Introduction to Deep Learning

- Image Recognition

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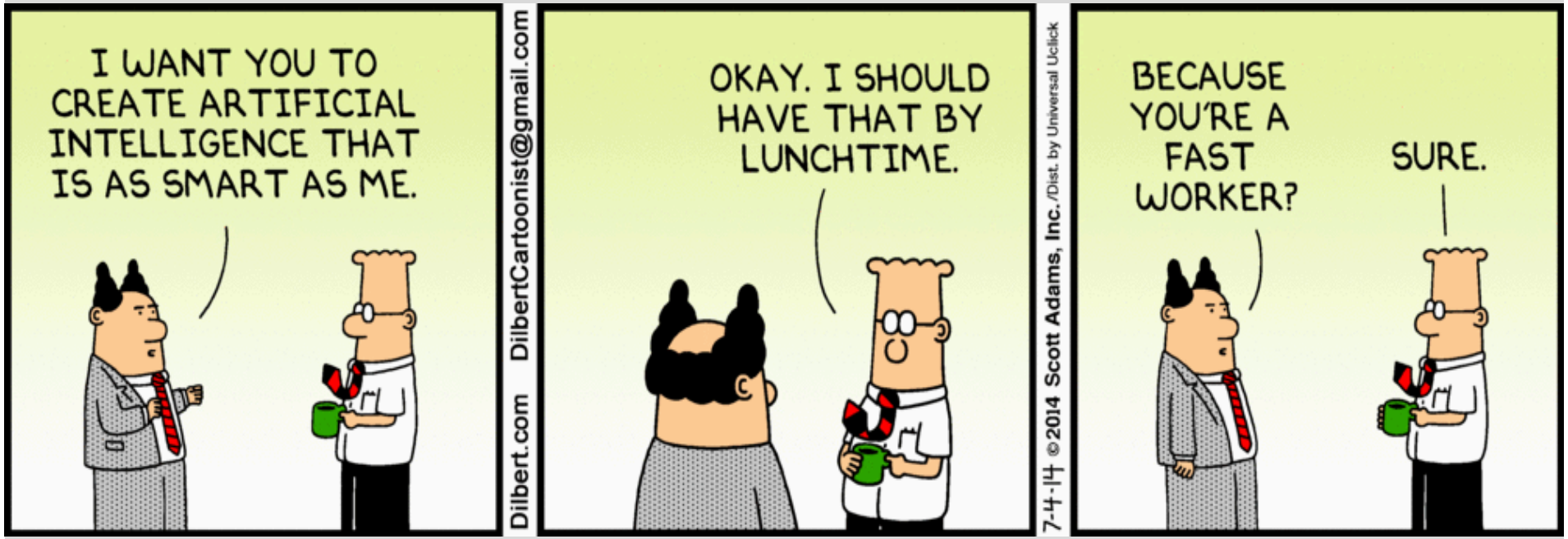

I WANT YOU TO CREATE ARTIFICIAL INTELLIGENCE THAT IS AS SMART AS ME.
Dilbert.com DilbertCartoonist@gmail.com
OKAY. I SHOULD HAVE THAT BY LUNCHTIME.
7-4-14 ©2014 Scott Adams, Inc./Dist. by Universal Uclick
BECAUSE YOU'RE A FAST WORKER?
SURE.

AGENDA/SCHEDULE

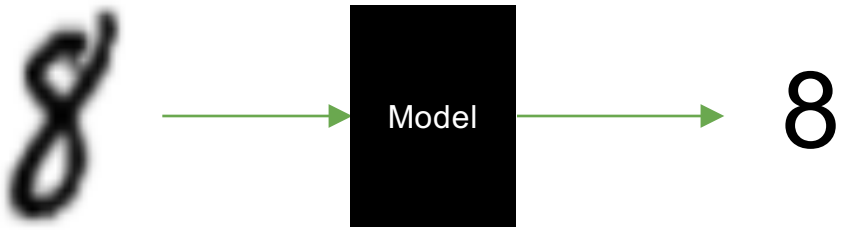
1) Motivation to Machine Learning/Deep Learning
    i. Biological Motivation, Hierarchical/Representation Learning
2) Introduction to Artificial Neural Networks/Deep Learning
    i. Neuron, Perceptron, Logistic, MLP, Rectified Linear Units
    ii. Backpropagation Algorithm, Gradient Descent(including SGD), Mini-batch
3) Image Recognition: Convolution Neural Networks
    i. Convolution
    ii. Sub-sampling, Pooling
    iii. Dropout
    iv. Architecture
4) Challenges in Deep Learning
    i. Vanishing Gradients & Local Minima
    ii. Overfitting


LEARNING

What is Learning?

How do we recognize the digits?

Machine Learning Framework



Inputs | Computation | Outputs

source: http://www.slideshare.net/indicods/deep-learning-with-python-and-the-theano-library

Recognizing Digit – An algorithm

How do we recognize the digits?

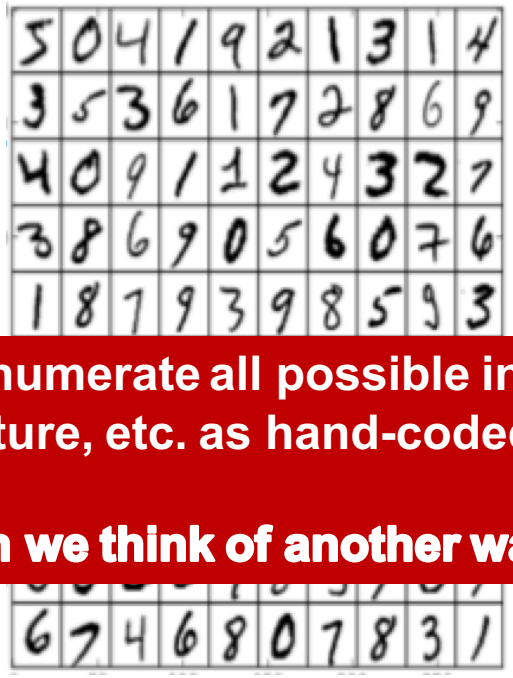
Use functions that compute relevant information to solve the problem

k Nearest-Neighbors

For each image, find"most similar" image. Guess that as the label.

Recognizing Digit – An algorithm

How do we recognize the digits?



Difficult to enumerate all possible interactions, spatial structure, etc. as hand-coded features.

Can we think of another way?


LEARNING –
Biological Inspiration

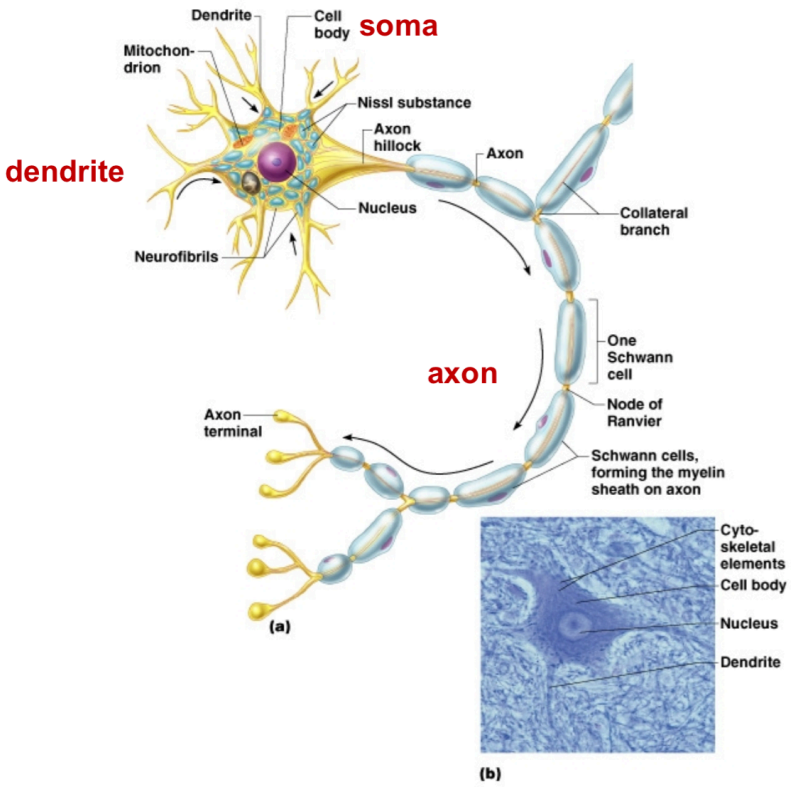
Questions about Learning

How is information detected?

How is it stored?

How does it influence recognition?

Brain



- Connected network of neurons.
- Communicate by electric and chemical signals

~ 10^{11} neurons

~1000 synapses per neuron

- Signals come in via dendrites into soma
- Signal goes out via axon to other neurons through synapses

Learnings from Neuro & Cognitive Science

Kids talk grammatically correct sentences even before they are taught formal langauge.

Kids learn after listening to a lot of sentences

→ Associations and Structural inferences. Understand context. Eg: Drinking water Vs River Vs Ocean

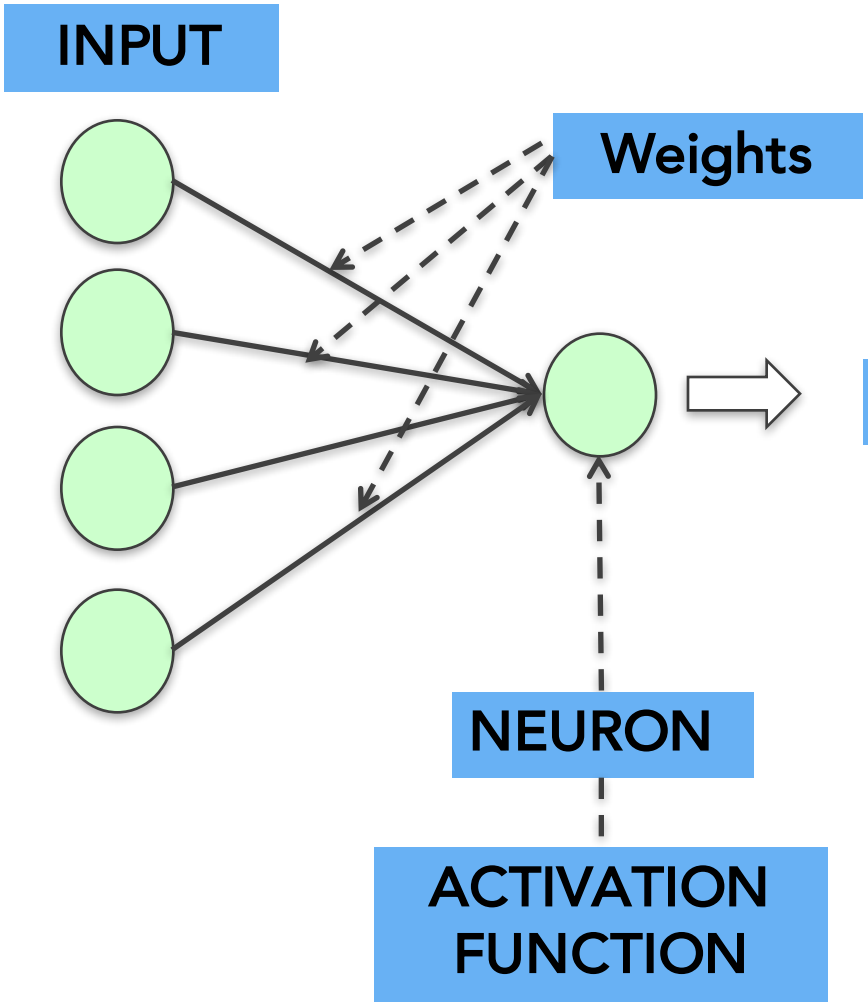
→ See/hear/feel first. Assimilate. Build the context hierarchically. Recognize. Respond.


Neural Network –
Building Blocks

DID YOU KNOW?

ZEBRAS ARE ACTUALLY BLACK WITH WHITE STRIPES, NOT WHITE WITH BLACK STRIPES.

Neuron, Activation Function

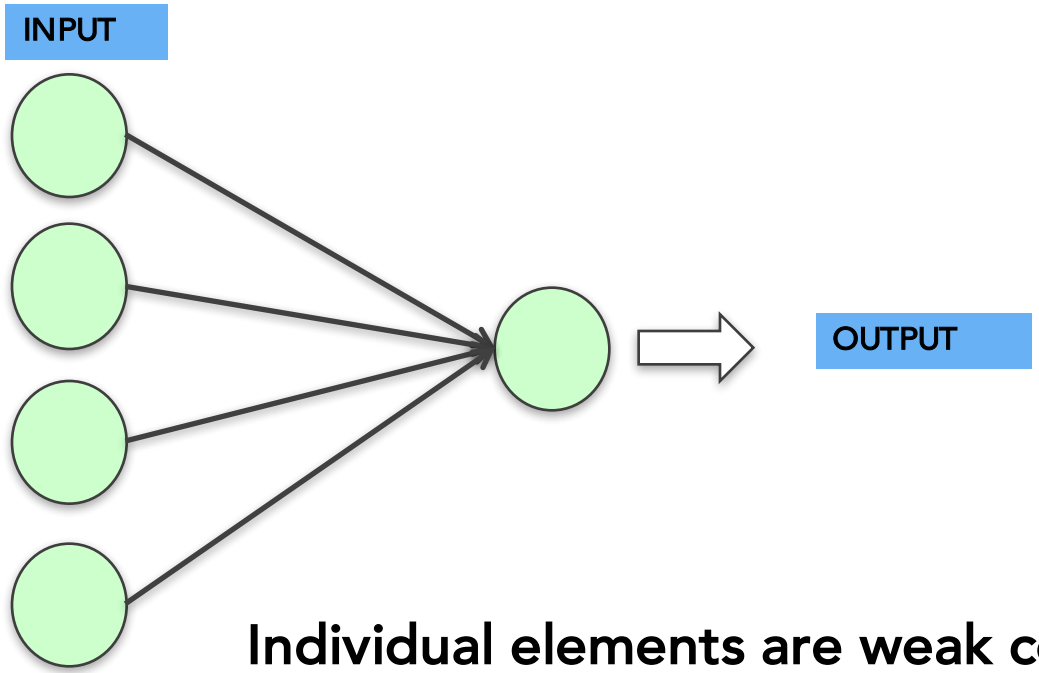


$$\text{Local field} : \sum_{d=0}^{D} w_d x_d$$

$$\text{Activation function} : \varphi(\cdot)$$

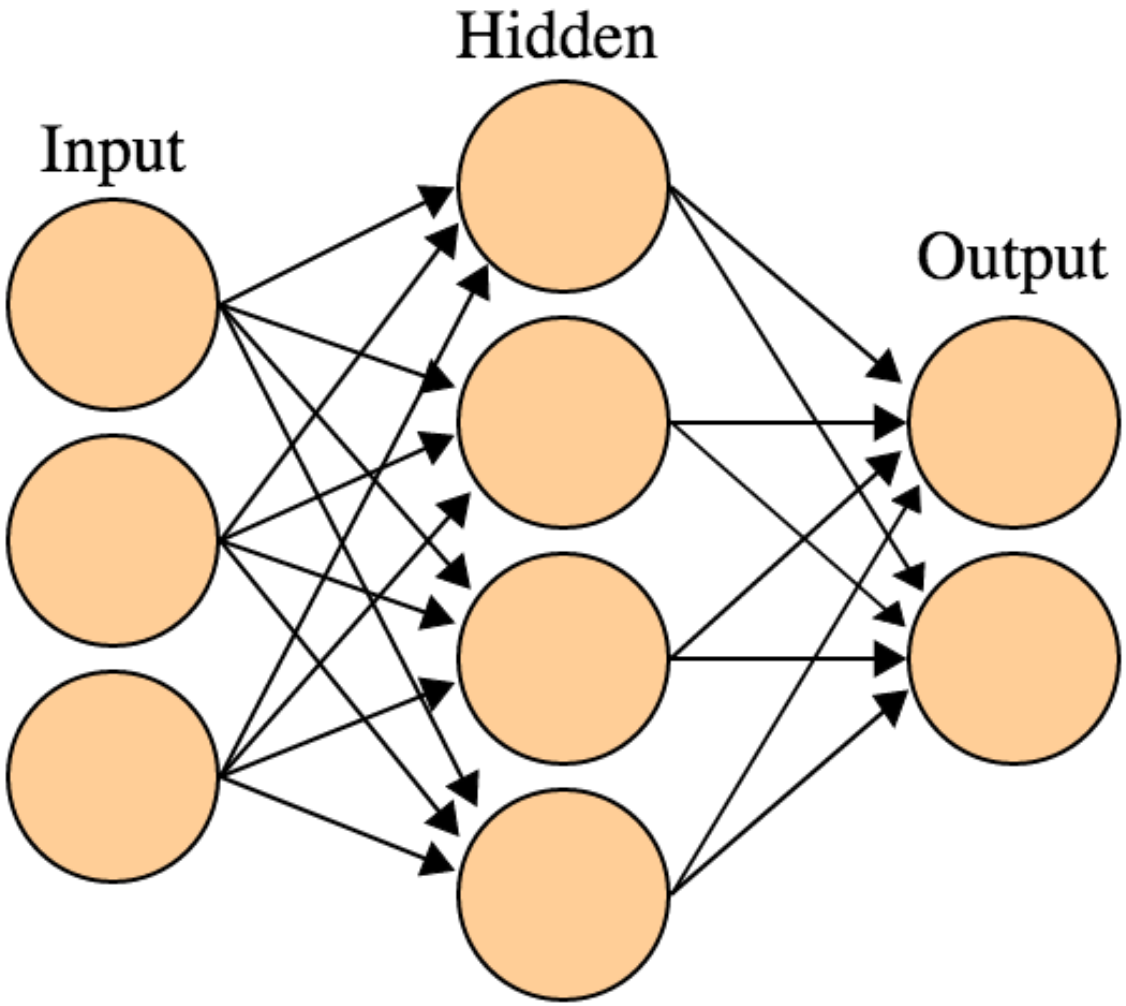
$$\text{Output} : h(\mathbf{x}) = \varphi\left(\sum_{d=0}^{D} w_d x_d \right)$$

Need: Networked Units



Individual elements are weak computational elements

A Simple Neural Network



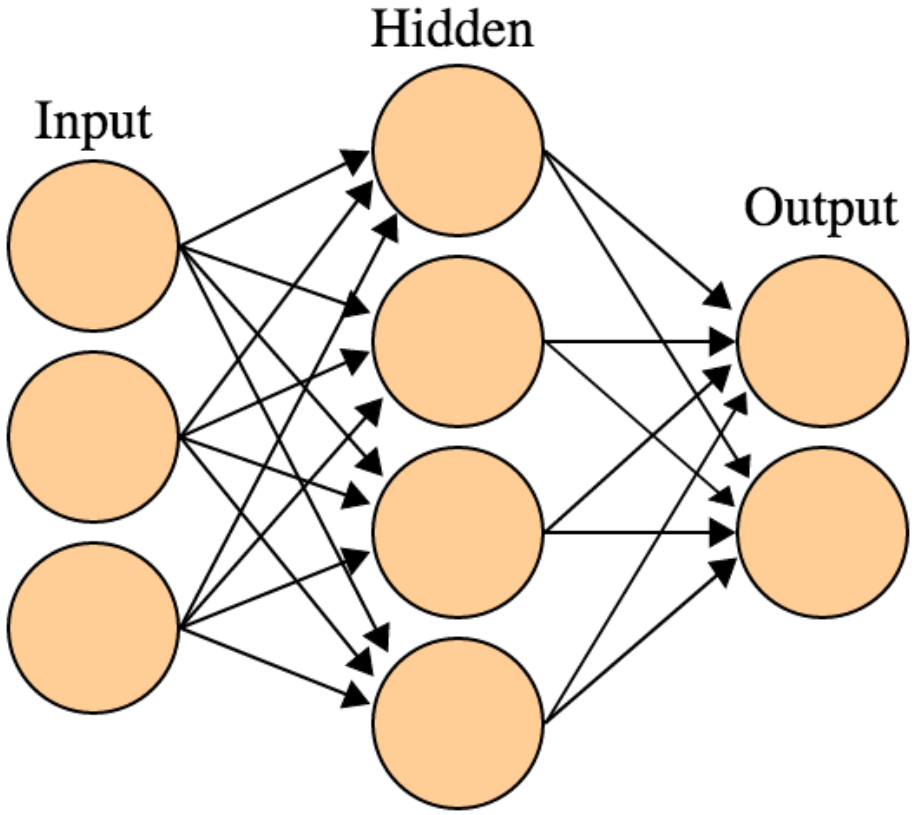
$$\text{Local field} : \sum_{d=0}^{D} w_d x_d$$

$$\text{Activation function} : \varphi(\cdot)$$

$$\text{Output} : h(\mathbf{x}) = \varphi\left(\sum_{d=0}^{D} w_d x_d \right)$$

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

Feed-forward Neural Network



» The network is formed by
– **Input layer** of source nodes
– **One or several hidden layers** of processing neurons
– **Output layer** of processing neuron(s)

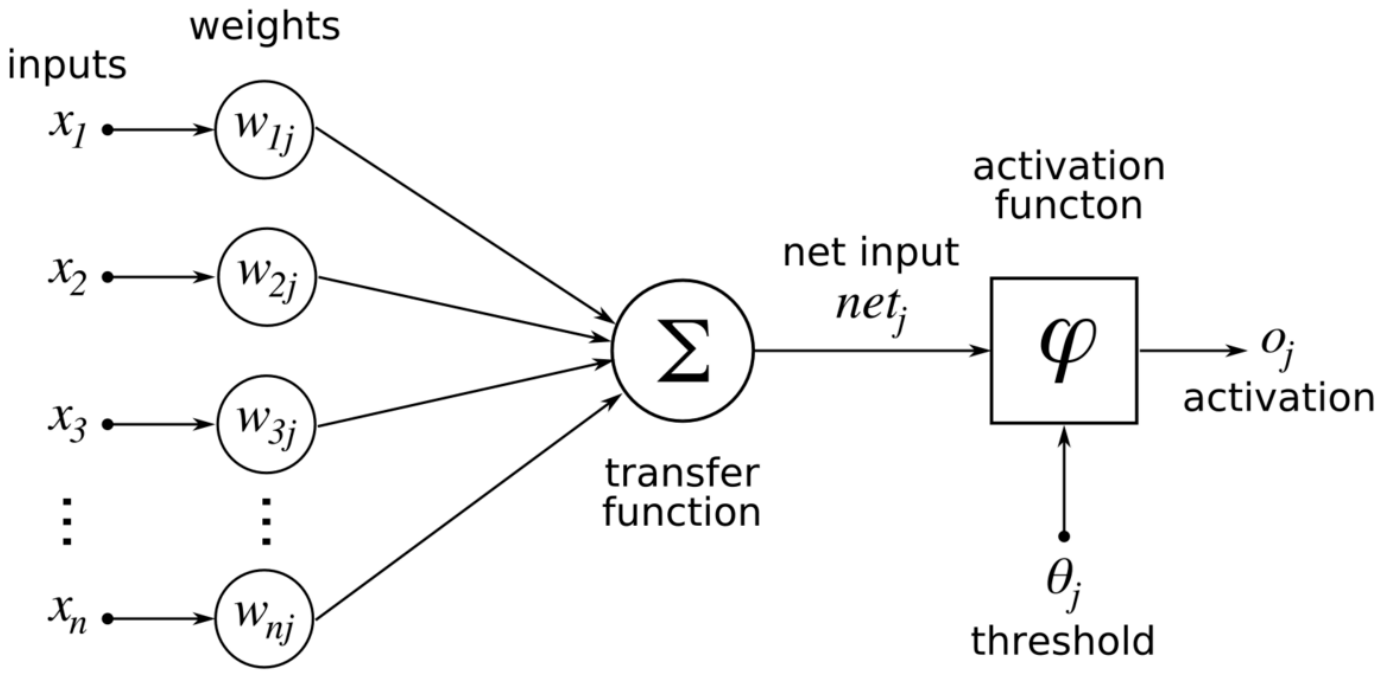
» Connections only between **adjacent layers**

» There are **no feedback** connections

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

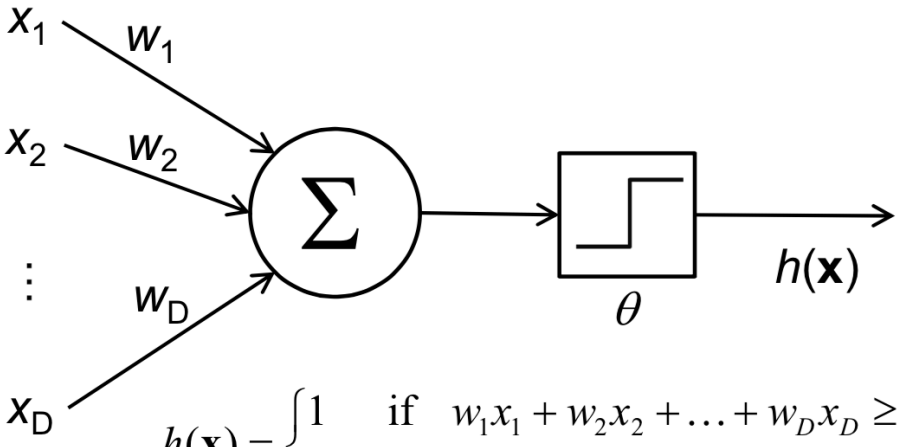
Activation Function

activation function of a node defines the output of that node given input(s)



source: https://en.wikibooks.org/wiki/Artificial_Neural_Networks/Activation_Functions

Perceptron

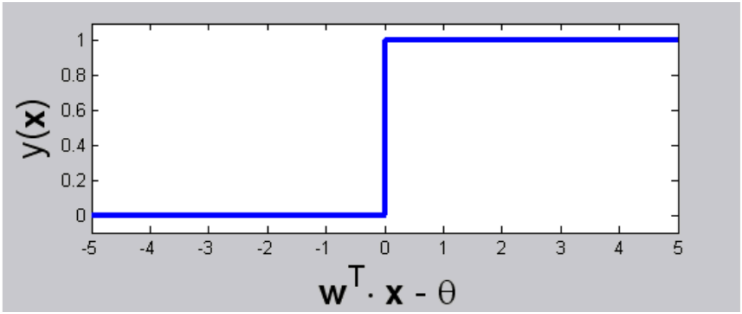


$$h(\mathbf{x}) = \begin{cases} 1 & \text{if } w_1 x_1 + w_2 x_2 + \ldots + w_D x_D \geq \theta \\ 0 & \text{if } w_1 x_1 + w_2 x_2 + \ldots + w_D x_D < \theta \end{cases}$$

$$\text{threshold}: \theta$$

In vector notation:

$$h(\mathbf{x}) = \begin{cases} 1 & \text{if } \mathbf{w}^T \cdot \mathbf{x} \geq \theta \\ 0 & \text{if } \mathbf{w}^T \cdot \mathbf{x} < \theta \end{cases}$$



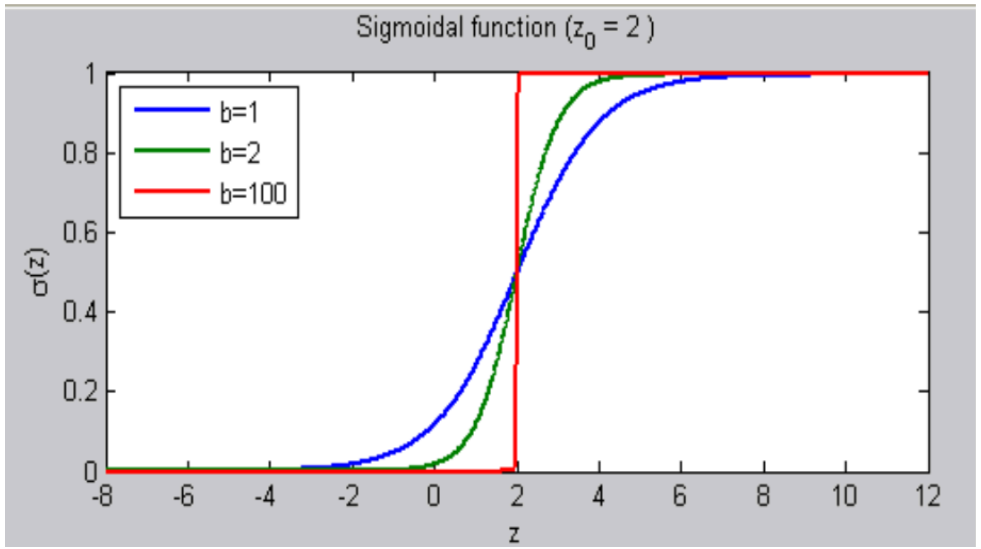
- Invented in 1957.
- Classifies input data into one of the output classes.
- Online learning possible

If the weighted input is more than the threshold, classify as 1. Else 0

McCulloch, W. S., and Pitts, W. "A Logical Calculus of Ideas Immanent in Nervous Activity." Bulletin of mathematical biophysics, 5, pp. 115-133 (1943). Reprinted in McCulloch, W. S., *Embodiments of mind*. Cambridge, MA: MIT Press.

source: ASDM Summer School on Deep Learning 2014

Sigmoid/Logistic



$$\sigma(z) \equiv \frac{1}{1+e^{-z}}; \quad \textbf{[logistic sigmoid]}$$

Local field : $\mathbf{w}^T \cdot \mathbf{x} = \sum_{d=0}^{D} w_d x_d$

Activation function : $\sigma(z) = \frac{1}{1+e^{-z}}$

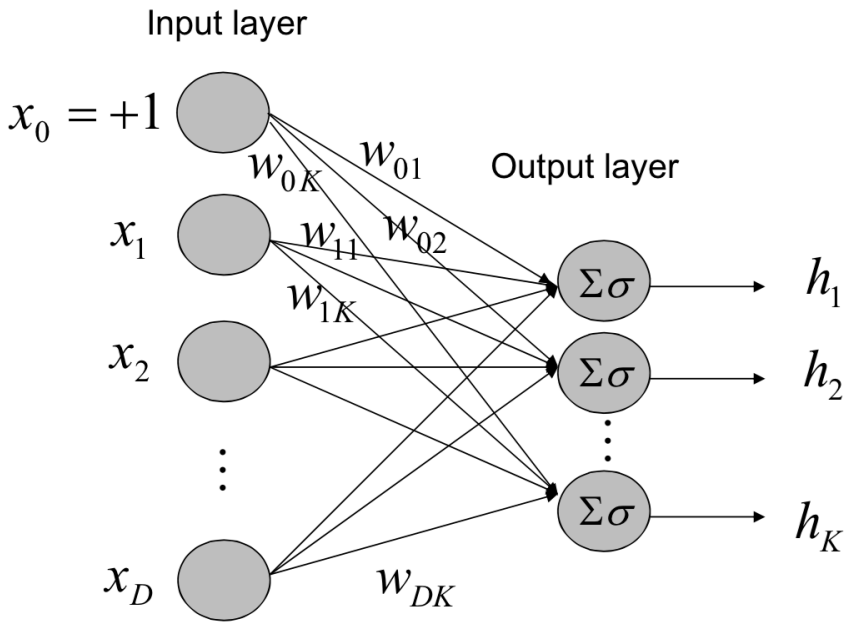
Output : $h(\mathbf{x}) = \sigma\left(\mathbf{w}^T \cdot \mathbf{x}\right)$

- Output is bounded between 0 & 1
- Domain: Complete set of Real numbers
- Smooth and continuous function.

- Symmetric
- Derivative can be quickly calculated
- Positive, Bounded, strictly positive

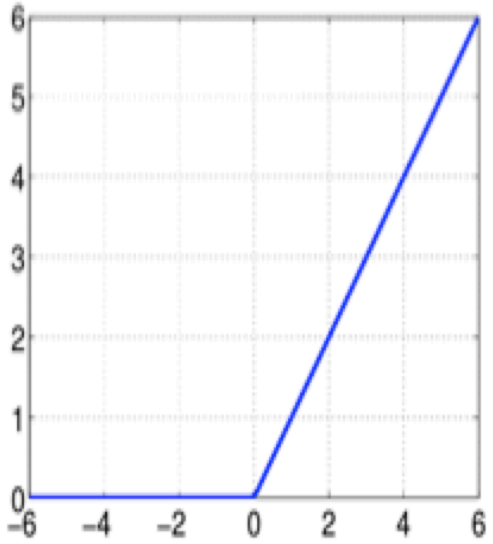
Softmax

Generalization of logistic regression for Multi-class classification



Rectified Linear Units

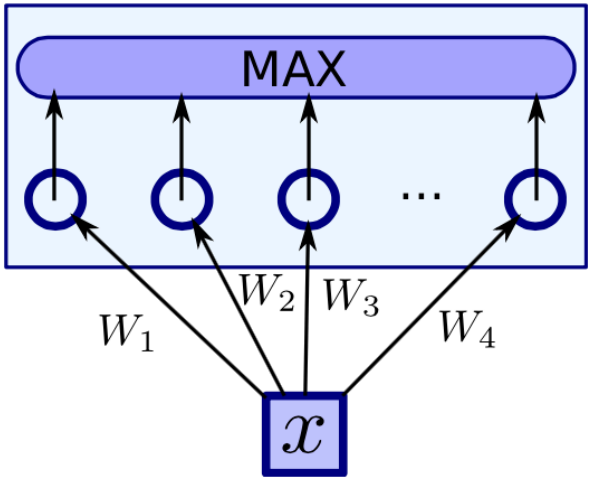
$$f(x) = \max\{0, x\}$$



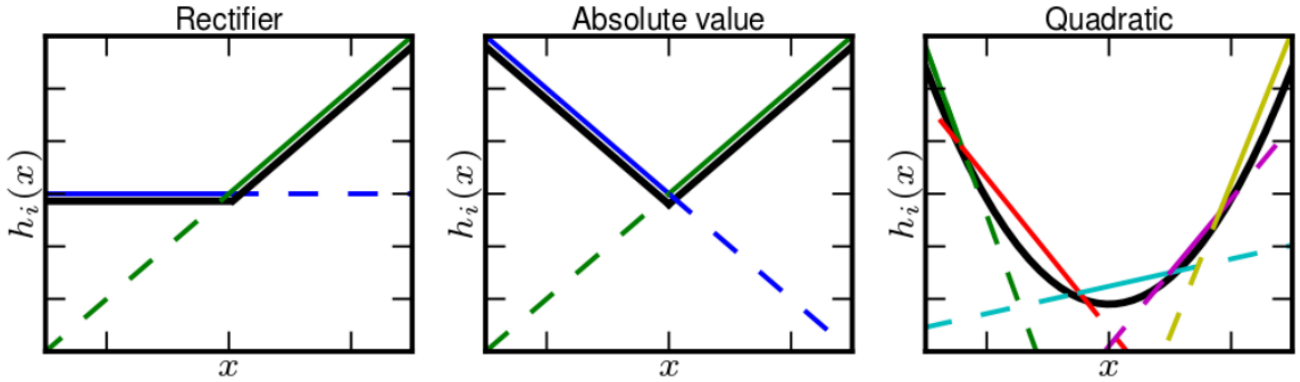
- ❑Cheap to compute (no products/exponentials)
- ❑Faster training
- ❑Sparser networks
- ❑Bounded below 0
- ❑Strictly increasing

Max-out

$$f(x) = \max_{i=1}^{k} (x^T W_i + b_i)$$



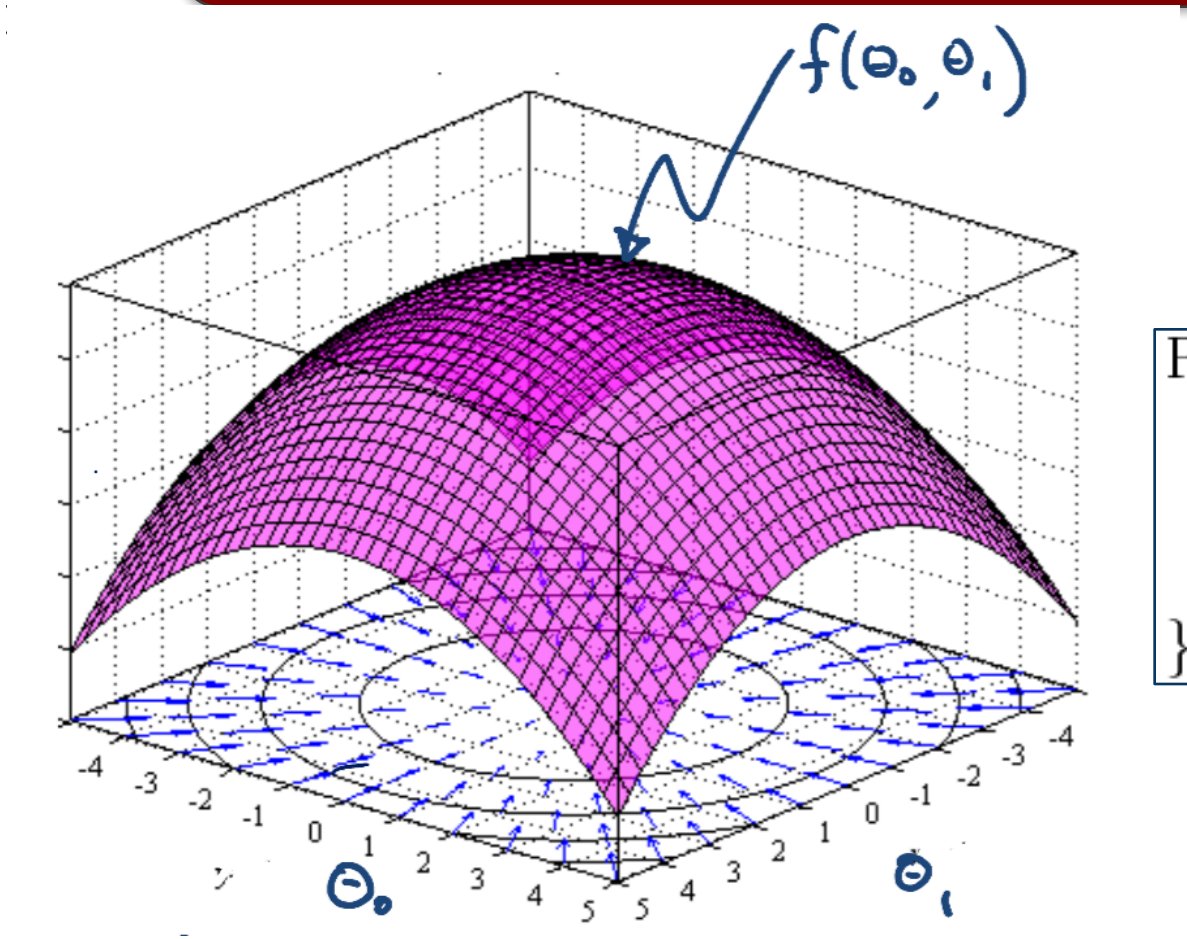
- Generalization of Rectified Linear
- Max of k linear functions -> piece-wise linear
- At large k, can approximate a non-linear function



source: ASDM Summer School on Deep Learning 2014

Learning in ANN – Gradient Descent

Goal: To find minimum of the loss function (minimize error of the model)

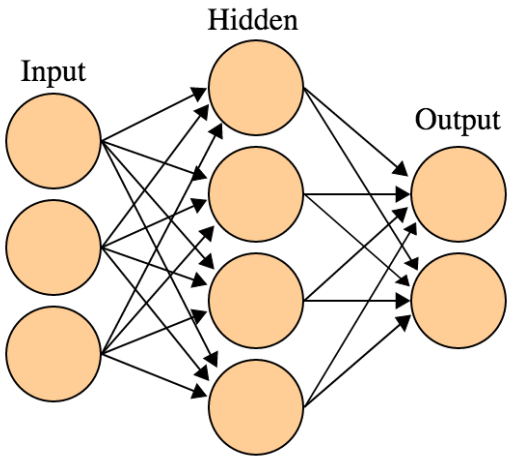


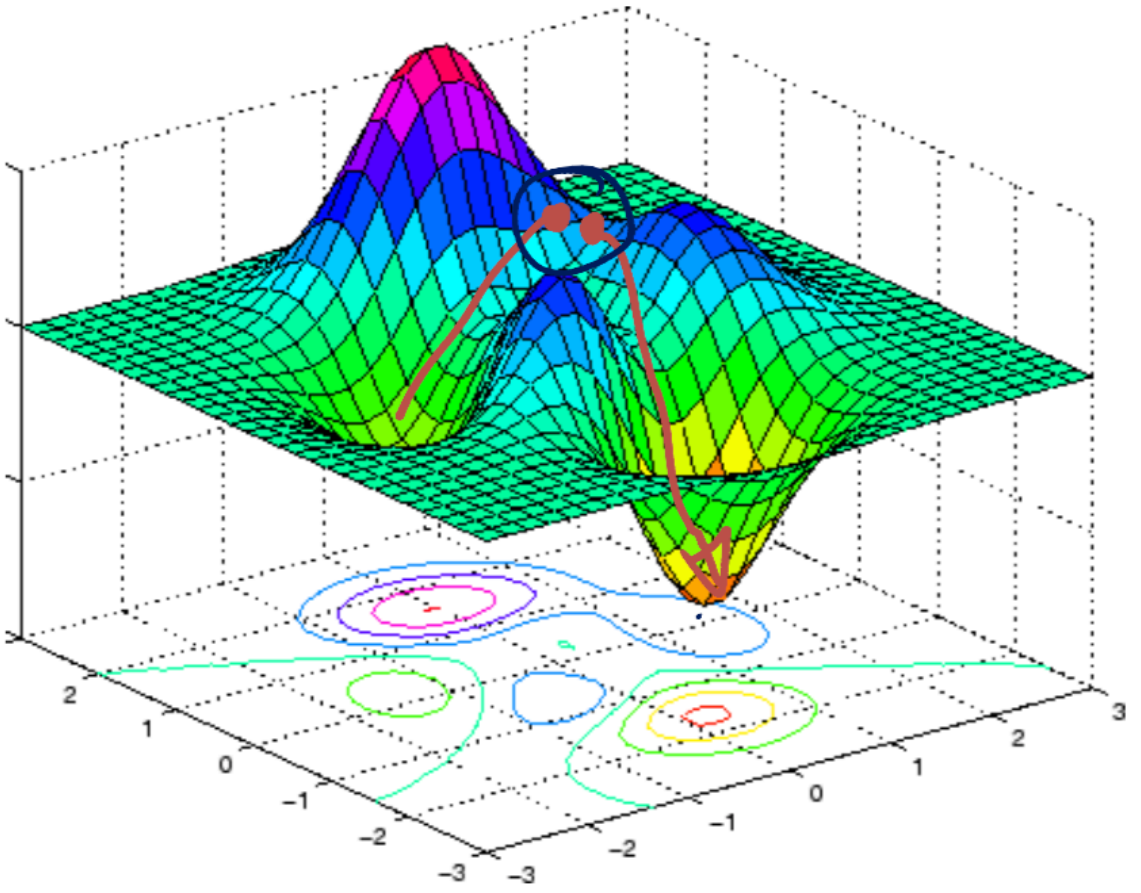
Repeat until convergence {

$$\theta_j \leftarrow \theta_j - \alpha \frac{\partial}{\partial \theta_j} J(\theta)$$

}

Er.... How to compute gradient?





Backpropagation Algorithm – Pseduo Code

Algorithm 1 Backpropagation learning algorithm

for d in data **do**

FORWARDS PASS

Starting from the input layer, use eq. 1 to do a forward pass trough the network, computing the activities of the neurons at each layer.

BACKWARDS PASS

Compute the derivatives of the error function with respect to the output layer activities

for layer in layers **do**

Compute the derivatives of the error function with respect to the inputs of the upper layer neurons

Compute the derivatives of the error function with respect to the weights between the outer layer and the layer below

Compute the derivatives of the error function with respect to the activities of the layer below

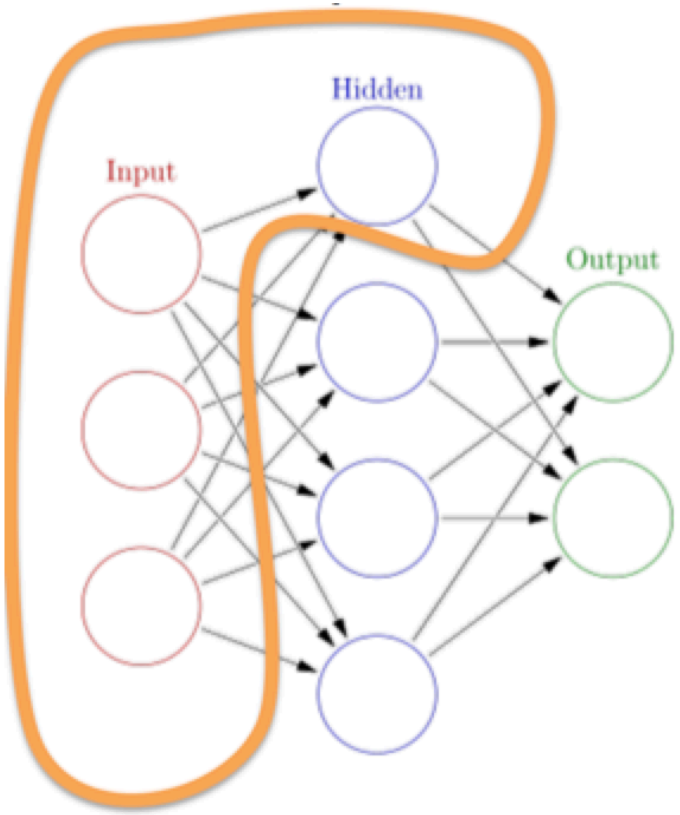
end for

Updates the weights.

end for

source: http://tex.stackexchange.com/questions/155614/description-of-algorithm-in-words

Backpropagation Algorithm



Computes gradient of the loss function w.r. to the weights.

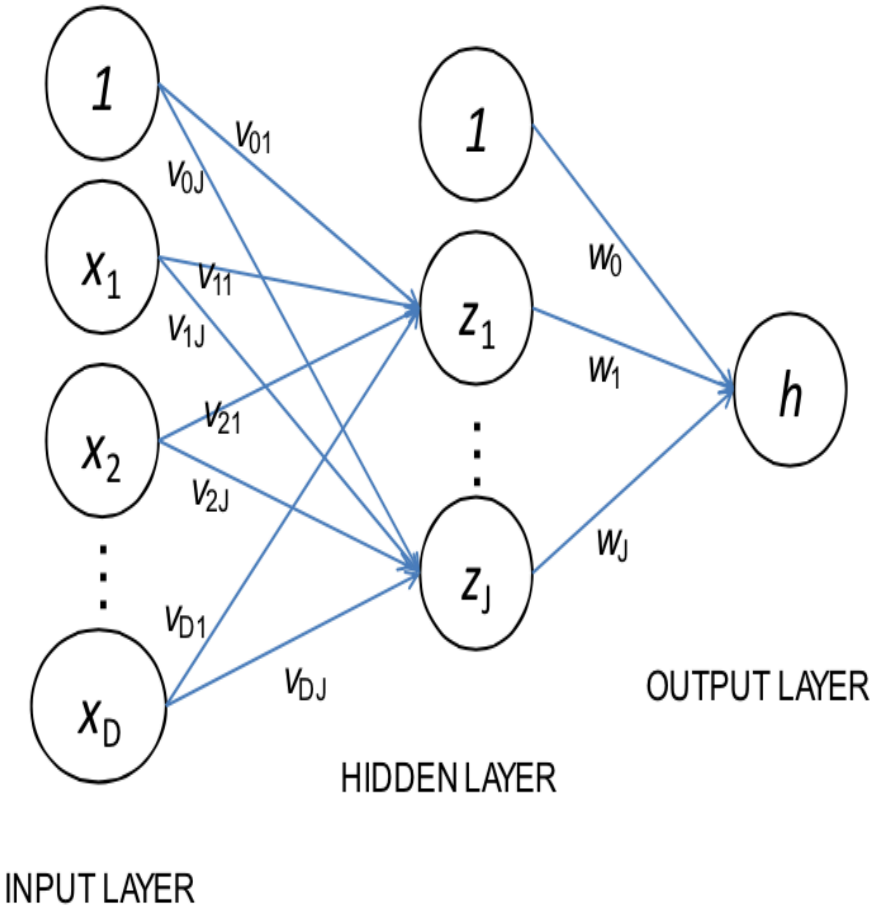
Backpropagate training error to generate deltas of all the neurons from hidden layers to output layer

Use gradient descent to update weights

SGD/Mini-Batch/Online

- Stochastic Gradient Descent: Instead of using all of the training data, train iteratively on "mini-batches"
- Online Learning: Mini-batch size is 1. Weights are adjusted for every single data point.

Multi-Layer Perceptron

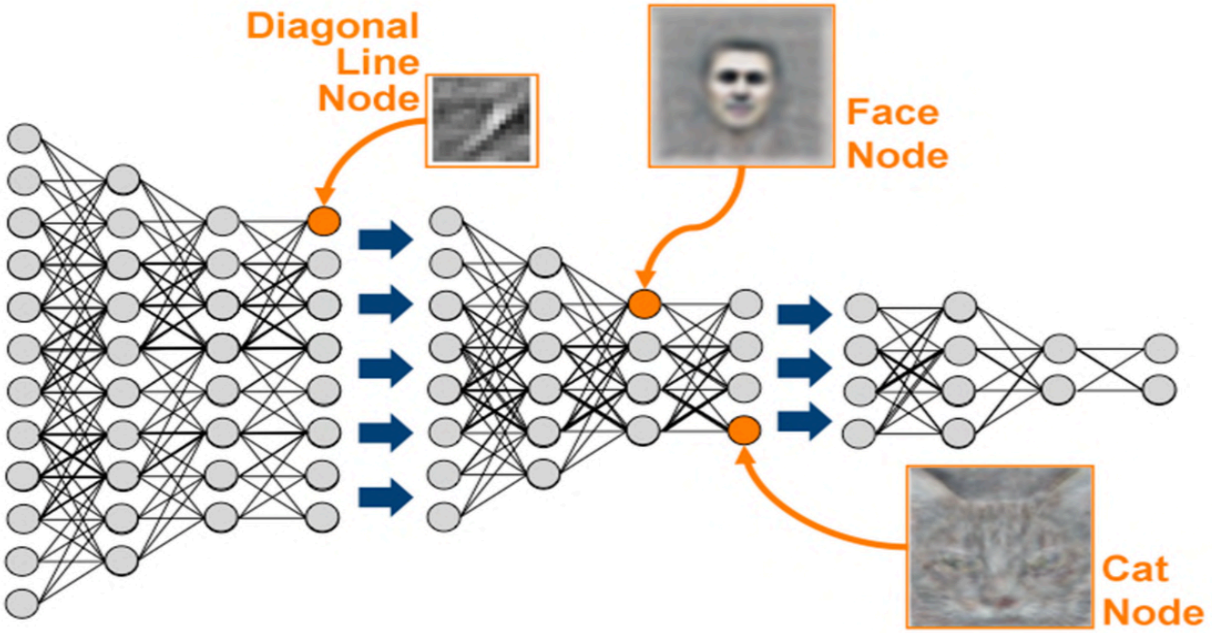


- Feedforward ANN
- Activation function: Mostly sigmoid
- Improvement over basic perceptron: Can classify data that aren't linearly separable


SOME DEEP LEARNING EXAMPLES

Video Classification

Google's neural net learns just by watching youtube videos



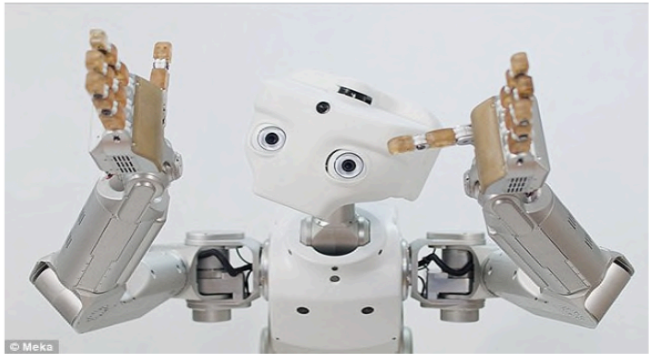


Image Recognition

source: http://www.cs.ubc.ca/~nando/

Image Generation – Google Inceptionism

source: http://googleresearch.blogspot.in/2015/06/inceptionism-going-deeper-into-neural.html


HANDS-ON

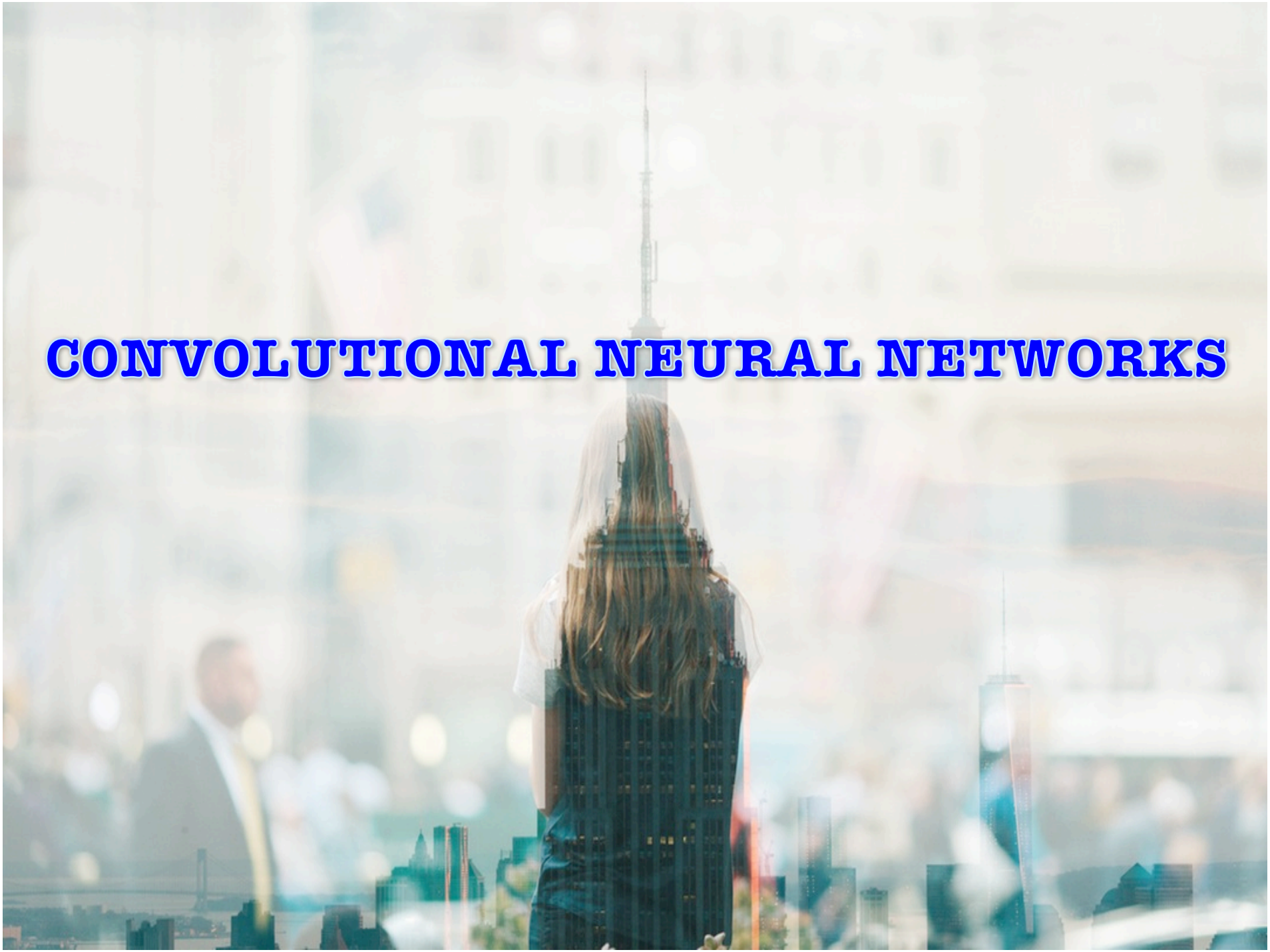
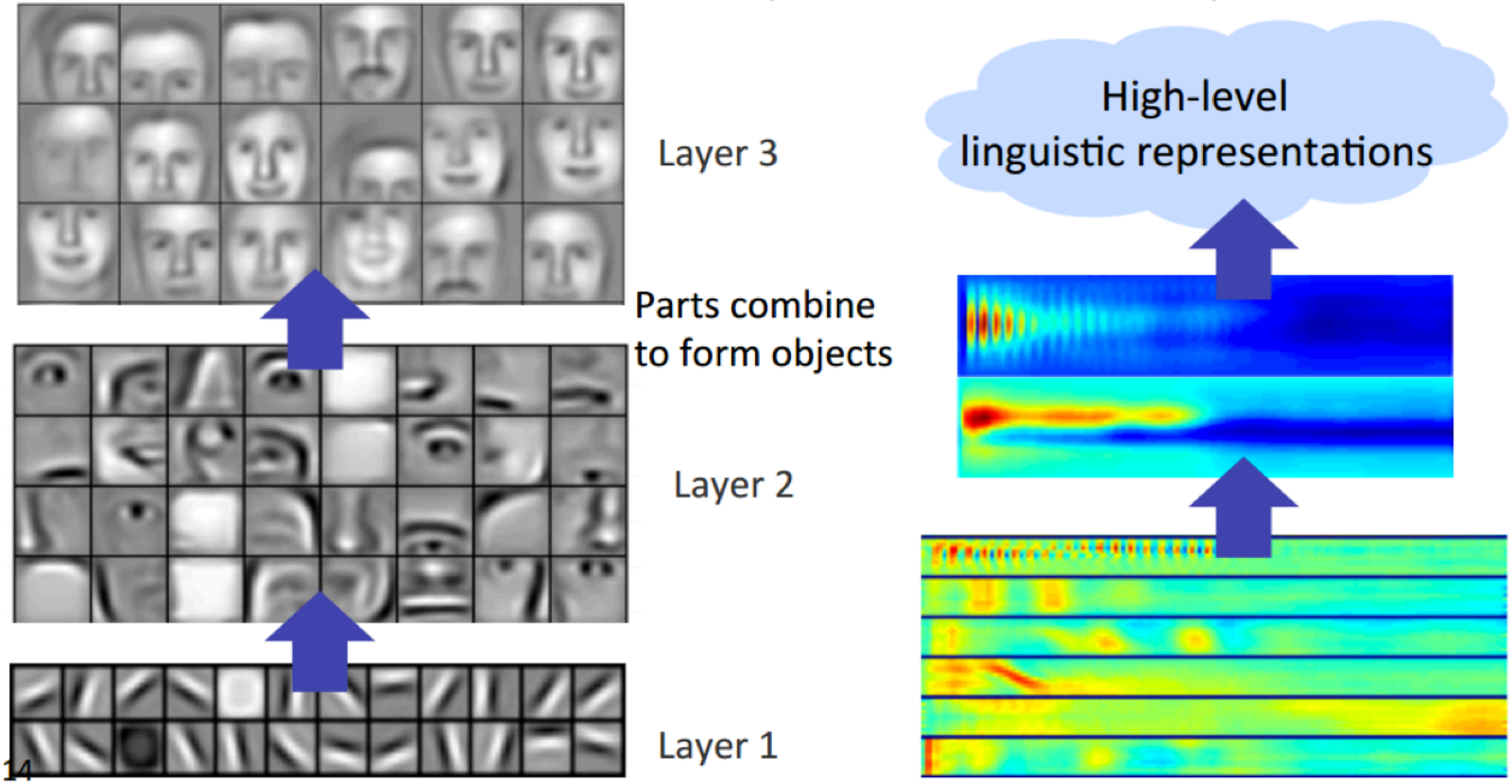

CONVOLUTIONAL NEURAL NETWORKS

Image Recognition/Classification

Successive model layers learn deeper intermediate representations



Prior: underlying factors & concepts compactly expressed w/ multiple levels of abstraction

Source: http://www.iro.umontreal.edu/~bengioy/talks

Convolution

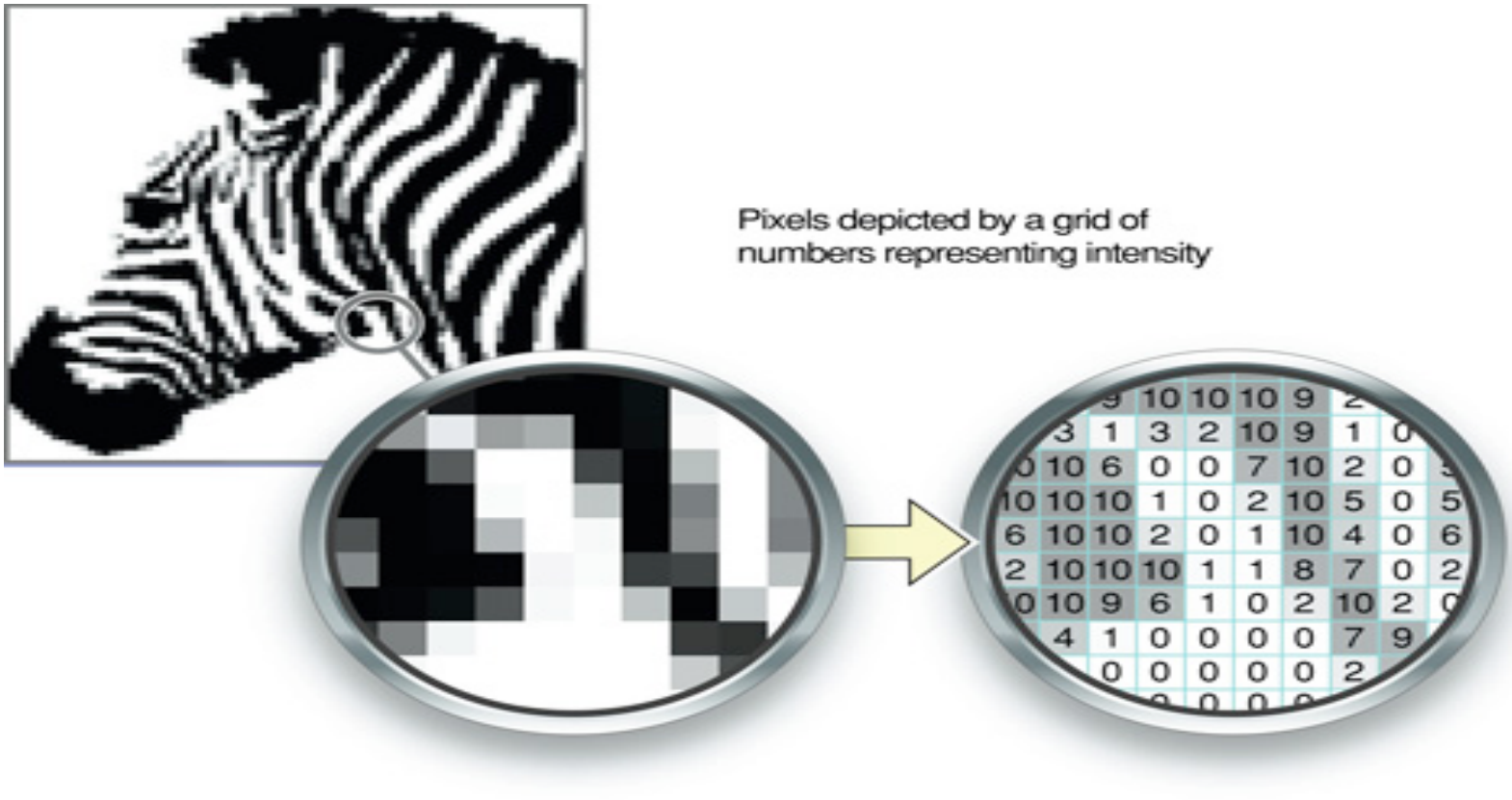
Image Processing Technique to change intensities of a pixel to reflect the intensities of the surrounding pixels. Eg: image effects like blur, sharpen, and edge detection

Original

Emboss

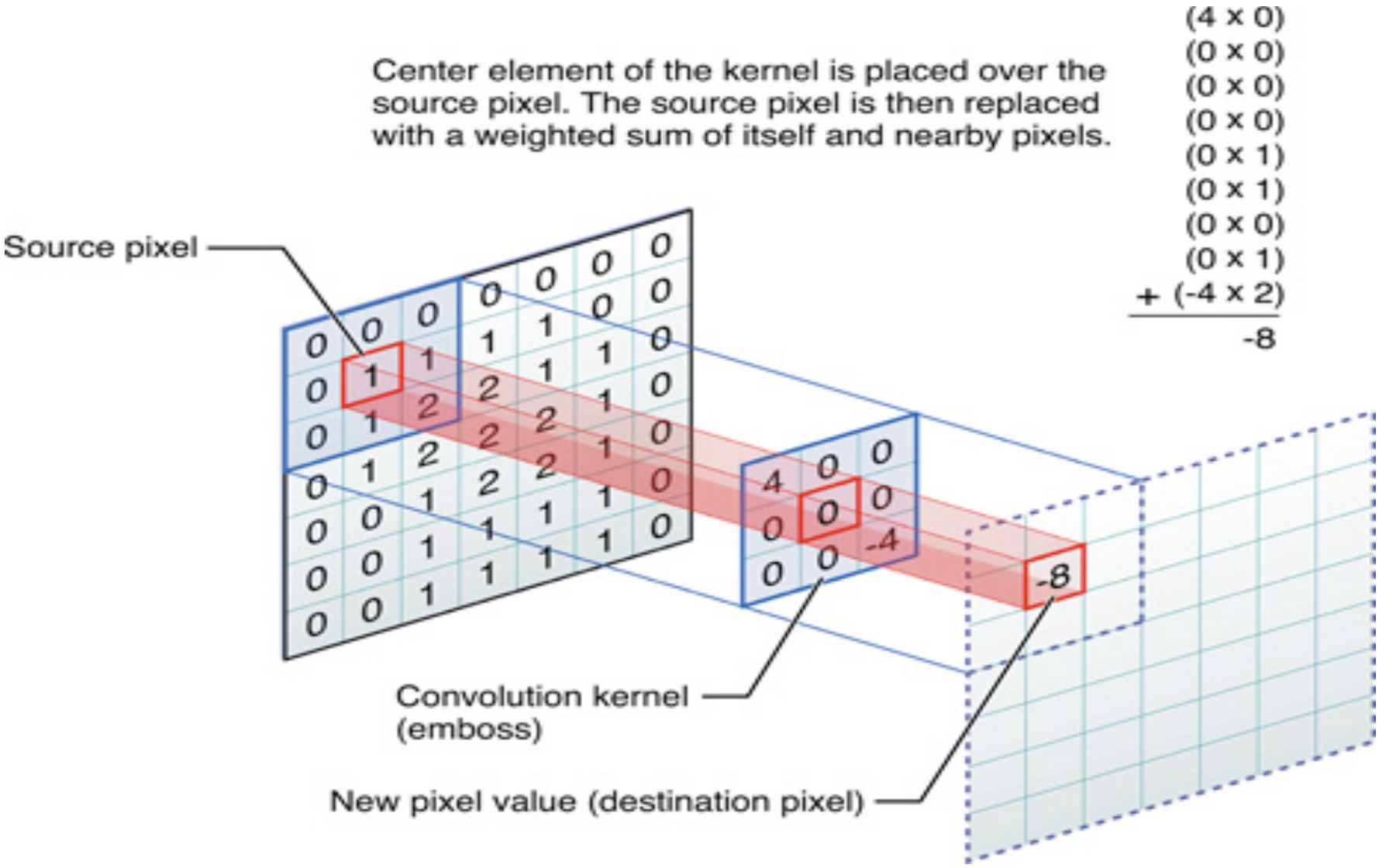
source: https://developer.apple.com/library/ios/documentation/Performance/Conceptual/vImage/ConvolutionOperations/ConvolutionOperations.html

Convolution



source: https://developer.apple.com/library/ios/documentation/Performance/Conceptual/vImage/ConvolutionOperations/ConvolutionOperations.html

Convolution



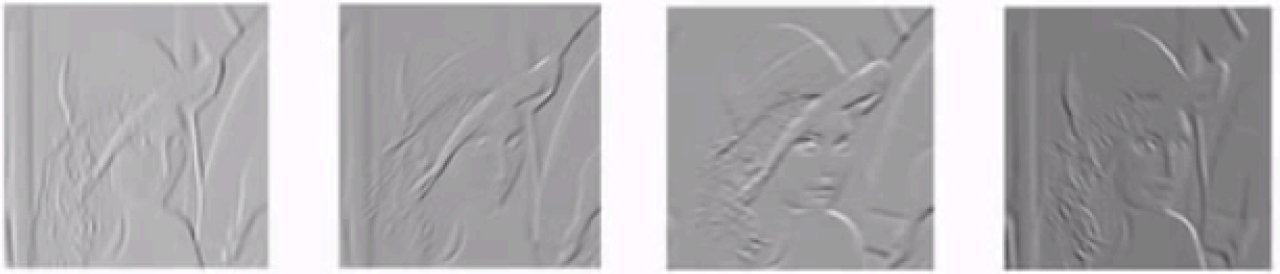
source: https://developer.apple.com/library/ios/documentation/Performance/Conceptual/vImage/ConvolutionOperations/ConvolutionOperations.html

Convolution – One more example

Lena

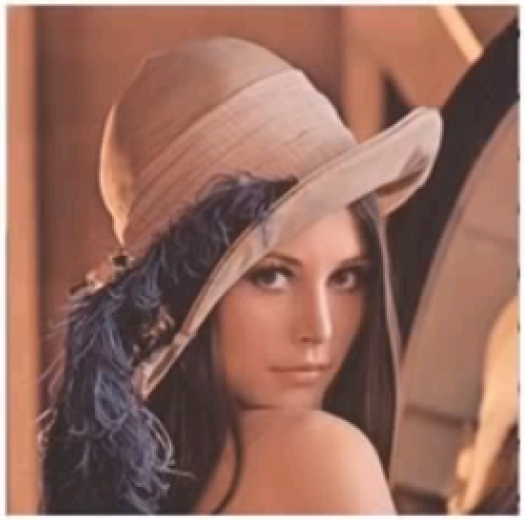
Gabor filters

Convolved by Gabor filters lena



source: http://web.ics.purdue.edu/~adundar/teaching.html

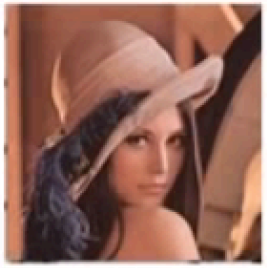
Sub-sampling



Input 508x508 pixels Lena

down-sampled by 2x2

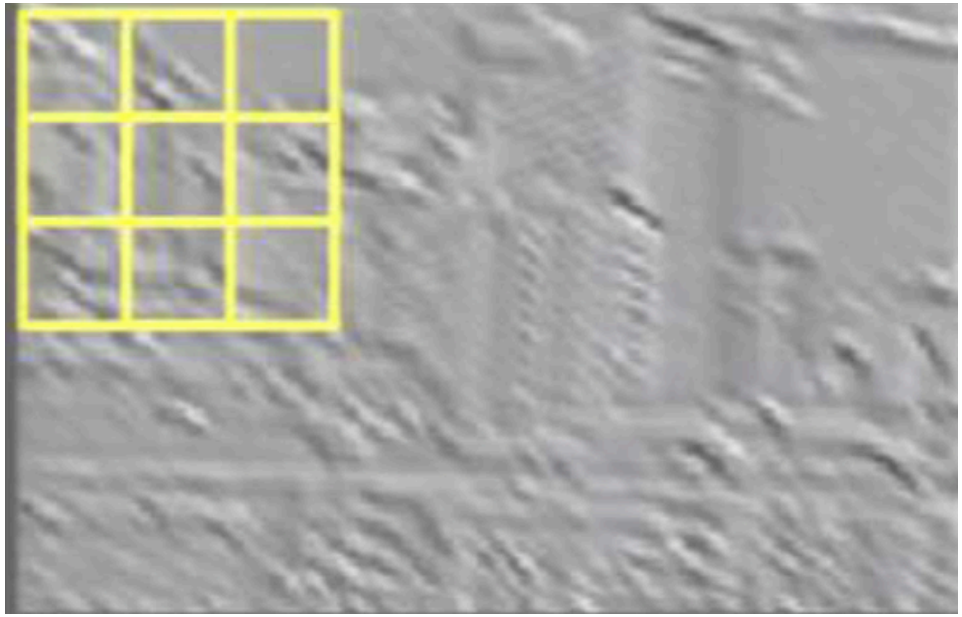
==========>

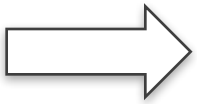


Input 254x254 pixels Lena

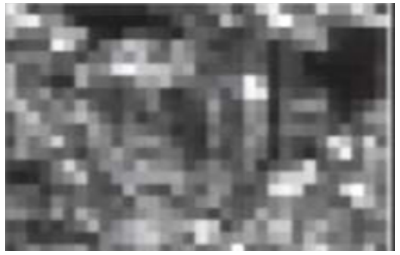
source: http://web.ics.purdue.edu/~adundar/teaching.html

Pooling

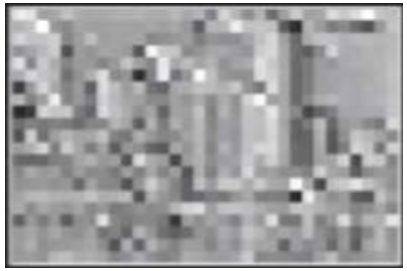




Max



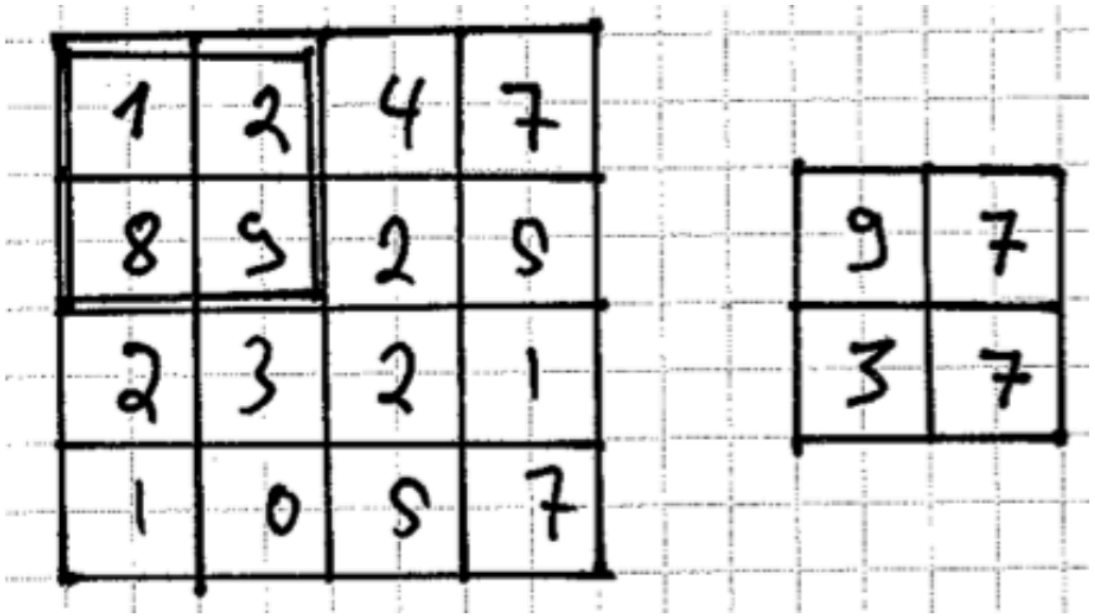
Sum



source: http://web.ics.purdue.edu/~adundar/teaching.html

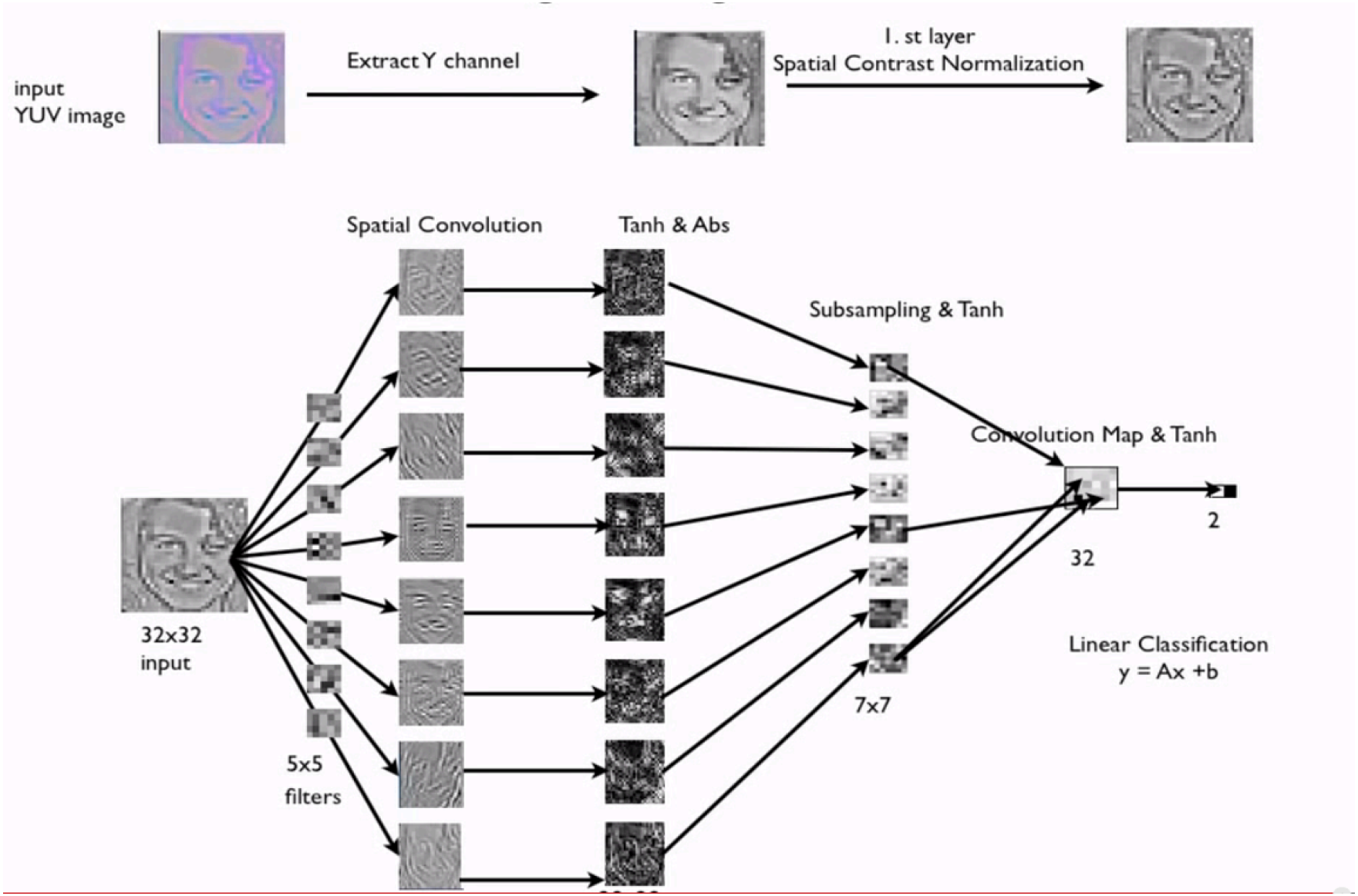
Max Pooling

Hinton: The pooling operation used in convolutional neural networks is a big mistake and the fact that it works so well is a disaster"



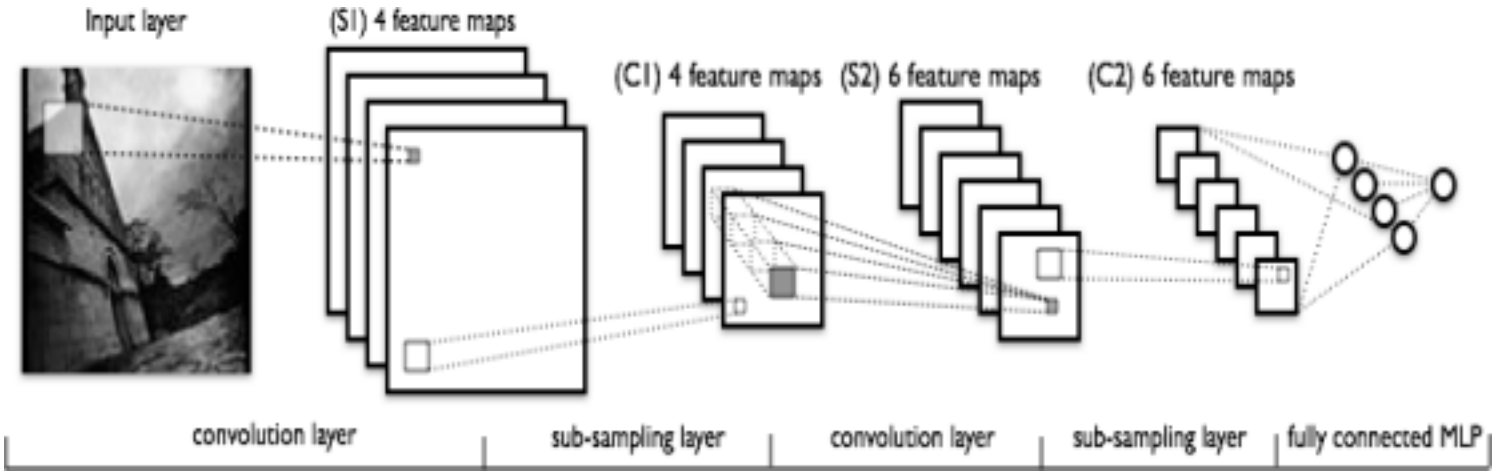
Simply join e.g. 2x2 adjacent pixels in one.

Basic Architecture



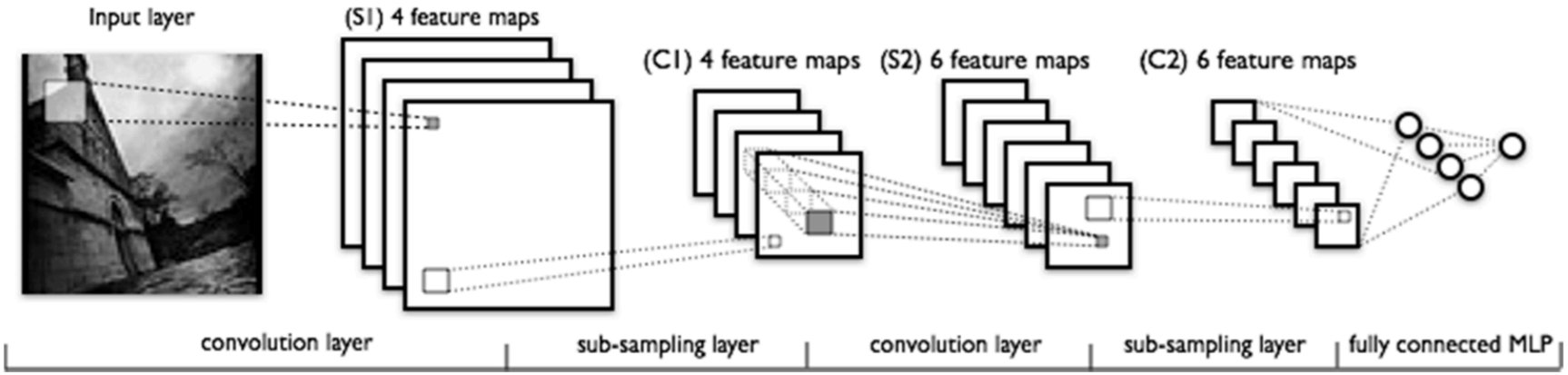
source: http://web.ics.purdue.edu/~adundar/teaching.html

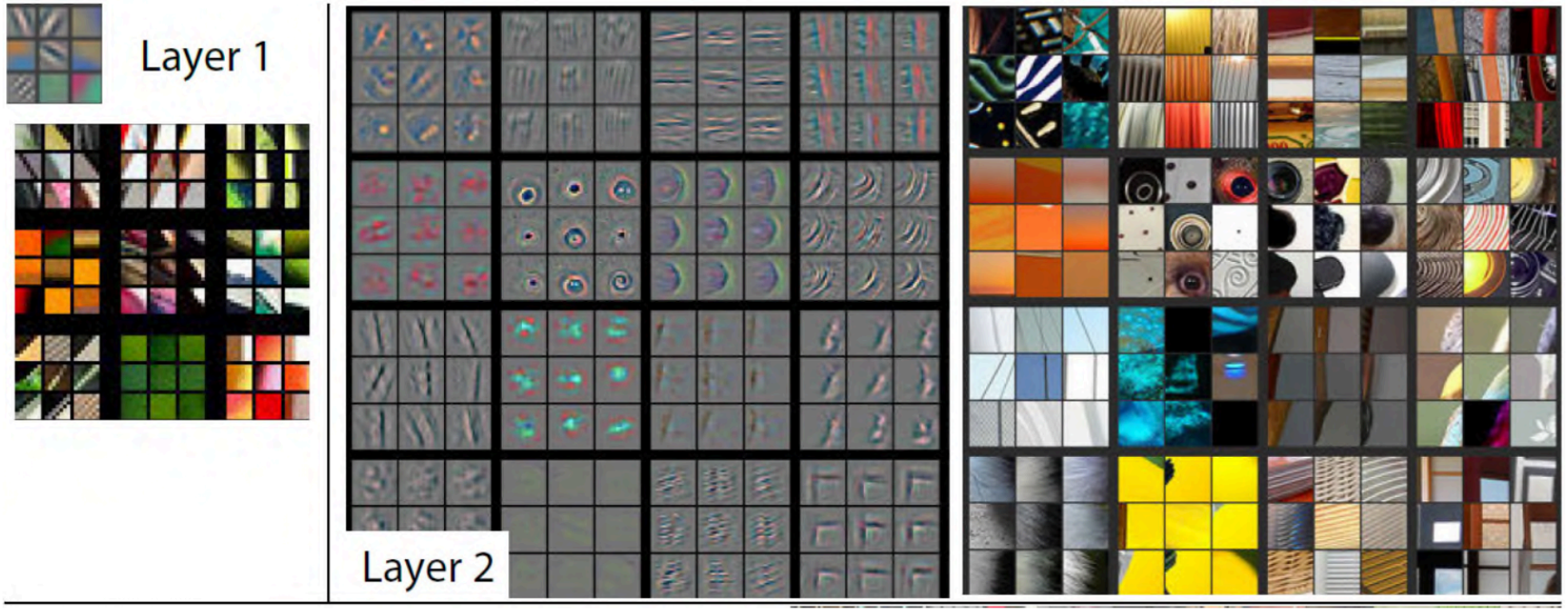
CNN Architecture



Source: http://deeplearning.net

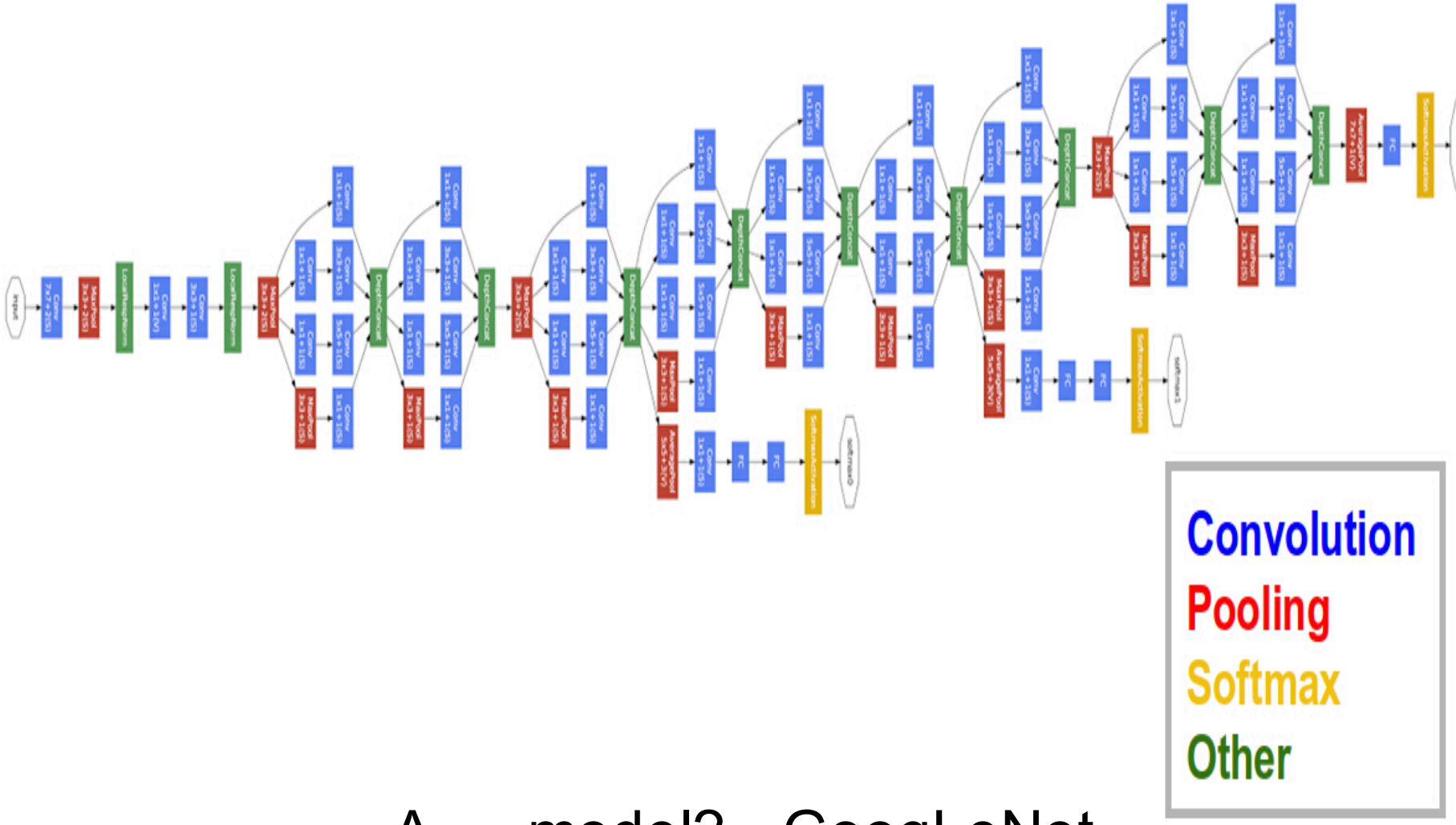
CNN Architecture





[Matthew Zeiler & Rob Fergus]

Example of a CNN model



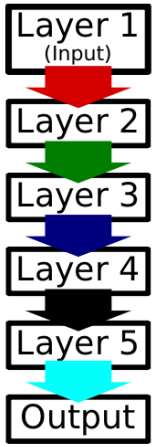
A … model? - GoogLeNet

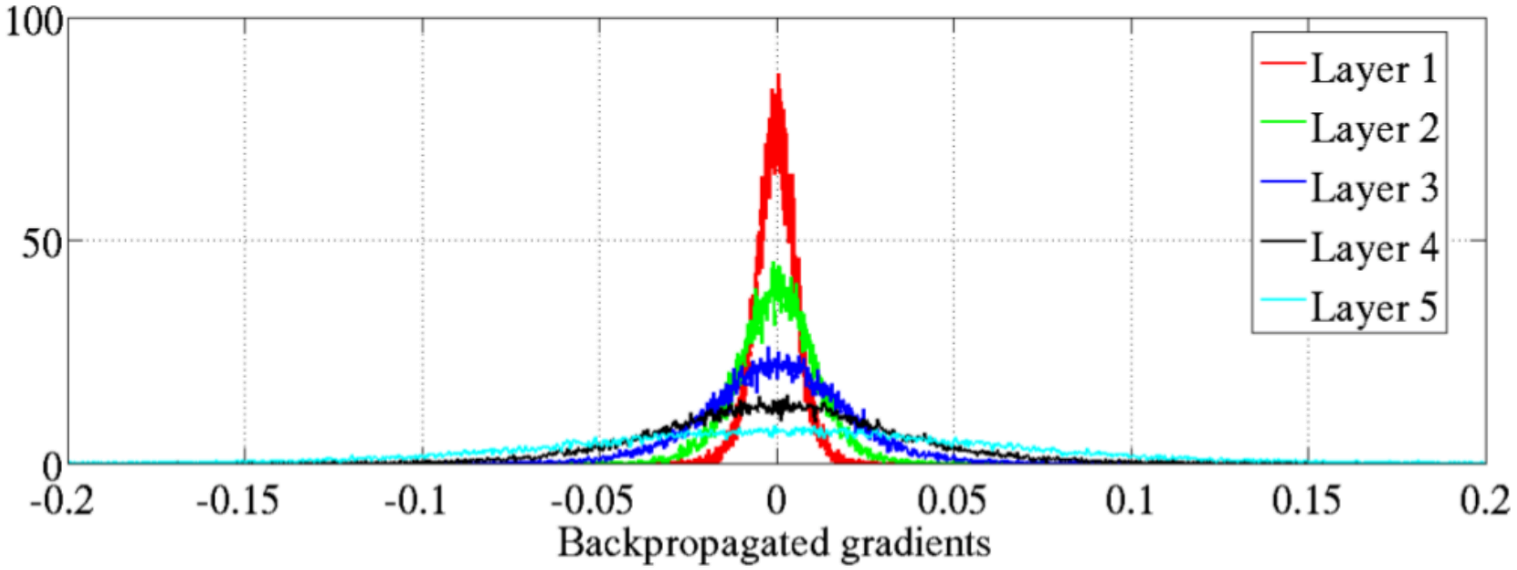
source: arXiv:1409.4842v1 [cs.CV] 17 Sep 2014


CHALLENGES IN DEEP LEARNING

People who are more likeable and attractive are generally perceived as more intelligent. This is called the "Halo Effect."

Vanishing Gradient





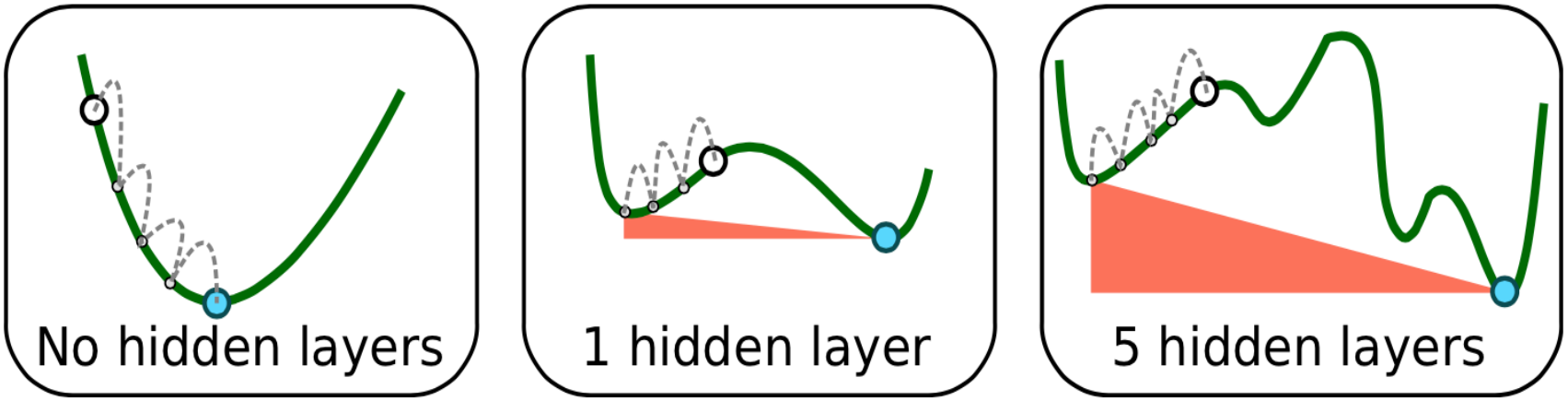
- In backpropagation, the gradient becomes zero in the layers nearest to the input.
- Intuition : layers near to the output have larger influence in the error rate.
- Training deep layers successfully is terribly slow.
- Until deep layers learn some sensible weights, subsequent layers are trying to learn mostly from noise.

(*) Glorot & Bengio. Understanding the difficulty in training deep feedforward neural networks.

source: ASDM Summer School on Deep Learning 2014

High Non-Linearity – Local Minima

- Backpropagation is a gradient descent method.
- Only guarantees finding a local minimum of the error function, which can be worse than the global minimum .
- When introducing more non–linearities in the network (more layers), local minima multiply .



- It is hard to find good weight configurations for a deep network.

source: ASDM Summer School on Deep Learning 2014

Alleviating vanishing gradients & local minima

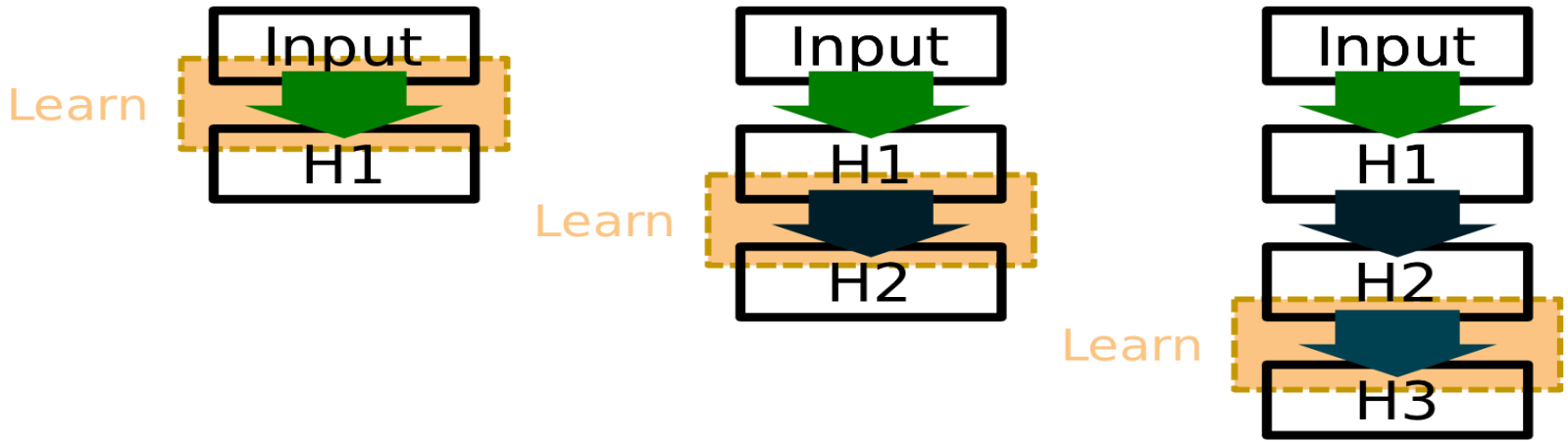
- Smart weight initialization
- Use RL and Maxout units
- Train for a longer time .
- Use restarts .

Incremental Pre-training

Instead of learning all the network weights jointly, build each layer iteratively .

Incremental Pre-training

- Start learning the layer nearest to inputs.
- proceed adding layers until last hidden layer
- When adding a new layer, weights from previous layers are kept fixed .
- One layer is learned at a time, vanishing gradients are avoided .



Incremental Pre-training

Two options for output

- Keep pre–trained weights fixed .
- Deep network ≃ feature generator : more useful features are obtained from the inputs.
- The output layer is trained as a perceptron , inputs are the features obtained.

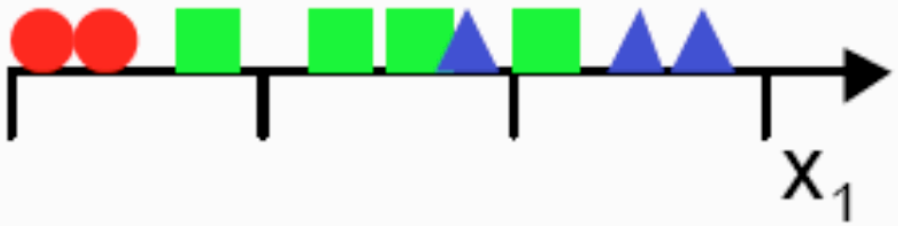
- Discriminative fine–tuning . Optimize jointly over all network weights (e.g. using BP).
- Pre–trained weights seem to be a better choice than random initialization .
- Slower Fine tuning


UNSUPERVISED LEARNING

Curse of Dimensionality

Single feature

Divide feature space into 3 simple bins

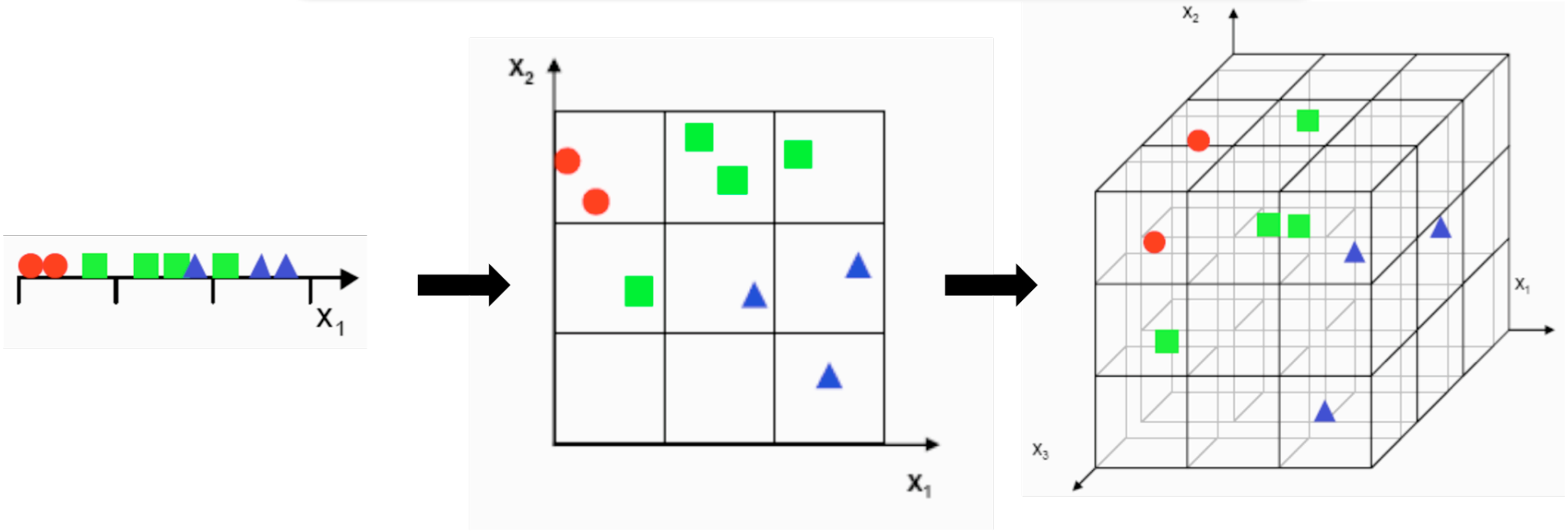


Too simplistic –
Too much overlap between classes.

source:http://nikhilbuduma.com/2015/03/10/the-curse-of-dimensionality/

Curse of Dimensionality

But by adding features to improve separability, the feature space explodes.



source: http://nikhilbuduma.com/2015/03/10/the-curse-of-dimensionality/

Feature Selection

Need: Automated feature selection

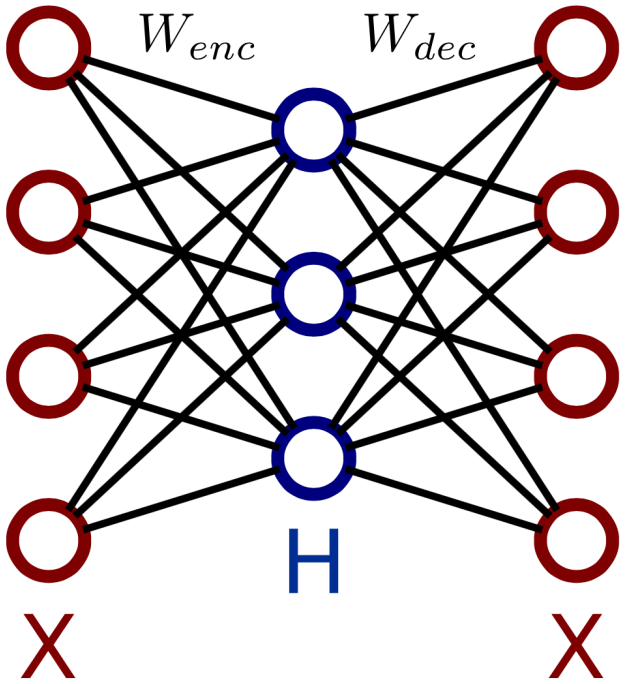
source: http://nikhilbuduma.com/2015/03/10/the-curse-of-dimensionality/

Autoencoders

GOAL: Efficient Reconstruction of Input Data

Use input as input and output of the network and train (Don't use the target)

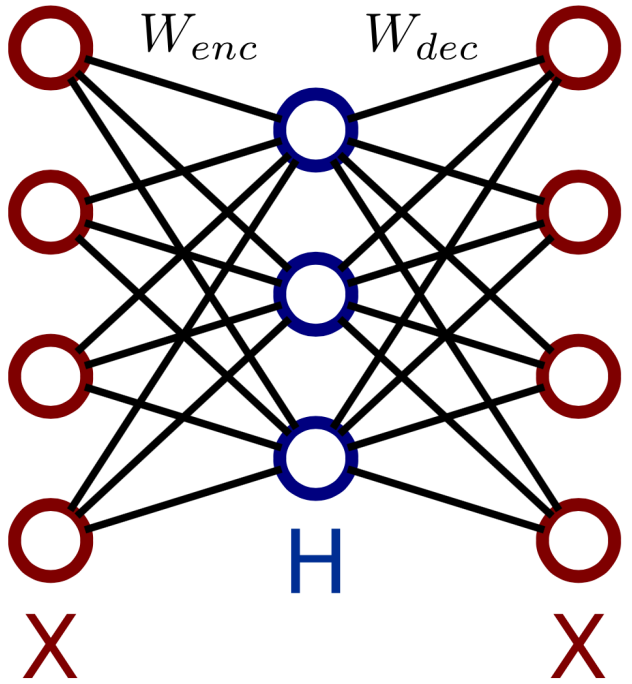
Learn the weights using a standard neural network method (e.g. backpropagation).



Autoencoders - Output

After learning,
W_{enc} : compresses the information in the data into the hidden units.

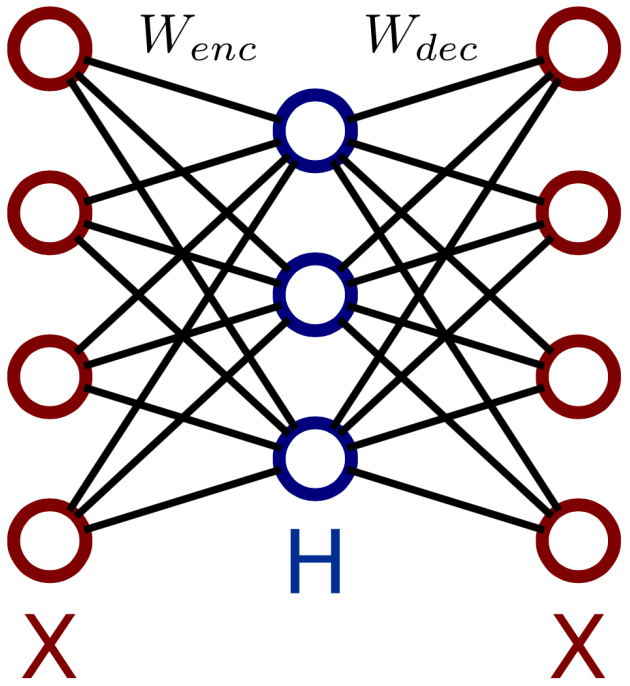
W_{dec} decompresses the info in the hidden units back to its original form *(with some loss)*.



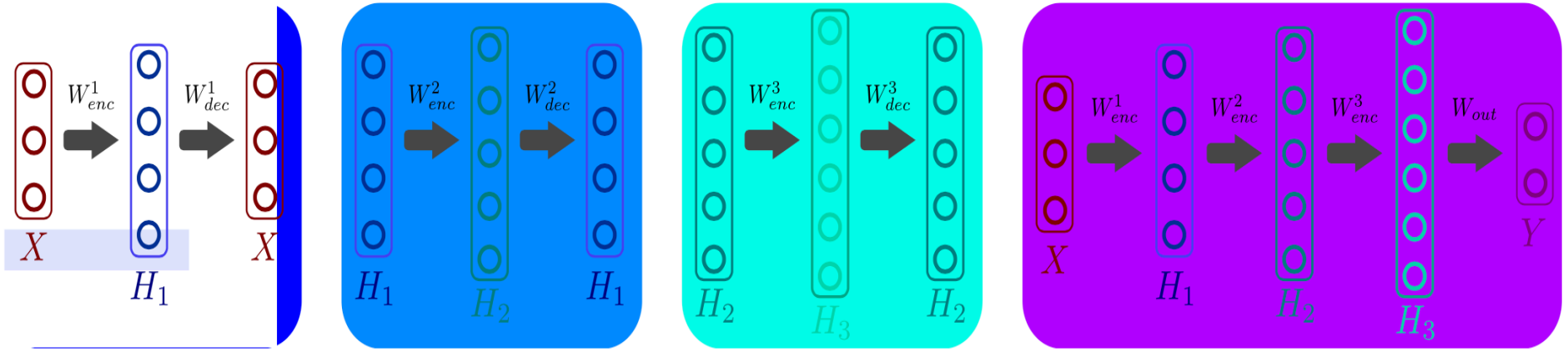
Autoencoders – To make them effective

Enforce sparsity .
(A network is sparse if only a few of its units >0 simultaneously)

Introduce random noise in the input patterns when training the network. (Only in the inputs!)



Deep Autoencoders



Train autoencoder to reconstruct the training data .

Proceed iteratively, building new autoencoders reconstructing the value of the hidden units of the previous stage.

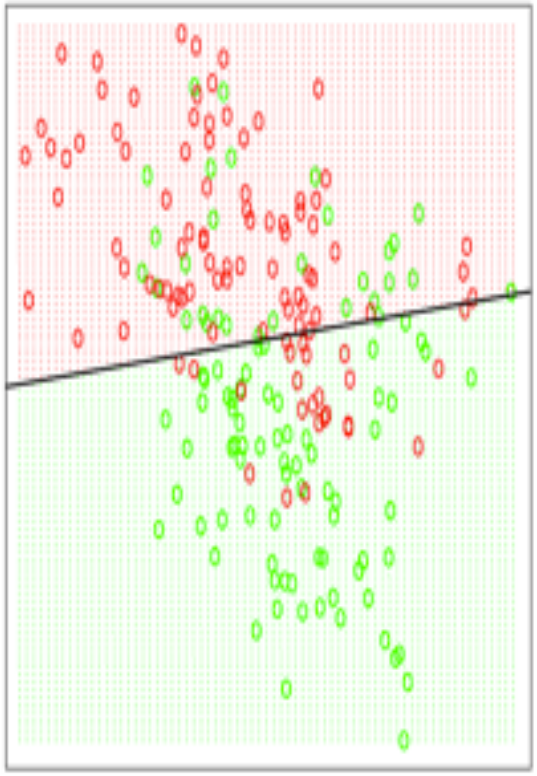
Create a feedforward network using the encoding weights W_{enc} from all the trained autoencoders. As output layer, use the training labels .

Fine–tuning : train the last layer or the full network using standard backpropagation.

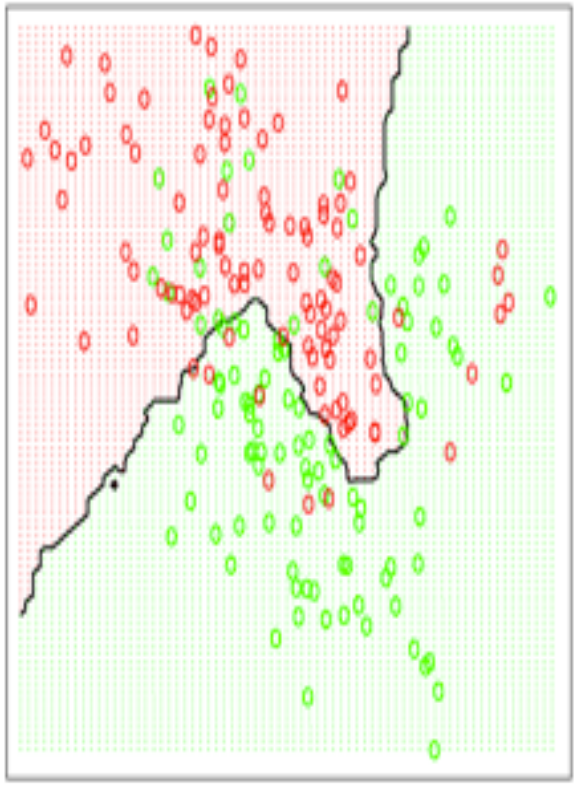

CHALLENGES IN DEEP LEARNING
- Continued

Overfitting

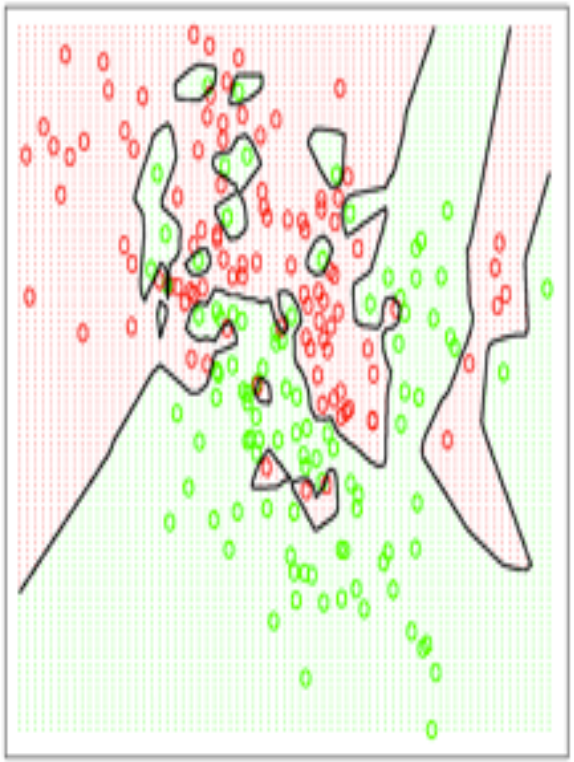
Underfitted Model



Good Model



Overfitted Model



source:http://mathbabe.org/2012/11/20/columbia-data-science-course-week-12-predictive-modeling-data-leakage-model-evaluation/

Some ways to address Overfitting

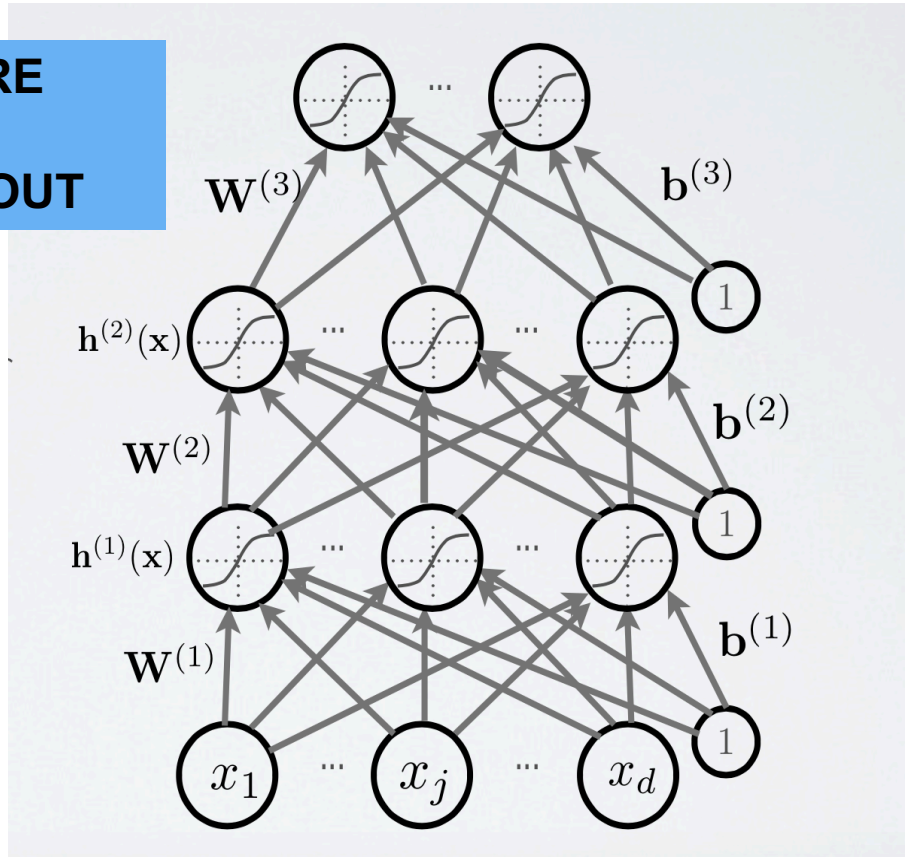
- Weight Decay
- L1/L2 Regularization
- Suitable Model Architectures (depth and width of the layers)
- Unsupervised Pre-training
- Dropout
- Data Augmentation

Dropout

- Cripple the network by removing hidden units stochastically
- In practice, probability of 0.5 works well.

BEFORE

DROPOUT



source: http://info.usherbrooke.ca/hlarochelle/neural_networks/content.html

Dropout

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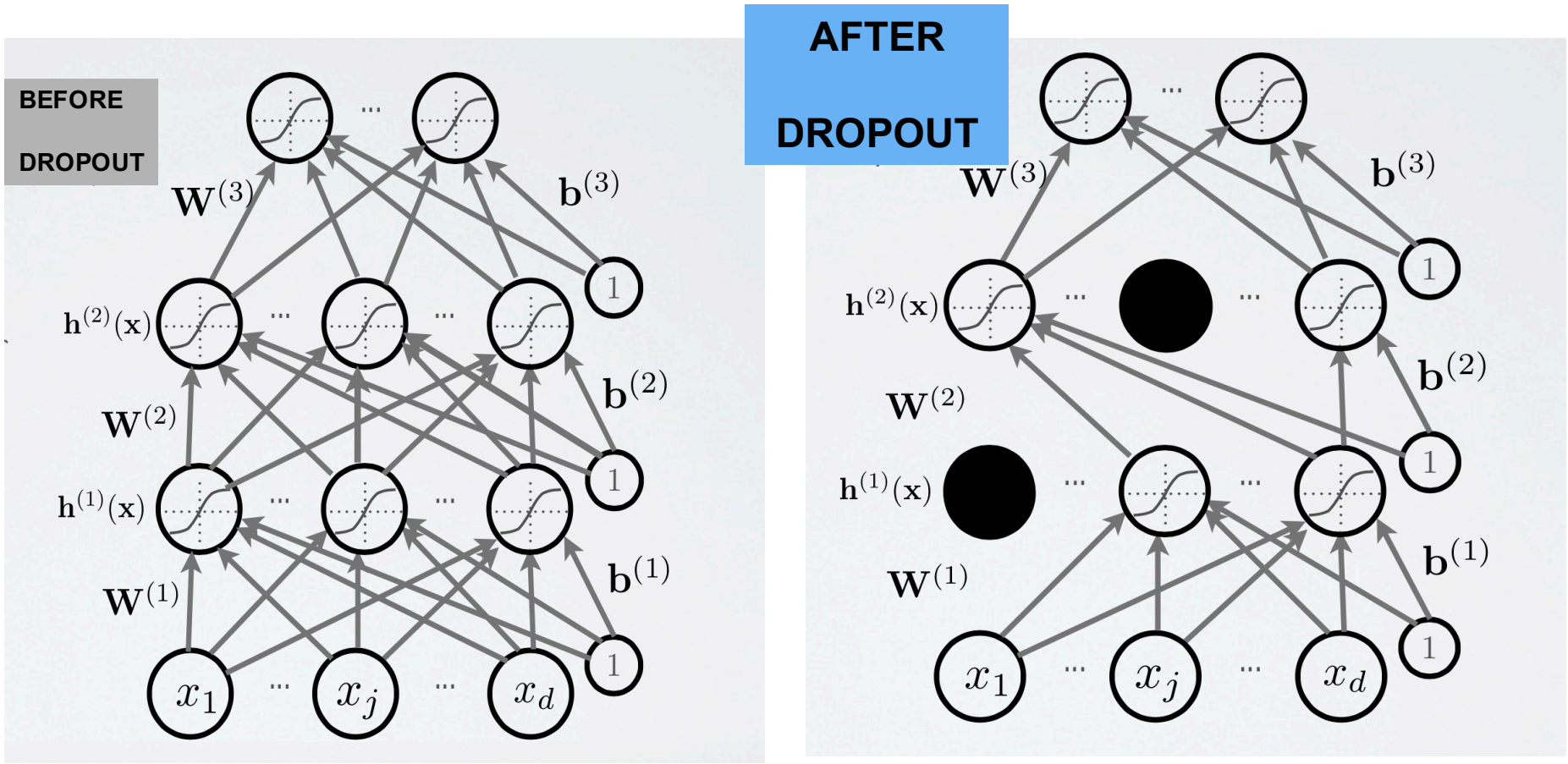


source: http://info.usherbrooke.ca/hlarochelle/neural_networks/content.html

Data Augmentation

Some ways to augment data:

- **Rotation**: random angle between 0° and 360°
- **Translation**: random shift between -10 and 10 pixels
- **Rescaling**: random scale factor between 1/1.6 and 1.6
- **Flipping**: yes or no
- **Shearing**: random angle between -20° and 20°
- **Stretching**: random with stretch factor between 1/1.3 and 1.3

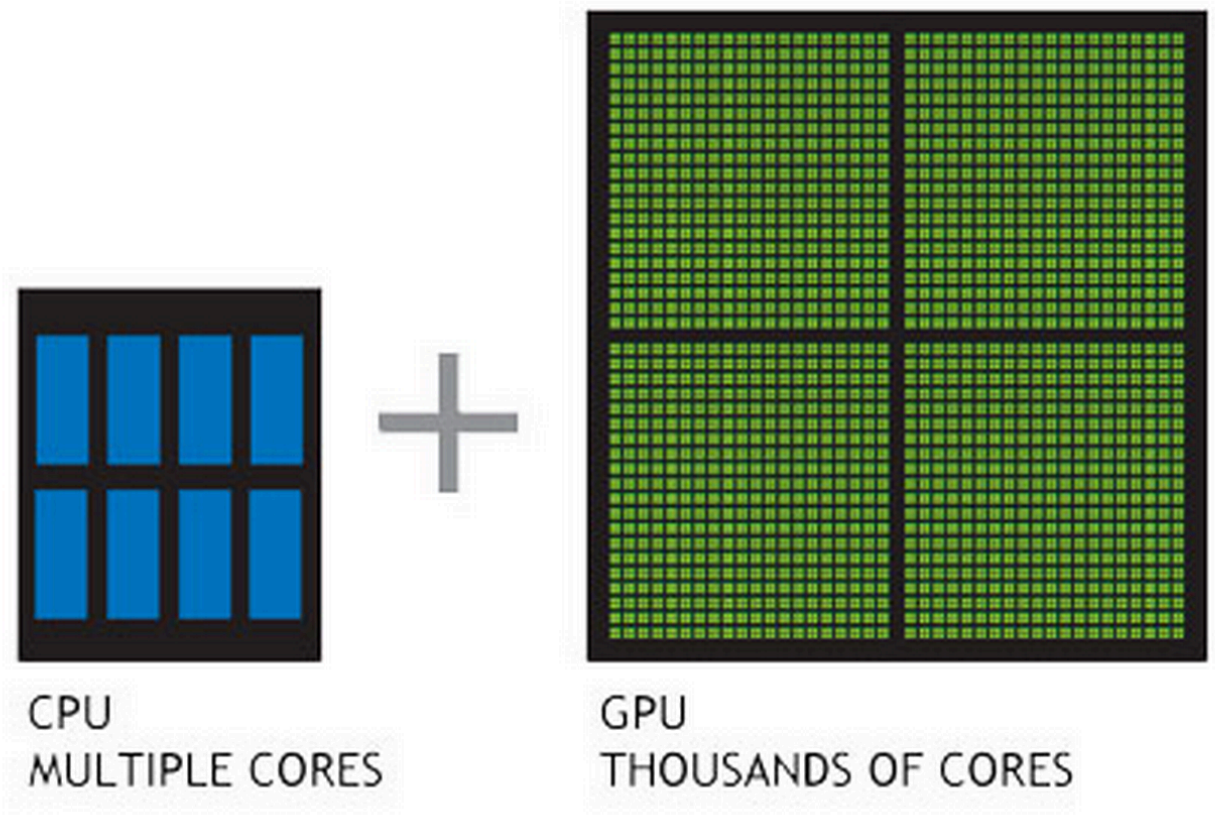

HANDS-ON


Graphical Processing Unit

Impact of GPU

Compared to CPUs 20x speedups are typical

GPUs have thousands of cores to process parallel workloads efficiently

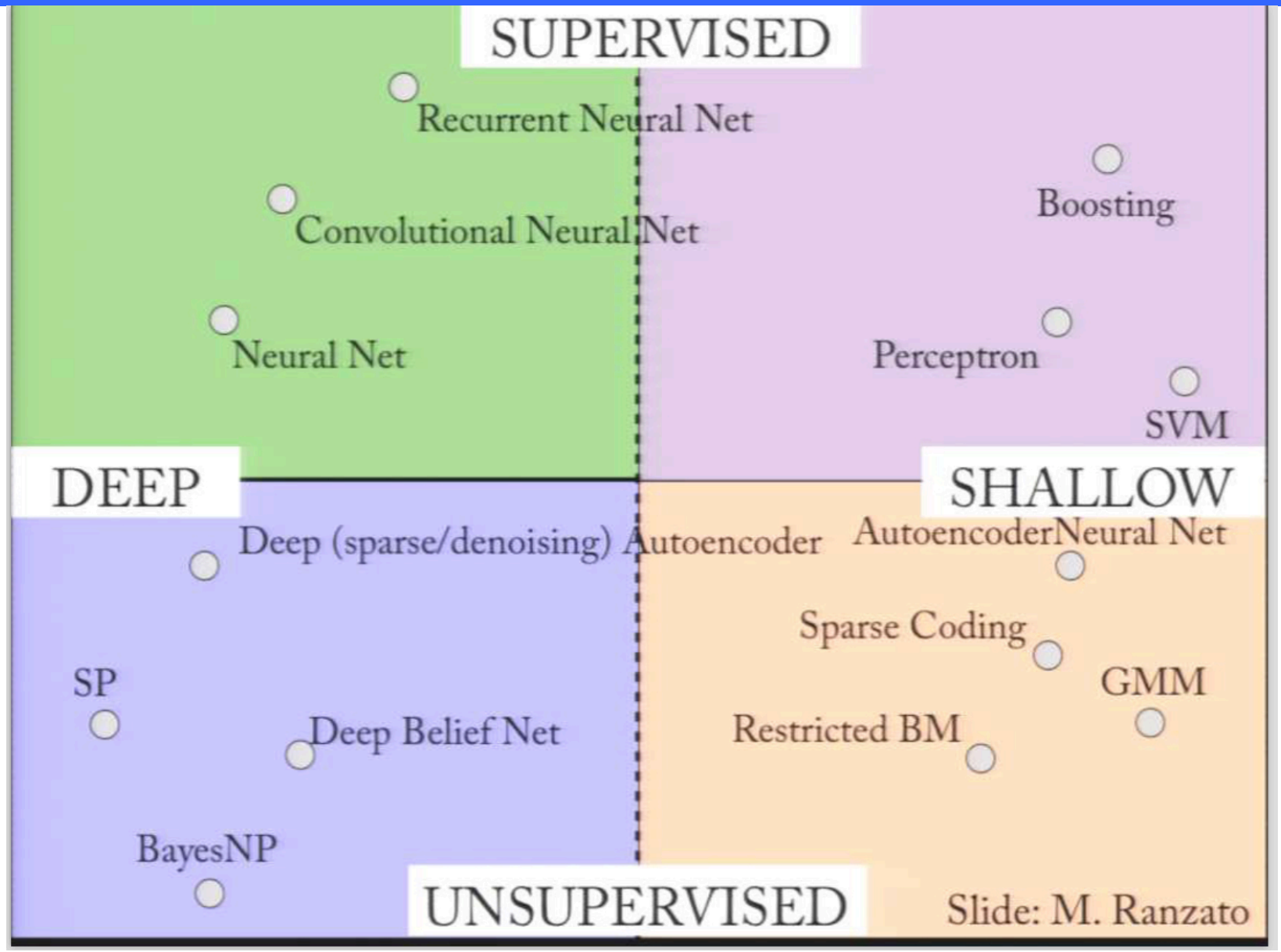


Source: http://www.nvidia.com/object/what-is-gpu-computing.html

Impact of GPU

- Accelerated computations on float32 data
- Matrix multiplication, convolution, and large element-wise operations can be accelerated a lot (5-50x)
- Difficult to parallelize dense neural networks on multiple GPU efficiently (Active area of research)
- Convolutional neural networks – unlike dense neural networks – can be run very efficiently on multiple GPUs. Their use of weight sharing makes data parallelism very efficient
- Copying of large quantities of data to and from a device is relatively slow.
- CUDA has released cuDNN.

Summary



Source: NIPS 2013 Tutorial