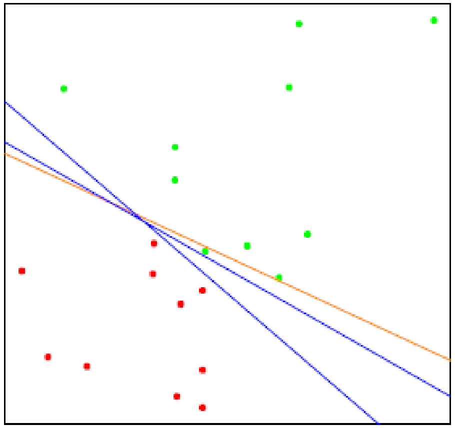


Deep Learning

Introduction to Machine Learning Algorithms

Ernir Erlingsson

PhD Student, University of Iceland & DEEP-EST Application Engineer

LECTURE 1

Deep Learning Introduction

June 6th, 2018
JSC, Germany

UNIVERSITY OF ICELAND
SCHOOL OF ENGINEERING AND NATURAL SCIENCES
FACULTY OF INDUSTRIAL ENGINEERING, MECHANICAL ENGINEERING AND COMPUTER SCIENCE

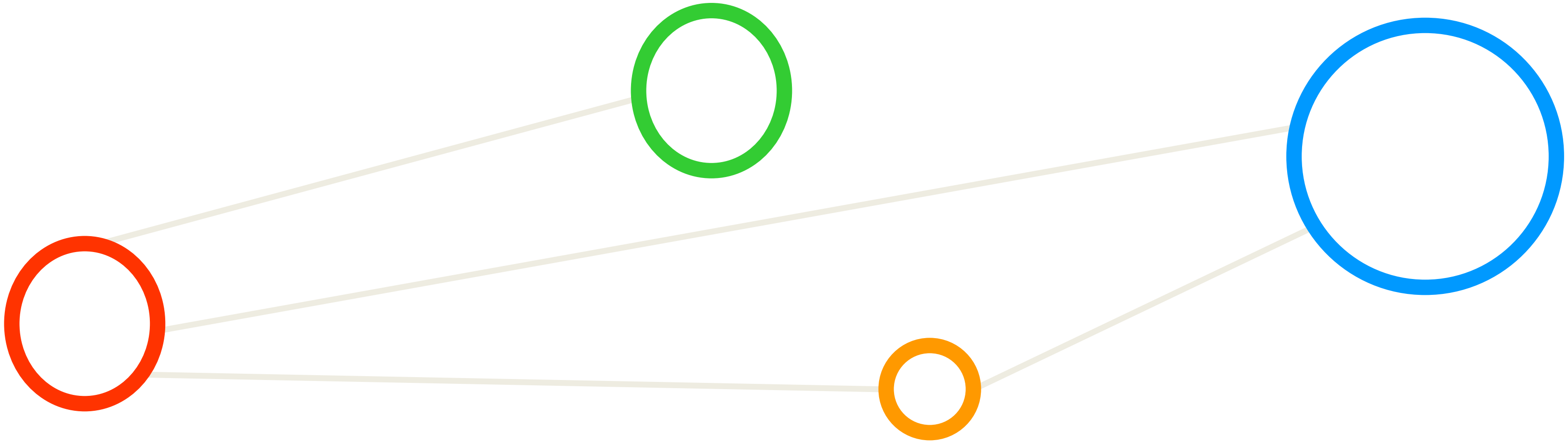
JÜLICH Forschungszentrum | HELMHOLTZ RESEARCH FOR GRAND CHALLENGES

DEEP Projects

Outline of the Course

- 1. Introduction to Deep Learning
- 2. Fundamentals of Convolutional Neural Networks (CNNs)
- 3. Deep Learning in Remote Sensing: Challenges
- 4. Deep Learning in Remote Sensing: Applications
- 5. Model Selection and Regularization
- 6. Fundamentals of Long Short-Term Memory (LSTM)
- 7. LSTM Applications and Challenges
- 8. Deep Reinforcement Learning

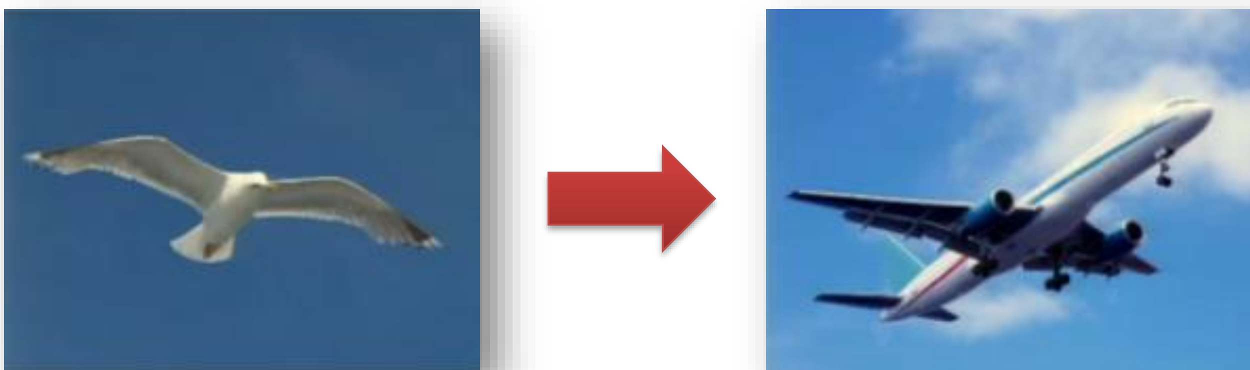
Deep Learning Introduction



Deep Learning - Introduction

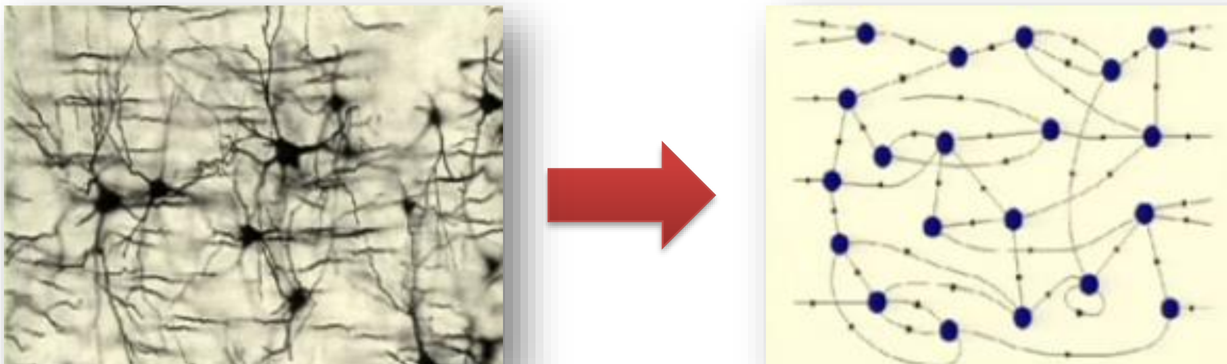
Where do human ideas and innovations come from ?

- Inspired by nature
  - First we **observe** and then we try to **replicate**



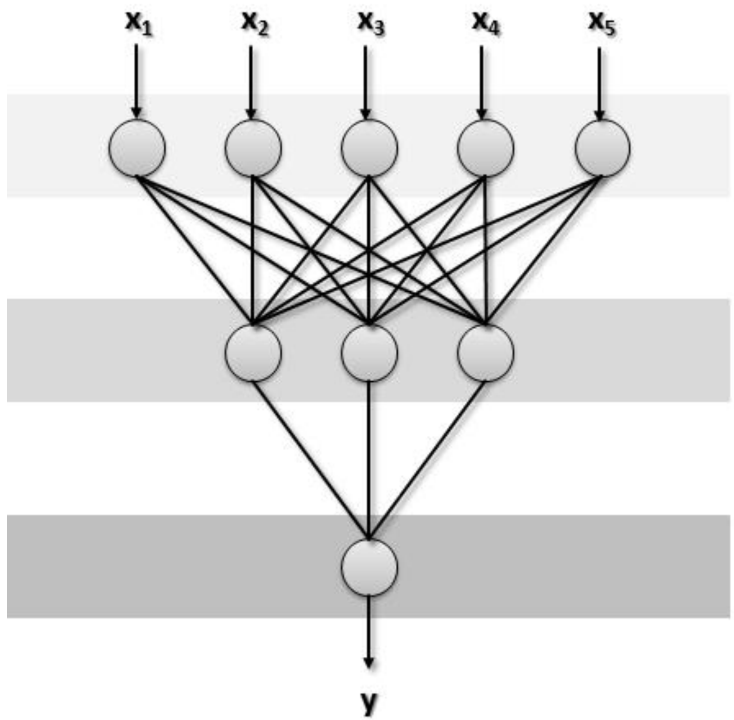
Deep Learning - Introduction

Neural Networks (NNs) is an attempt at replicating neural functions of the brain to solve problems.



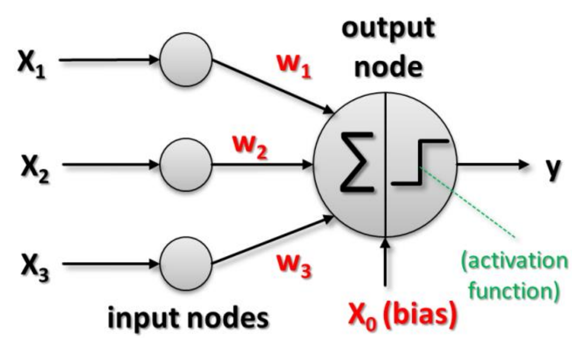
Caveat: Not considered to be an accurate model but rather based on how neurons interconnect. Furthermore, we don´t know well enough how the brain operates to properly replicate it, e.g. what is a consciousness ?

Artificial Neural Network (ANN)

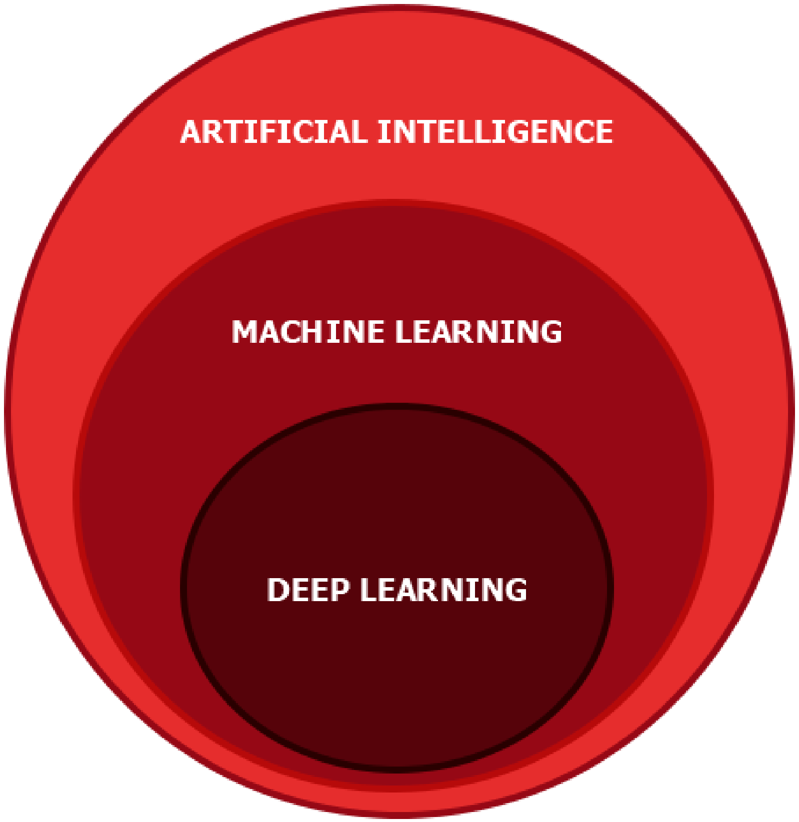


- A computational model of biological learning
- synomous with deep learning
- The nodes simulate neurons and the edges simulate synapses with weight values.

- Neurons modelled as perceptron's that “fire” their activation function when the sum of weights crosses a certain threshold.



Deep Learning – Definition



- **Artificial Intelligence**
  - The concept of machines being able to carry out tasks in a way we would consider intelligent
- **Machine Learning**
  - Computer systems that improve with experience and data
- **Deep Learning**
  - Is a subset of machine learning where the system is represented as nested hierarchical features, where each feature is defined in relation to simpler features.

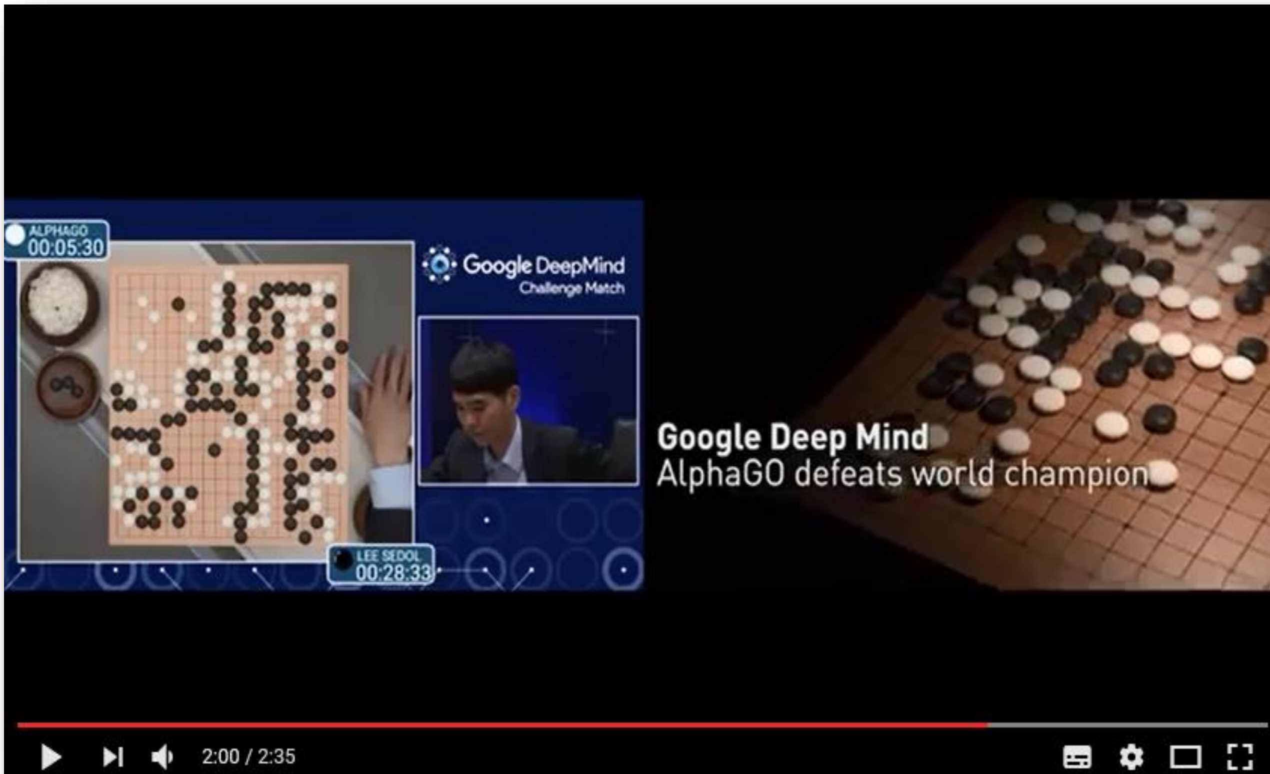
Deep Learning – Introduction

- Deep learning is a brand that comes in many ever-increasing flavours. It is also known as:
  - Cybernetics (1940s)
  - Neural networks (1980s)
  - Deep learning (2006)

- Has gained traction very fast with no immediate signs of slowing down and is sometimes characterized as a buzzword

- It is used for supervised, semi-supervised and unsupervised learning.
  - *Supervised learning uses labelled data*
  - *Semi-supervised uses mostly unlabelled data but not all.*
  - *Unsupervised learning uses only unlabelled data*

Deep Learning – What is it



[1] The Deep Learning Revolution, YouTube

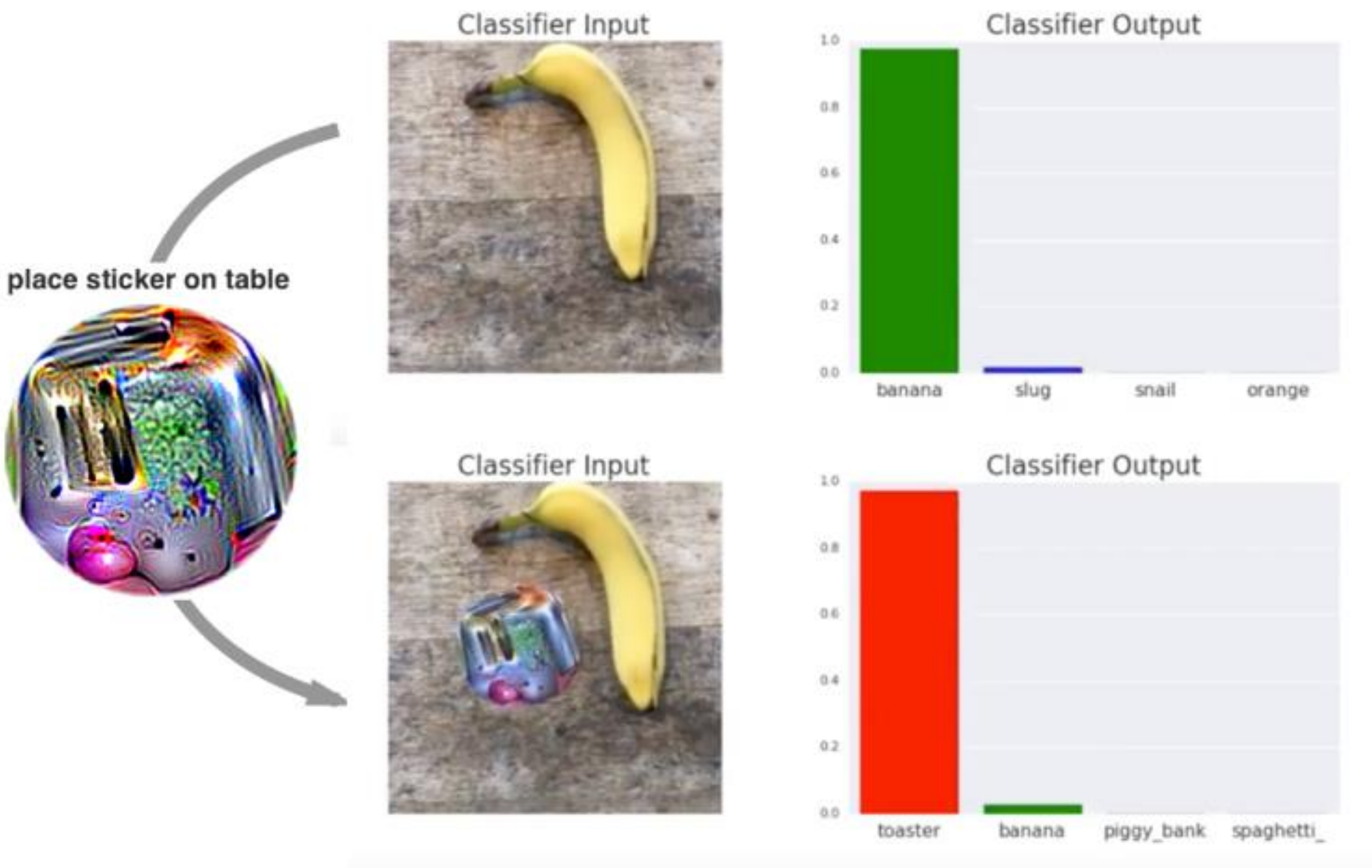
Deep Learning – Introduction

- Application areas
  - Computer vision
  - Automatic speech recognition
  - Natural language processing
  - Bioinformatics
  - And much more...

- It´s effects is currently is both *overestimated* and *underestimated*.

Deep Learning Risks

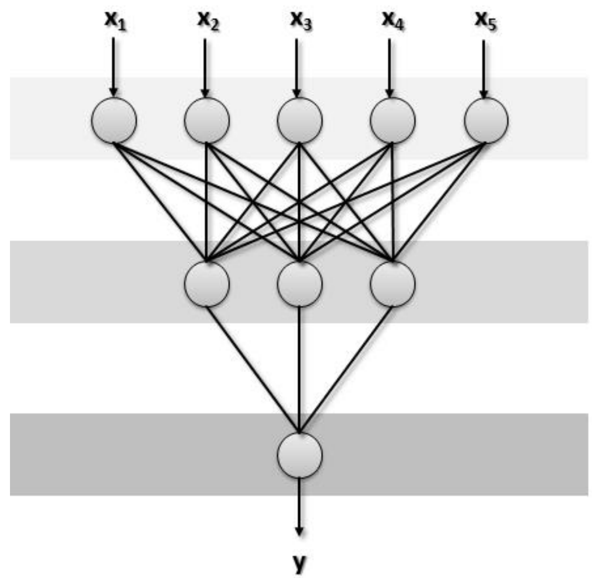
- Very easy to fool, e.g. via adversial patches

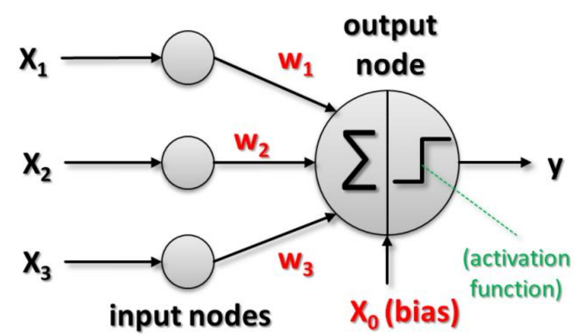


[2] Tom B. Brown, Dandelion Mané, Aurko Roy, Martín Abadi, Justin Gilmer, ‘Adversial Patch’

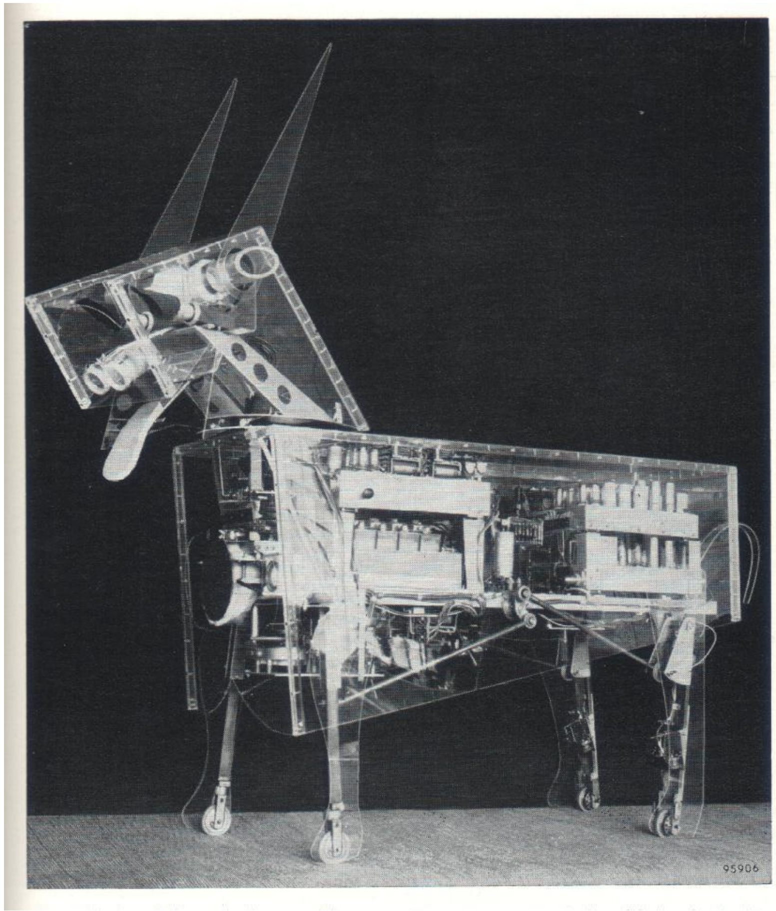
Neural Networks - Timeline

- 1943: The first mathematical model of the human brain
- 1957: Perceptron
- 1965: The first multi-layered network
- 1987: Multi-layered Perceptron (backpropagation)
- 1995: Support Vector Machines (SVMs)
- 1998: Gradient based learning
- 2006: Deep Neural Network
- 2011: AlexNet (CNNs)
- 2014: Generative Adversarial Networks (GANs)





Deep Learning - Introduction



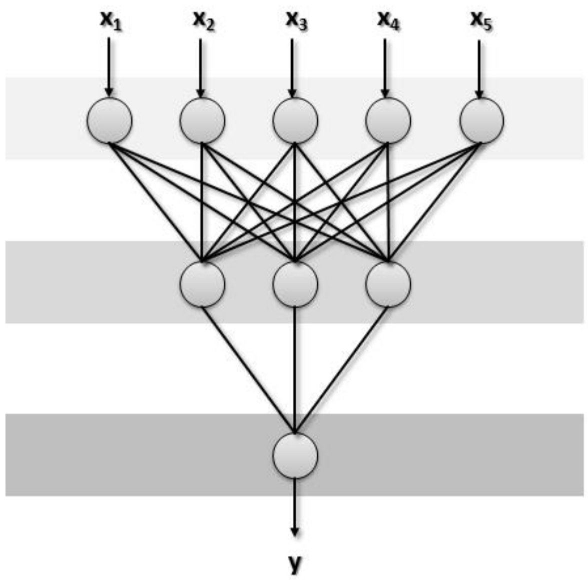
1950s Cybernetics: Cyber the dog

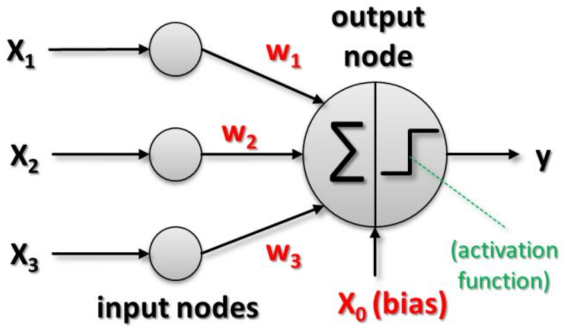
[3] 'Cybernetic Zoo' web page

Neural Networks - Resurgence

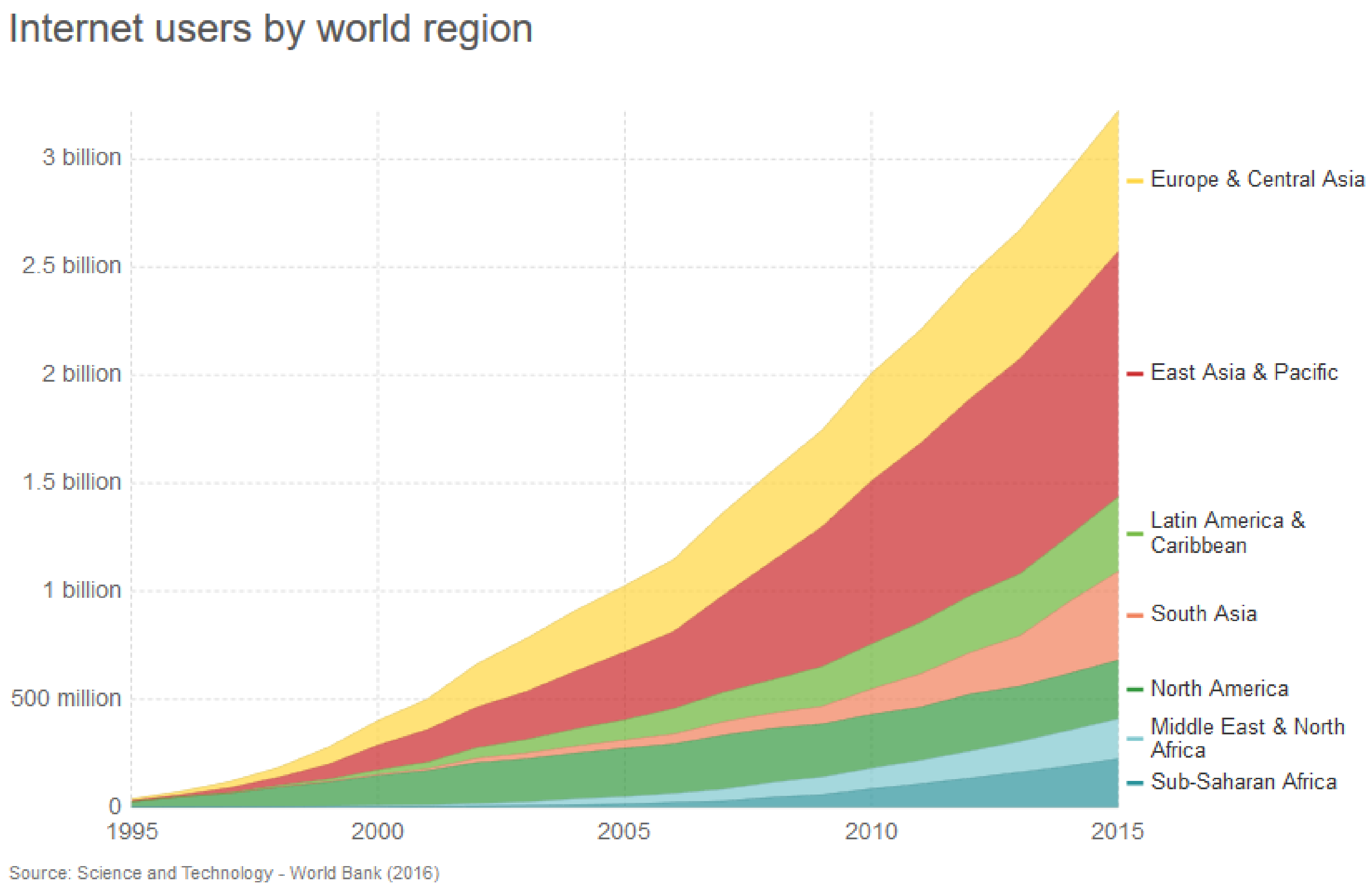
The renaissance of neural networks via deep learning, accelerated by:

- Big Data
  - The first web page 1992
  - 163 zettabytes (1 million petabytes) by 2025





Big Data – Internet Users



[4] Our world in data, Online

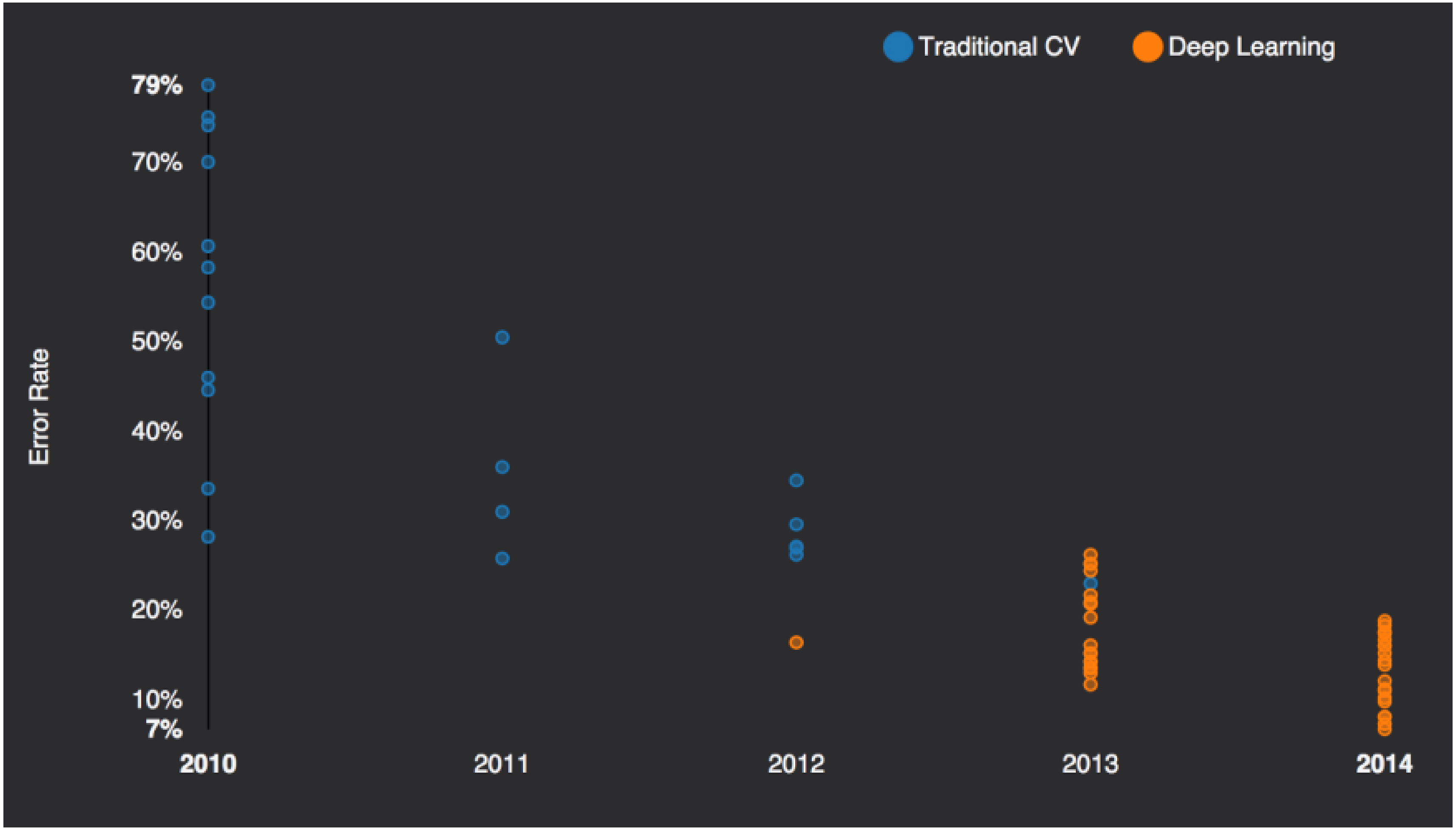
Big Data - ImageNet Dataset

- Dataset: **ImageNet**
  - Total number of images: *14.197.122*

High level category	# synset (subcategories)	Avg # images per synset	Total # images
amphibian	94	591	56K
animal	3822	732	2799K
appliance	51	1164	59K
bird	856	949	812K
covering	946	819	774K
device	2385	675	1610K
fabric	262	690	181K

[5] ImageNet Web page

Big Data - ImageNet Dataset



[6] J. Dean et al., 'Large-Scale Deep Learning'

Neural Networks - Resurgence

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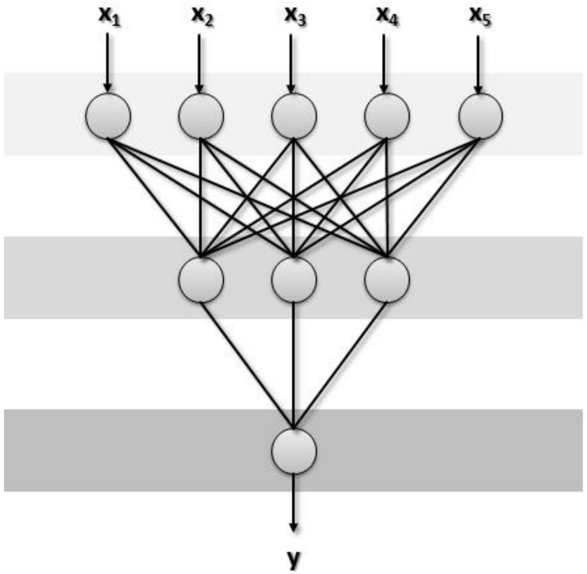
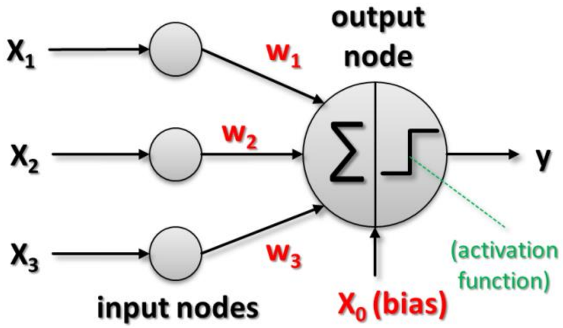
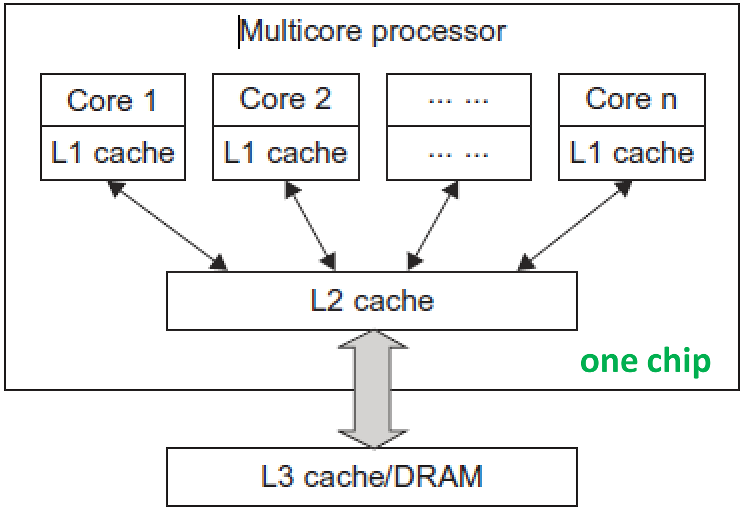
- Advances in Computation
  - Multi-core CPUs
  - Many-core GPUs





Advances in Computation - Multi-core CPUs

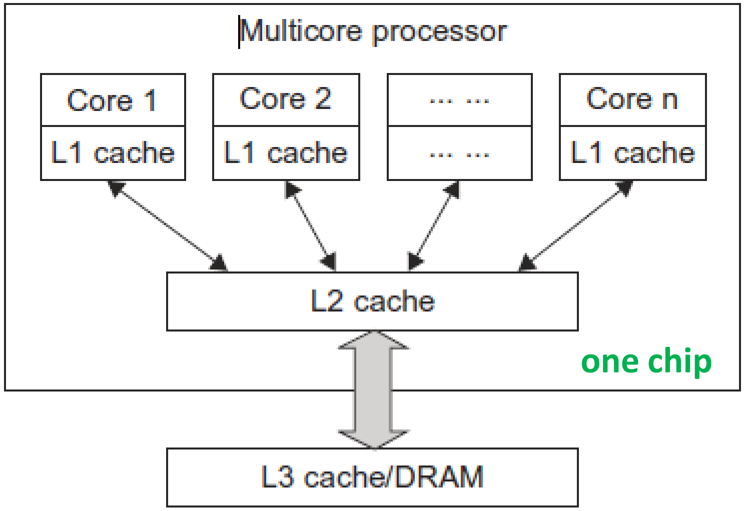
- Significant advances in CPU (or microprocessor chips)
  - **Multi-core architecture** with dual, quad, six, or n processing cores
  - Processing cores are all on one chip
- Multi-core CPU chip architecture
  - Hierarchy of caches (on/off chip)
  - L1 cache is private to each core; on-chip
  - L2 cache is shared; on-chip
  - L3 cache or Dynamic random access memory (DRAM); off-chip



[7] Distributed & Cloud Computing Book

Advances in Computation - Multi-core CPUs

- Clock-rate for single processors increased from 10 MHz (Intel 286) years to 4 GHz (Pentium 4) in 30 years



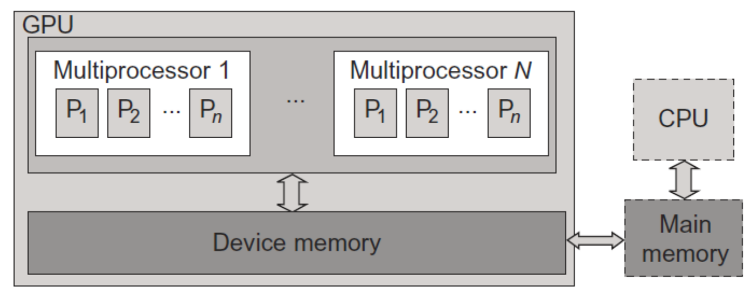
[7] Distributed & Cloud Computing Book

- Clock rate increase with higher 5 GHz reached a limit due to power limitations / heat

- Multi-core CPU chips have quad, six, or n processing cores on one chip and use cache hierarchies

Advances in Computation - GPGPUs

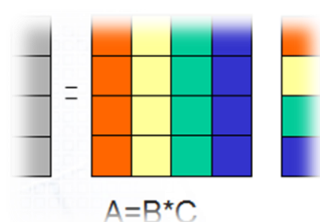
- The graphics Processing Unit (GPU) is repurposed as General-Purpose GPUs (GPGPUs) and used for computing.
- Slower than CPUs but more than makes up for it with sheer volume, i.e. consists of *very many* simple cores
  - High throughput computing-oriented architecture
  - Use massive parallelism by executing a lot of concurrent threads
  - Handle an ever increasing amount of multiple instruction threads
  - CPUs instead typically execute a single long thread as fast as possible
- Simplicity leads to leass power consumption
- Many-core GPUs are already used in large clusters and within massively parallel supercomputers

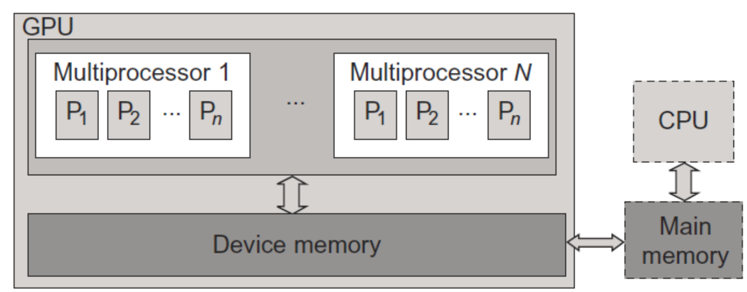


[7] Distributed & Cloud Computing Book

Advances in Computation - GPGPUs

- GPUs accelerate computing thru massive parallelism, with thousands of threads.
- GPUs are designed to compute a large number of floating point operations in parallel
- GPU accelerator architecture example - NVIDIA card
  - GPUs can have **256 cores** on one single GPU chip (NVIDIA TEGRA X1)
  - Each core can work with **eight threads** of instructions
  - GPU is able to concurrently execute 256 * 8 = **2048 threads**
  - Interaction and thus major (bandwidth) bottleneck between CPU and GPU is via memory interactions
  - E.g. applications that use matrix – vector multiplication

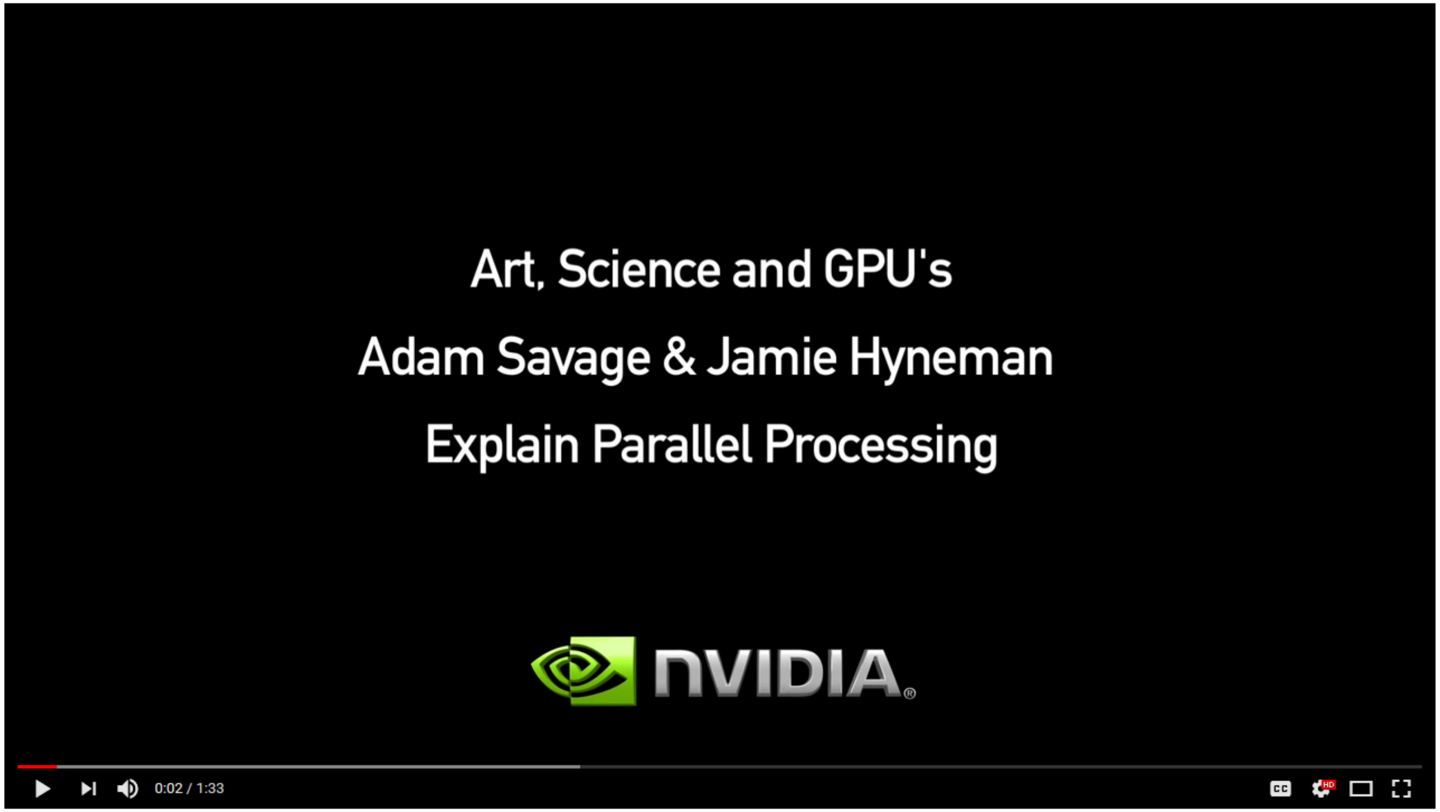




[7] Distributed & Cloud Computing Book

(other well known accelerators & many-core processors are e.g. Intel Xeon Phi → run 'CPU' applications easier)

[Video] GPGPUs & Applications



[8] **Mythbusters Demo GPU versus CPU**

Neural Networks - Resurgence

The renaissance of neural networks via deep learning, accelerated by:

- Big Data
  - The first web page 1992
  - 163 zettabytes (1 million petabytes) by 2025
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  - Multi-core CPUs
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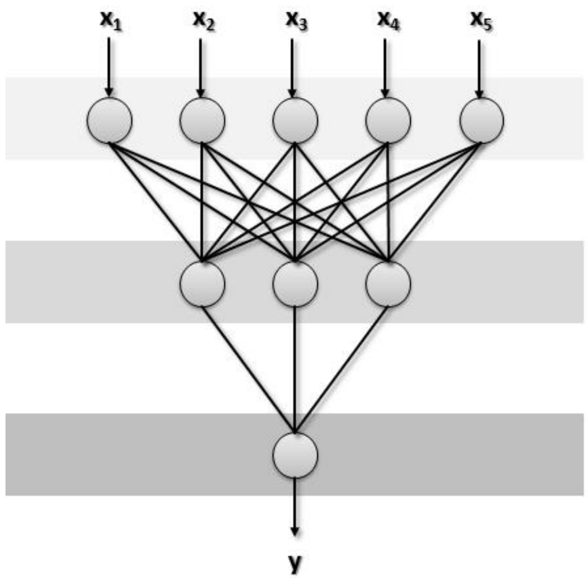
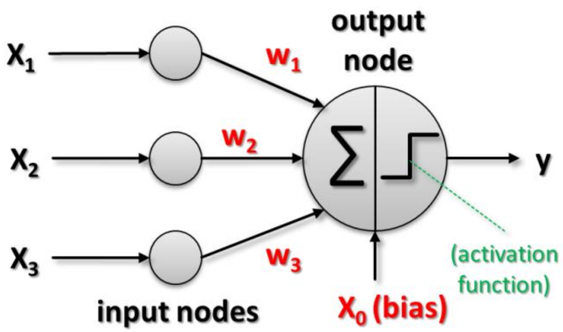


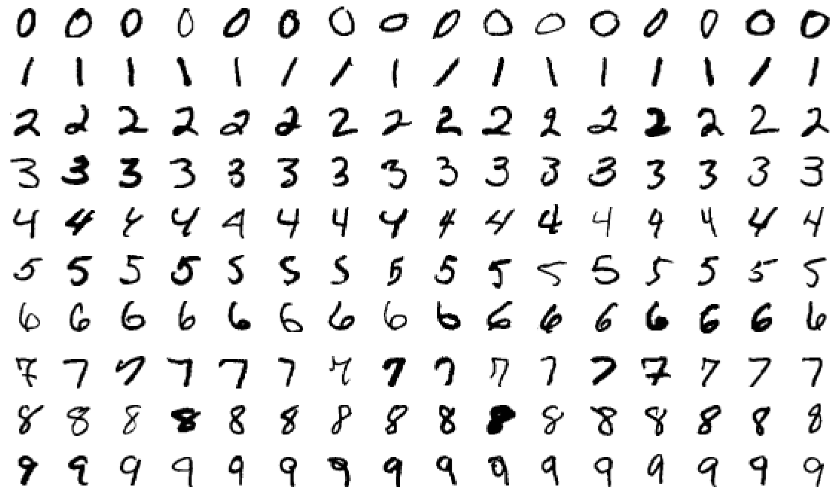


The MNIST dataset

An image collection of hand-written digits available online, with:

- 60.000 training examples
- 10.000 testing examples

The dataset is considered to be the fruit-fly of machine-learning.



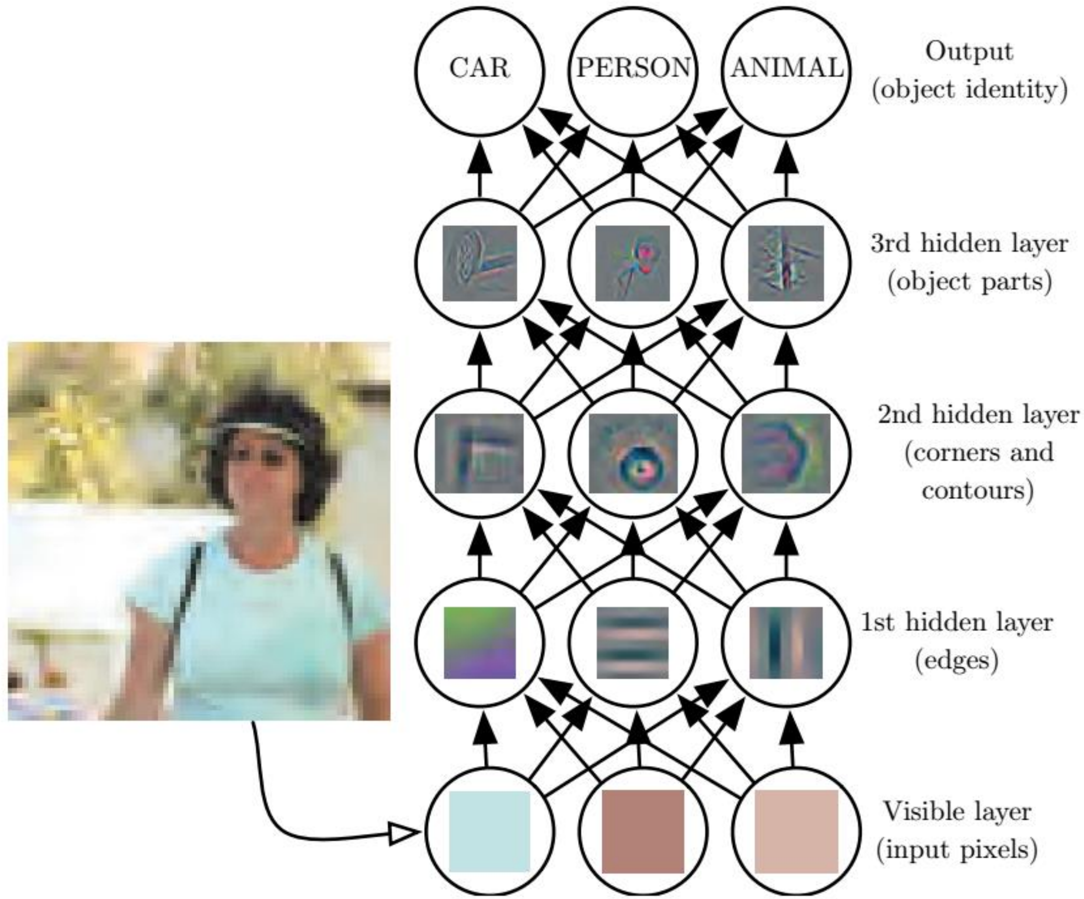
- Best classification accuracy to-date, with a 0.23% error-rate, through the use of Convolutional Neural Networks
- Support Vector Machines (SVMs) also performing well, with the lowest error-rate of 0.56%

[9] The MNIST Database

Deep Learning Architectures

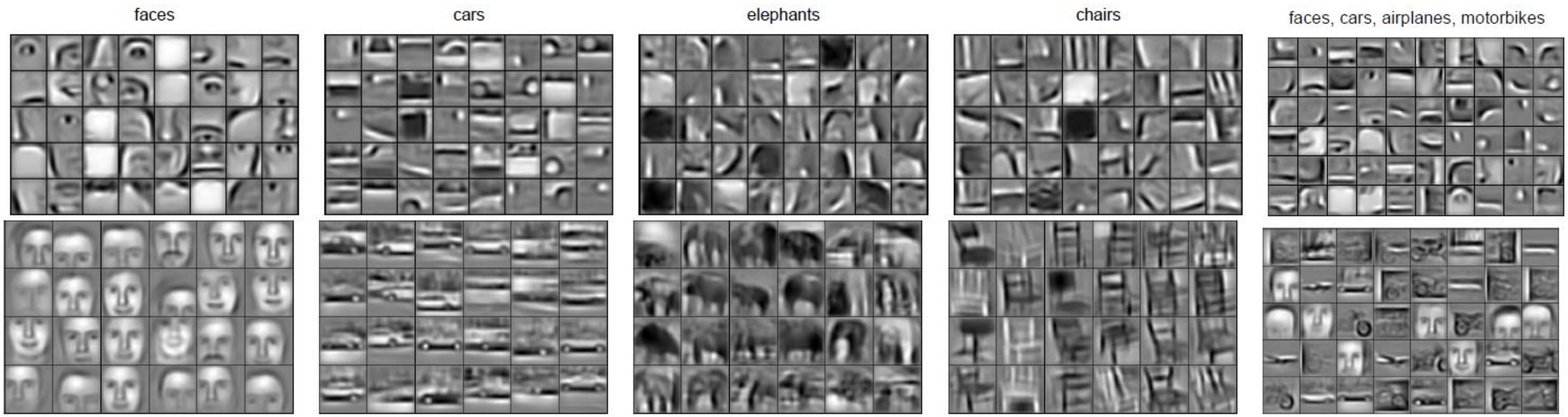
- Deep Neural Network (DNN)
  - ‘Shallow ANN‘ approach with many hidden layers between input/output

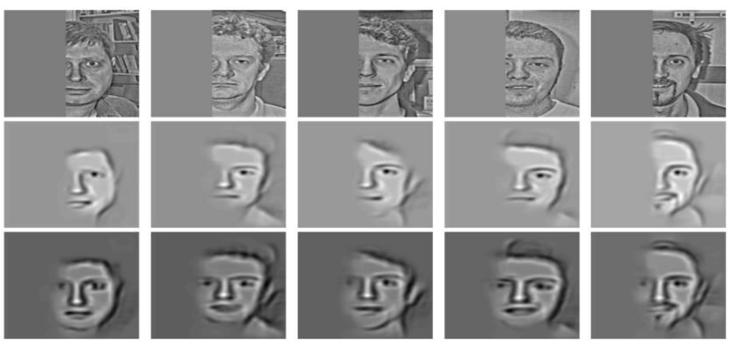
Deep Neural Networks (DNNs)



[10] Ian Goodfellow, Yoshua Bengio, and Aaron Courville 'Deep Learning'

DNN – Feature Learning Benefits



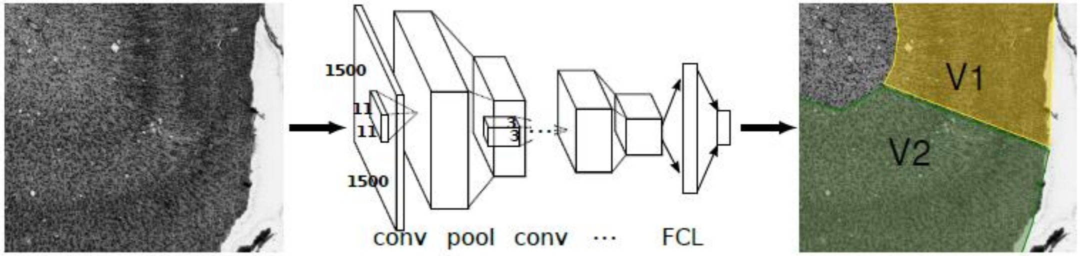


[11] H. Lee et al., 'Convolutional Deep Belief Networks for Scalable Unsupervised Learning of Hierarchical Representations'

- **Traditional machine learning applied feature engineering before modeling**
- **Feature engineering requires expert knowledge, is time-consuming and a often long manual process, requires often 90% of the time in applications, and is sometimes even problem-specific**
- **Deep Learning enables feature learning promising a massive time advancement**

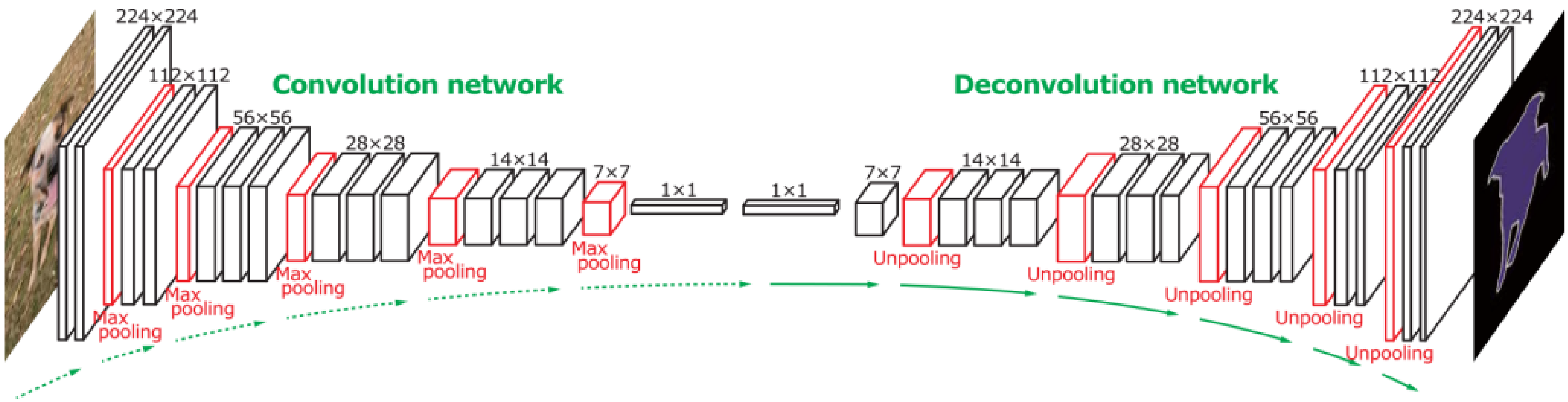
Deep Learning Architectures

- Deep Neural Network (DNN)
  - ‘Shallow ANN‘ approach with many hidden layers between input/output
- Convolutional Neural Network (CNN, sometimes ConvNet)
  - Connectivity pattern between neurons inspired by the visual cortex



Convolutional Neural Networks

- Inspired by connectivity patterns between neurons in the animal visual cortex.
- Usually built with three types of layers:
  - Convolution layers using kernels
  - Pooling layers (downsampling)
  - Fully connected layers (classification vote)



[12] Azoft, Fully convolutional Neural Network

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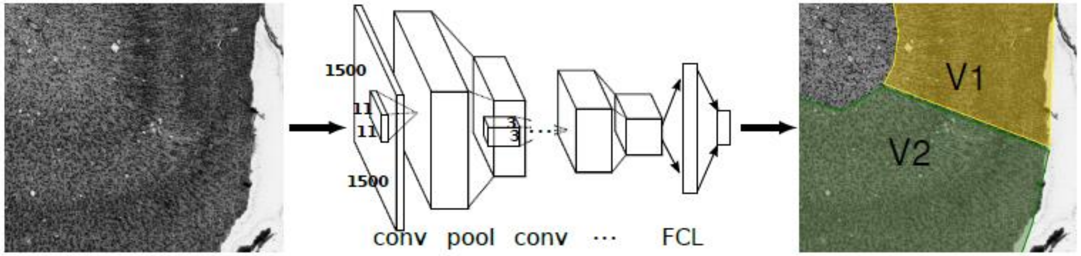
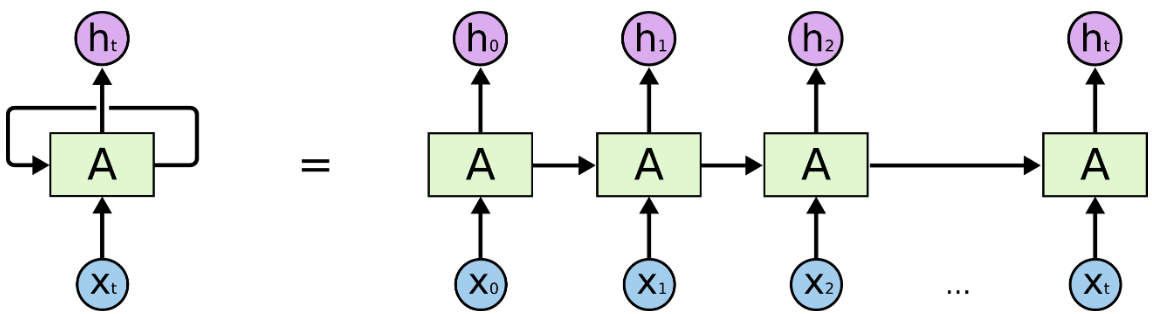


- Recurrent Neural Network (RNN)
  - ‘ANN‘ but connections form a directed cycle; state and temporal behaviour

Recurrent Neural Networks (RNN)

- A recurrent neural network can be thought of as multiple copies of the same network, each passing a message to a successor
- RNNs have been applied very successfully to a variety of problems, e.g. speech recognition, language modeling, translation, image captioning
- Essential to these successes is the use of "LSTMs", a very special kind of recurrent neural network



[13] Colah's blog, Understanding LSTM Networks

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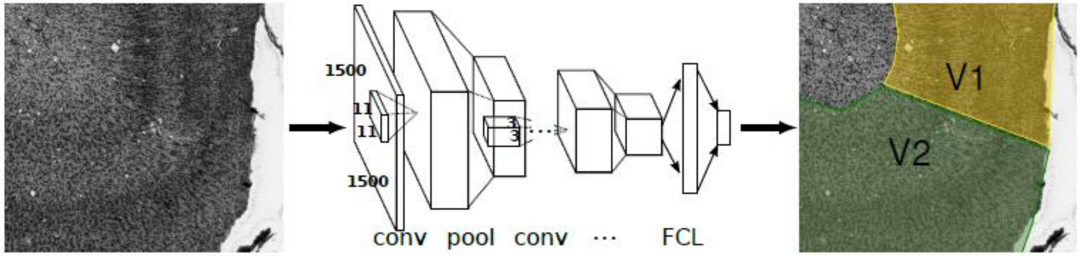
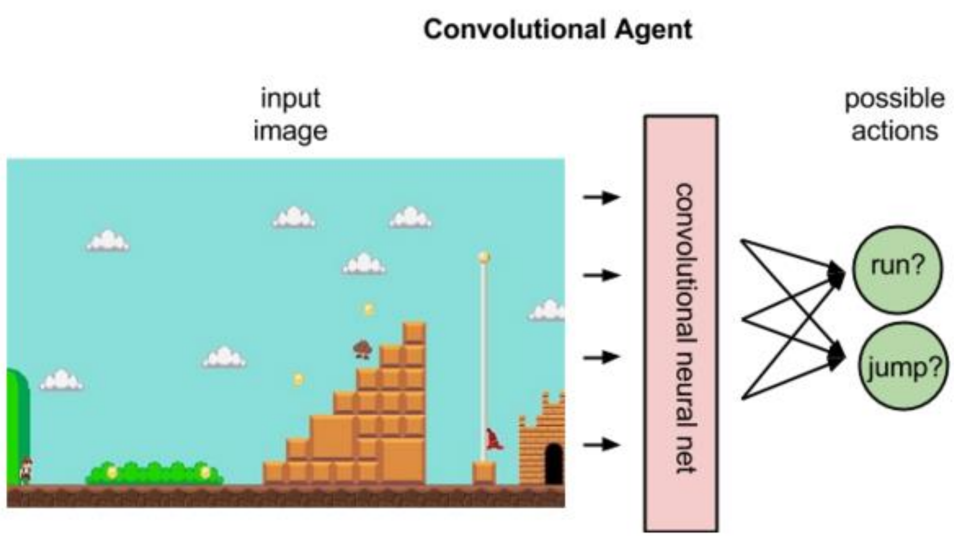


- Recurrent Neural Network (RNN)
  - ‘ANN‘ but connections form a directed cycle; state and temporal behaviour
- Deep Reinforcement Learning (DRN)
  - Unsupervised goal-oriented algorithms

Deep Reinforcement Learning

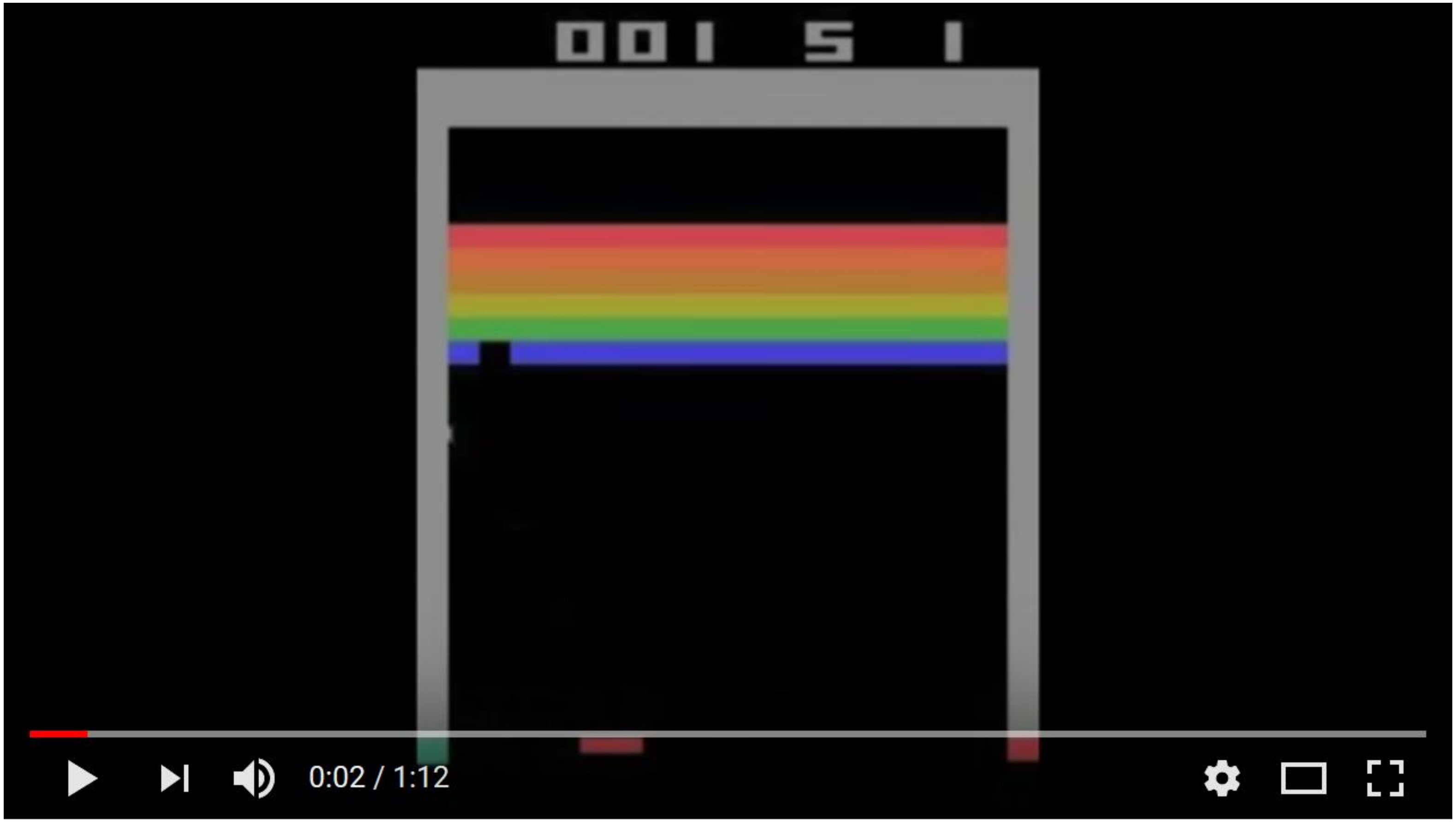
- Reinforcement learning refers to goal-oriented algorithms, which learn how to attain a complex objective (goal) or maximize along a particular dimension over many steps; for example, maximize the points won in a game over many moves.

$$Q(s_t, a_t) \leftarrow (1-\alpha) \cdot \underbrace{Q(s_t, a_t)}_{\text{old value}} + \underbrace{\alpha}_{\text{learning rate}} \cdot \overbrace{\left(\underbrace{r_t}_{\text{reward}} + \underbrace{\gamma}_{\text{discount factor}} \cdot \underbrace{\max_a Q(s_{t+1}, a)}_{\text{estimate of optimal future value}} \right)}^{\text{learned value}}$$



[14] DL4J, A Beginner's guide to deep reinforcement learning

Deep Q Learning (DQN)



[15] DQN

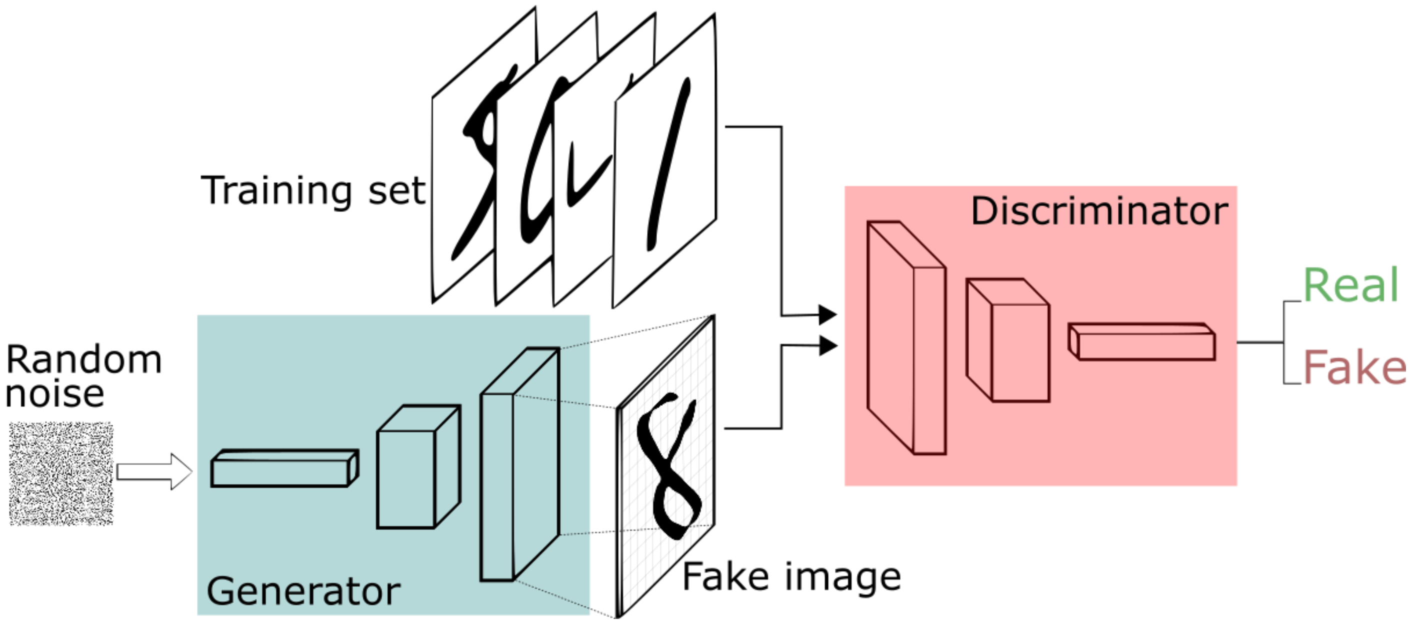
Generative Adversial Networks (GANs)

Big improvements in the quality of the produced image output from GANs in relatively few years.
- Has surpassed the “uncanny valley” obstacle

[16] GAN: A Beginner’s Guide to Generative Adversarial Networks

Generative Adversial Networks (GANs)

- Discriminative algorithms
  - Predict a label or category for an input given the feature set
- Generative Adversial Network (GAN)
  - Predict the features given a label



[10] Ian Goodfellow, Yoshua Bengio, and Aaron Courville 'Deep Learning'

Generative Adversial Networks (GANs)

[17] Progressive Growing of GANs for Improved Quality, Stability, and Variation

Capsule Networks

- Orientation and relative spatial relationships are captured well by CNNs

Capsule Networks are designed to address this problems

[18] Capsule Networks

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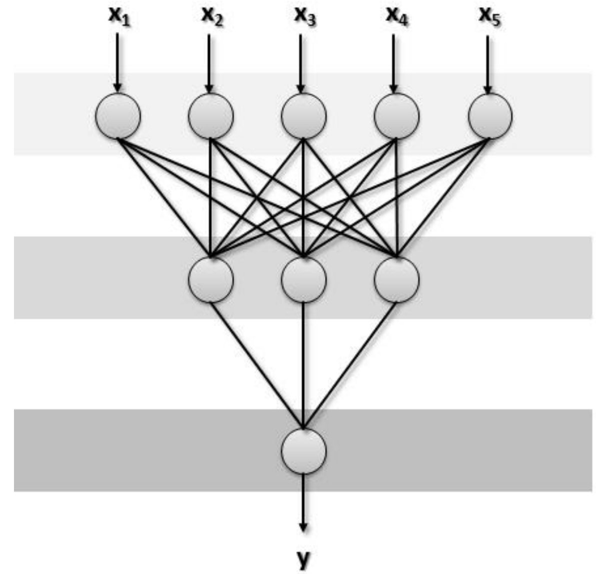
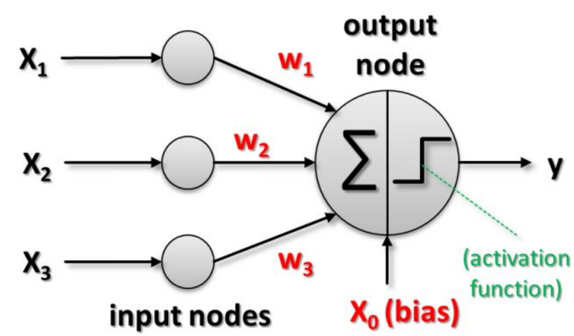
- Improved architecture and techniques
  - Convolutionan Neural Networks (CNNs)
  - Recurrent Neural Networks (RNNs)
  - Generative Adversarial Networks (GANs)
- Better Tools
  - Numpy, Tensorflow, Keras, Scikit-learn, Jupyter… and many more





Deep Learning – Tools of the Trade

Caffe

TensorFlow

Keras

theano

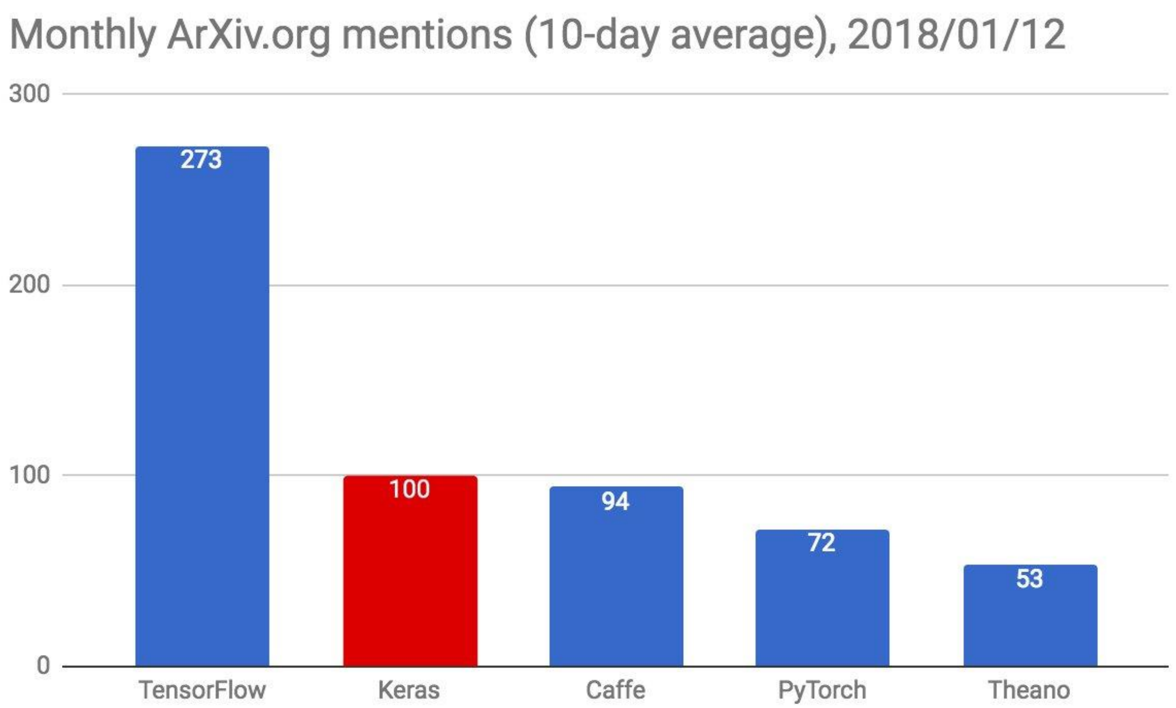
Caffe2

PYTORCH

Deep Learning – Tools of the Trade

- The top 5 mentions on arXiv.org, many more exist
- Free and Open Source (FOSS) frameworks, libraries and extensions
- Mostly used with Python, a major contributer to its growing popularity.
- Initiated and maintained by a mixture of both academia and industry

Deep Learning – Tools of the Trade



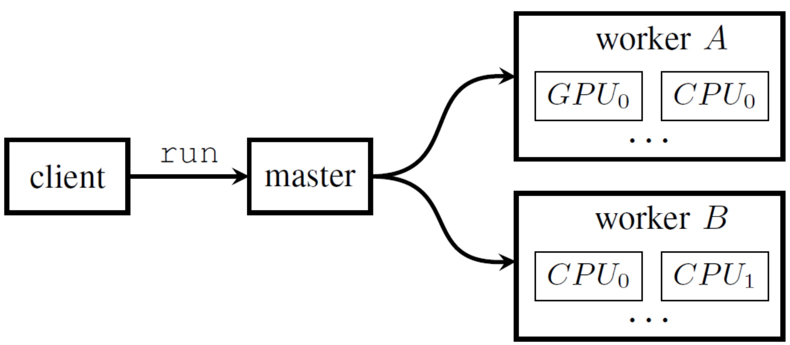
Keras with Tensorflow Backend – GPU Support

- Keras is a high-level deep learning library implemented in Python that works on top of existing other rather low-level deep learning frameworks like Tensorflow, CNTK, or Theano
- The key idea behind the Keras tool is to enable faster experimentation with deep networks
- Created deep learning models run seamlessly on CPU and GPU via low-level frameworks

Keras *[13] Keras Python Deep Learning Library*

- Tensorflow is an open source library for deep learning models using a flow graph approach
- Tensorflow nodes model mathematical operations and graph edges between the nodes are so-called tensors (also known as multi-dimensional arrays)
- The Tensorflow tool supports the use of CPUs and GPUs (much more faster than CPUs)
- Tensorflow work with the high-level deep learning tool Keras in order to create models fast

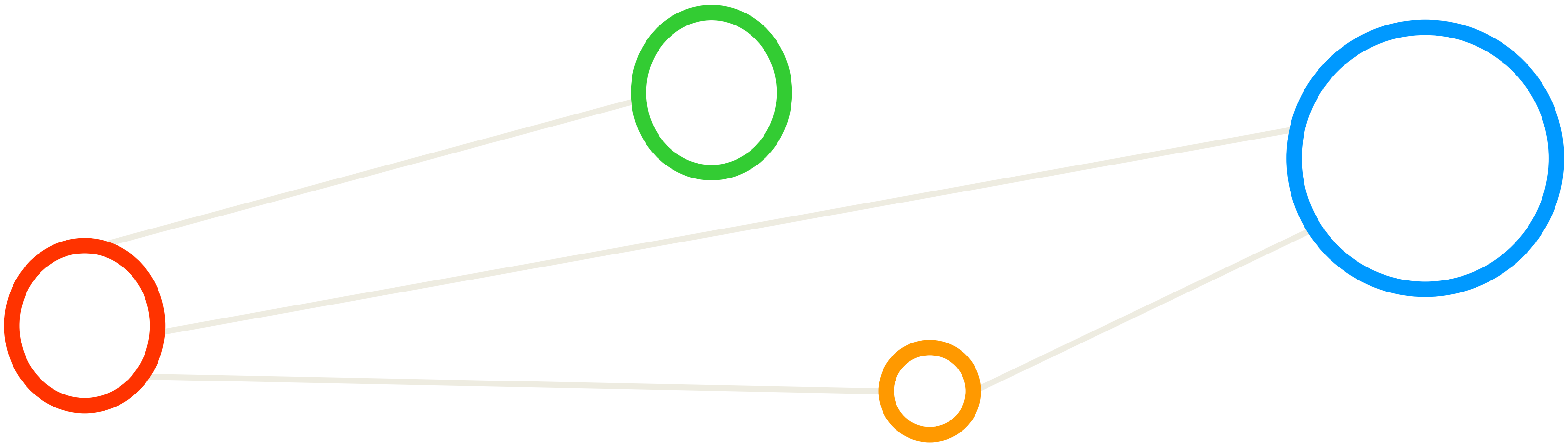
[19] Tensorflow Deep Learning Framework



[20] A Tour of Tensorflow

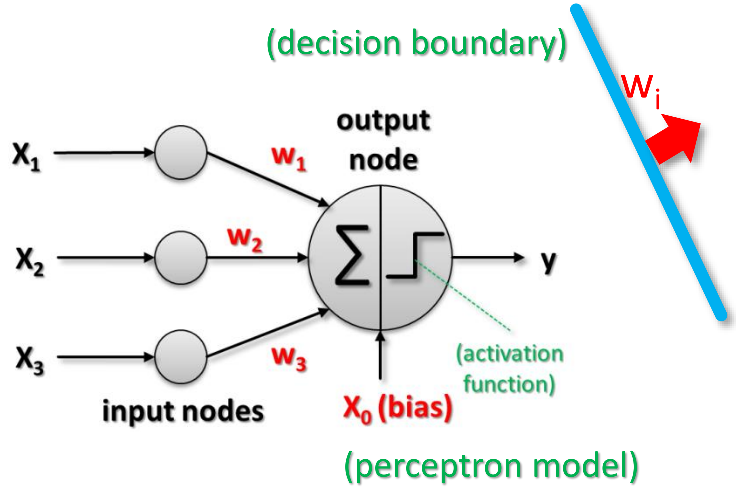
TensorFlow

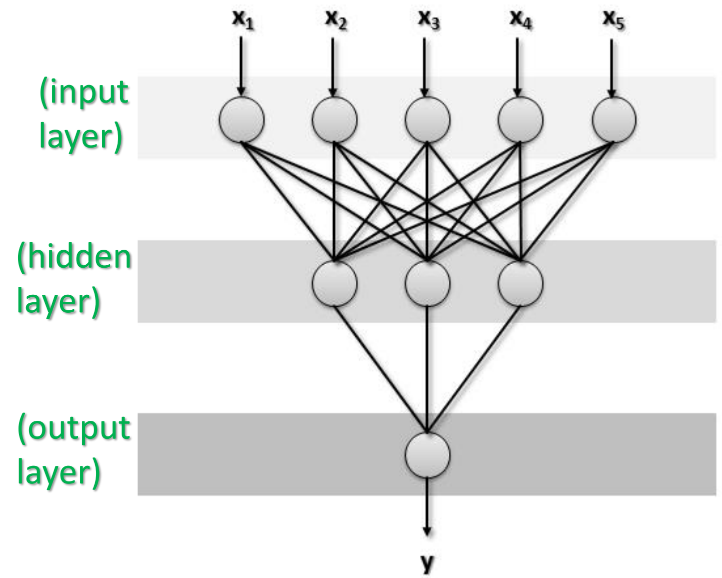
Deep Neural Networks – How they work



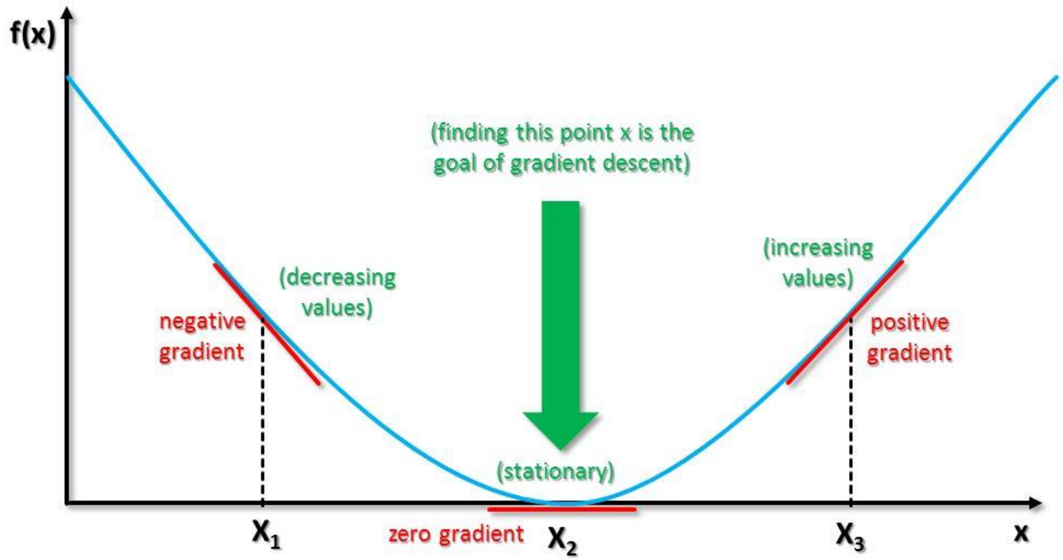
Multi Layer Perceptrons – Artificial Neural Networks

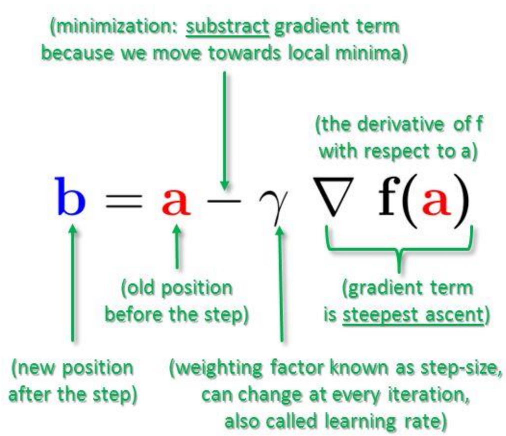
- Key Building Block
  - Perceptron learning model
  - Simplest linear learning model
  - Linearity in learned weights w_i
  - One decision boundary
- Artificial Neural Networks (ANNs)
  - Creating more complex structures
  - Enable the modelling of more complex relationships in the datasets
  - May contain several intermediary layers
  - E.g. 2-4 hidden layers with hidden nodes
  - Use of activation function that can produce output values that are nonlinear in their input parameters

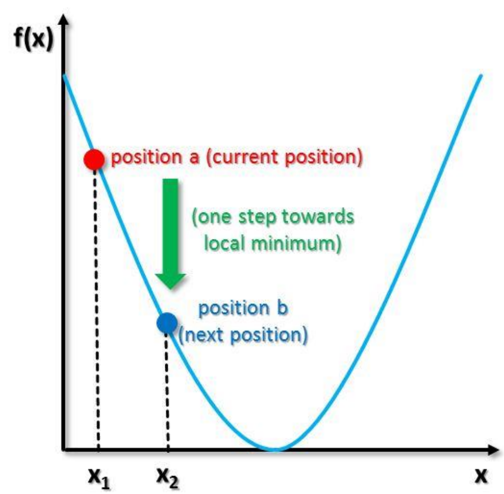




Gradient Descent Method (1)







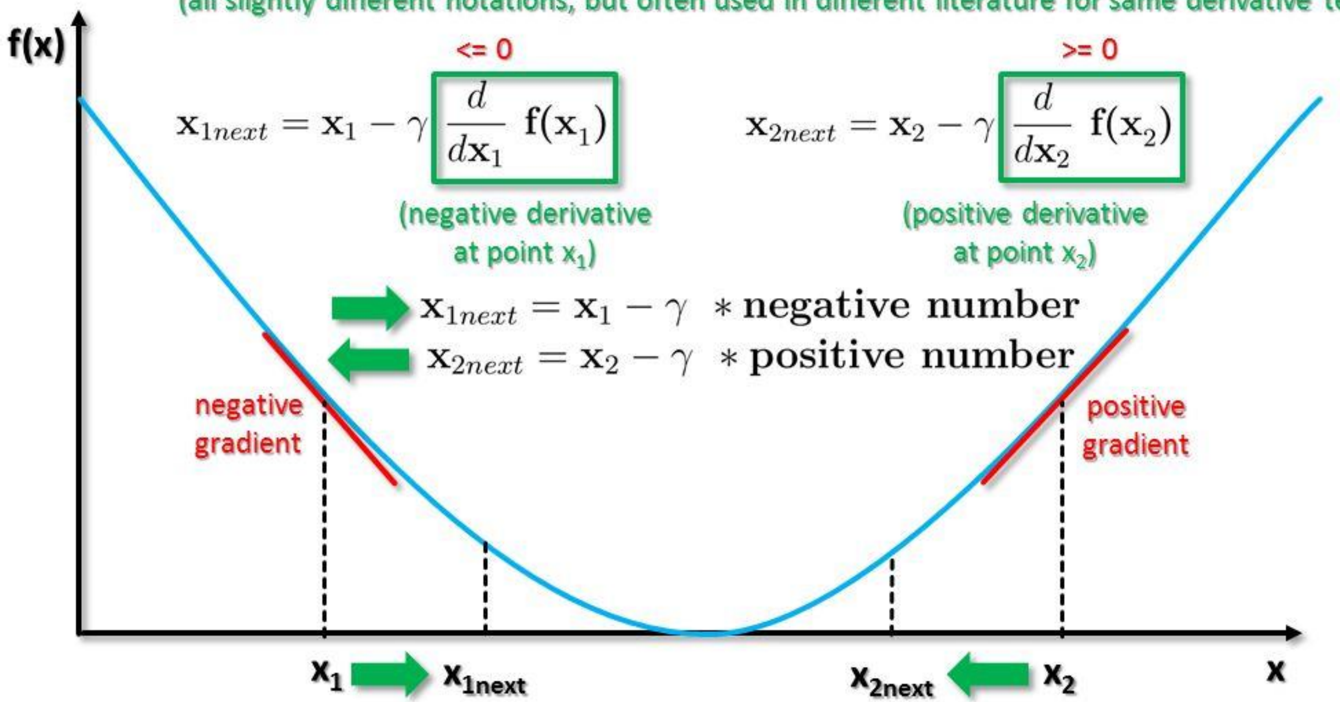
[21] Big Data Tips, Gradient Descent

Gradient Descent Method (2)

- **Gradient Descent (GD) uses all the training samples available for a step within a iteration**
- **Stochastic Gradient Descent (SGD) converges faster: only one training samples used per iteration**

$$\mathbf{b} = \mathbf{a} - \gamma \, \nabla \, f(\mathbf{a}) \quad \mathbf{b} = \mathbf{a} - \gamma \, \frac{\partial}{\partial \mathbf{a}} \, f(\mathbf{a}) \quad \mathbf{b} = \mathbf{a} - \gamma \, \frac{d}{d\mathbf{a}} \, f(\mathbf{a})$$

(all slightly different notations, but often used in different literature for same derivative term)



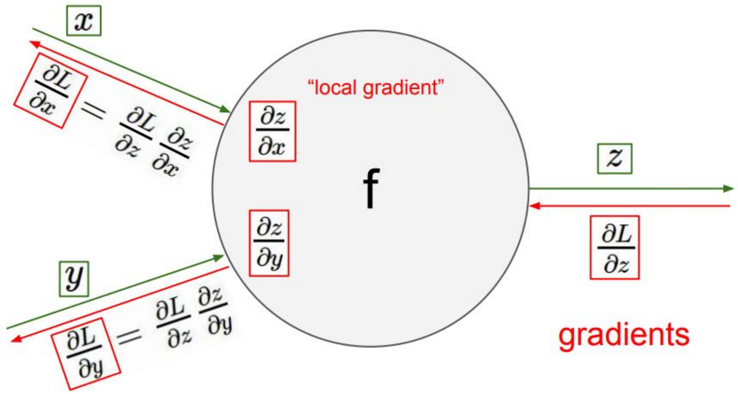
[21] Big Data Tips, Gradient Descent

Loss Functions and Backpropagation

- Gradient Descent is mostly used in combination with a Loss function, which is used for model evaluation

$$\mathrm{MSE}_{\mathrm{test}} = \frac{1}{m} \sum_i (\hat{\boldsymbol{y}}^{(\mathrm{test})} - \boldsymbol{y}^{(\mathrm{test})})_i^2 .$$

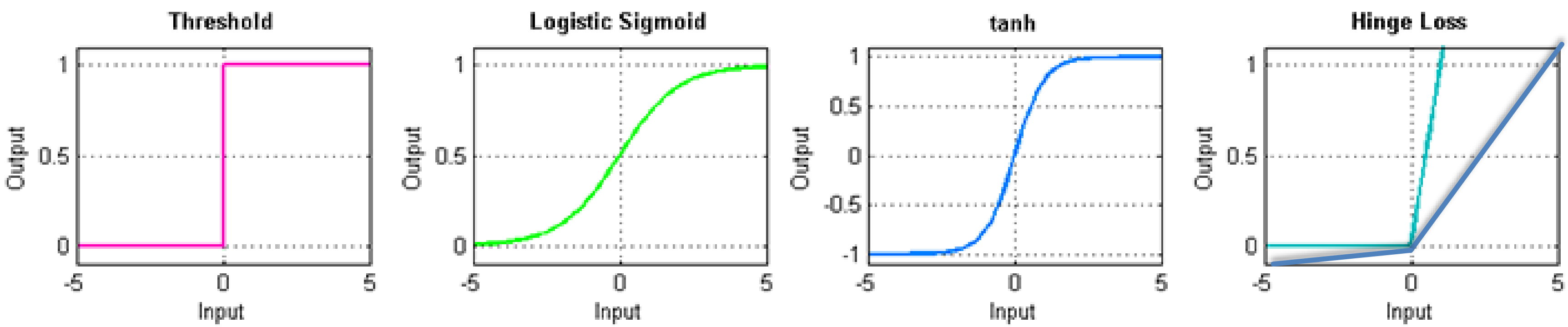
- Backpropagation is employed to update the weights and bias of every edge using the chain-rule from calculus, i.e. taking the derivative to determine the modification gradient.



[22] Becoming Human, Backpropagation

Activation functions

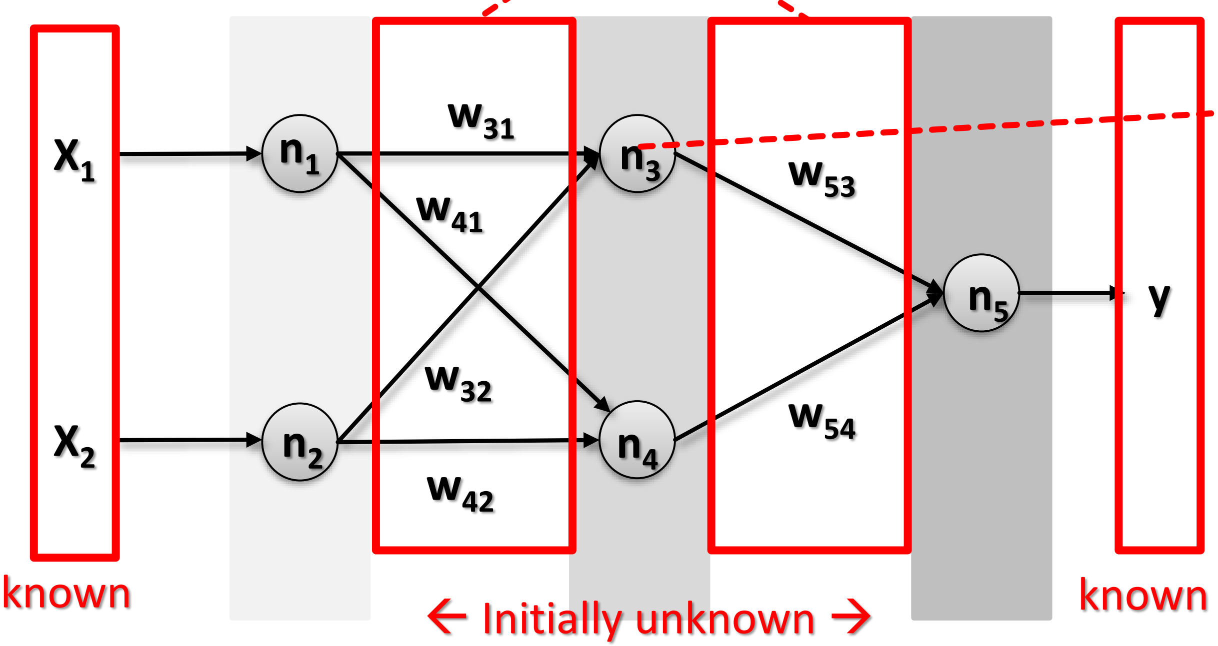
- Multiple activation function types are used in practice, and often several different types in a single neural network.
- Their selection is quintessential component to achieve non-linear convergence.



ANN – Backpropagation Algorithm (BP) Basics

- One of the most widely used algorithms for supervised learning
  - Applicable in multi-layered feed-forward neural networks

- **'Gradient descent method' can be used to learn the weights of the output and hidden nodes of a artificial neural network**



- **Hidden nodes problem: computing error term hard: ∂ E / ∂ wj**
- **Their Output values are unknown to us (here)…**

- **The backpropagation algorithm solves exactly this problem with two phases per iteration(!)**

Deep Learning Material

Books freely available online

- http://www.deeplearningbook.org/
- http://www-bcf.usc.edu/~gareth/ISL/

Coursera

https://www.coursera.org/specializations/deep-learning

Stanford lecture collection

https://www.youtube.com/watch?v=vT1JzLTH4G4&list=PL3FW7Lu3i5JvHM8ljYj-zLfQRF3EO8sYv

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Slides Available at http://www.morrisriedel.de/talks