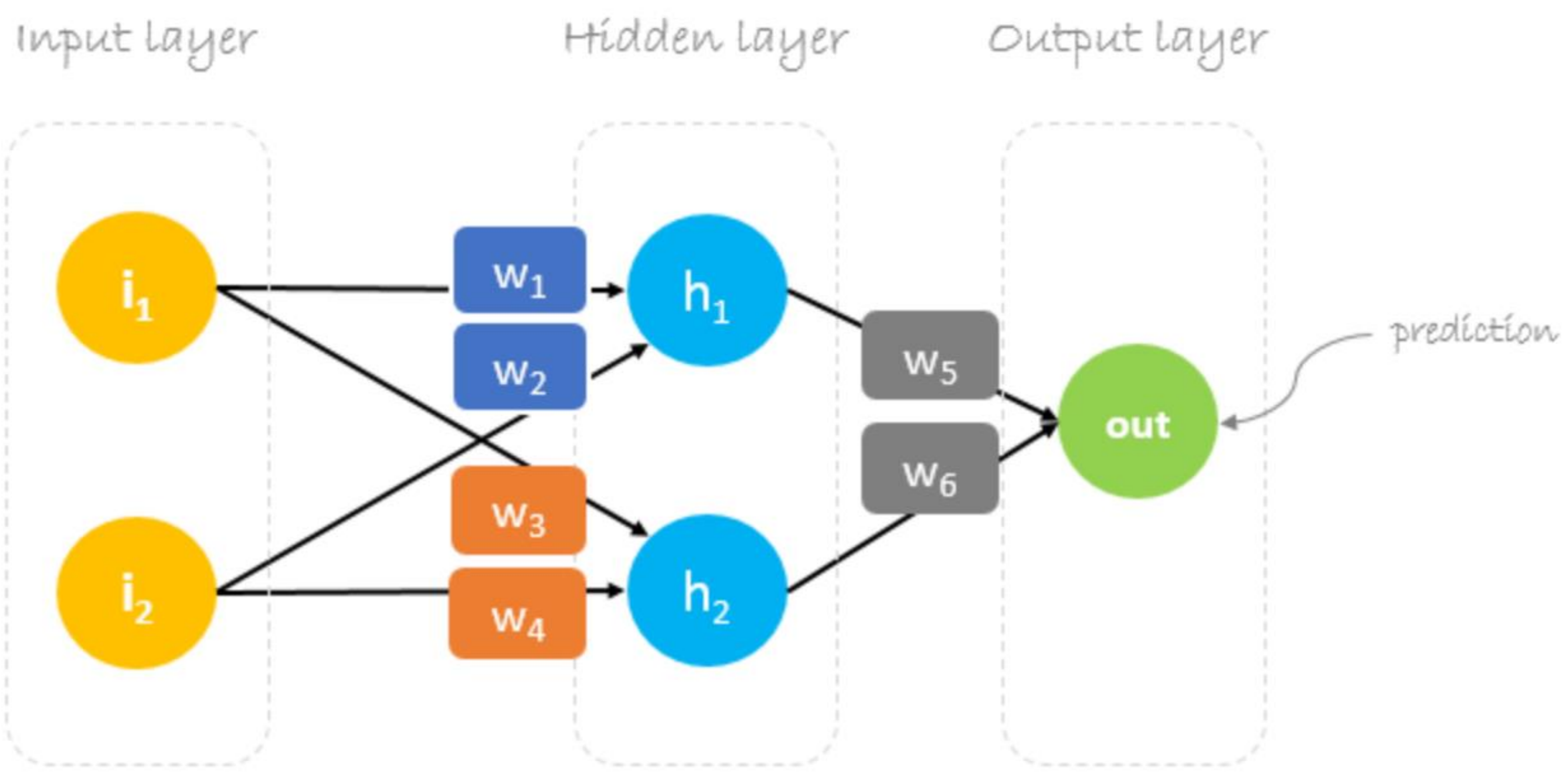
In 1975, Paul Werbos created the back-propagation algorithm, which could successfully train multilayer perceptrons and introduced various new applications of multilayer neural networks. This innovation led to a resurgence in neural network research and further popularized the method to solve real problems.

https://www.ibm.com/developerworks/library/cc-cognitive-neural-networks-deep-dive/index.html



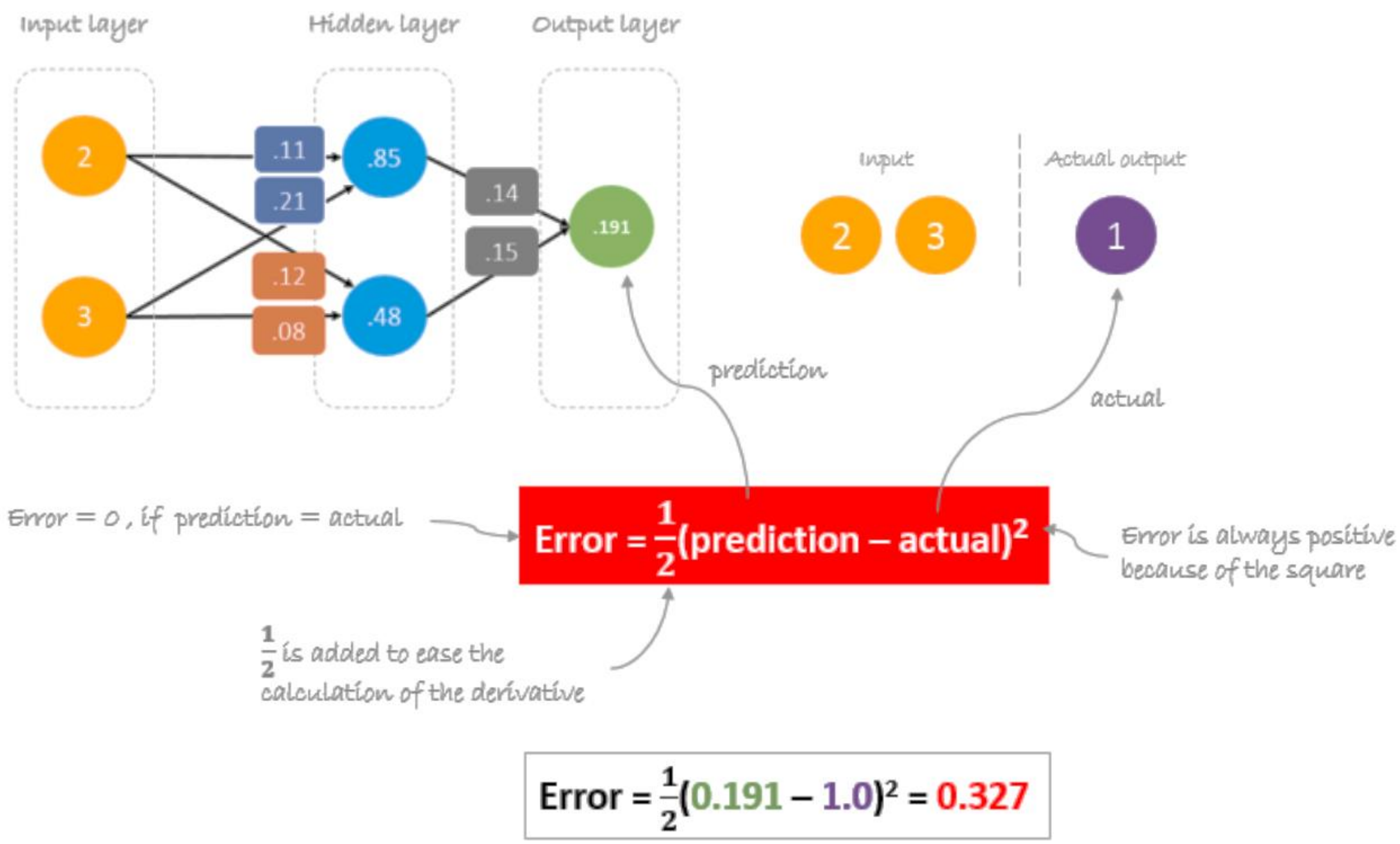
http://hmkcode.github.io/ai/backpropagation-step-by-step/

Deduction



http://hmkcode.github.io/ai/backpropagation-step-by-step/

Forward Path



http://hmkcode.github.io/ai/backpropagation-step-by-step/

The question now is

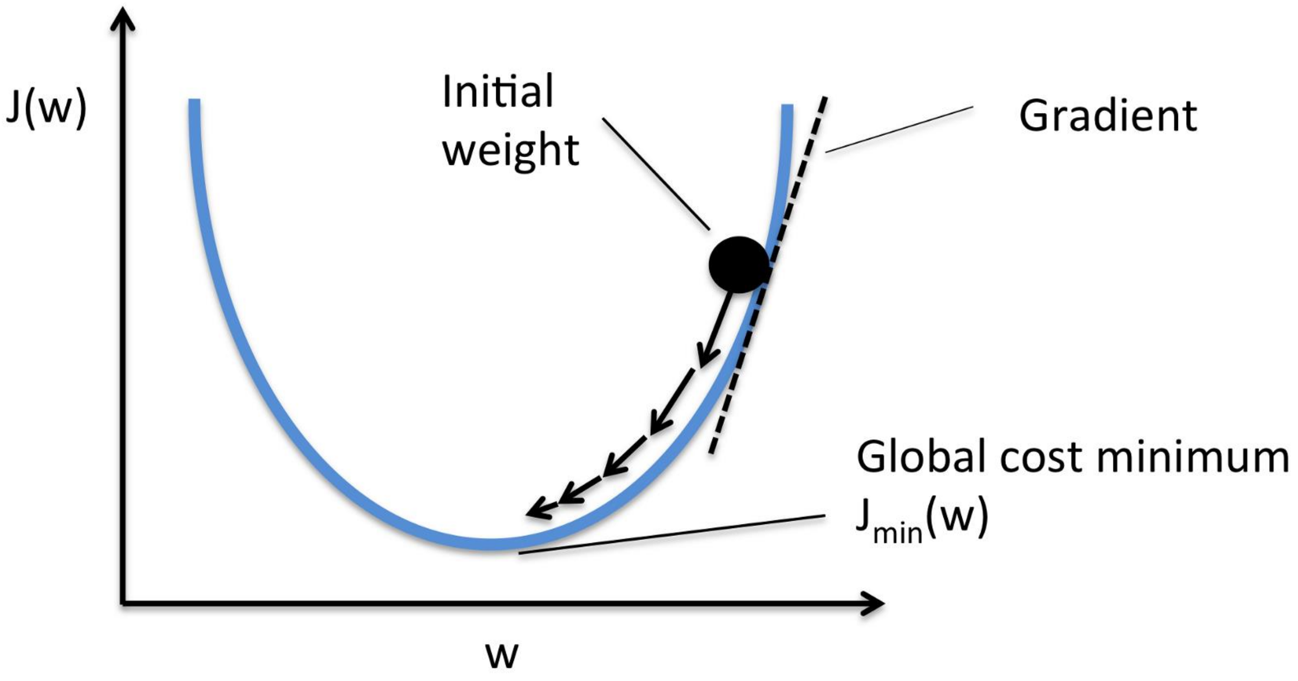
How to change\update the weights value so that the error is reduced?

The answer is

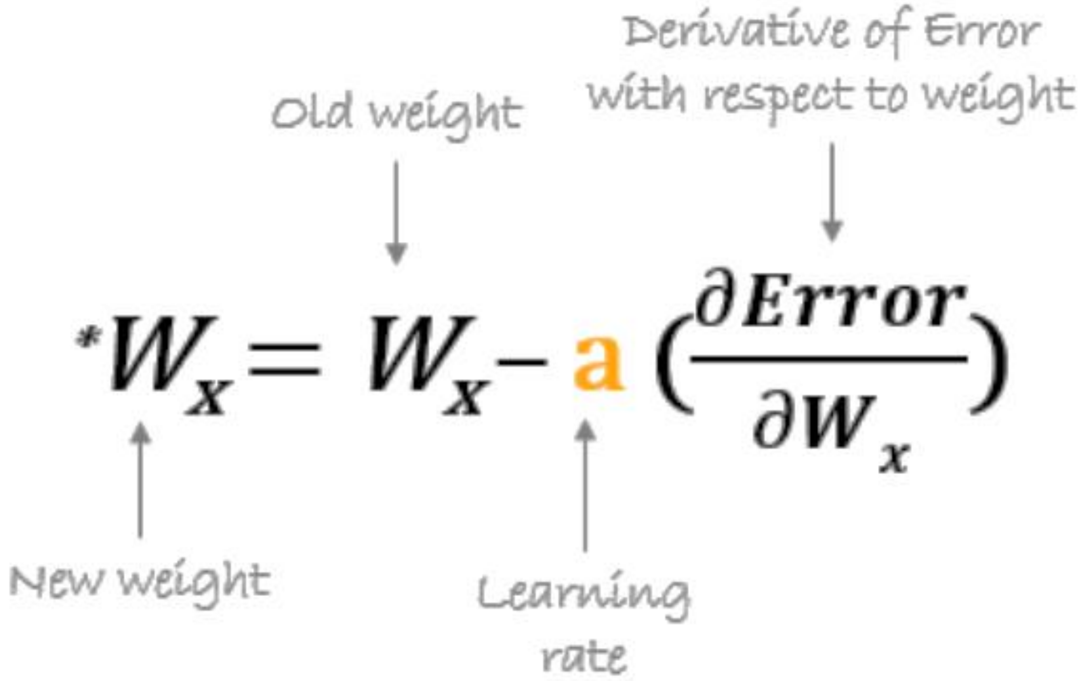
Backpropagation!

Back Propagation & Gradient Descent

Backpropagation, short for "backward propagation of errors", is a mechanism used to update the **weights** using gradient descent. It calculates the gradient of the error function with respect to the neural network's weights. The calculation proceeds backwards through the network

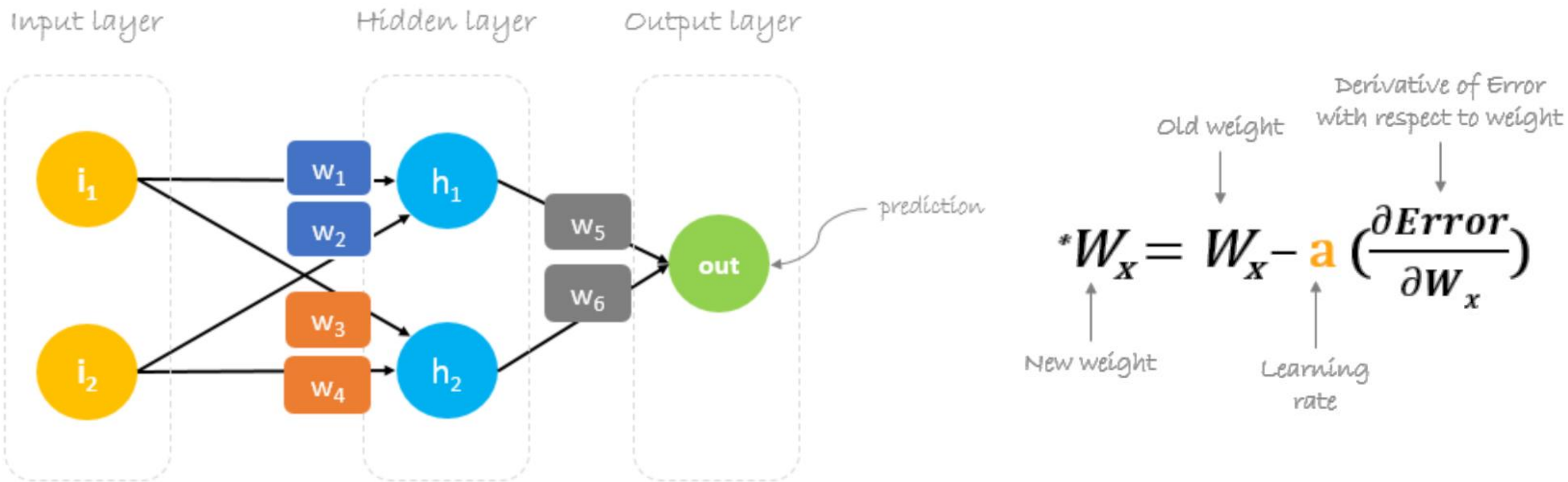


https://hackernoon.com/gradient-descent-aynk-7cbe95a778da



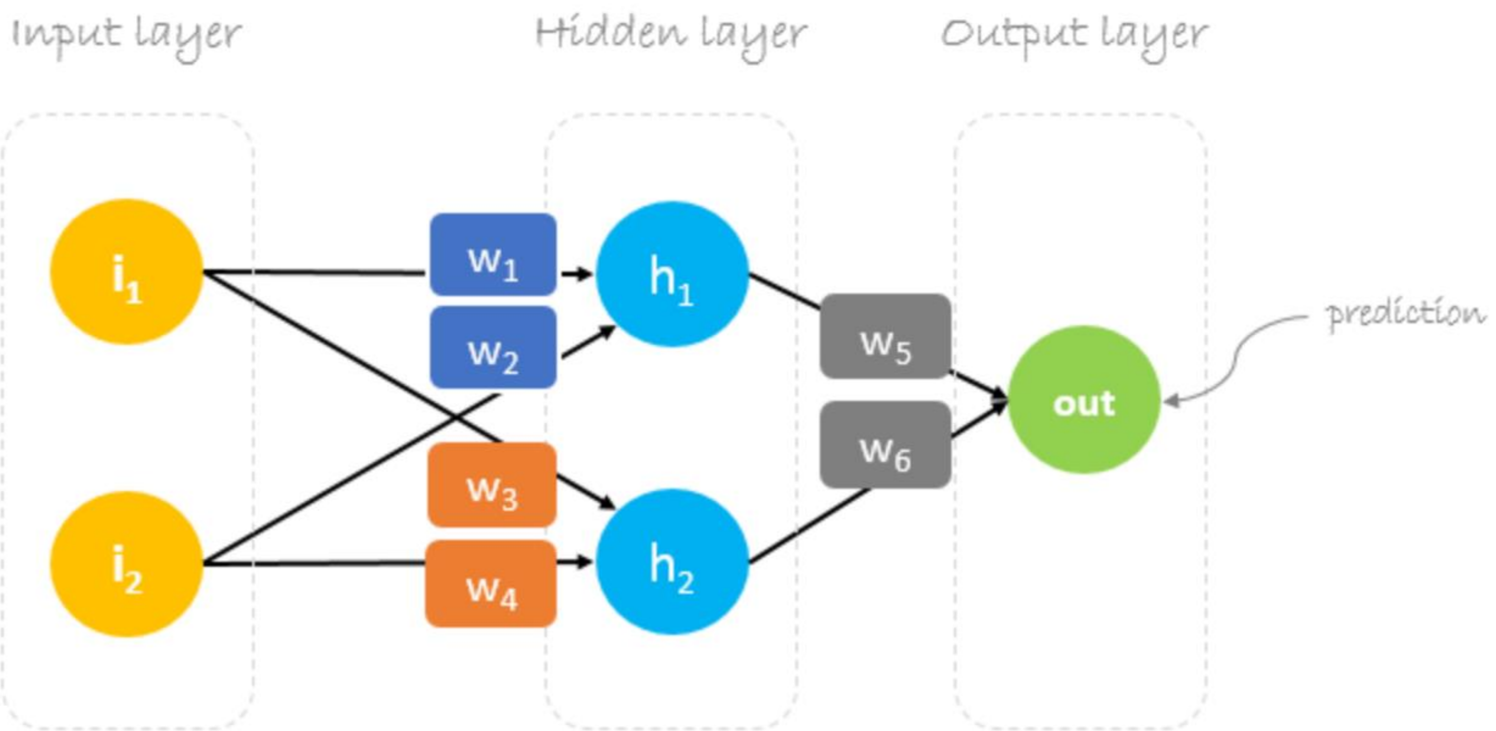
http://hmkcode.github.io/ai/backpropagation-step-by-step/

Get One W



http://hmkcode.github.io/ai/backpropagation-step-by-step/

Results



Δ = prediction – actual

$${}^*w_6 = w_6 - a\,(h_2\,.\,\Delta)$$

$${}^*w_5 = w_5 - a\,(h_1\,.\,\Delta)$$

$${}^*w_4 = w_4 - a\,(i_2\,.\,\Delta w_6)$$

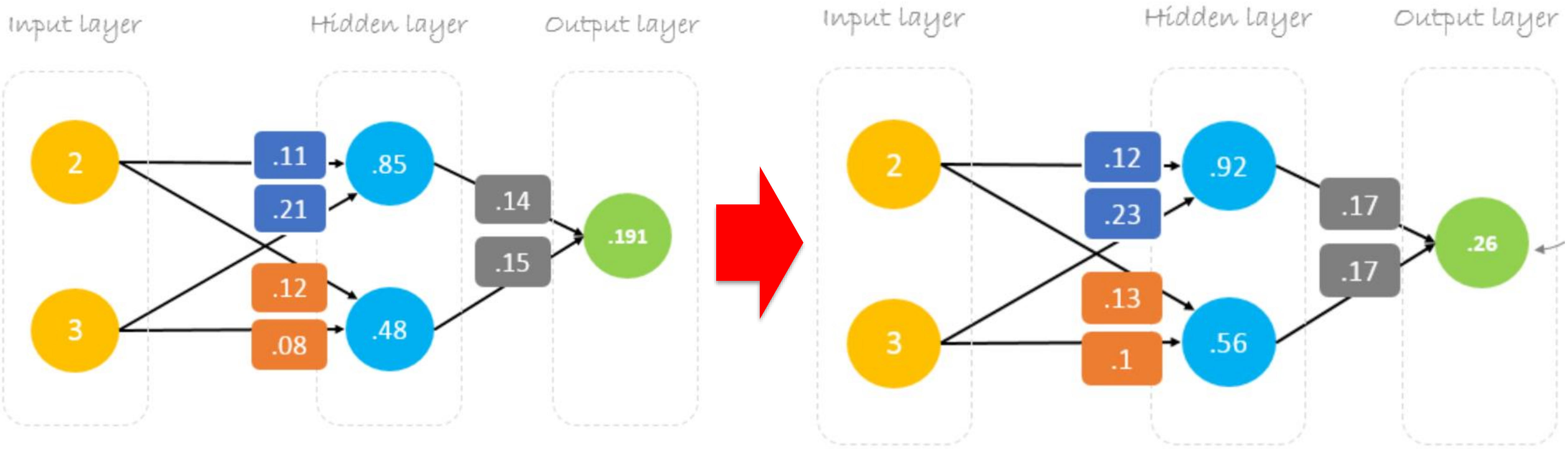
$${}^*w_3 = w_3 - a\,(i_1\,.\,\Delta w_6)$$

$${}^*w_2 = w_2 - a\,(i_2\,.\,\Delta w_5)$$

$${}^*w_1 = w_1 - a\,(i_1\,.\,\Delta w_5)$$

http://hmkcode.github.io/ai/backpropagation-step-by-step/

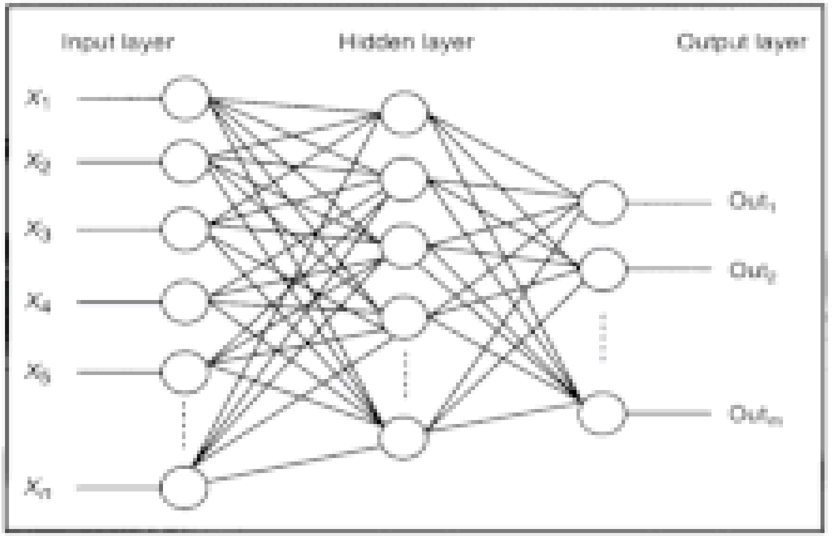
Backward Path



http://hmkcode.github.io/ai/backpropagation-step-by-step/

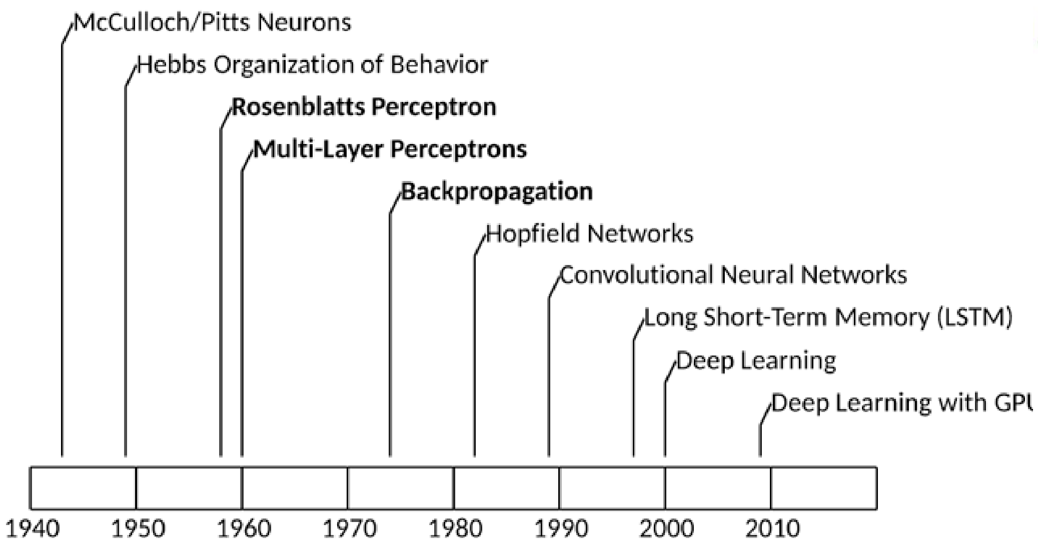
Summarize on How To Train Neural Network

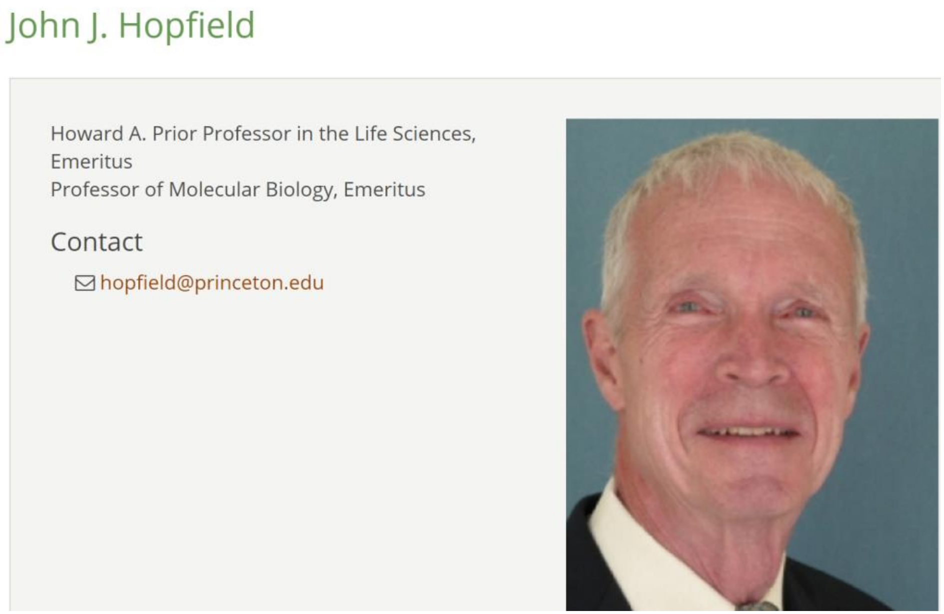
1

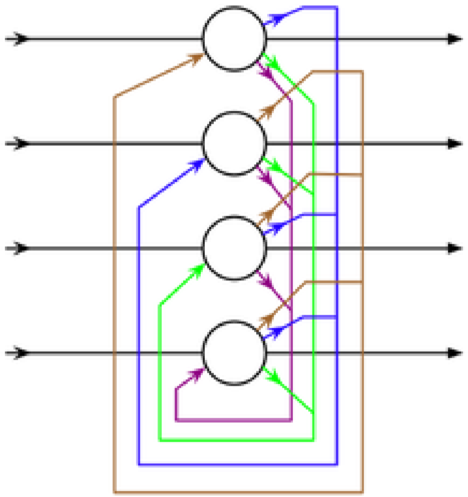


https://devashishshankar.com/2015/11/13/demystifying-deep-neural-networks/

1D+1D = “2D” Temporal Modal







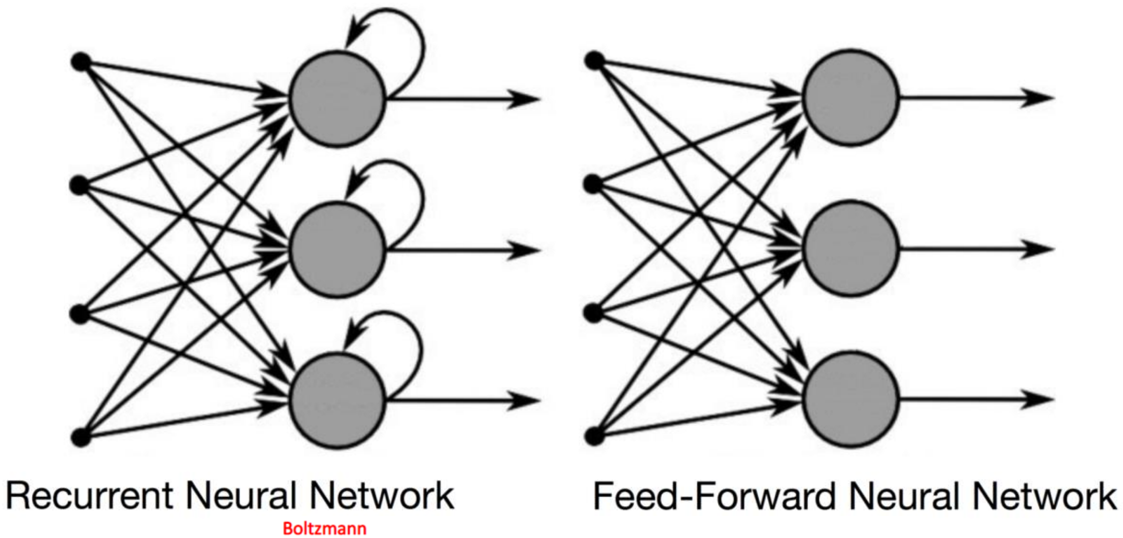
Hopfield, John J., David I. Feinstein, and Richard G. Palmer. "" Unlearning" has a stabilizing effect in collective memories." Nature (1983).

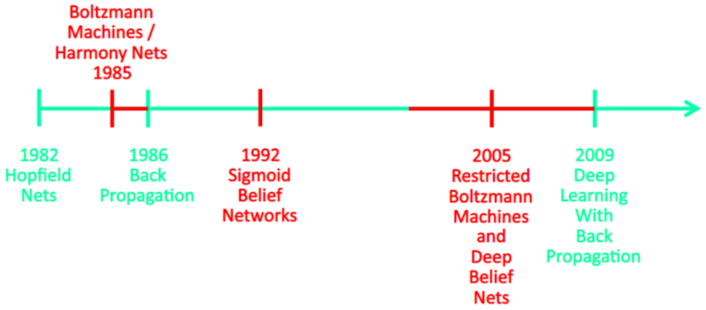
Recurrent Neural Network (RNN)

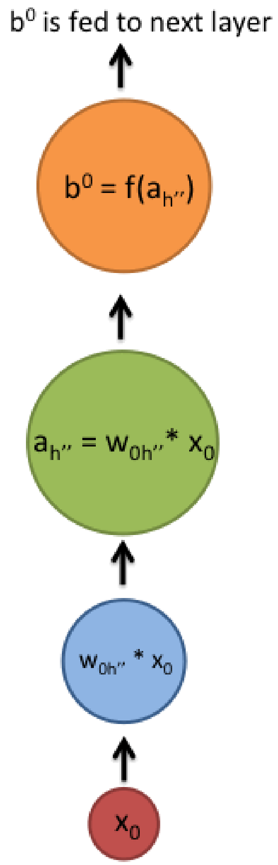
https://en.wikipedia.org/wiki/Hopfield_network

https://www.ibm.com/developerworks/library/cc-cognitive-neural-networks-deep-dive/index.html

Feed-forward and Recurrent Network

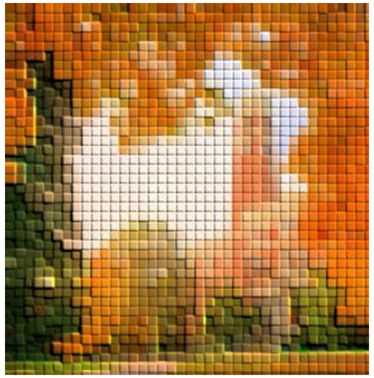


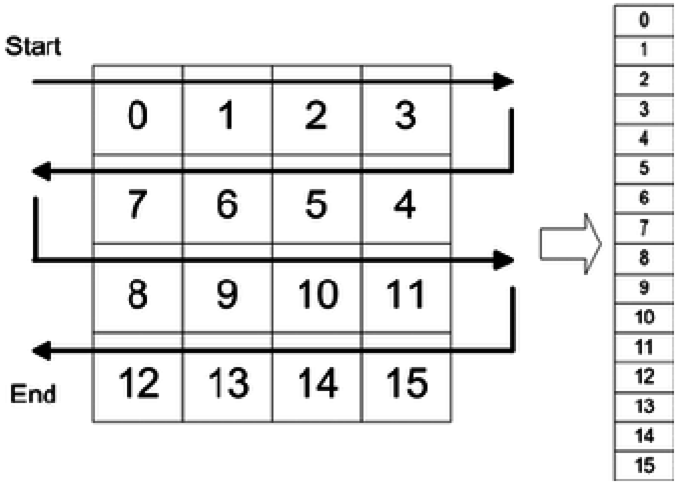


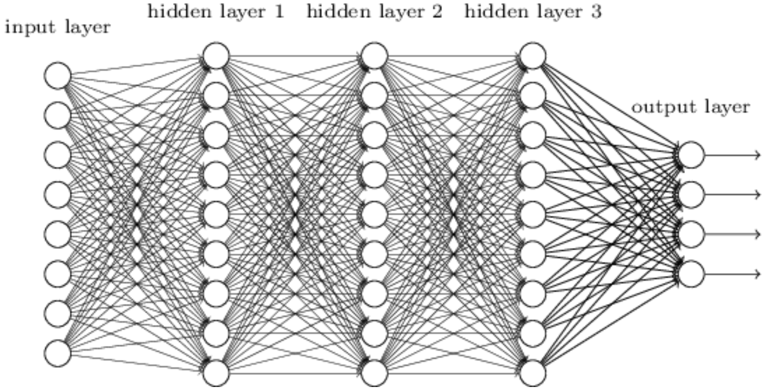


https://towardsdatascience.com/recurrent-neural-networks-and-lstm-4b601dd822a5 https://www.leiphone.com/news/201608/syAwLNx4bGPuFYI1.html https://slideplayer.com/slide/3383596/

2D Data (Image) ?

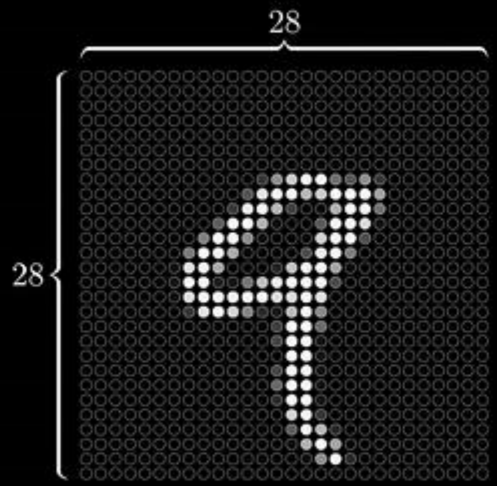




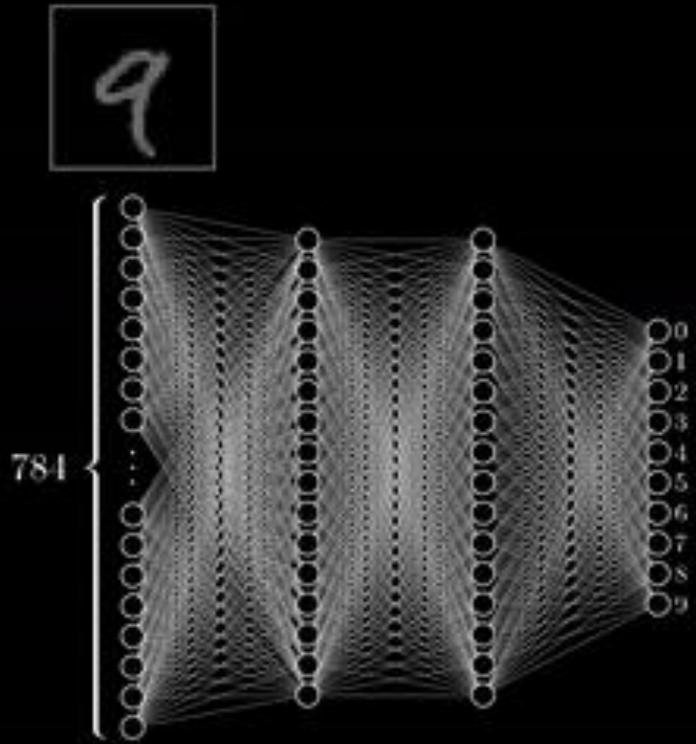


https://www.usnews.com/best-colleges/vanderbilt-3535
https://www.researchgate.net/figure/Scanning-2D-blocks-left-into-1D-vector-as-input-into-logical-transform-middle-the_fig4_228345705

Dense Neural Network

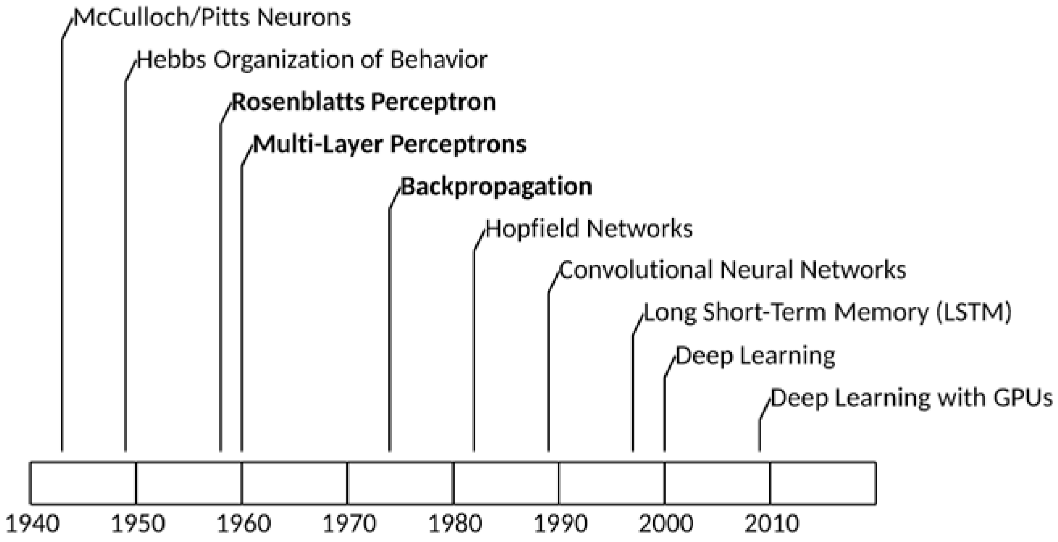


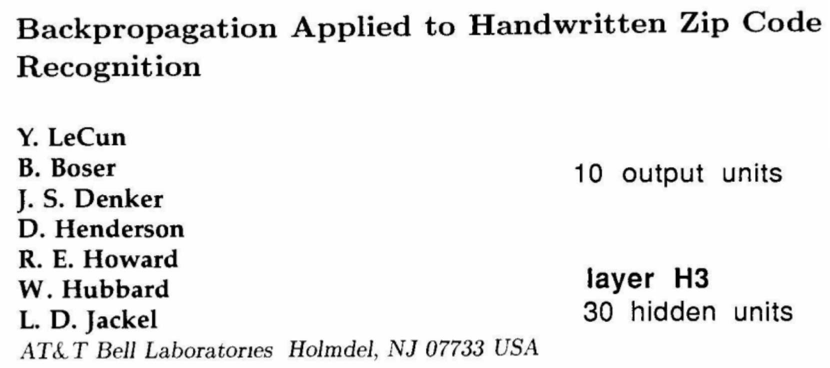
https://gfycat.com/gifs/search/deep+neural+networks



http://homdor.com/search/deep-neural-networks

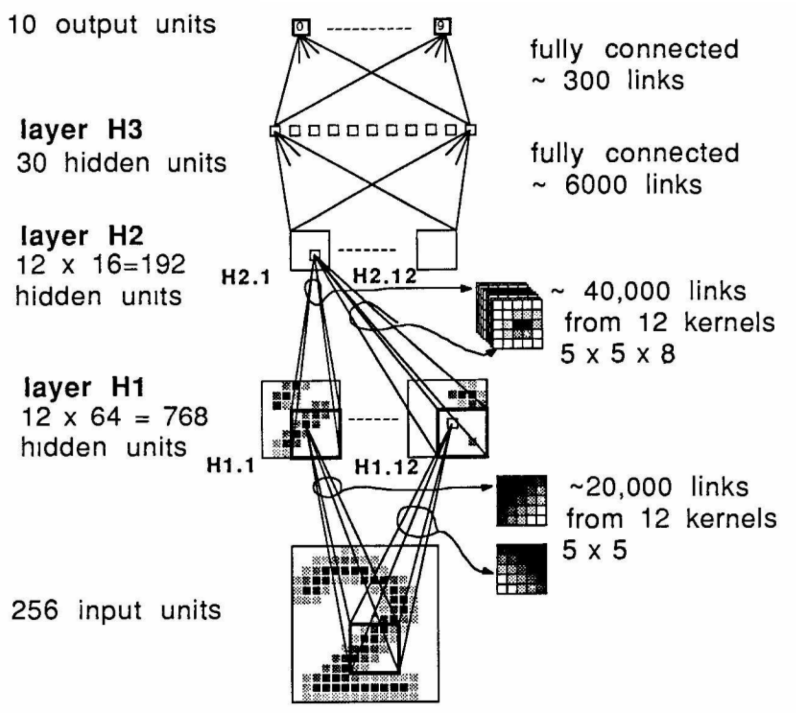
Convolutional Neural Network





Backpropagation Applied to Handwritten Zip Code Recognition

Y. LeCun
B. Boser
J. S. Denker
D. Henderson
R. E. Howard
W. Hubbard
L. D. Jackel
AT&T Bell Laboratories Holmdel, NJ 07733 USA



Modern convNets were proposed in an article by Yann LeCun et al of 1989. He used backprop to train a Neocognitron-like architecture and refined the architecture trying different variations of the model.

https://www.ibm.com/developerworks/library/cc-cognitive-neural-networks-deep-dive/index.html

http://espirituteresafidalgo.blogspot.com/2017/03/teresa-fidalgo-girl-of-road.html

Convolutional Network Demo from 1993

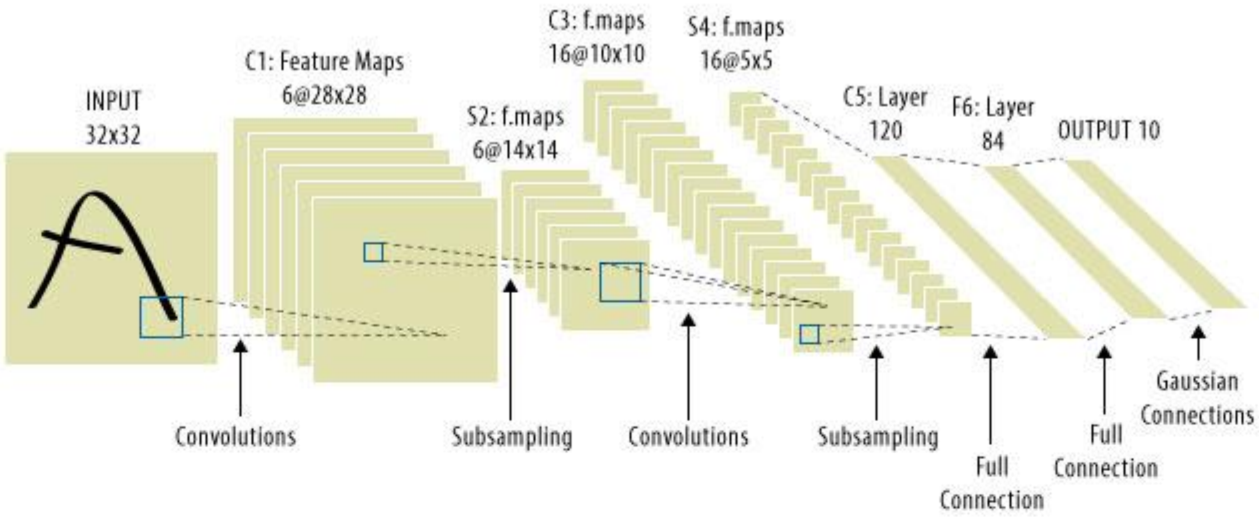
https://gfycat.com/gifs/detail/AchingCluelessEchidna

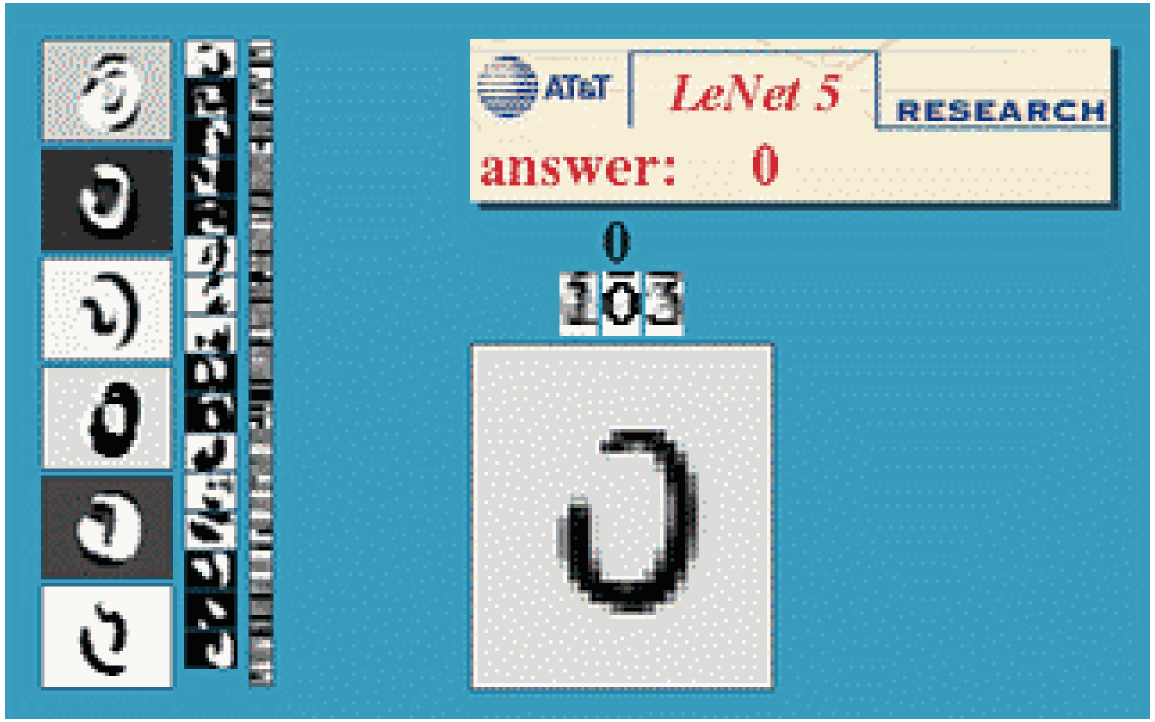
Convolutional Neural Network

PROC. OF THE IEEE, NOVEMBER 1998 1

Gradient-Based Learning Applied to Document Recognition

Yann LeCun, Léon Bottou, Yoshua Bengio, and Patrick Haffner



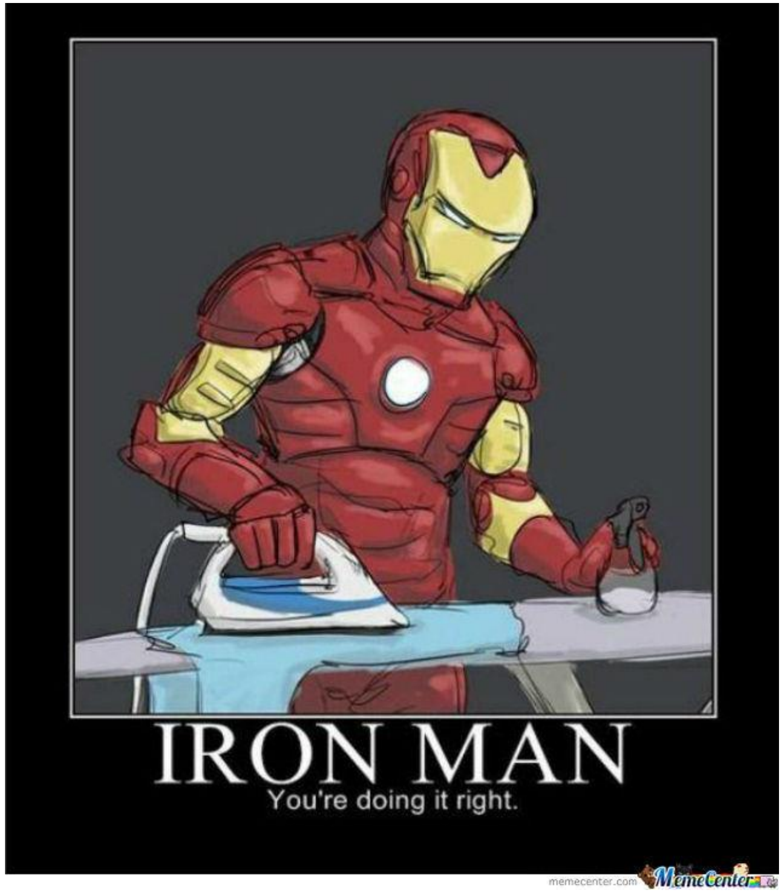


http://yann.lecun.com/exdb/lenet/

Computer Vision

https://www.empireonline.com/shopping/movies/top-iron-man-merch/

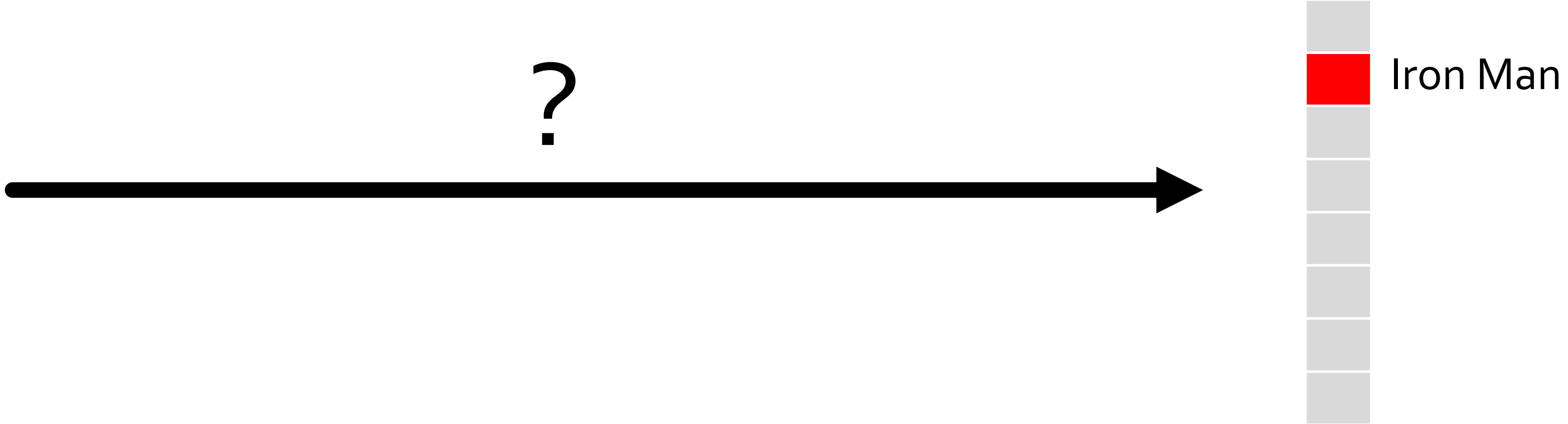
https://www.playstation.com/en-us/games/marvels-iron-man-vr-ps4/

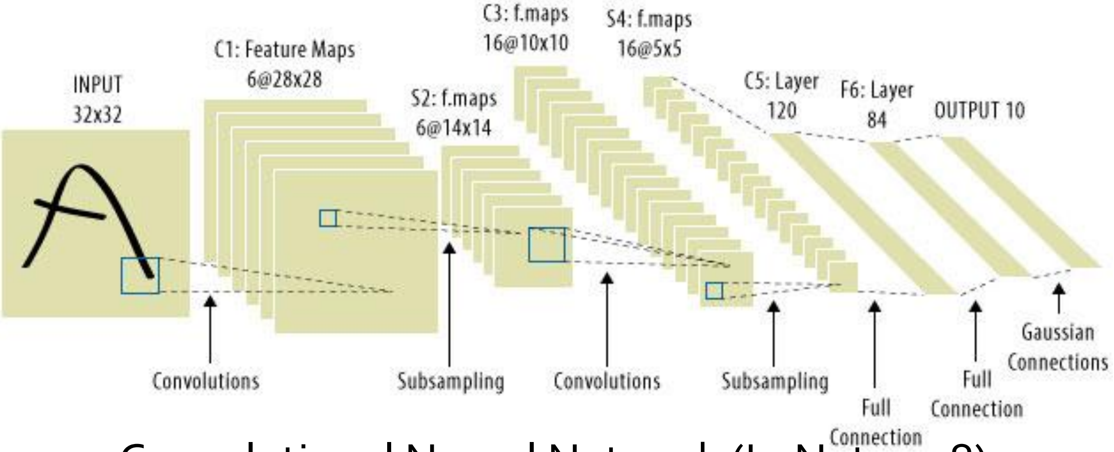


https://www.memecenter.com/fun/1136662/stupid-iron-man

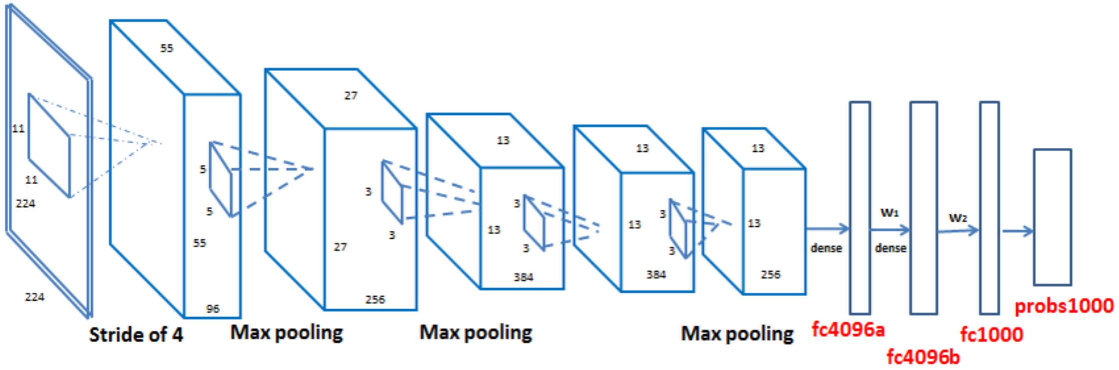
https://www.stupid.com/iron-man-comics-bust-bank.html

What can we do?





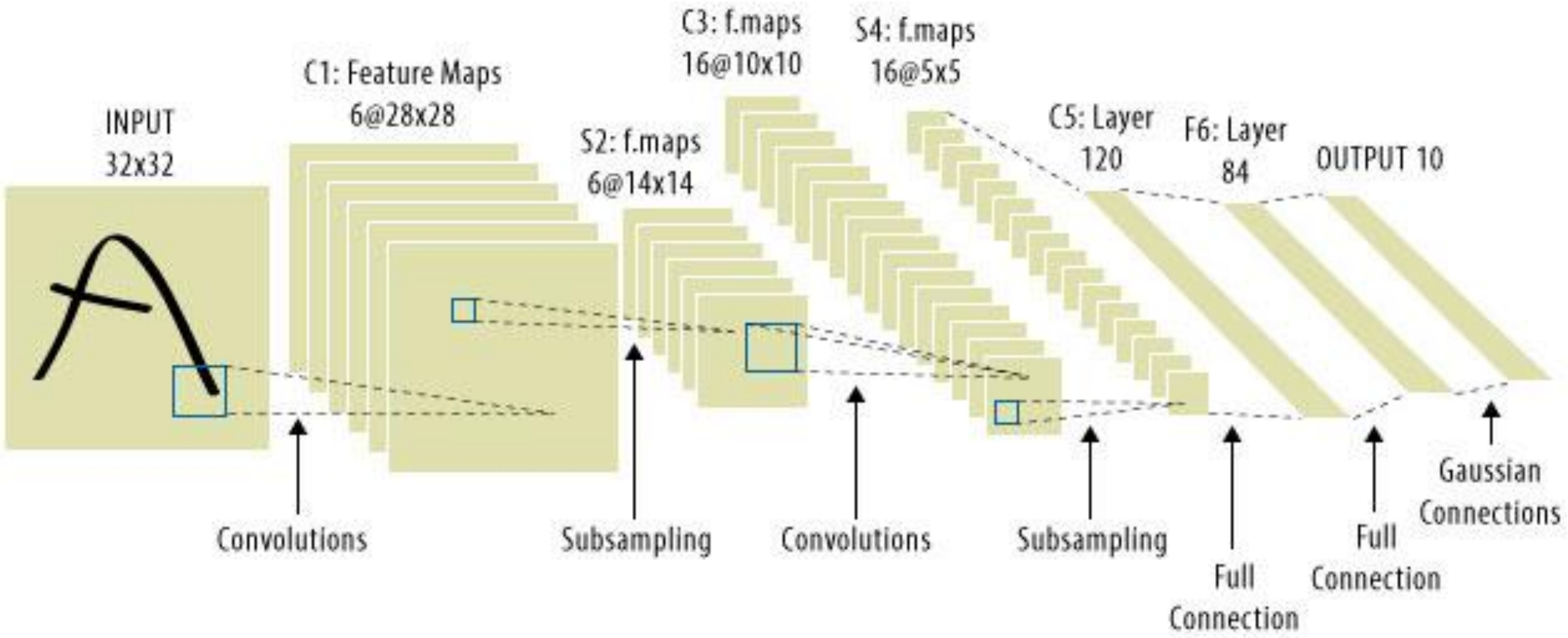
Convolutional Neural Network (LeNet 1998)



Deep Convolutional Neural Network (AlexNet 2012)

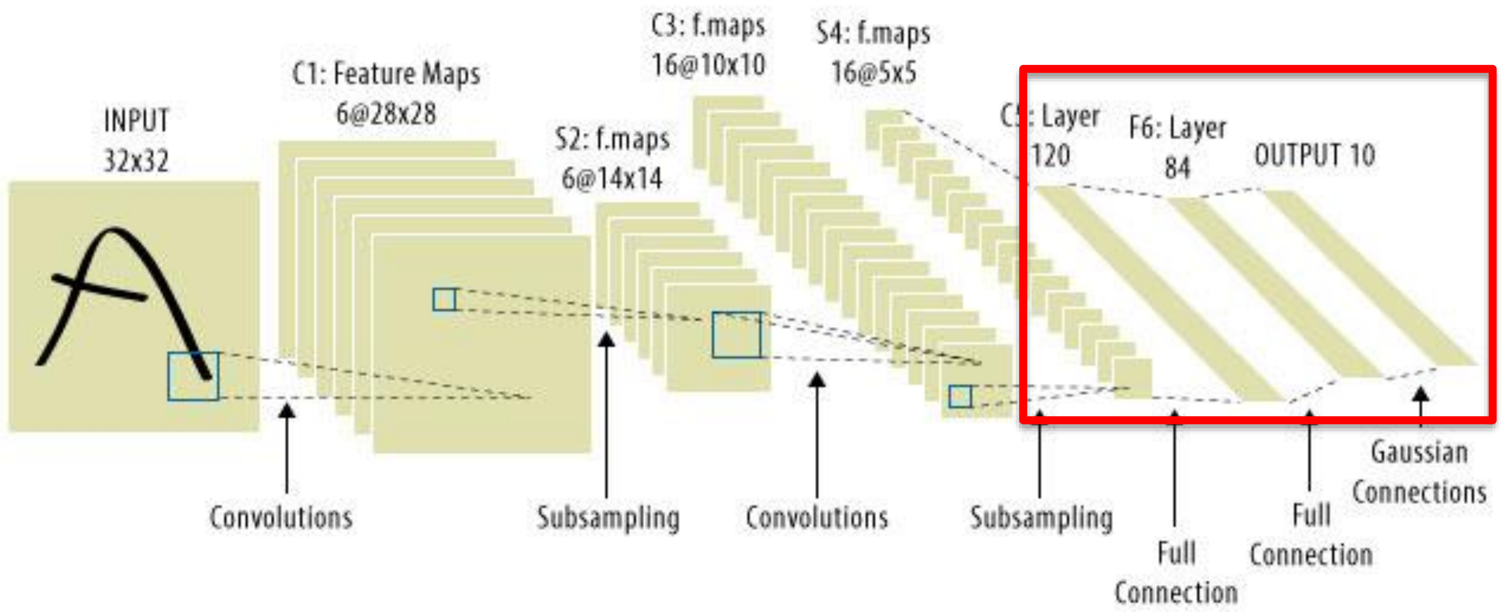
https://www.researchgate.net/figure/AlexNet-Architecture-To-be-noted-is-copied-2_fig1_300412100

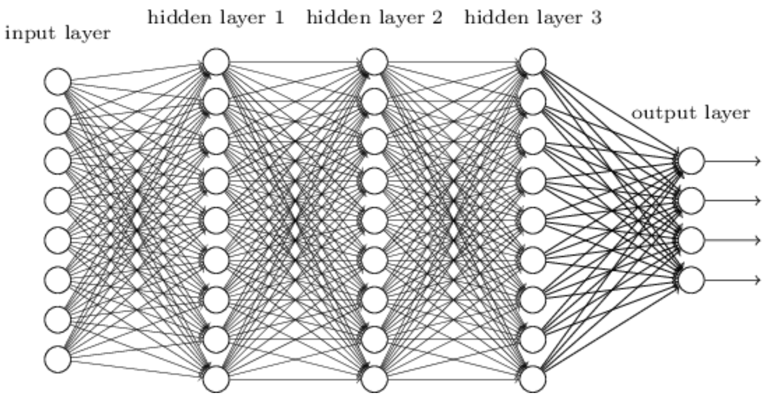
CNN for Image



Convolutional Neural Network (LeNet 1998)

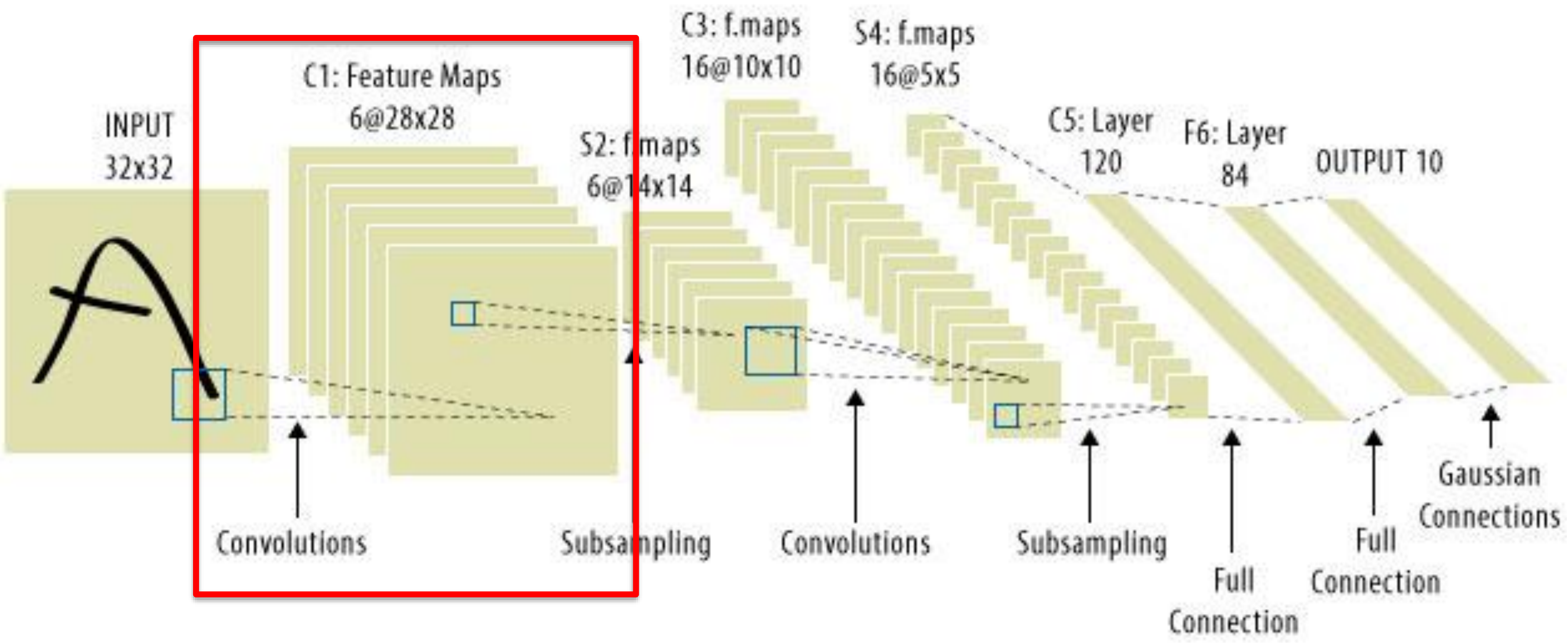
Fully Connection





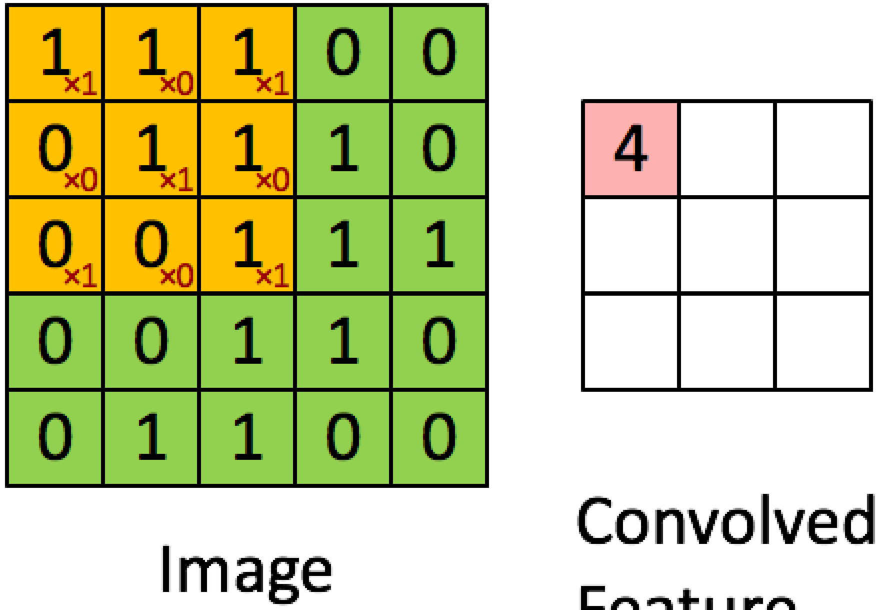
Convolutional Neural Network (LeNet 1998)

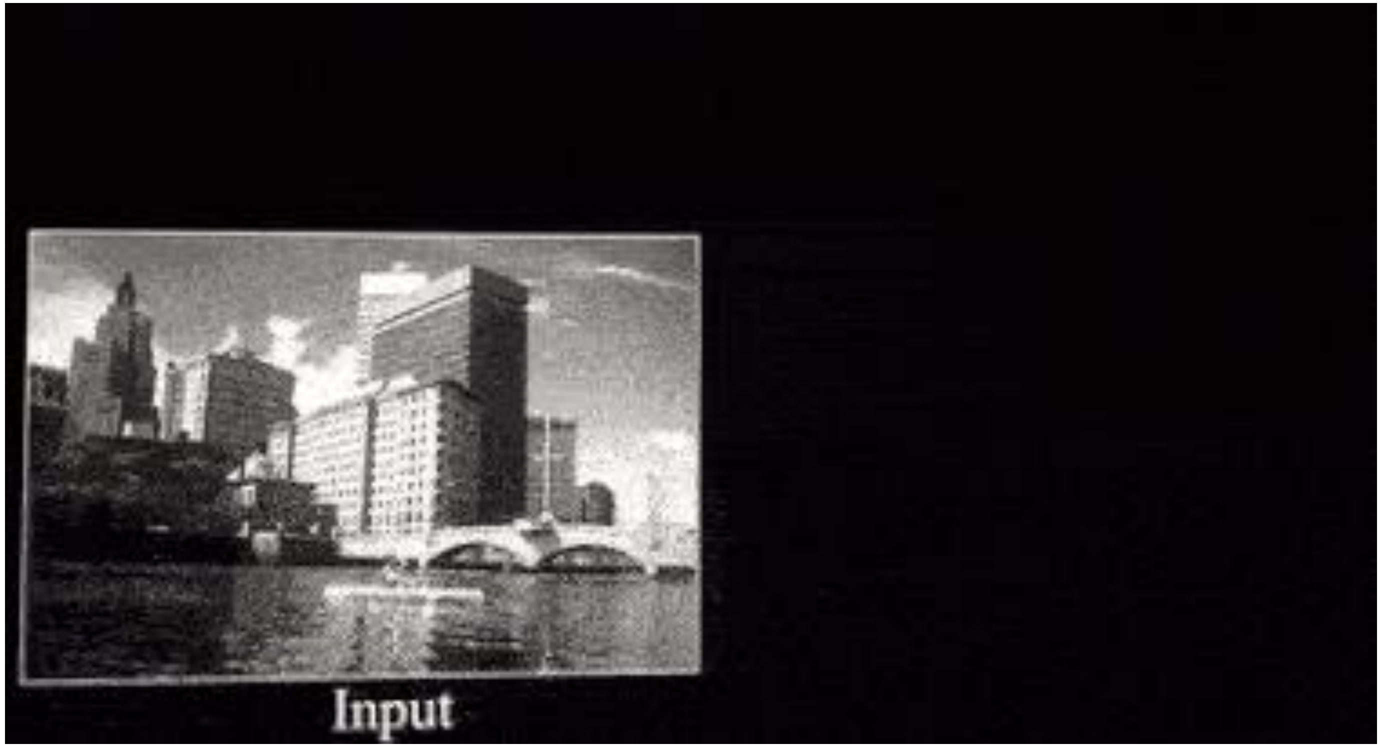
Convolutions



Convolutional Neural Network (LeNet 1998)

Image Representation 2: Convolution

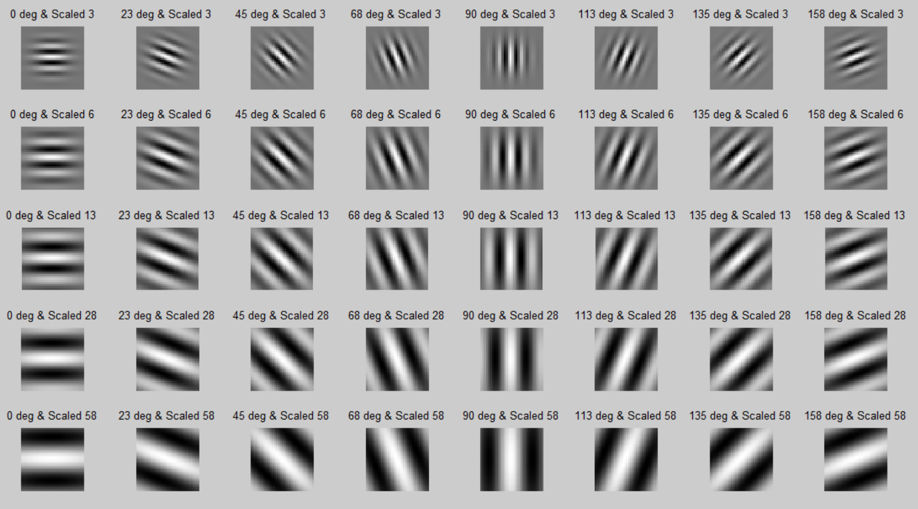




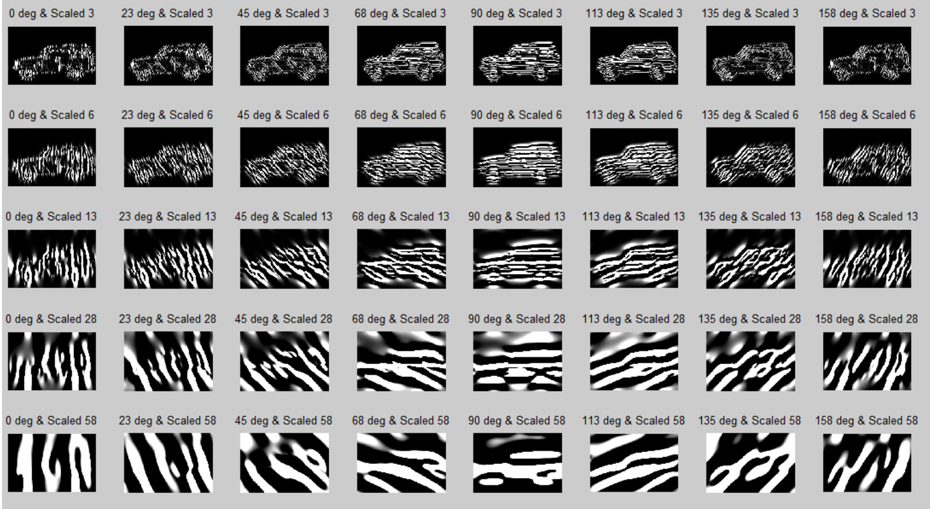
http://ufldl.stanford.edu/wiki/index.php/Feature_extraction_using_convolution

https://leonardoaraujosantos.gitbooks.io/artificial-inteligence/content/convolutional_neural_networks.html

Handcrafted Feature



Gabor Filter

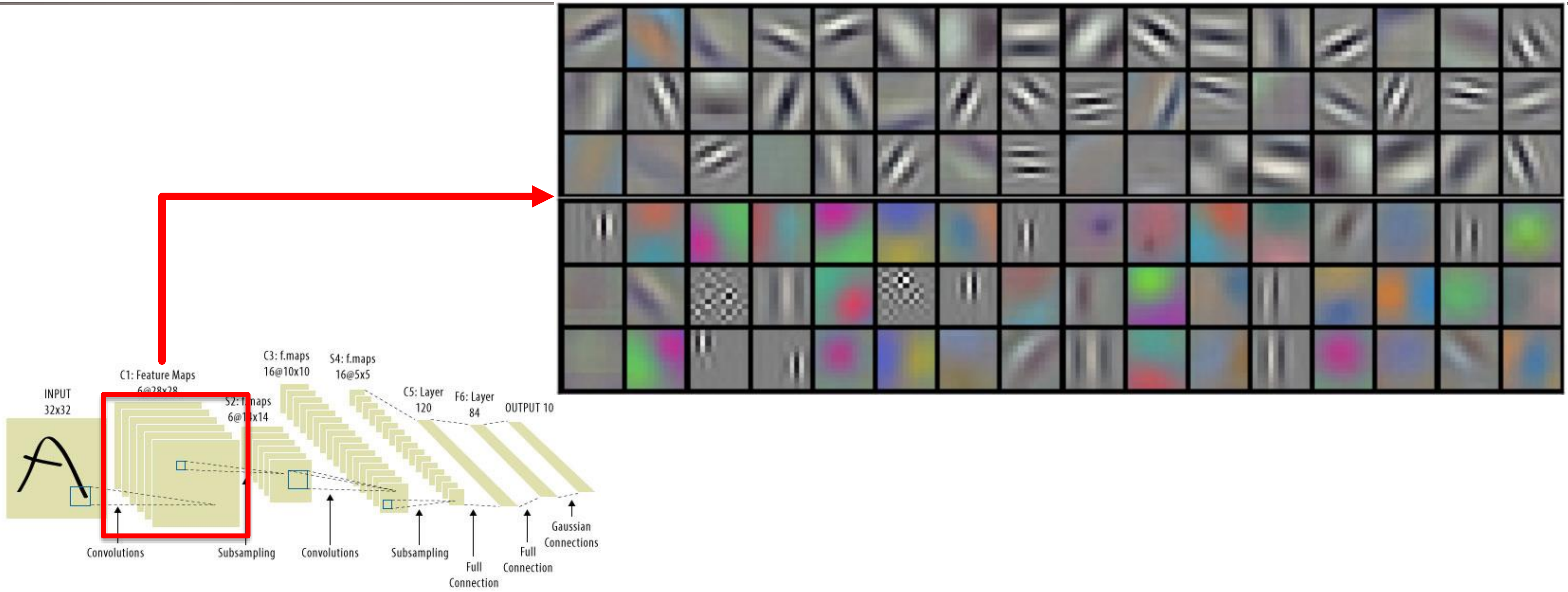


Features

Not as good as human’s performance

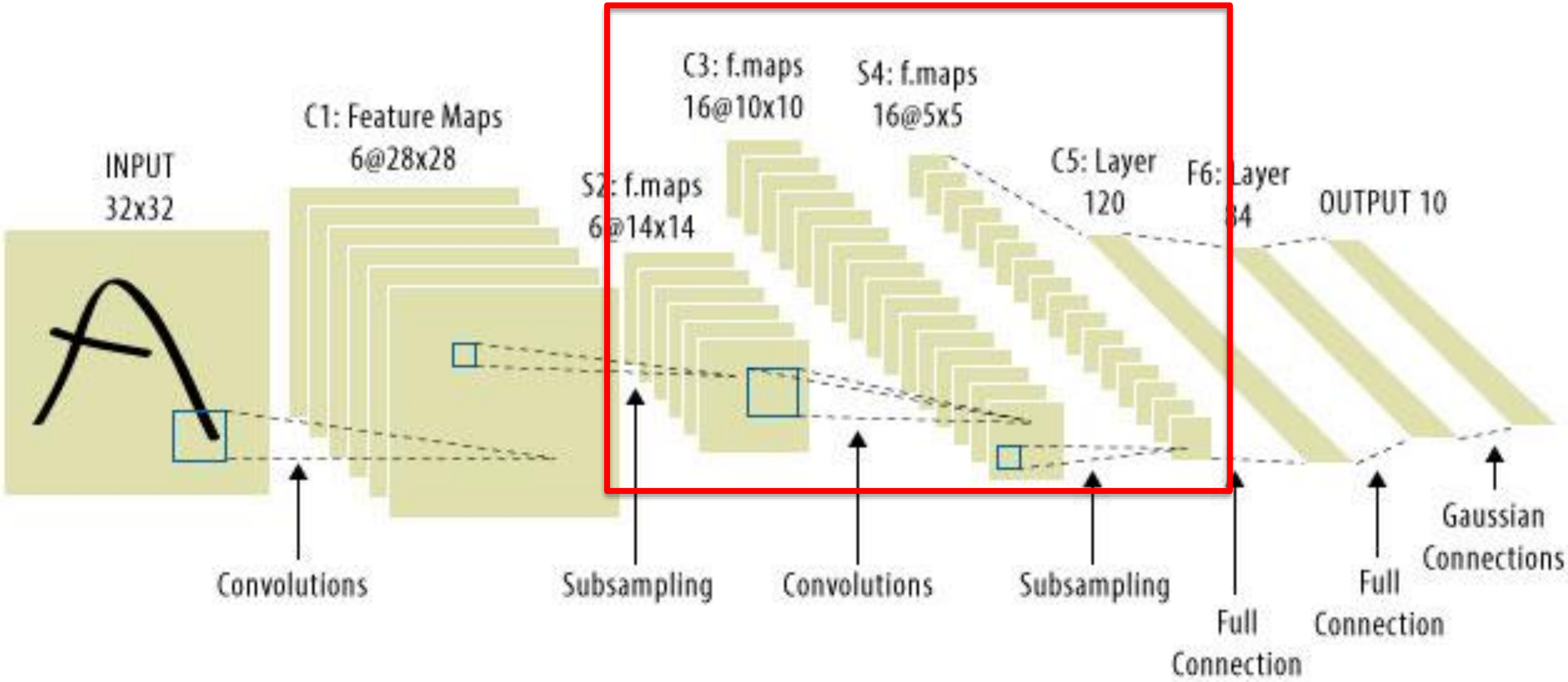
https://stackoverflow.com/questions/20608458/gabor-feature-extraction

Convolutions



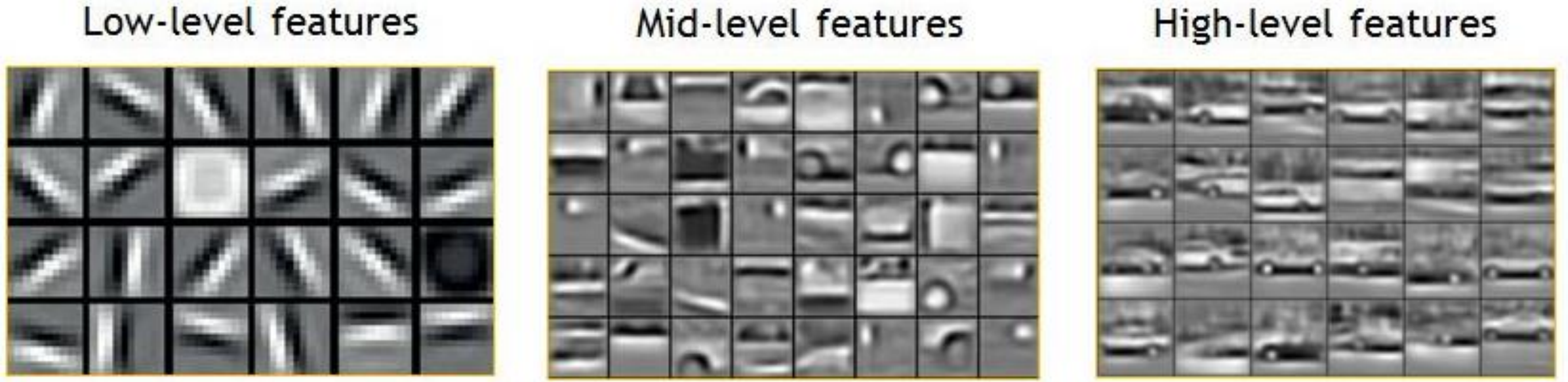
https://arstechnica.com/science/2018/12/how-computers-got-shockingly-good-at-recognizing-images/3/

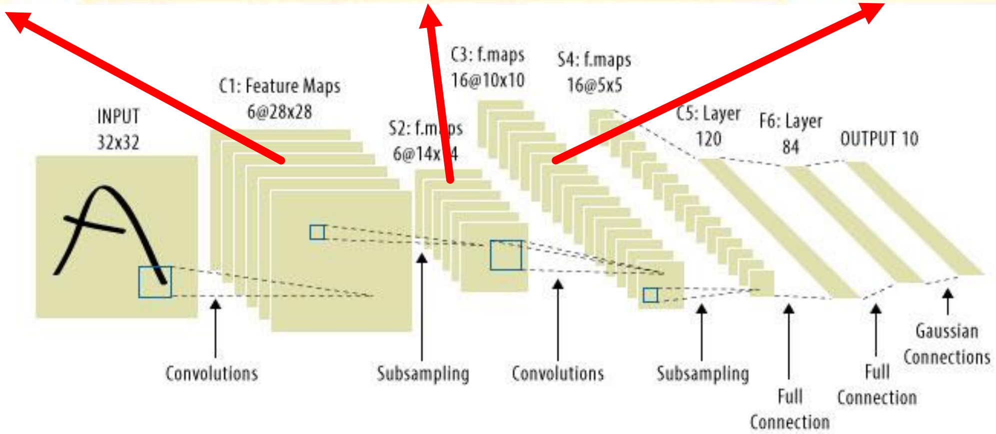
Why ?



Convolutional Neural Network (LeNet 1998)

Different Layers

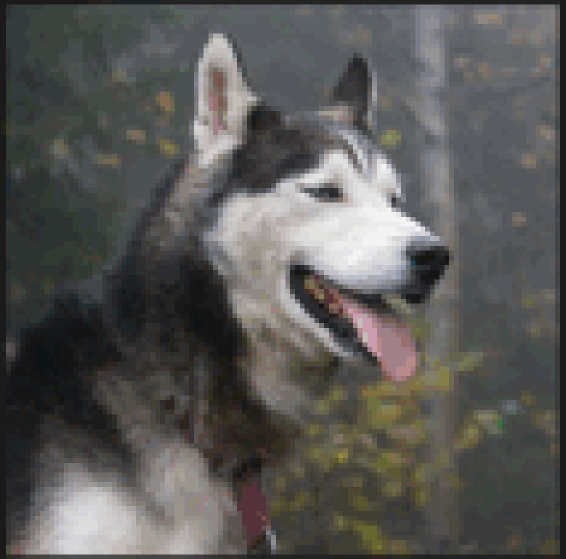


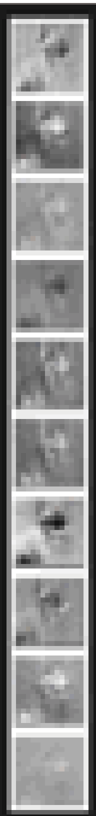


“Audi A7”

https://www.all-electronics.de/wp-content/uploads/2016/05/Bild31.jpg

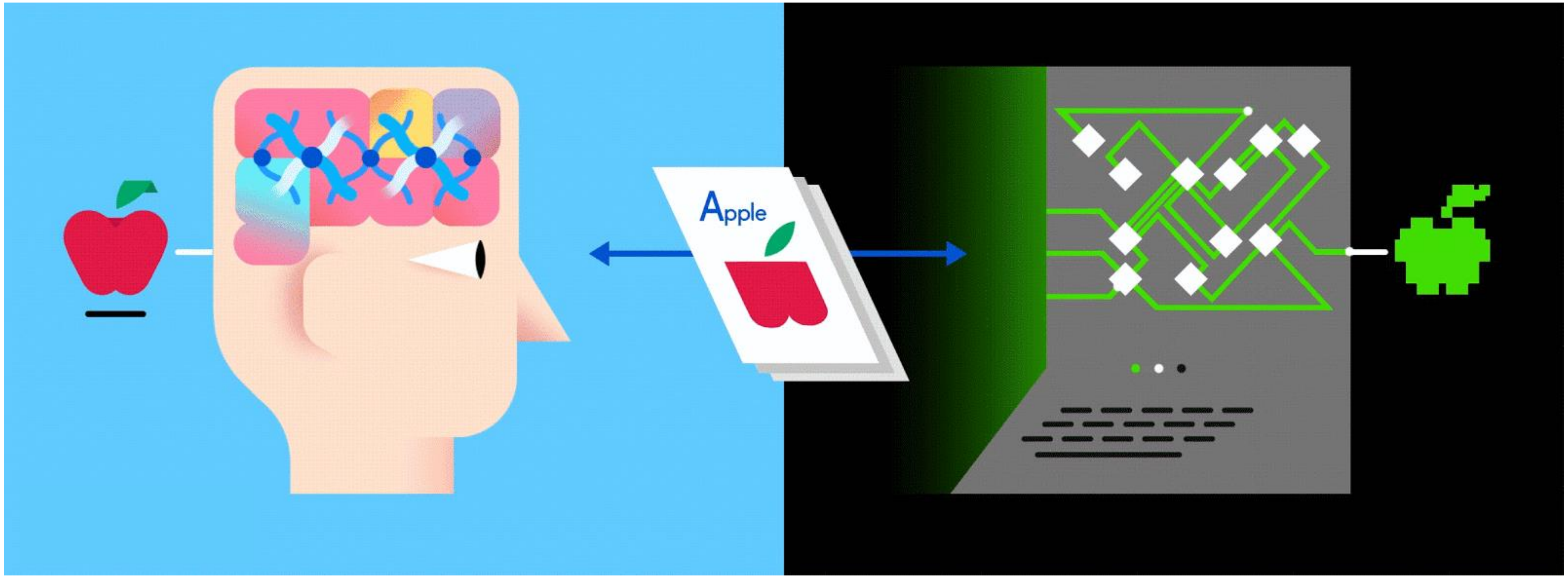
CNN Features





http://karpathy.github.io/2015/10/25/selfie/

Summarize



https://techcrunch.com/2017/04/13/neural-networks-made-easy/

Neural network is able to perform X➔ Y non-linear fitting.
More layers will have stronger fitting ability.
CNN provides an efficient way of training a neural network for images.

In this class

https://www.empireonline.com/shopping/movies/top-iron-man-merch/