Introduction to Deep Learning

Artificial Intelligence in the New Era

About the Course

Module 1: Brief introduction to machine learning, supervised, unsupervised and reinforcement learning.

Neural networks, Logistic regression, Forward and Backward propagation, Vanishing and exploding gradient problems.

Improving neural network performance: Hyperparameters tuning, Regularization and optimization.

Introduction to deep learning, Challenges in training deep neural networks, Dropout regularization.

Optimization: Mini batch gradient descent, RMSProp, Adam optimization.

Introduction to Python, Tensorflow and Keras. Implementing first neural network in Keras.

About the Course

Module2:

Convolutional neural network (CNN): Convolution and pooling layers, Activation maps and dimension of output volume, important CNN architectures, AlexNet, GoogLeNet, VGG, ResNet and other emerging networks.

Application of CNN in classification problems. Building a CNN based classification model in Keras. Concept of transfer learning. Applications of CNN classifier to agriculture, surveillance and medical fields.

Module3:

Sequence modeling: introduction to Recurrent Neural Network (RNN), Introduction to types of RNNs. Vanishing gradient problem and LSTM and GRU solutions.

Applications to Language modeling - chatbots, sentiment classification and machine translation. Attention model and beam search methods.

Building an Image captioing model using CNN and RNN

About the Course

Module4:

Applications of Deep CNN in object detection problems. Specific CNN architectures for object detection. Two stage and single stage methods. Sliding Window, R-CNN, Fast R-CNN and Faster R-CNN. Real-time implementation CNN models. YOLO, SSD and recent architectures.

Darknet Framework and use of transfer learning for object detection.

Module5:

Autoencoder (AE), types of AEs, Undercomplete and overcomplete AEs and their uses. Stacked AE, Sparse AE, Denoising AEs.

Generative Adversarial Networks and their applications. Challenges in training GANs, Mode collapse, Nonconvergence and vanishing gradients, Some basic solutions, Min-Batch GAN, Supervision with label, InfoGAN, Conditional GAN.

Applications of GAN in generating realistic images, text-to-image translation, image-to-image translation, and data augmentation.

About the Course

Tex\Reference Books

1. Ian Goodfellow,Yoshua Bengio, Aaron Courville, Deep Learning, MIT Press, 2016.
2. Ragav Venkatesan and Baoxin Li, Convolutional Neural Networks in Visual Computing: A Concise Guide (Data-Enabled Engineering), CRC Press, 2018.
3. Habibi Aghdam, Hamed, Jahani Heravi, Elnaz, Guide to Convolutional Neural Networks, Springer, 2018.

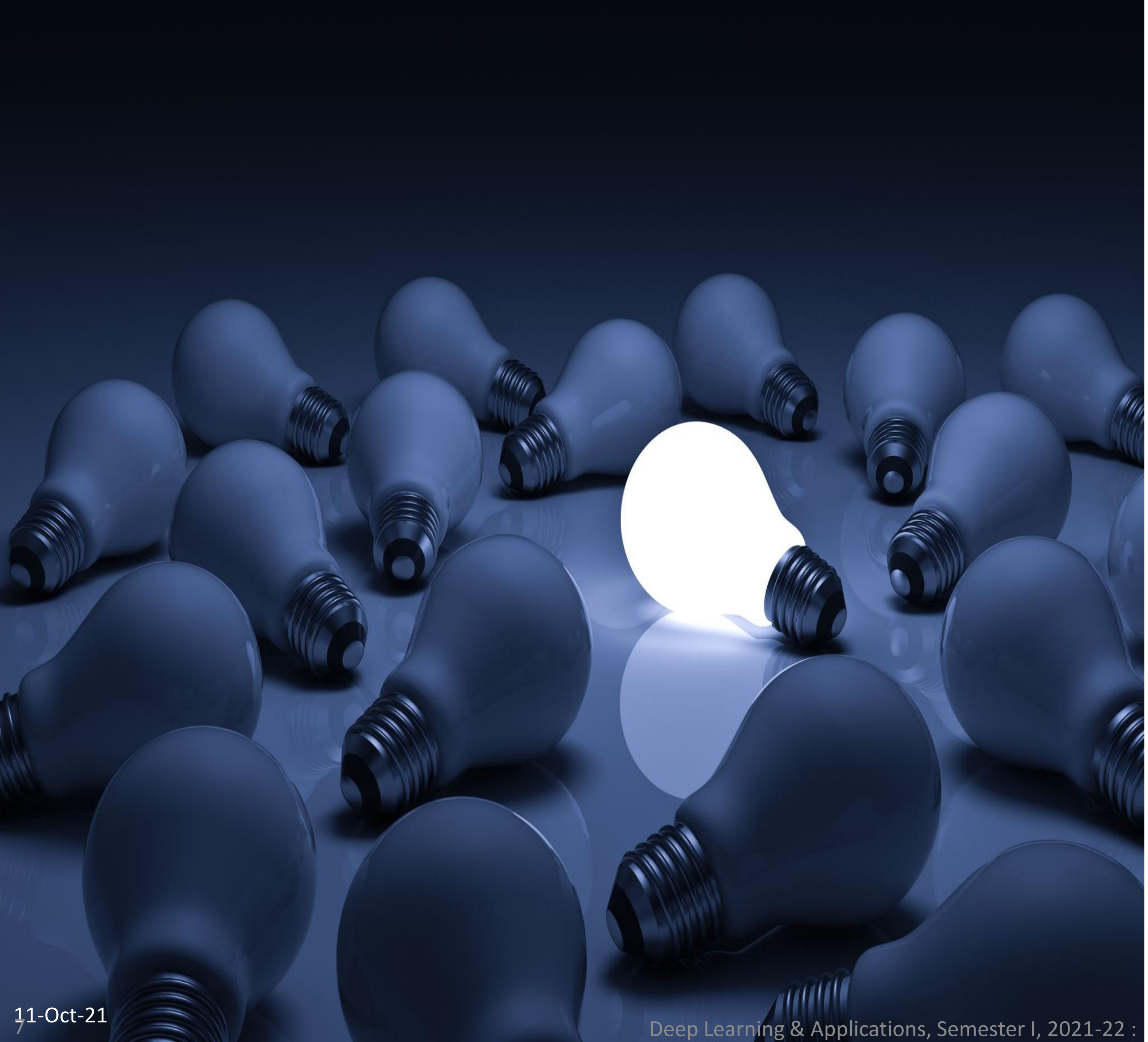
Teaching Assistants: Ms Poornima Singh Thakur and Ms Shubhangi Chaturvedi

Evaluation & Grading : Relative Grading, Mid Sem 30%, End Sem 40%, Tests/Assignments 10%, Project 20% [bonus marks : upto 3 for attendance and upto 3 for outstanding projects]

Note: Please refrain from any kind of academic dishonesty in exams, projects and assignments. If found indulged in such an activity, you may be awarded an F grade.

Today

- Introduction to AI and Machine Learning

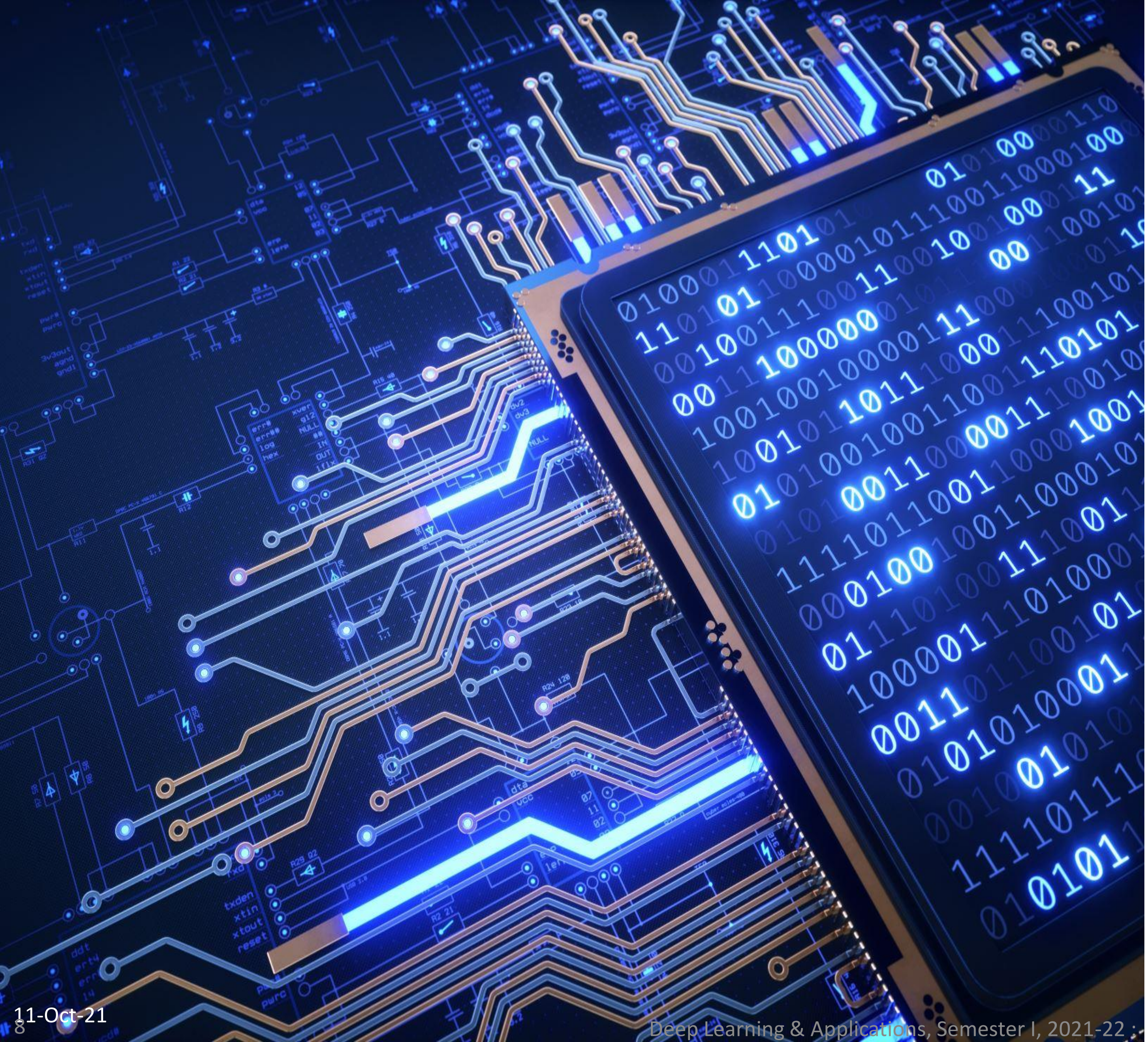


Intelligence

- What is Intelligence ?
  - the ability to learn, understand and think in a logical way about things; the ability to do this well.

    (Oxford Dictionary)
  - the ability to learn, understand, and make judgments or have opinions that are based on reason.

  (Cambridge Dictionary)



Artificial Intelligence

- What is Artificial Intelligence ?
  - Systems that think and act like humans?
  - Systems that have a rational behaviour?
  - Attributes like emotions, reactions?

Examples of Artificial Intelligence


Image source: https://en.wikipedia.org/

Image source: https://spectrum.ieee.org/

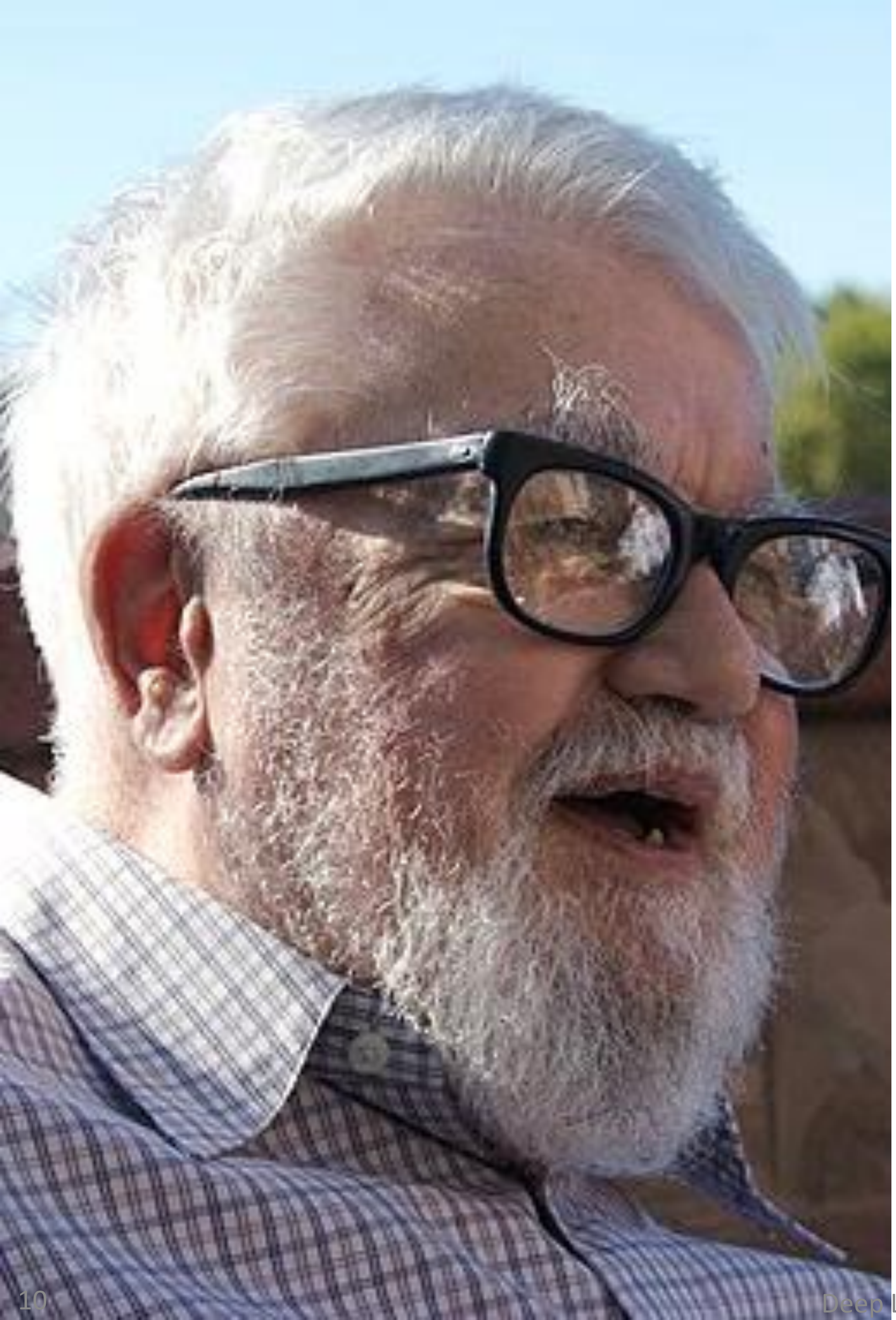

Image source: https://www.tesla.com/

Alexa

Google Assistant

Siri

Image source: https://www.alexeko.com/



Artificial Intelligence

"It is the science and engineering of making intelligent machines, especially intelligent computer programs. It is related to the similar task of using computers to understand human intelligence, but AI does not have to confine itself to methods that are biologically observable."

—John McCarthy (2004) , Stanford University

Artificial Intelligence

"Artificial intelligence is a constellation of many different technologies working together to enable machines to sense, comprehend, act, and learn with human-like levels of intelligence. Maybe that's why it seems as though everyone's definition of artificial intelligence is different: AI isn't just one thing."

https://www.accenture.com

Artificial Intelligence

- The term Artificial Intelligence began to evolve when a small group of scholars from a variety of fields in 1940s-50s started exploring the possibility of **creating an artificial brain**.

Cybernetics and early neural networks [1940-50s]

Nobert Wiener

Dartmouth Conference 1956

AI Emerges

John McCarthy

Turing's test [1950s]

Alan Turing

Types of Artificial Intelligence

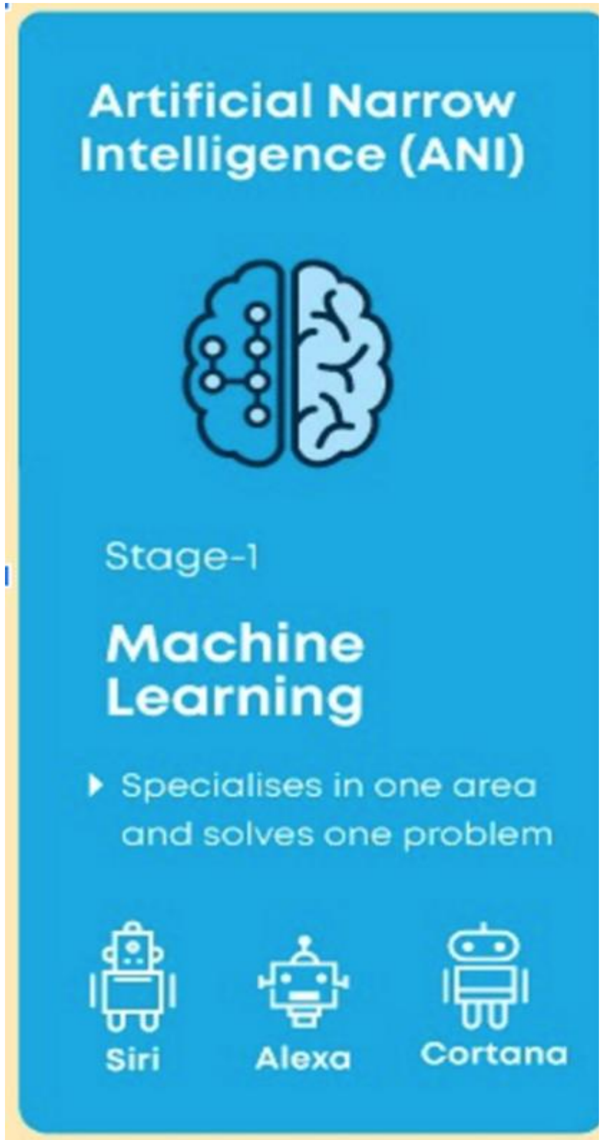
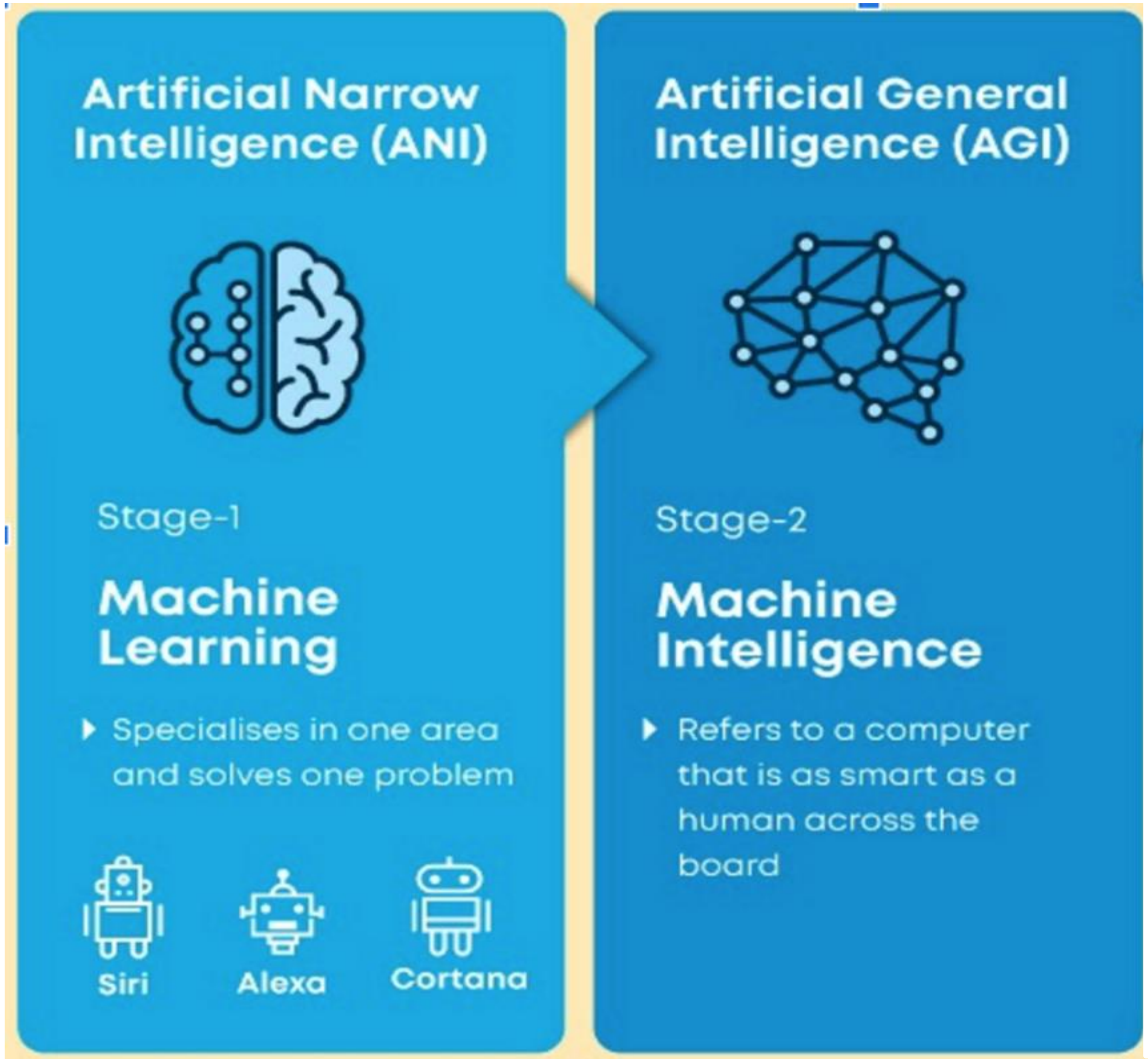


Image source: https://medium.datadriveninvestor.com/

Types of Artificial Intelligence



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Types of Artificial Intelligence

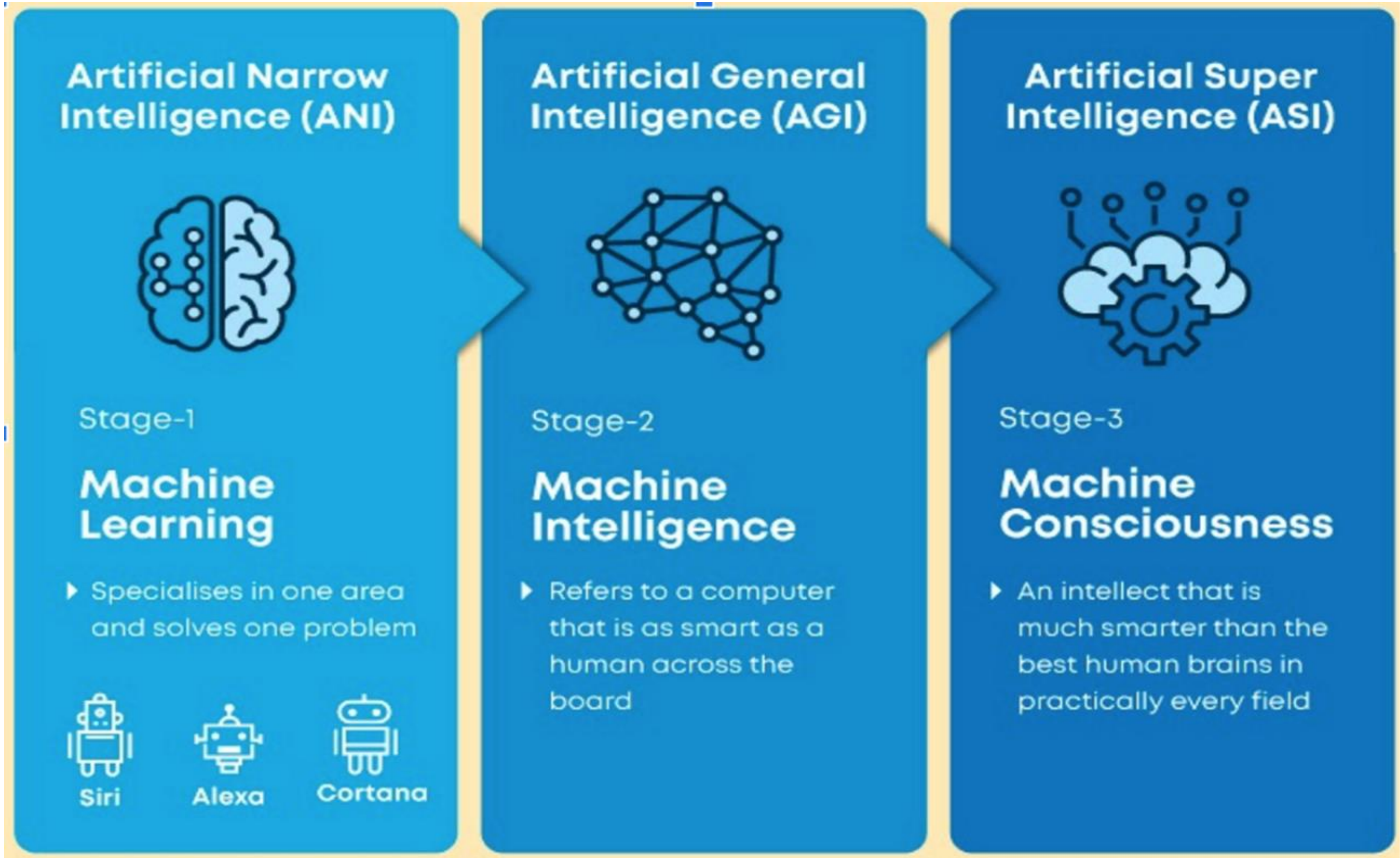


Image source: https://medium.datadriveninvestor.com/

Types of Artificial Intelligence

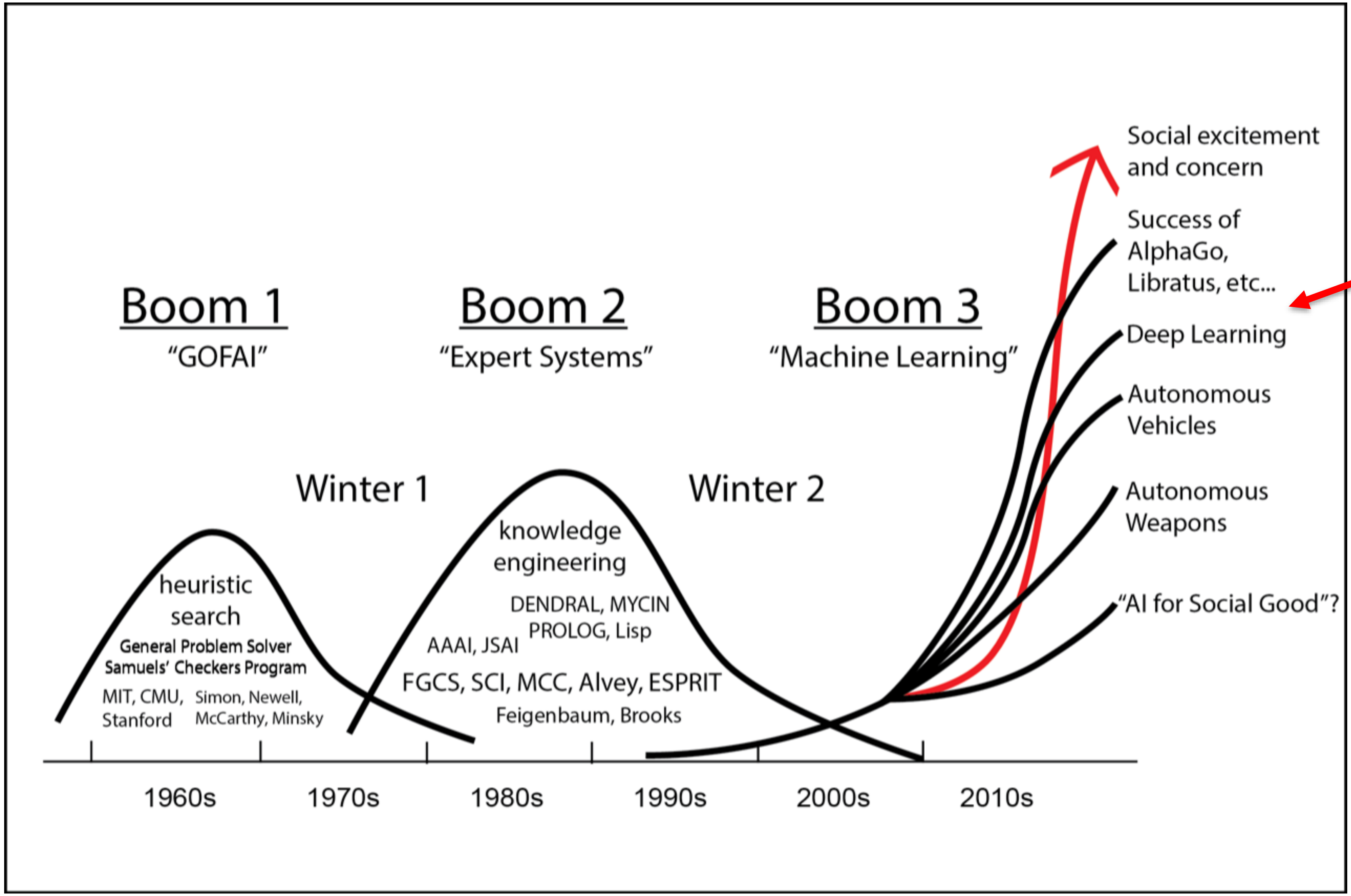
- Weak AI or Artificial Narrow Intelligence is AI trained and focused to perform specific tasks or a set of closely related tasks. like weather prediction, fraud detection, machine translation, video caption generation.
- Strong AI – Artificial General Intelligence and Artificial Super Intelligence. (Not yet achieved)
  - "A machine would have an intelligence equaled to humans; it would have a self-aware consciousness that has the ability to solve problems, **learn**, and plan for the future." https://www.ibm.com/cloud/learn/what-is-artificial-intelligence

Intelligence and Learning

- **Herbert Alexander Simon,** a cognitive psychologist –

  “Learning denotes changes in the system that are adaptive in the sense that they enable the system to do the tasks drawn from the same population more efficiently and more effectively the next time.”
- **Arthur Robert Jensen**, Educational psychologist –
- “A review of evidence on the relationship between individual differences in measures of learning and of intelligence suggests that no clear distinction can be made between the cognitive processes that contribute to individual differences in these two definitionally different realms.”

Evolution of Artificial Intelligence



Deep Learning brought the AI to the forefront again

First AI Winter 1973 :
The Lighthill report, effect on funding

Second AI Winter 1987:
market for specialized AI hardware collapsed.

[Image source: https://www.technologystories.org/ai-evolution/](https://www.technologystories.org/ai-evolution/)

Artificial Intelligence Machine Learning & Deep Learning

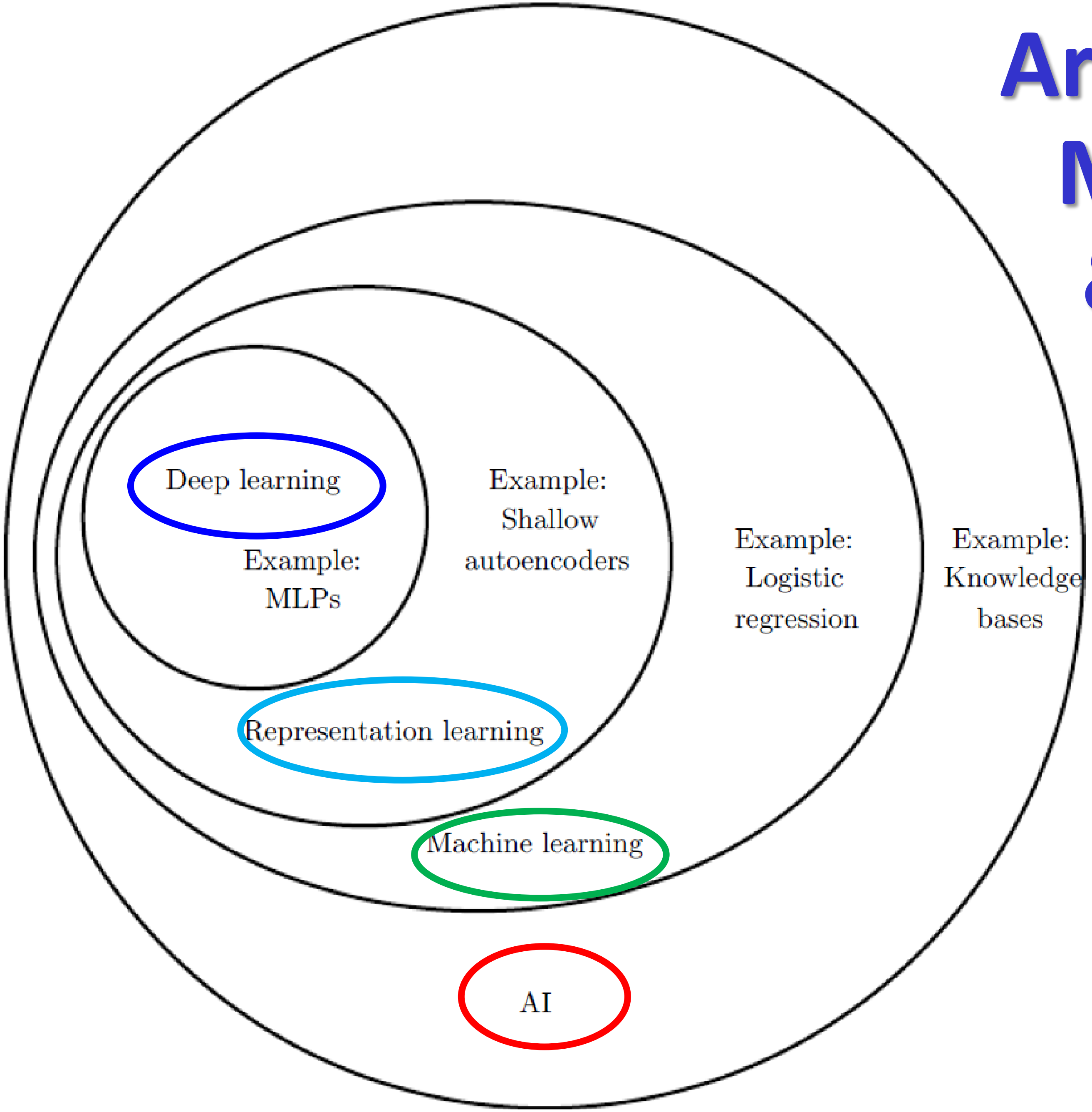
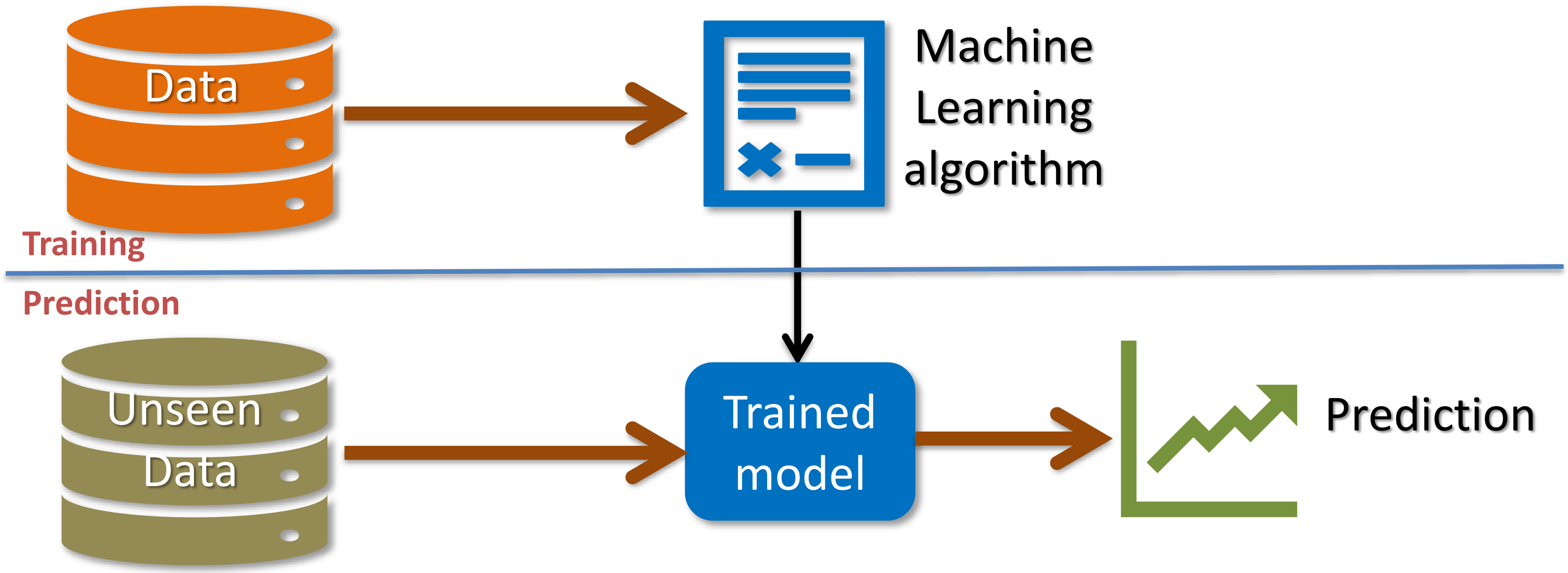


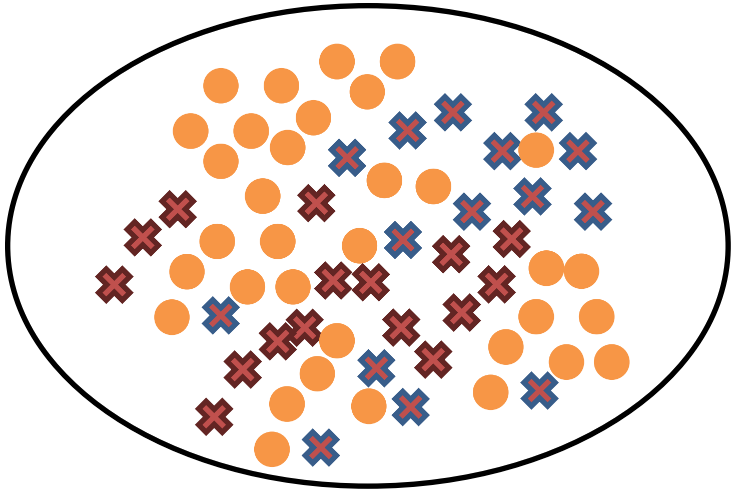
Figure source: Ian Goodfellow, Deep Learning, MIT Press, 2016

Machine Learning

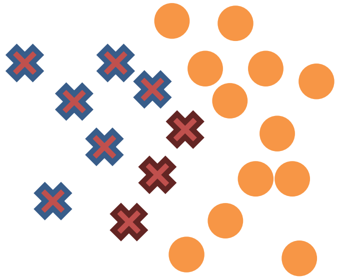
- Machine learning (ML) is a field of computer science that gives computers the ability to **automatically learn without being explicitly programmed.**
- Learning from experience on data to make predictions.



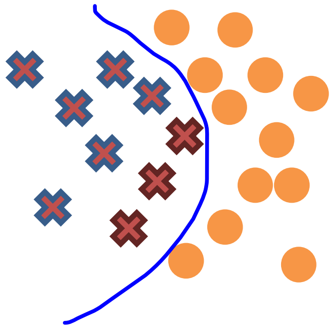
Training and Testing



Universal set



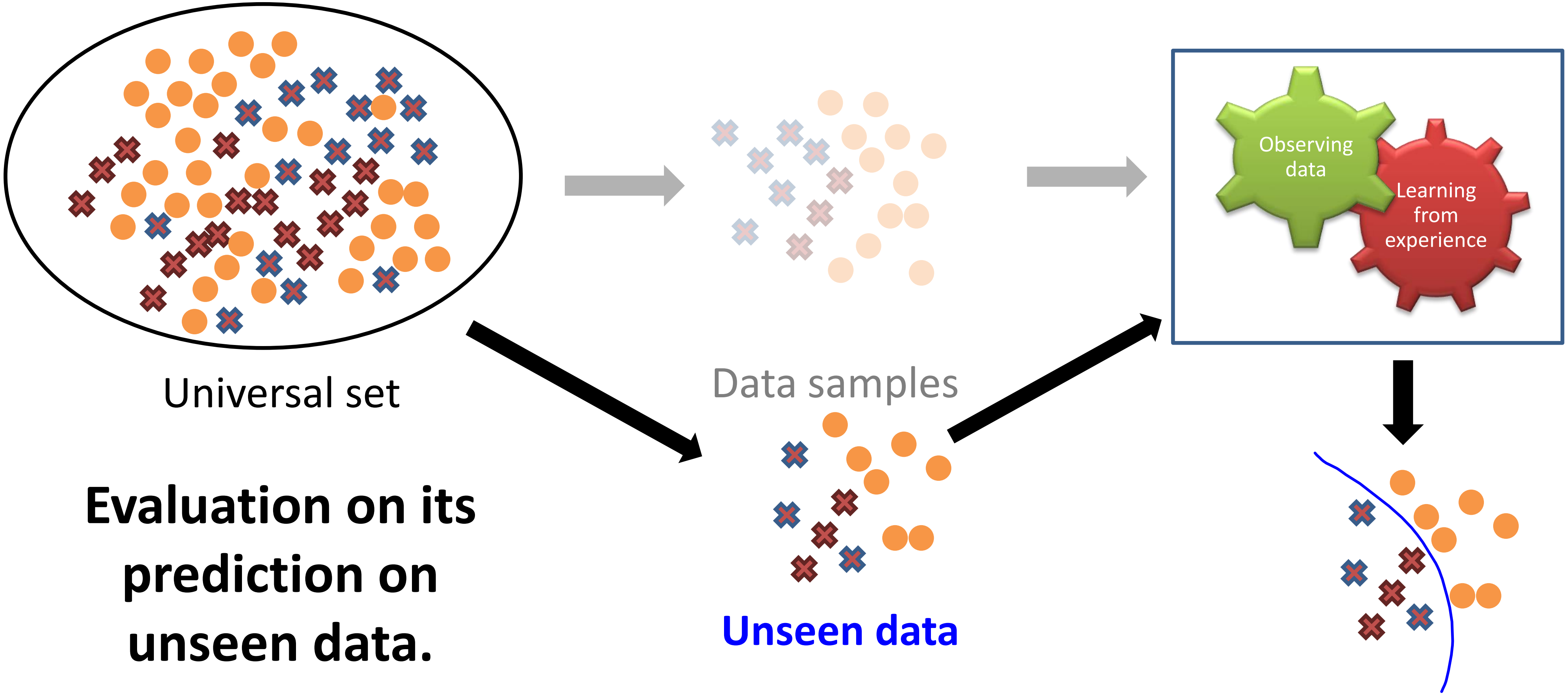
Data samples



Learns to understand patterns for making **predictions.**

Training is the process of making the system able to learn.

Training and Testing



Evaluation on its prediction on unseen data.

Machine Learning Algorithm

- A machine learning algorithm is an algorithm that is able to learn and **extract patterns** from data.
- **Learning** –
  - A computer program is said to learn from
    - experience E
    - with respect to some class of tasks T
    - and performance measure P
  - if its performance at tasks in T , as measured by P , improves with experience E.” (*Mitchell , 1997*)

Learning Algorithms…

- General Tasks
  - Classification, Regression, Transcription , Machine Translation etc.
- Performance measures
  - Depends on the type of problem: Examples include –
    - accuracy, error rate etc.
  - Performance is measured on a dataset called test dataset, that is different from the dataset used to train the algorithms.
  - Often difficult to choose a performance measure that corresponds well to the desired behavior of the system.
- Experience
  - Algorithms are termed as supervised learning or unsupervised learning algorithms based on the experience they are allowed to have on datasets.

Types of Learning Algorithms

Three broad categories of learning

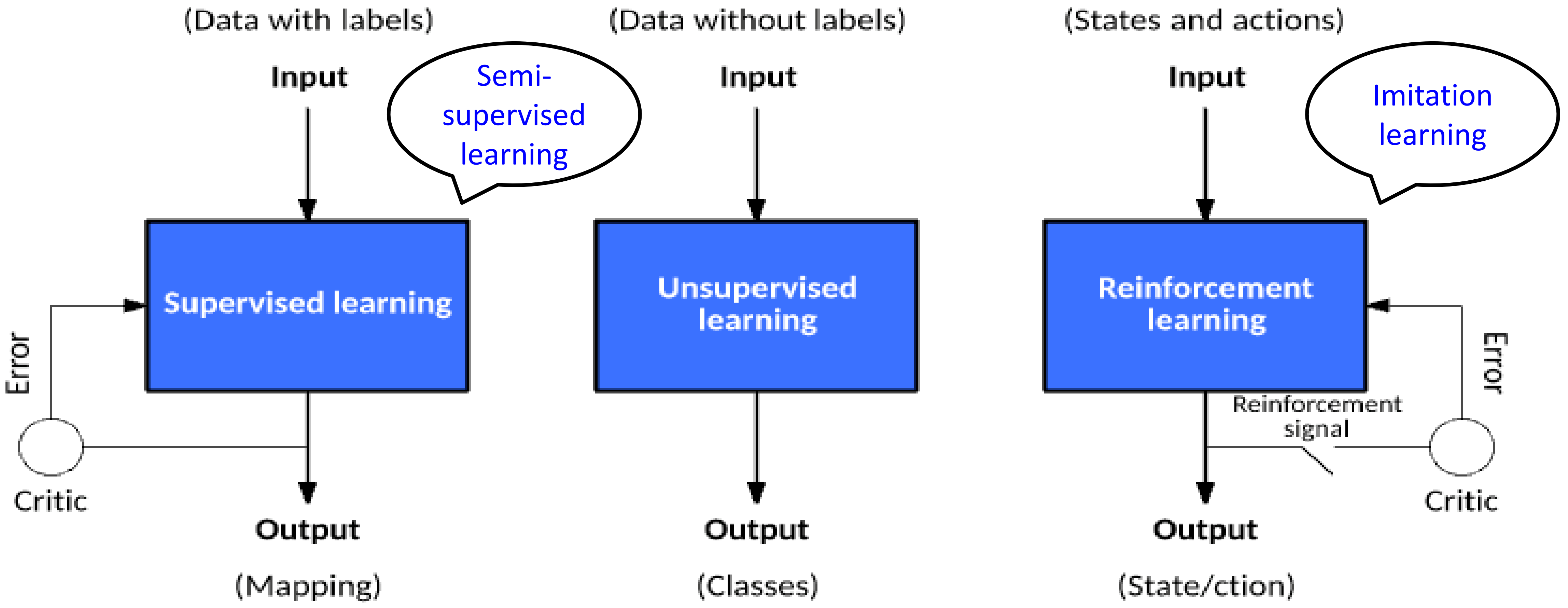


Image source: https://developer.ibm.com/

Limitations of Traditional ML Systems

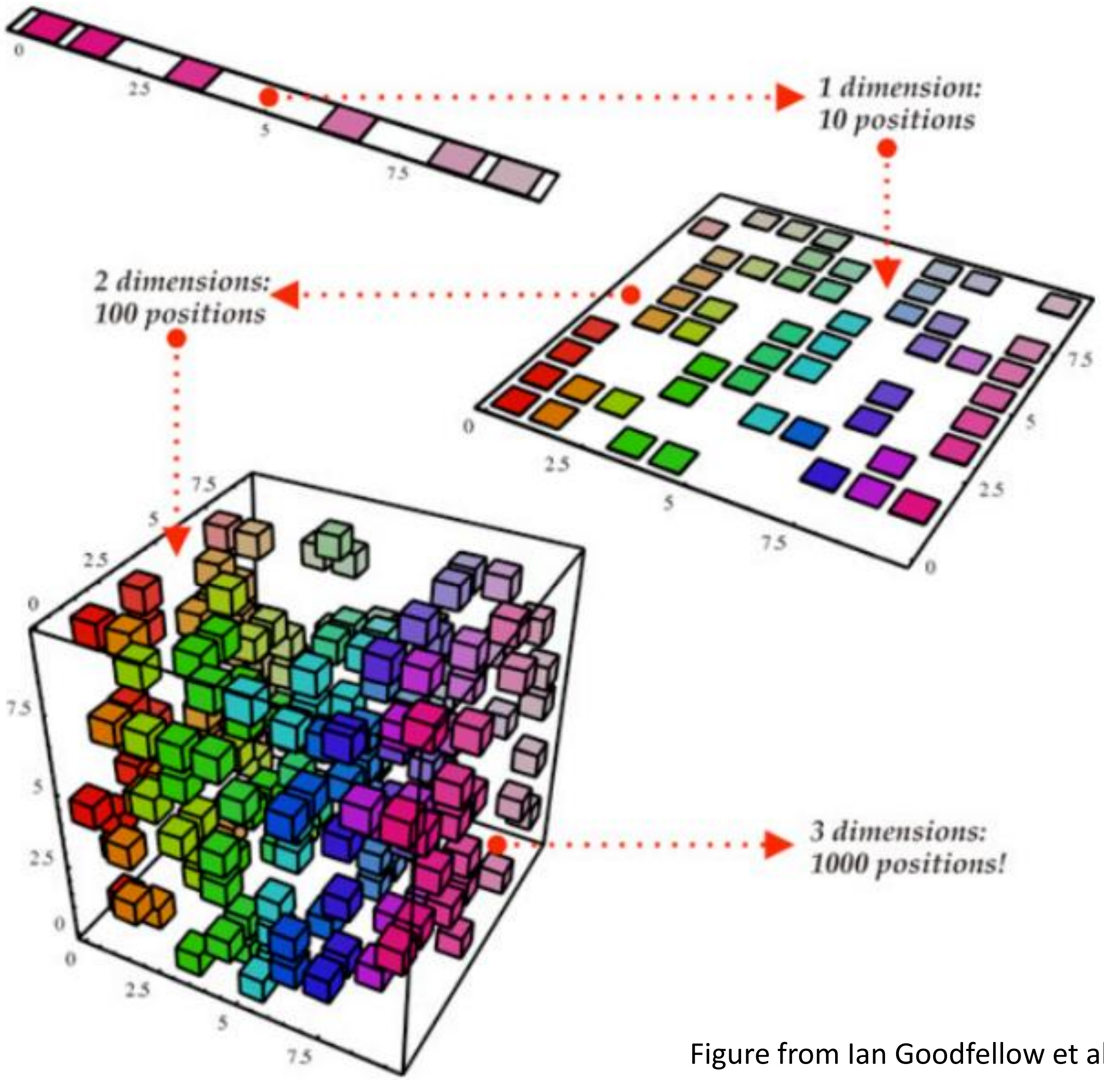


Figure from Ian Goodfellow et al. Book

Curse of dimensionality

Many machine learning problems become exceedingly difficult when the number of dimensions in the data is high.

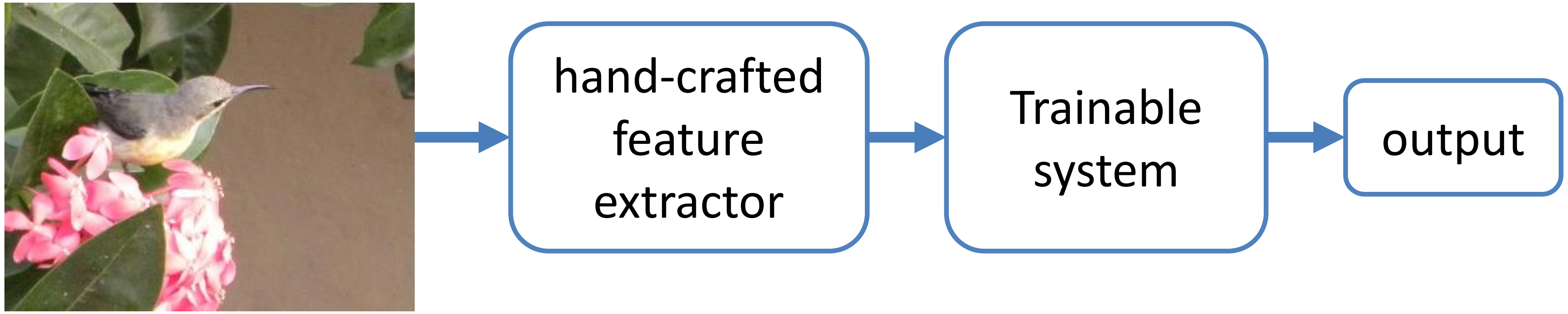
(Hughes/Peaking phenomenon)

Curse of Dimensionality

- Hughes phenomenon (or peaking phenomenon)
- With a fixed number of training samples, the predictive power of a classifier or regressor first increases as the number of dimensions/features used is increased but then decreases.
- Examples of ML problems with high dimensional data
  - Speech recognition
  - Object detection in images

Limitations of Traditional ML Systems…

- Traditional machine learning uses manually designed features that are
  - Often over-specified and incomplete.
  - Mostly application-dependent, cannot be generalized easily to other applications.
  - Time consuming in design and validation.
- Developing hand-crafted features is a costly and complex job.



ML vs Deep Learning

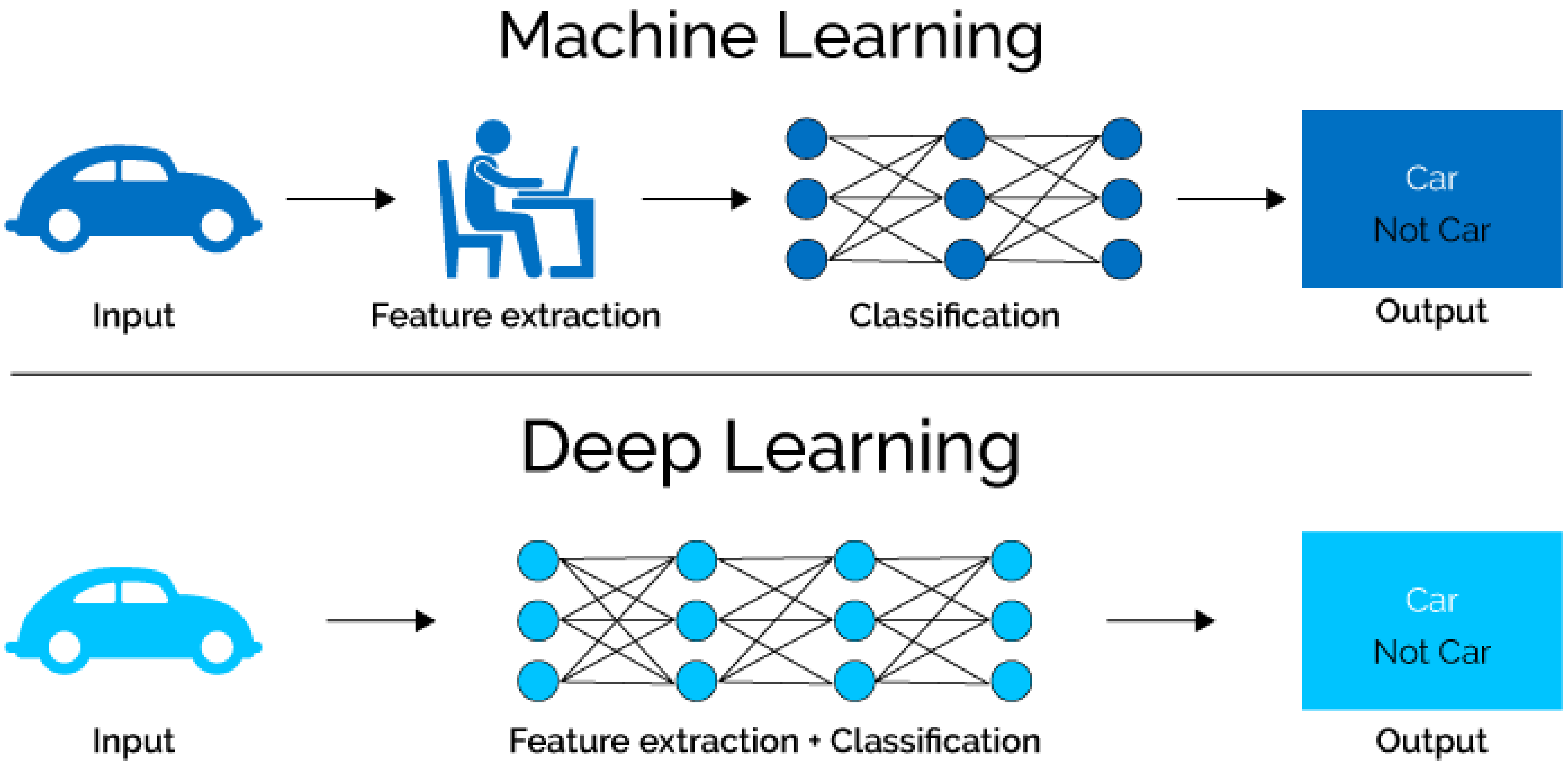


Image source: Unknown

Deep Learning

- Deep learning learns rich hierarchical representations (features) automatically by extracting features at different levels.
- Provides a **flexible** learnable framework.
- Trained algorithms work for **a broad range of problems**.

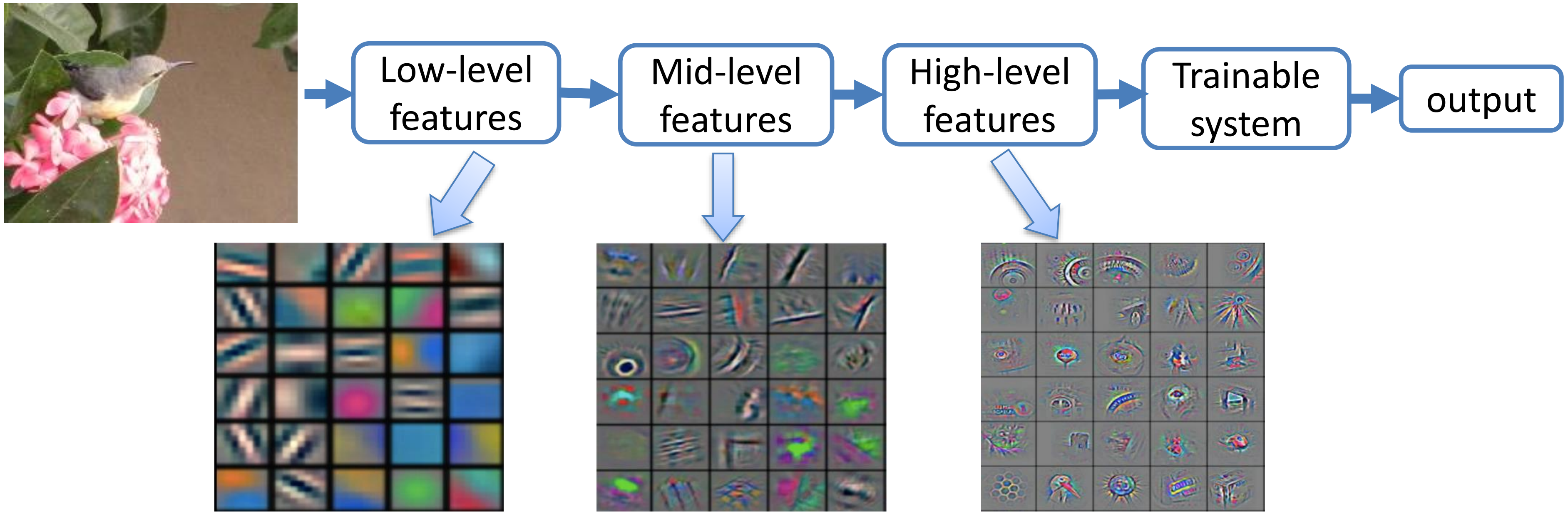


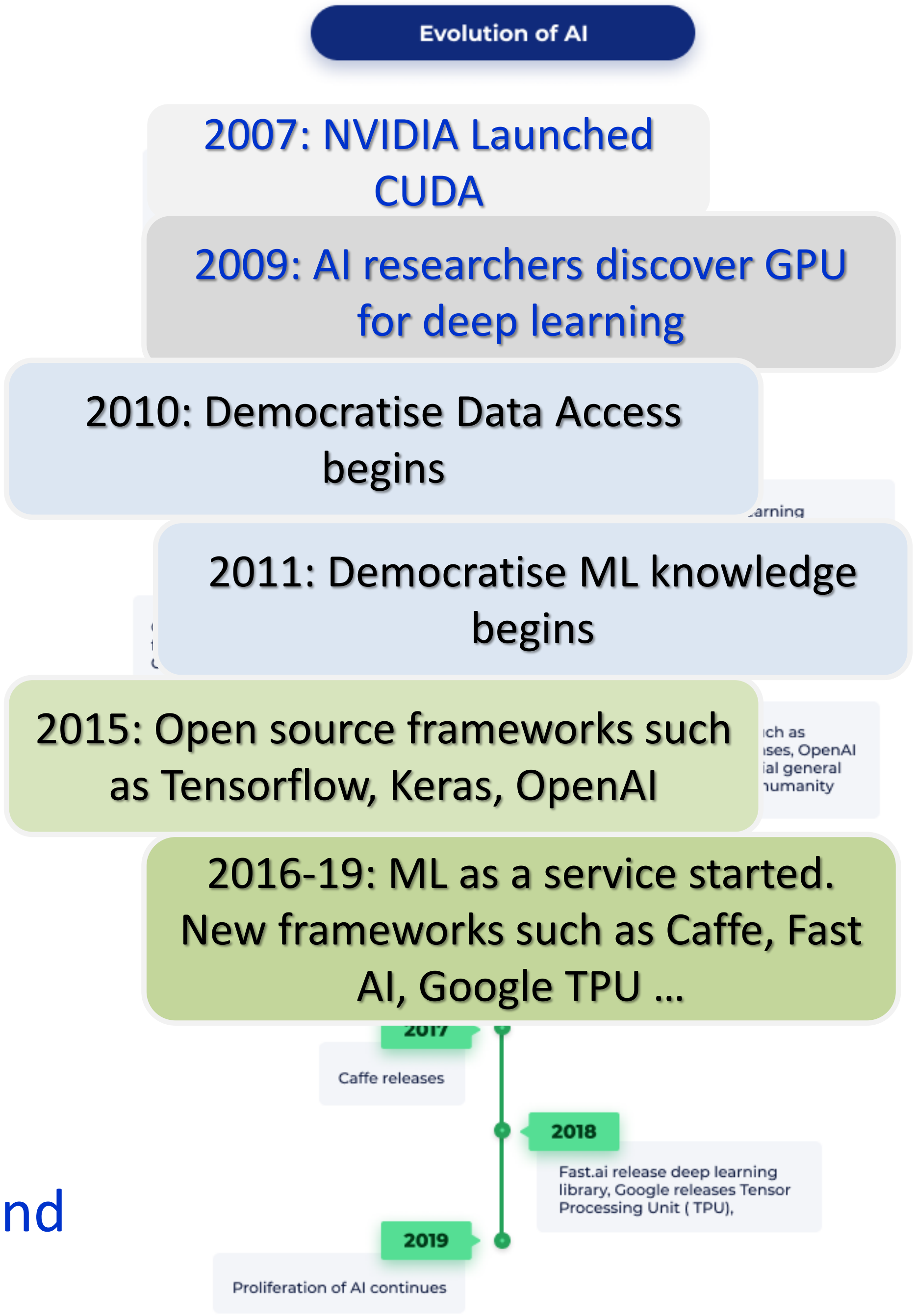
Figure source: Zeiler and Fergus, 2013: Feature visualization of convolution NN on ImageNet database.

Deep Learning Success Mantra

- Increased availability of data
- Significant improvement in computing power
- Increased model size
- **New way of learning representations** (auto-feature extraction)
- Deep Neural Network Architectures that generalize well and are flexible enough to address a broad range of tasks.

AI Technology Advancements with Deep Learning

- Four major catalysts
  - Democratization of AI knowledge.
  - Data and Computing Power
    - Cloud and GPU
  - Proliferation of new tools and frameworks
    - Tensorflow, Keras, PyTorch.
  - AI as a service.
    - Azure AI, AWS AI, Google Cloud AI and IBM Cloud AI.



Source: https://www.lftechnology.com/

Deep Learning Ingredients

- Artificial Neural Networks (ANN) as a learning machine
- Data
- Algorithms to train ANNs
- Computing resources

Tomorrow

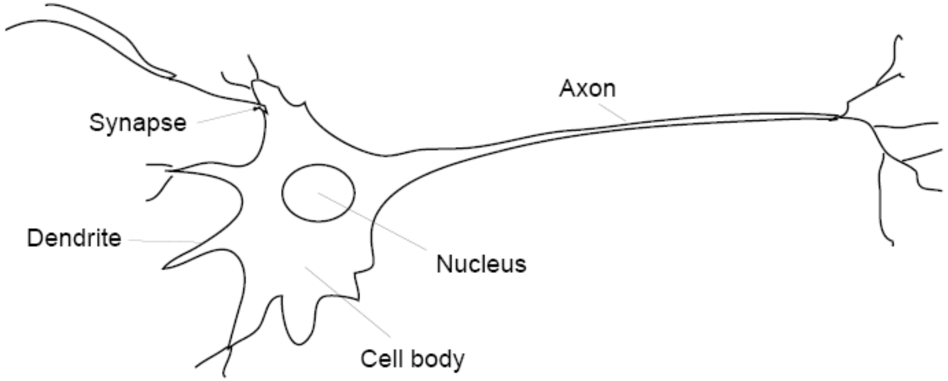
- Artificial Neural Networks

Artificial Neural Network (ANN)

- An information processing paradigm inspired by human brain's information processing mechanism.

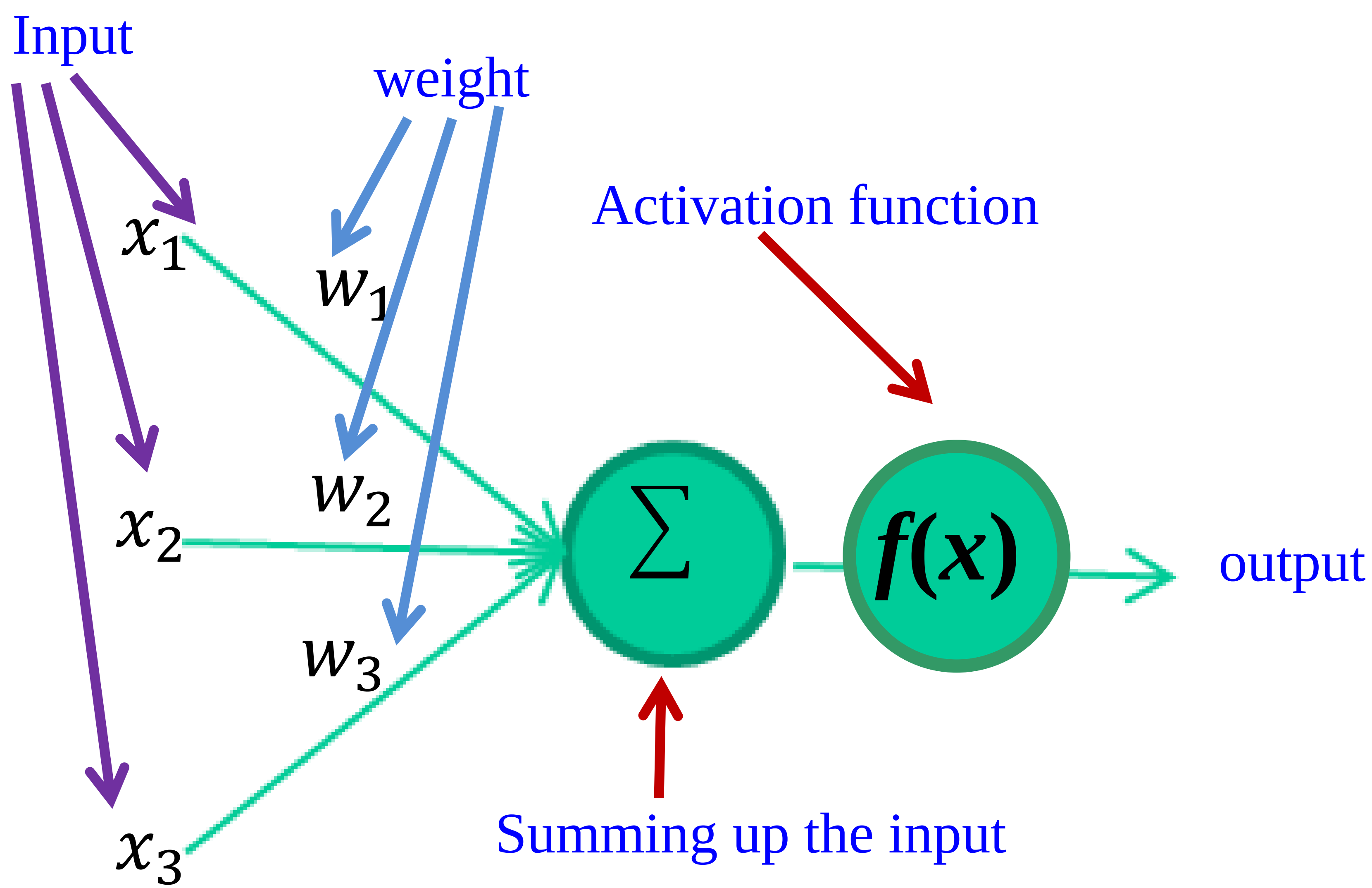
- Composed of a large number of highly interconnected processing elements called neurons working in unison to solve specific problems.
  - ANNs learn by examples like human being.

Neurons in the Brain



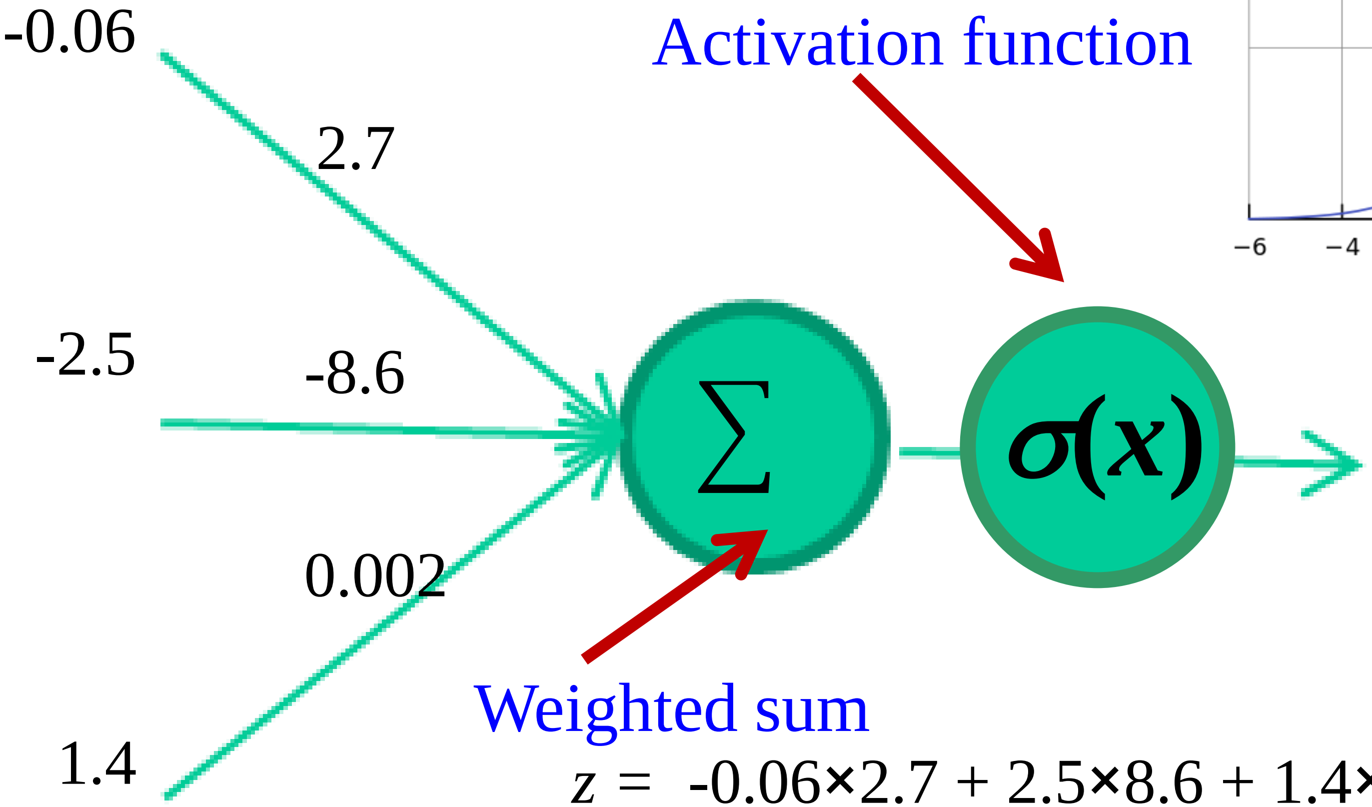
- The main purpose of neurons is to receive, analyze and transmit further the information in a form of signals (electric pulses).
- When a neuron sends information, we say it “fires”.
- Acting through specialized projections known as dendrites and axons, neurons carry information throughout the neural network.

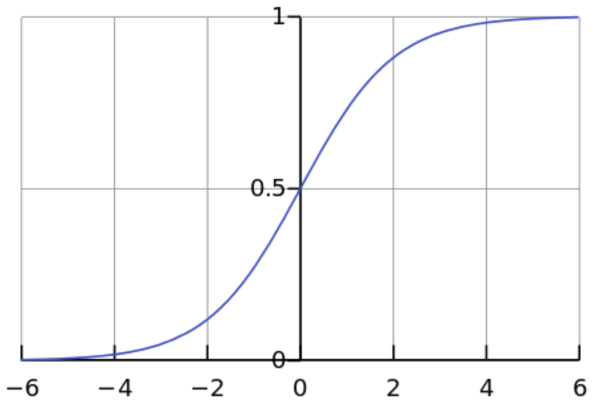
Mathematical Model: Neuron



Mathematical Model: Neuron

An Example





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

$$z = -0.06\times2.7 + 2.5\times8.6 + 1.4\times0.002 = 4.0048$$

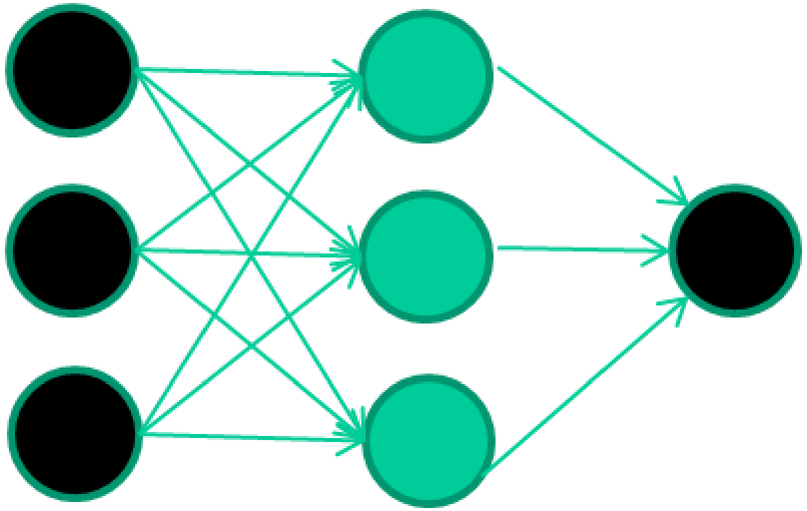
$$\sigma(z) = 0.982$$

Mathematical Model: NN

A dataset

Features			***class***
1.4	2.7	1.9	0
3.8	3.4	3.2	0
6.4	2.8	1.7	1
4.1	0.1	0.2	0

etc …



Mathematical Model: NN…

Train the NN

Features			*class*
1.4	2.7	1.9	0
3.8	3.4	3.2	0
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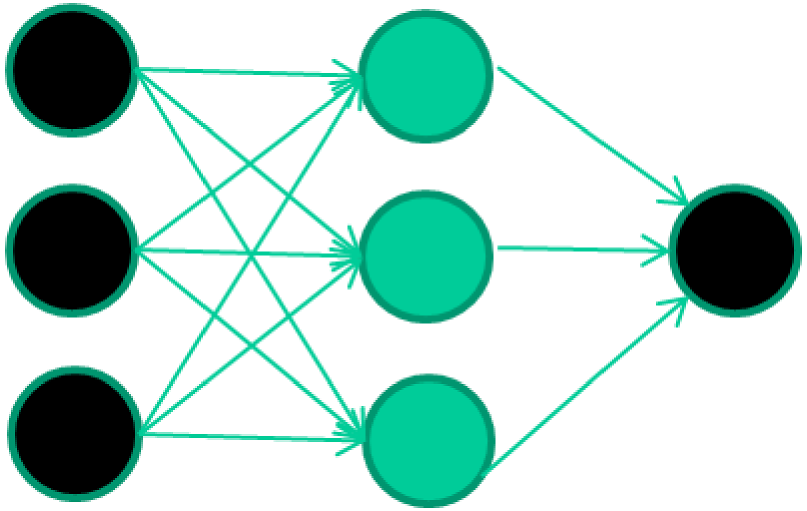

Mathematical Model: NN…

Train the NN
Initialise with random weights

Features			*class*
1.4	2.7	1.9	0
3.8	3.4	3.2	0
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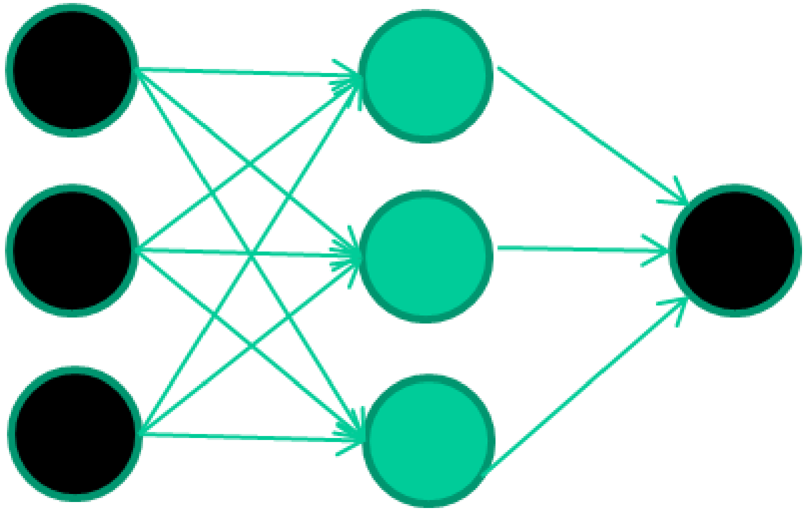
etc …			

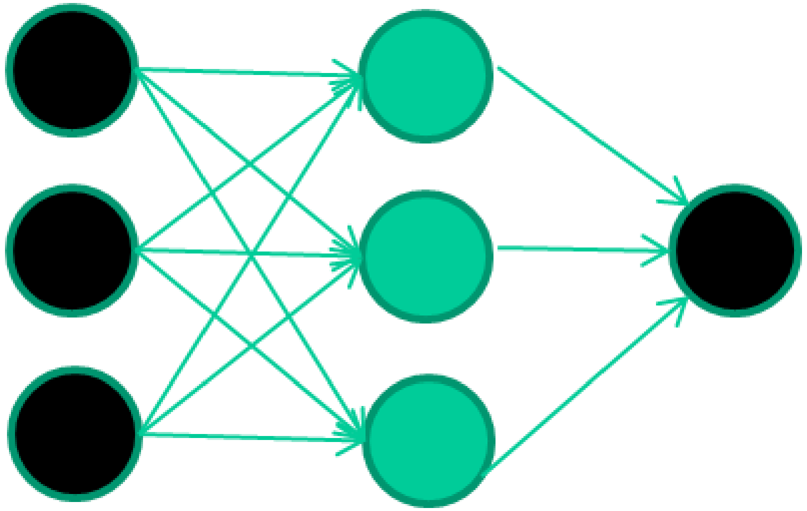


Mathematical Model: NN…

Train the NN
Initialise with random weights
Present a training pattern and feed it to the NN.
Get an output and compare with actual value.

Training Data

Features			*class*
1.4	2.7	1.9	0
3.8	3.4	3.2	0
6.4	2.8	1.7	1
4.1	0.1	0.2	0
etc …			



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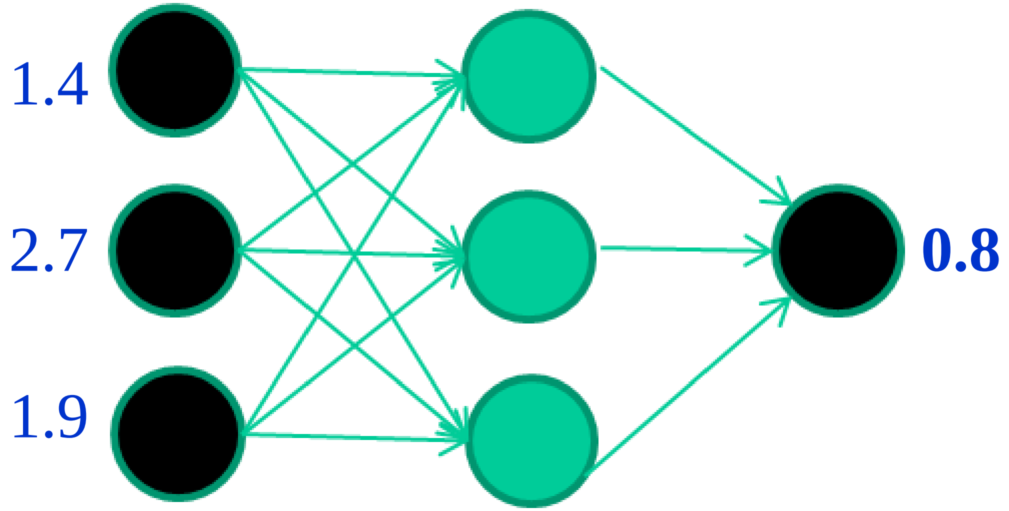
etc …



Mathematical Model: NN…

Train the NN
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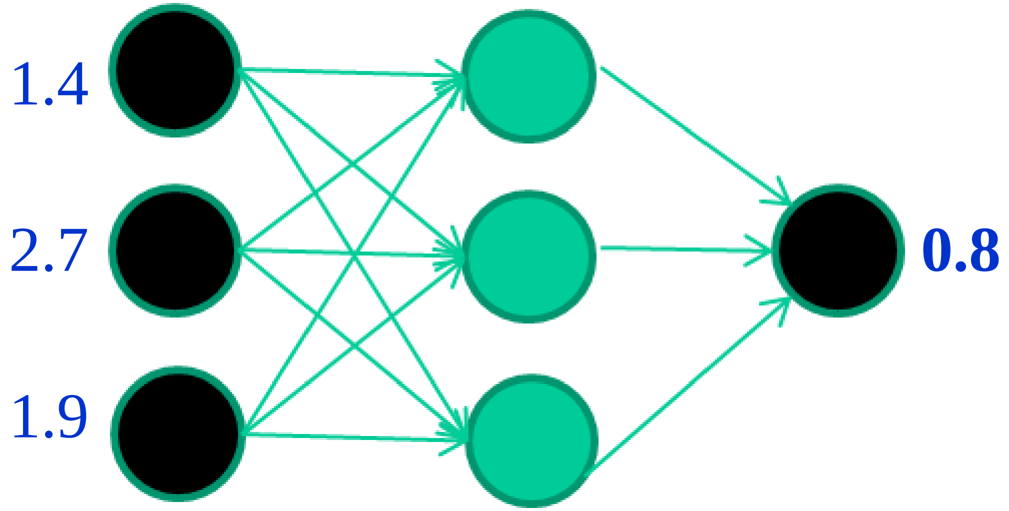
Training Data

Features			*class*
1.4	2.7	1.9	0
3.8	3.4	3.2	0
6.4	2.8	1.7	1
4.1	0.1	0.2	0
etc …			

Expected output



Mathematical Model: NN…

Train the NN
Initialise with random weights
Present a training pattern and feed it to the NN.
Get an output and compare with actual value.

Training Data

Features			***class***
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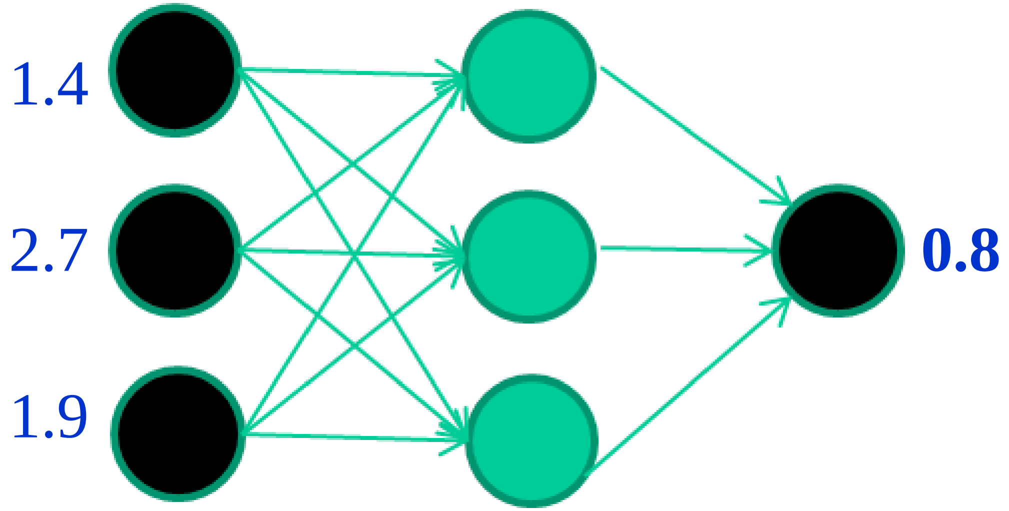
etc …			

Expected output



Error = 0.8

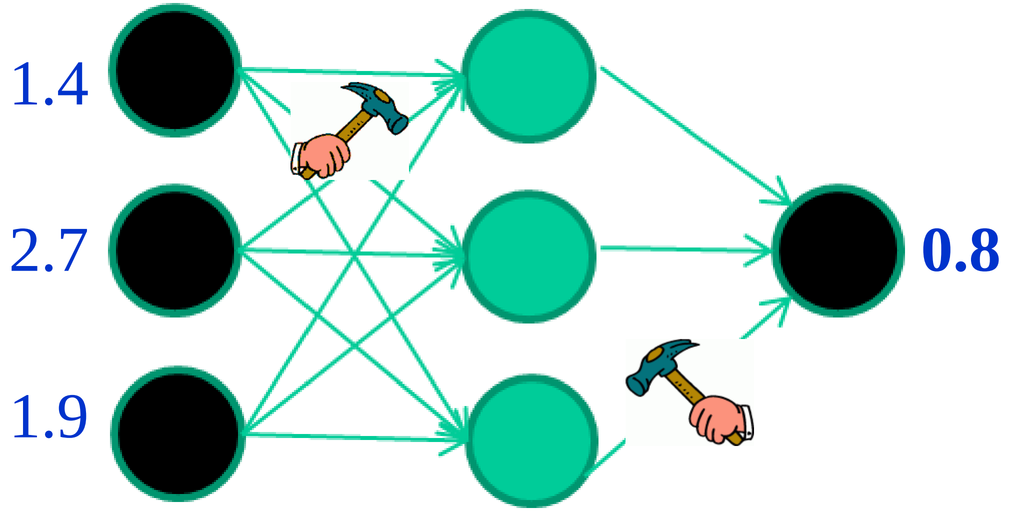
Mathematical Model: NN…

Train the NN
Initialise with random weights
Present a training pattern and feed
Present a training pattern and feed it to the NN.
Get an output and compare with actual value.
Adjust and update the weights.

Training Data

Features			***class***
1.4	2.7	1.9	0
3.8	3.4	3.2	0
6.4	2.8	1.7	1
4.1	0.1	0.2	0
etc …			

Expected output



Error = 0.8

Mathematical Model: NN…

Train the NN

Initialise with random weights

Present a training pattern and feed it to the NN.

Get an output and compare with actual value.

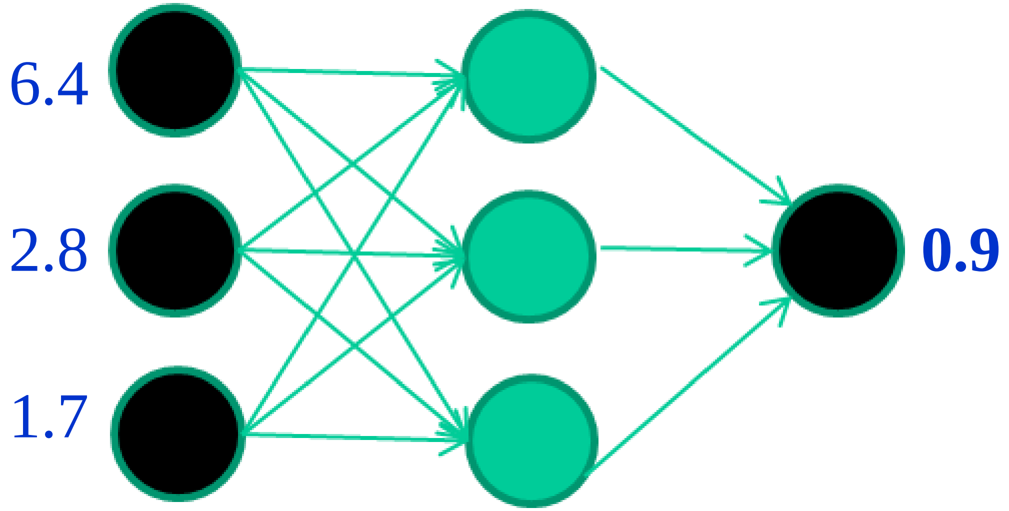
Adjust and update the weights.

Present a training pattern and feed it to the NN

Training Data

Features			***class***
1.4	2.7	1.9	0
3.8	3.4	3.2	0
6.4	2.8	1.7	1
4.1	0.1	0.2	0
etc …			

Training pattern



Error = - 0.1

Mathematical Model: NN…

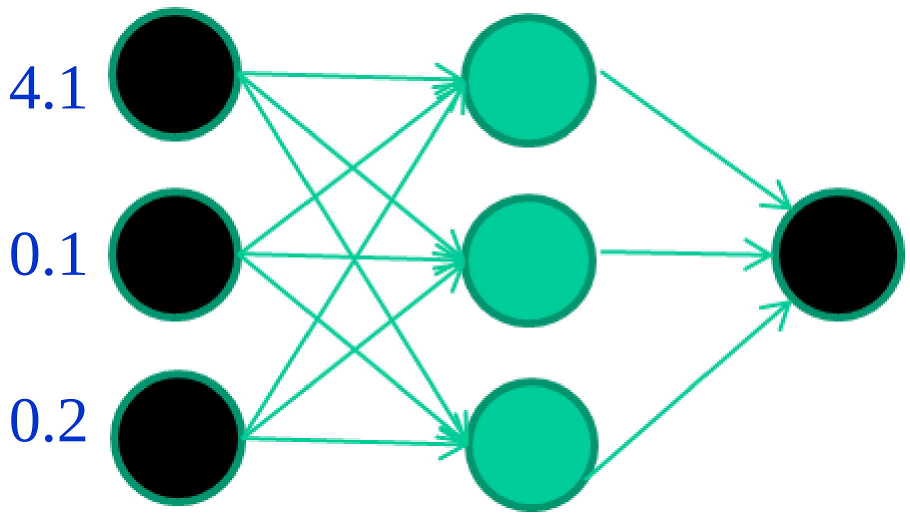
Initialise with random weights
Present a training pattern and feed it to the NN.
Get an output and compare with actual value.
Adjust and update the weights.
Present a training pattern and feed it to the NN.
Repeat the process to reduce the error.

Training Data

Features			***class***
1.4	2.7	1.9	0
3.8	3.4	3.2	0
6.4	2.8	1.7	1
4.1	0.1	0.2	0

etc …

Next training pattern



Mathematical Model: NN…

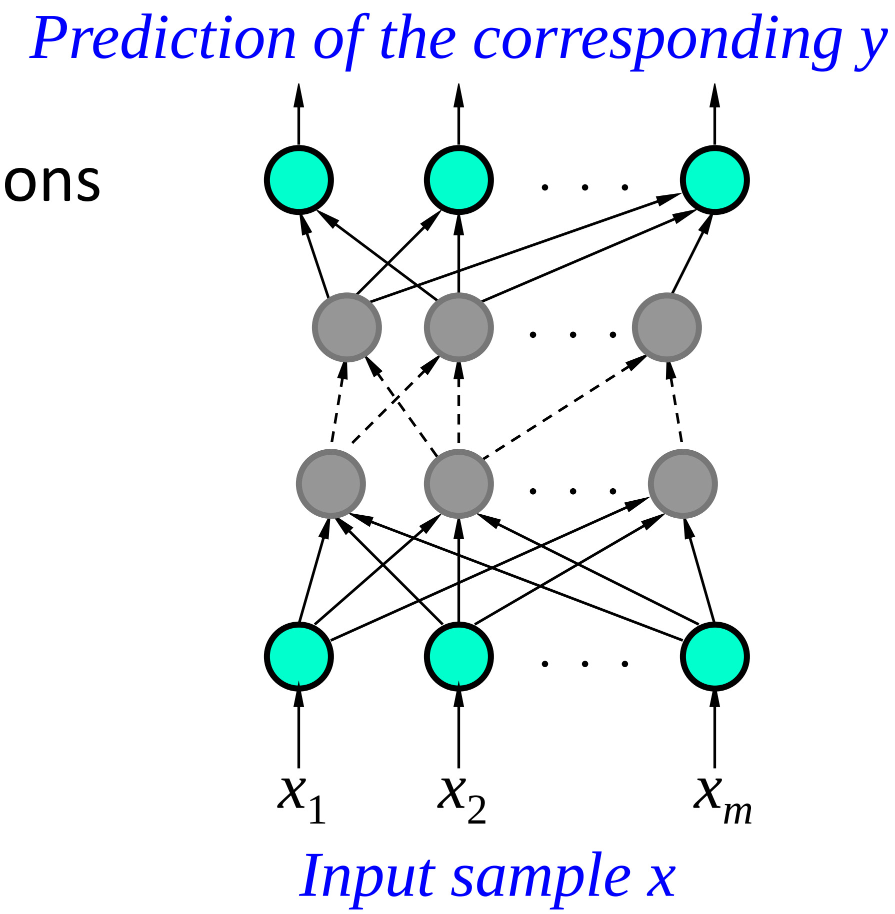
- Weight adjustment process is repeated thousands and thousands of times.
- Each time a random training example is taken, weights are slightly adjusted to tune the system for reducing error of approximation.
- It may not be an efficient adjustment on many other cases.
- But eventually the process of weight adjustments leads to a good enough model for producing an effective classifier.
- It works well in many real applications.

Multilayer Perceptron

- Universal Approximation Theorem (Cybenko, 1989)
  - Any continuous function over a compact domain can be accurately approximated using a neural network with one hidden layer only.
- If layers increase, accuracy of approximation increases.
- To deal with nonlinearity and for better approximation of more complex functions, multi-layer perceptron models were introduced.
- Let us see how a feed forward NN works with multiple layers of neuron (called units).

Feed Forward NNs

- Graph representation:
  - nodes: neurons
  - arrows: signal flow directions

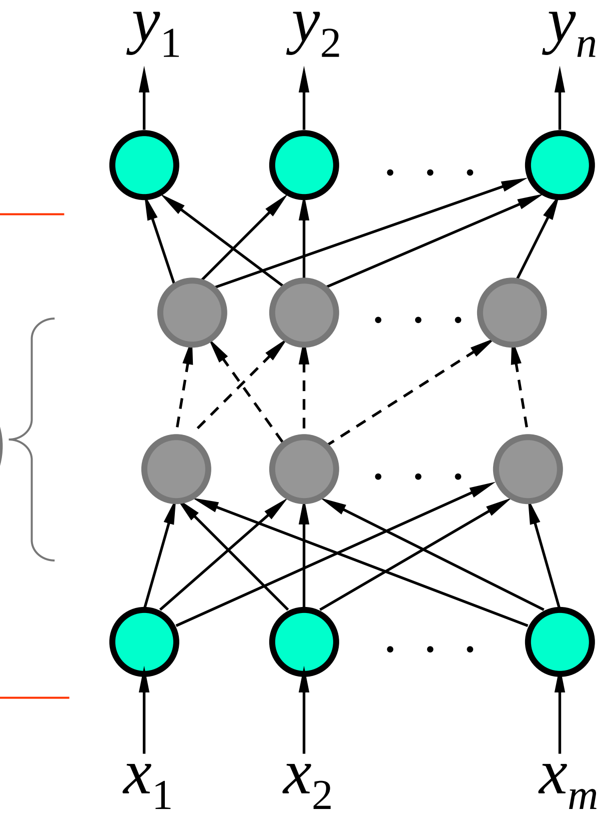


Feed Forward NNs

Output Layer (Decision Layer)

Hidden Layer(s)

Input Layer

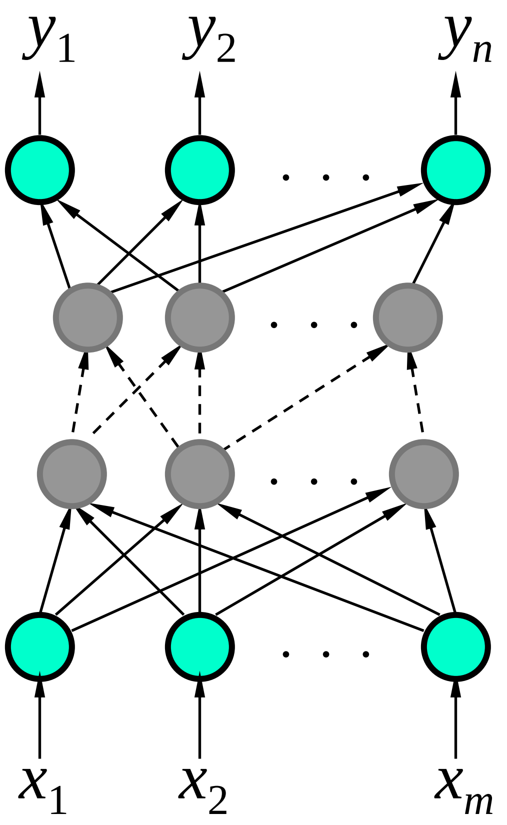


Input sample x

Knowledge and Memory

- The output behavior of a network is determined by the weights.
- Weights – Memory of an NN.
- Large number of nodes
  - increases the storage "capacity";
  - ensures that the knowledge is robust;
  - fault tolerance.
- Changing weights leads to new information

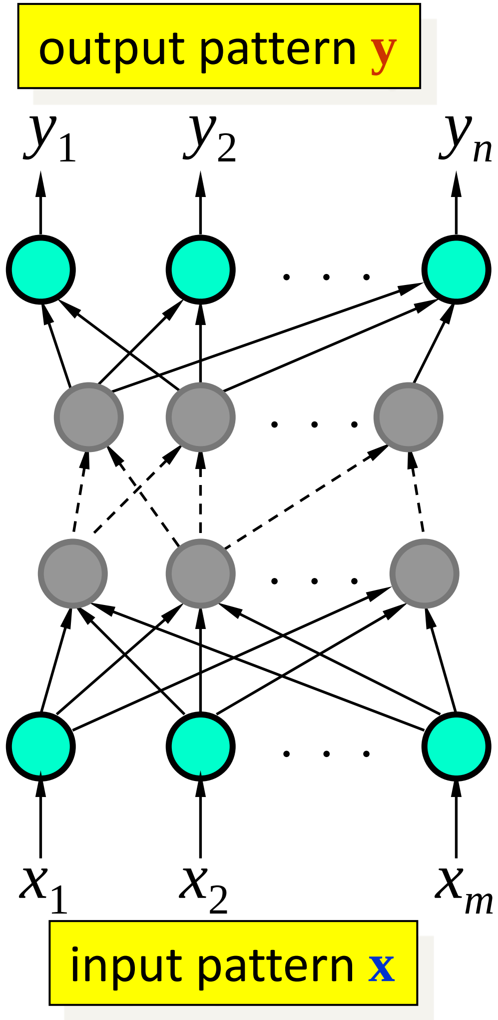
Prediction of the corresponding y



Input sample x

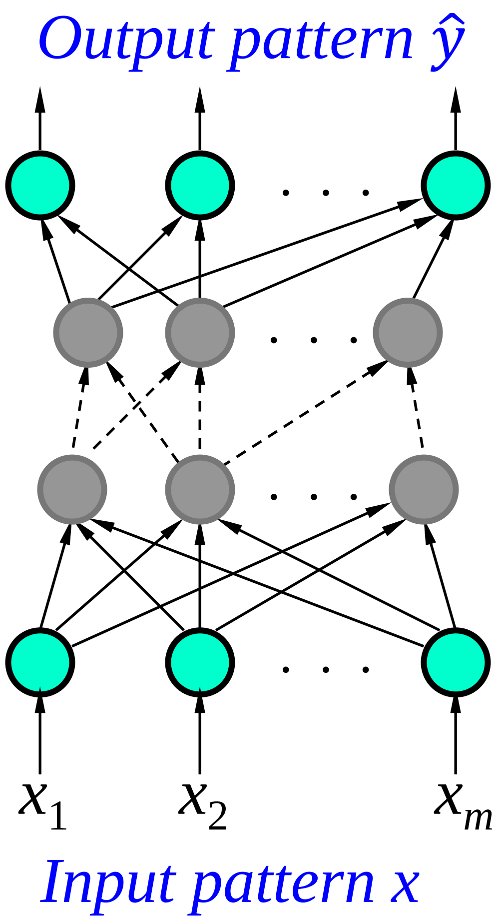
Pattern Classification

- Function: $\mathbf{x} \rightarrow \mathbf{y}$
- The NN's output is used to distinguish between and recognize different input patterns.
- Different output patterns correspond to a particular class of input patterns.
- Networks with hidden layers can be used for solving more complex problems than just a linear pattern classification.



Generalization

- By proper training, a neural network may produce reasonable answers for input patterns **not seen during training** (generalization).



Multilayer Perceptron

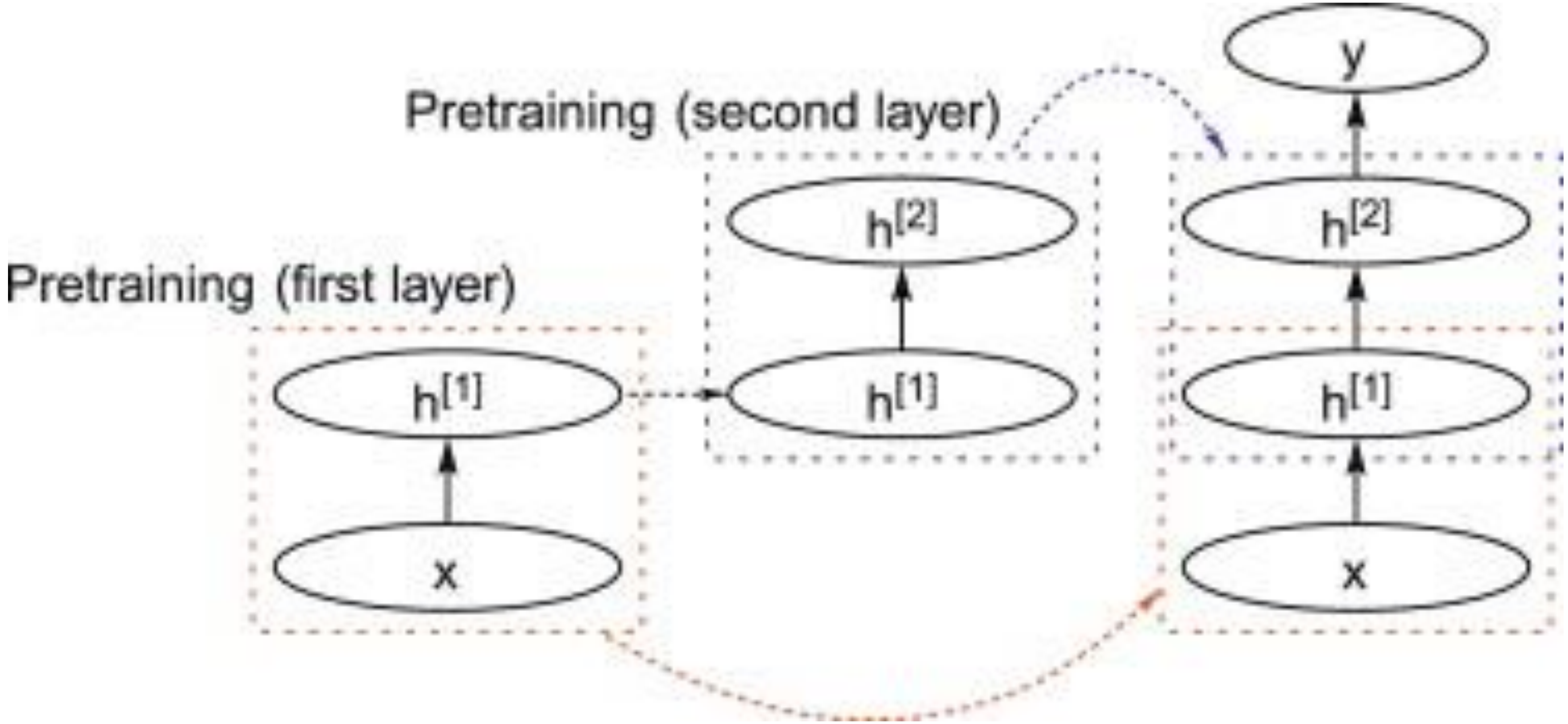
- Theoretically, accuracy of approximation increases if the number of layers increase.
- However, practically it was not feasible.

- Several reasons, like vanishing gradient problem, not enough data, not enough computing power etc.
- Research on improving the learning performance led to several variants of NNs – Restricted Boltzmann Machine, Deep Belief Networks.

Deep Belief Network

- Played as a Catalyst in the performance improvement of Neural Networks with several layers.
- A simple way to train deep networks (DBN) to perform better and fast.
- Hinton et al. , 2006.
  - DBN learn to probabilistically reconstruct its inputs using unsupervised learning.
  - Layers act as feature detectors.
  - After learning, a DBN is further trained with supervision to perform classification.

Deep Belief Network



DBN and later developments made the deep neural networks as a powerful tool for solving many challenging problems like

Machine Translation, object detection in images, speech recognition.

Image source: https://www.sciencedirect.com/topics/engineering/deep-belief-network

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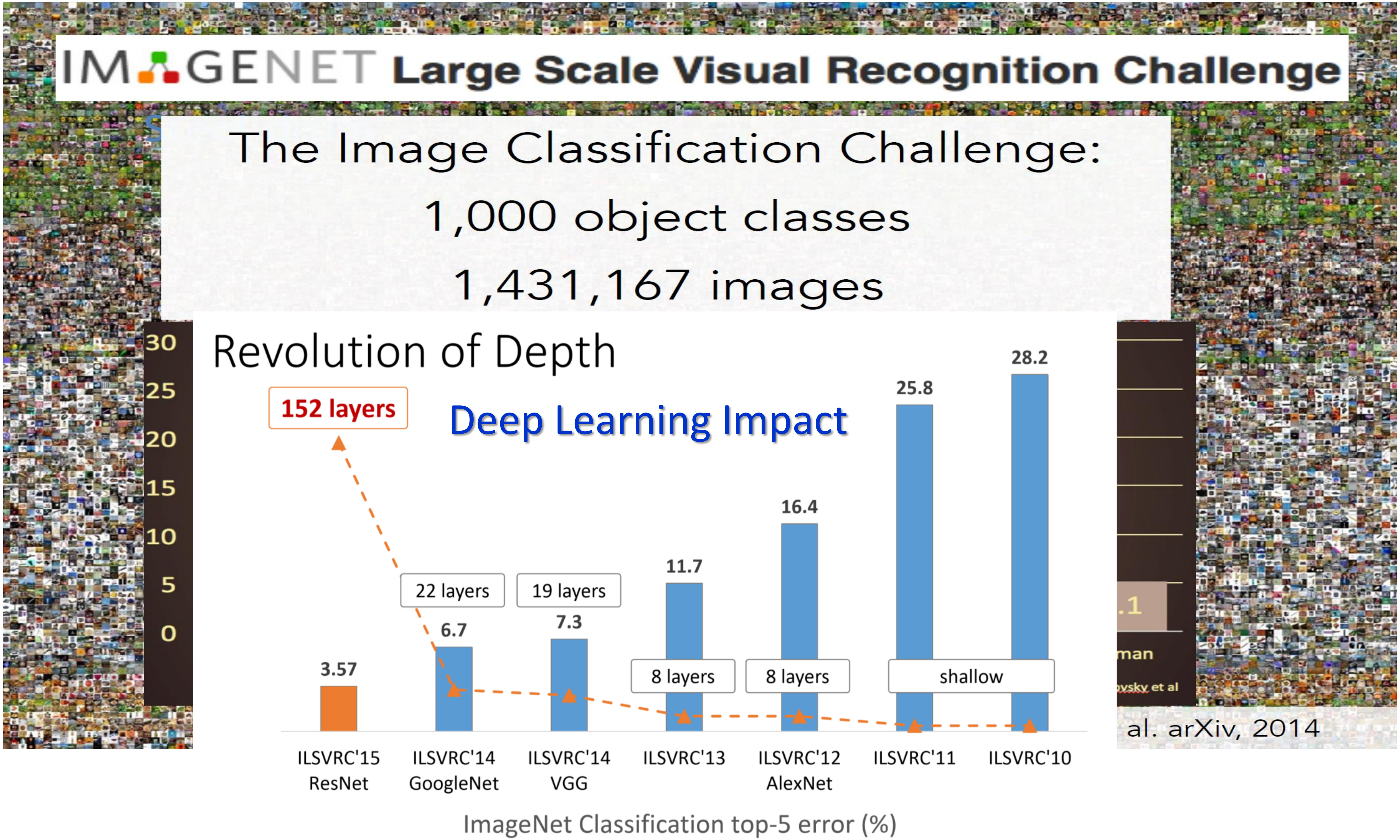

Reference: Kaiming He, Xiangyu Zhang, Shaoqing Ren, & Jian Sun, 2015 ; Fei Fei Li, Lecture Slides, Introduction to CNN

Deep NN Architectures

- Conventional Neural Networks
- Convolution Neural Networks
- Recurrent Neural Networks
- New concepts are emerging every year
  - Generative Adversarial Networks: 2014
  - Residual Networks: 2015
  - Capsule Networks: 2017
  - U-Net and V-Net and more ….

Deep Learning Limitations

- Unlike human, it needs a large amount of data to learn.
- If the test data's characteristics are not similar to train data, deep learning models do not show any good performance.
  - Deep learning is shallow. The algorithms are good at memorizing, but not good at understanding the characteristics of data.
- Works like a black-box. Millions of parameters don't give much understanding about the system.
  - Which architecture, what type of filters, which hyperparameters are more influential ? Nothing clear…
- Dealing with very high dimensional data is still a problem, not theoretically, but practically.

Some Funny Examples
Wrong Object Detections by DNNs

Left: A man is holding a dog in his hand
Right: A woman is holding a dog in her hand
Image: @SouperSarah

NeuralTalk2: A flock of birds flying in the air
Microsoft Azure: A group of giraffe standing next to a tree
Image: Fred Dunn, https://www.flickr.com/photos/gratapictures - CC-BY-NC

[Source: https://aiweirdness.com/](https://aiweirdness.com/)

Summary

- Artificial Neural Networks are the Basic building Blocks of Present Growth in Artificial Intelligence.
- Deep learning frameworks are based on neural network based machine learning methods.
- Deep learning differs from traditional ML methods.
  - No need to manually selection features learning algorithms.
- Deep Learning Technologies have brought significant improvement in performances of machines in tasks like machine translations, object detection, data hiding etc.
- AI Industry with deep learning technologies is likely to witness exploding growth in the next 4-5 years.

Main References

- Ian Goodfellow, Deep Learning, MIT Press, 2016.
- Geoffrey Hinton, 2007 NIPS Tutorial on Deep Belief Nets
- Andrew Ng, Coursera course on Deep Learning (deeplearning.ai)
- Wikipedia and several online image sources mentioned on slides.

Next Session

- Mathematical formulation of Neural Networks.
- How is the Neural network trained.

Thanks!

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