CS551: Introduction to Deep Learning

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General Information

- Instructors
  - Joydeep Chandra
  - Arijit Mondal
- Teaching assistants
  - Asres
  - Shruti

- Course webpage: `www.iitp.ac.in/~arijit/`, then follow `Teaching`

Course structure

- Introduction to big data problem
- Neural network
- Deep Feedforward Network
- Introduction to open-source tools
- Regularization
- Optimization
- Convolutional Neural Network
- Recurrent Neural Network
- Transformer
- Graph Neural Network
- Generative Adversarial Network
- Autoencoder
- Deep Reinforcement Learning
- Apprilcations - Time series, NLP, Vision

Evaluation policy

- Two quizzes & projects - 20%
- Midsem - 30%
- Endsem - 50%

Books

- Ian Goodfellow, Yoshua Bengio and Aaron Courville, "Deep Learning", MIT Press, 2016.
- Jerome H. Friedman, Robert Tibshirani, and Trevor Hastie, "The elements of statistical learning", Springer Series in Statistics, 2009.
- Charu C Aggarwal, "Neural Networks and Deep Learning", Springer.
- Aston Zhang, Zachary C. Lipton, Mu Li, Alexander J. Smola, "Dive into Deep Learning"
- Iddo Drori, "The Science of Deep Learning", Cambridge University Press
- Simon O. Haykin, "Neural Networks and Learning Machines", Pearson Education India
- Richard S. Sutton, Andrew G. Barto, "Reinforcement Learning: An Introduction", MIT Press
- Christopher M. Bishop, Hugh Bishop, "Deep Learning: Foundations and Concepts", Springer

Introduction

Problem space

- Problems — *a matter or situation regarded as unwelcome or harmful and needing to be dealt with and overcome*
- Target is to solve the same on a computer

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- Problems can be intellectually challenging for human being but relatively straight forward for a computer
  - Travelling salesman problem, chess
- Problems can be easy for common people but difficult for computer (even expressing it in a formal way)
  - Identifying an object, car (say), in a picture

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- Primary focus will be in the *second category* problems

Problem Solving Strategies for Big Data

- Need to solve problems efficiently and accurately when the input data is huge ($\sim$ GB, TB order)

- Finding a deterministic algorithm is difficult
  - Need to find out features
  - Requires significant effort for model building
  - Need to have domain knowledge

- Statistical inference is found to be suitable
  - Feature selection is not crucial
  - Model will learn from past data

Applications: Computer vision

- 2d to 3d conversion
- Street view generation
- Image classifications
- Image segmentation

Image source: Internet

Applications: Activity Recognition

- Recognize activities like walking, running, cooking, etc. from still image or video data

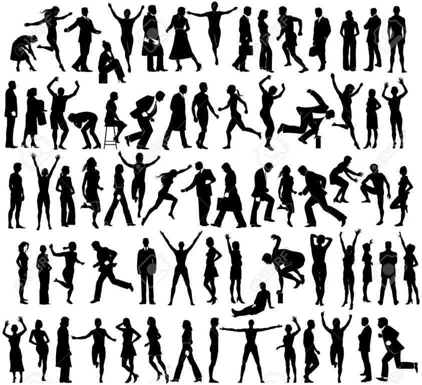


Image source: Internet

Applications: Image Captioning

- Automated caption generation for a given image

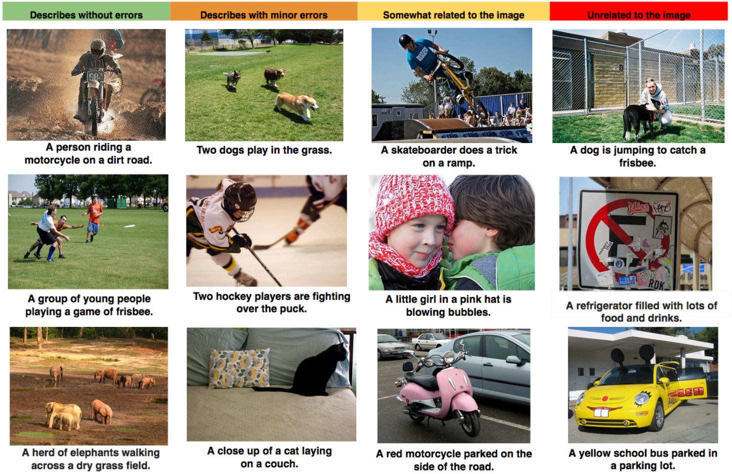


Image source: Internet

Applications: Object Identification

- Identify objects in still image or in video stream

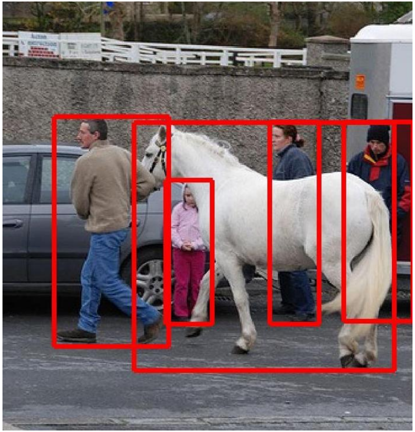


Image source: Internet

Applications: Automated Car

- Self driving car

Image source: Internet

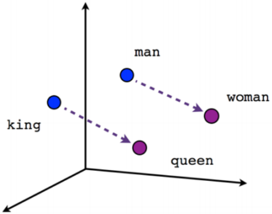
Applications: Drones & Robots

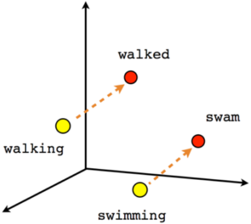
- Managing movement of robot or drones

Image source: Internet

Applications: Natural Language Processing

- Recommender system
- Sentiment analysis
- Question answering
- Information extraction from website
- Automated email reply





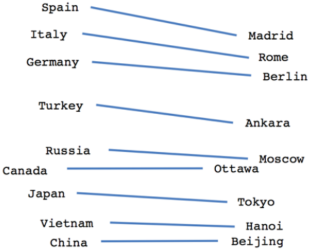


Image source: Internet

Applications: Speech processing

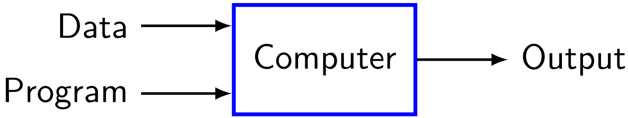
- Conversion of speech into text
- Generation of particular voice for a given text

Image source: Internet

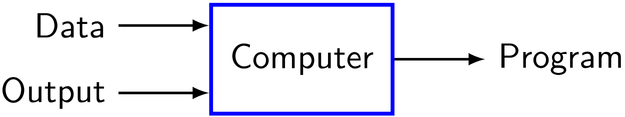
Other possible applications

- Language translation
- Weather prediction
- Genomics
- Drug discovery
- Particle physics
- Surveillance
- Cryptography
- Generative AI and many more.

Traditional Programming vs ML/DL

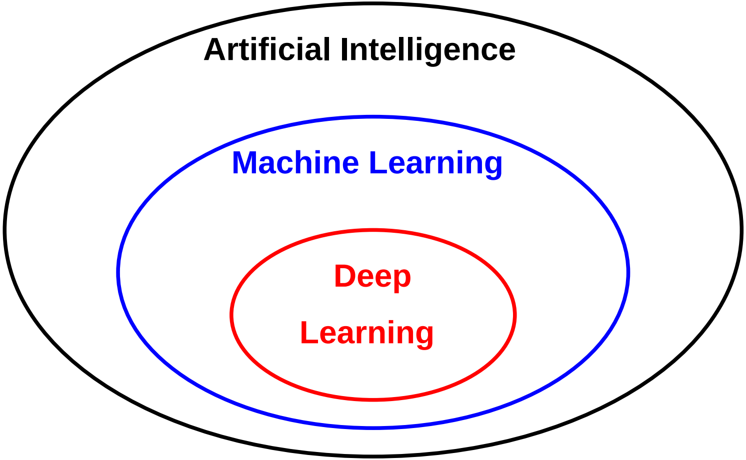


Traditional programming



Machine learning

AI Hierarchy



Issue of Representation

- Representation of data in an efficient/structured manner is crucial for solving problems more effectively
  - Searching of a set of elements in a given list (sorted/unsorted)
  - Arithmetic operations on Arabic and Roman numerals
  - Primality test of n when n is represented as $11111\ldots111$ (n-number of one)

- Structured representation can help in predicting future values

Choice of Representation

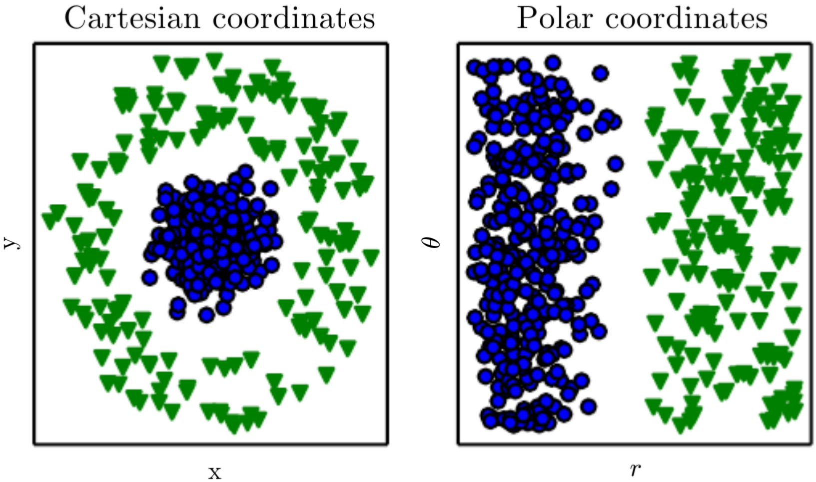


Image source: Deep Learning book

Learning representation/feature

- Traditional approaches
  - Pattern recognition
    - Input, output of the problem

- End to end learning
  - System automatically learns internal representation

AI-ML Tasks

- Heavily depends on features
- Requires good domain knowledge
- Feature extraction is not easy job
  - Identify a car
    - How to describe wheel
    - Shadow/brightness
    - Obscuring element

Representation Learning

- Learned representation often result in better performance compared to hand design
- Allows the system to rapidly adapt to new task
- Need to discover a good set of features
- Manual design of features is nearly impossible

Design of Features

- Goal is to separate out variation factors
- These factors are separate sources of influence
- It may exist as unobserved object or unobserved forces that affect observable quantity
  - Speech - Factors are age, sex, accent, etc
  - Image - Position, color, brightness, etc.

Deep Learning

- Try to address the problem of representation learning
- Representation are expressed in terms of other simpler representation
- Develop complex concept using simpler concept

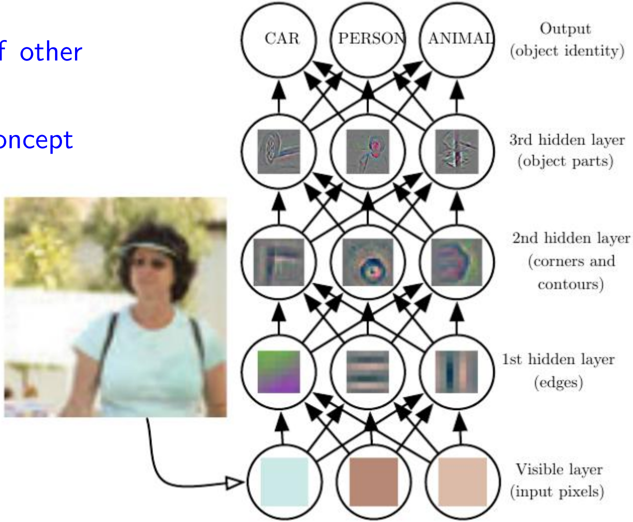


Image source: Deep Learning Book

Simple to Complex Features

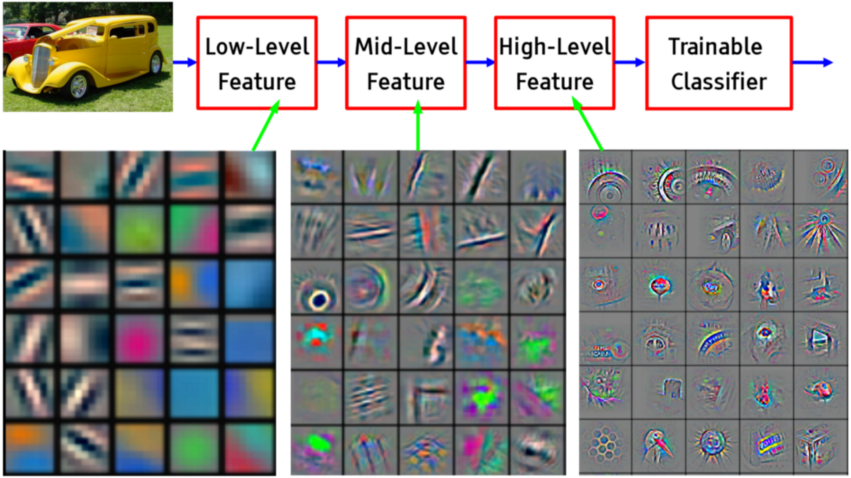


Image source: Deep Learning Tutorial by Yann LeCun Marc'Aurelio Ranzato, ICML, 2013

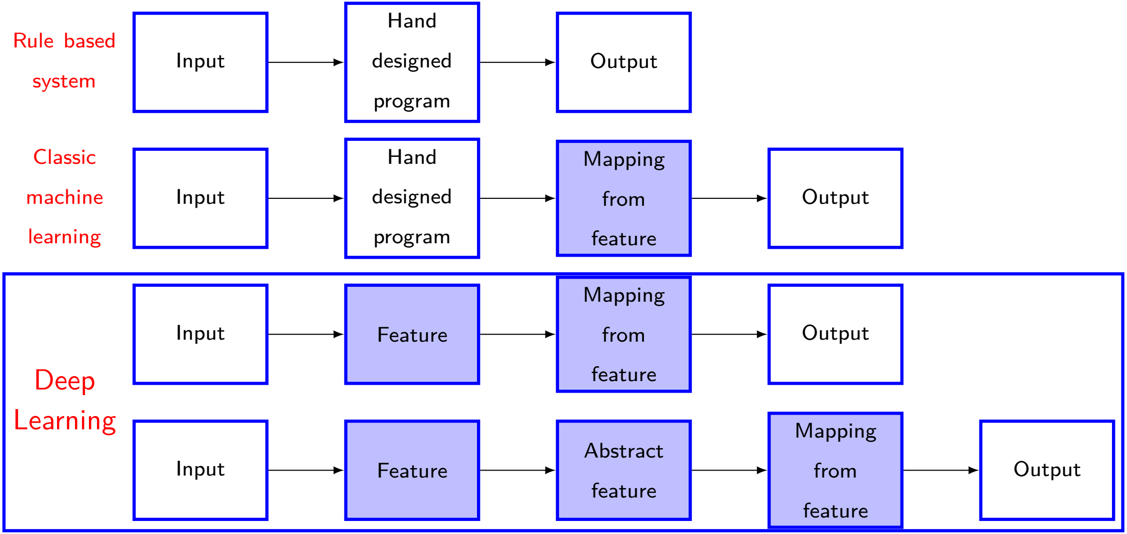
Conventional Machine Learning

Image source: Deep Learning by Yann LeCun, Yoshua Bengio & Geoffrey Hinton

Deep Learning Model

- Feed-forward deep network or multilayer perceptron
- Mathematical functions that map input to output
- Composed of simpler functions
- Each layer provides a new representation
- Learning right representation

Representation learning



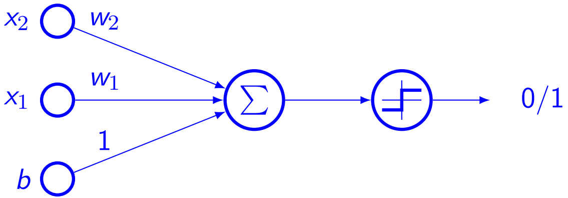
History

- Has many names and view point
  - Cybernetics (1940-1960)
  - Connectionism (1980-1990) (neural net)
  - Deep learning (2006+)

- More useful as the amount of data is increased
- Models have grown in size as increase in computing resources
- Solving complex problem with increasing accuracy

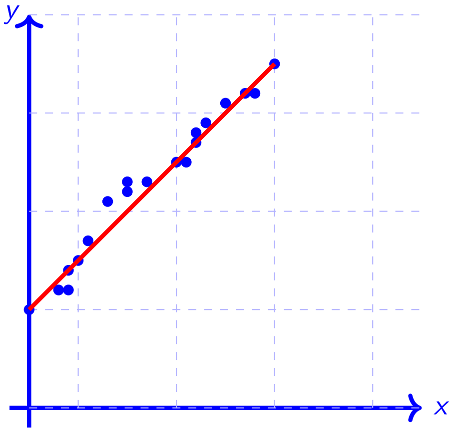
History of basic model

- The first learning machine: the Perceptron
  - Built at Cornell, 1960
- Perceptron was linear classifier on top of simple feature extractor
- Most of the practical applications of ML today use glorified linear classifiers or glorified template matching.
- Significant effort is required for identifying relevant features
- Typically it will solve $y = sign\left(\sum_{i=1}^{N}(w_i \times f_i(X) + b)\right)$

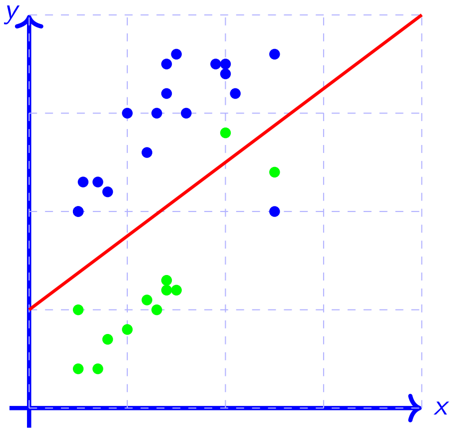


Broad Categories of Problem

- Regression

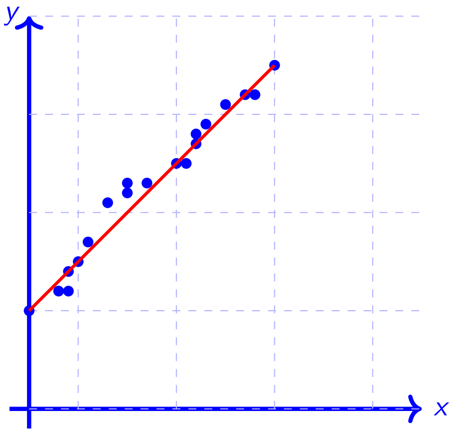


- Classification

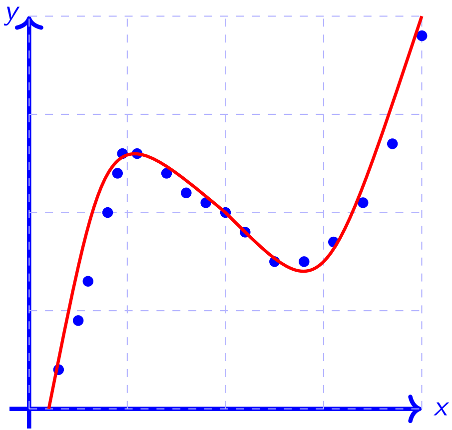


Regression

- Regression (linear)

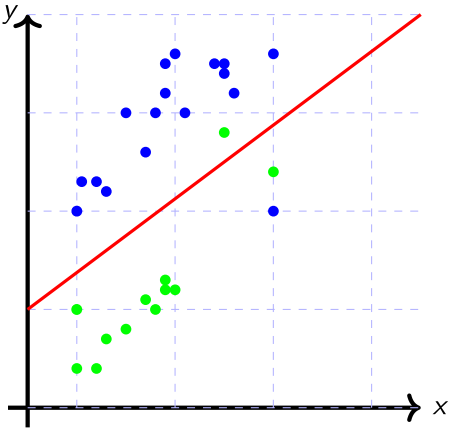


- Regression (Non-linear)

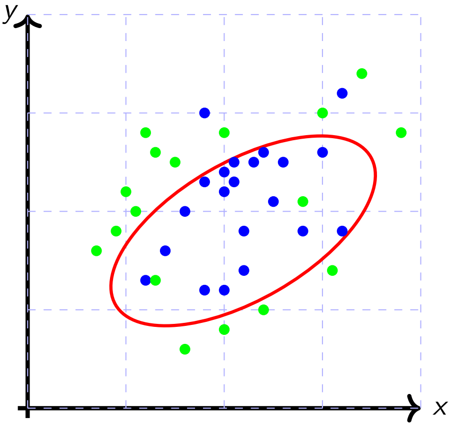


Classification

- Linear

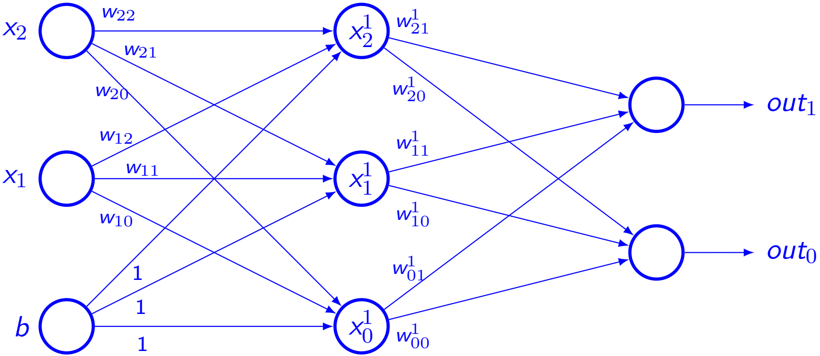


- Non-linear

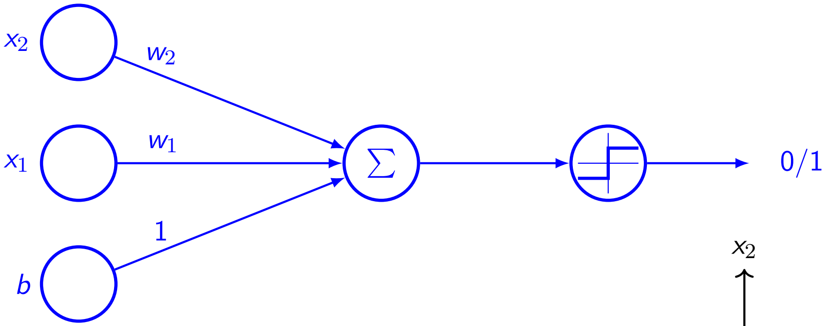


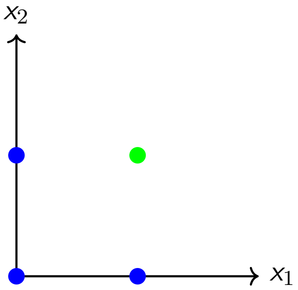
Artificial Neural Network

- A simple model



Example NN: AND gate





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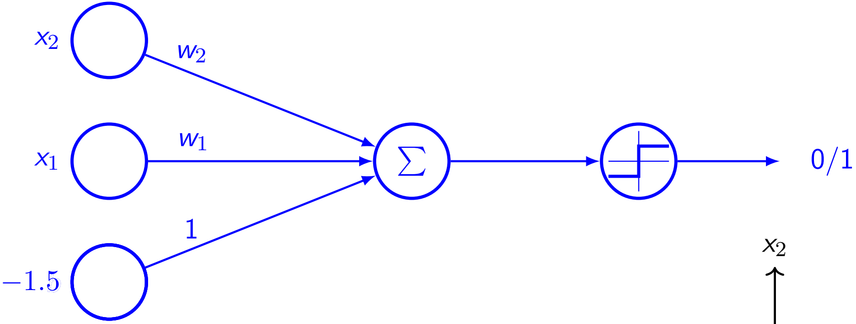

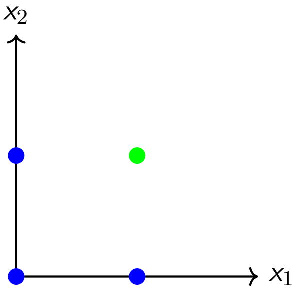

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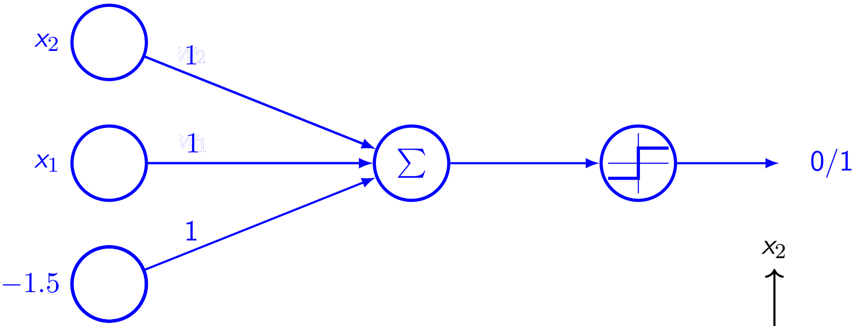

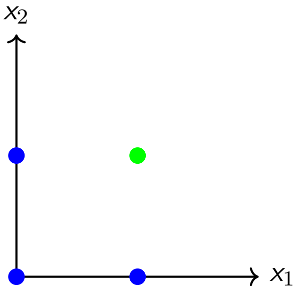

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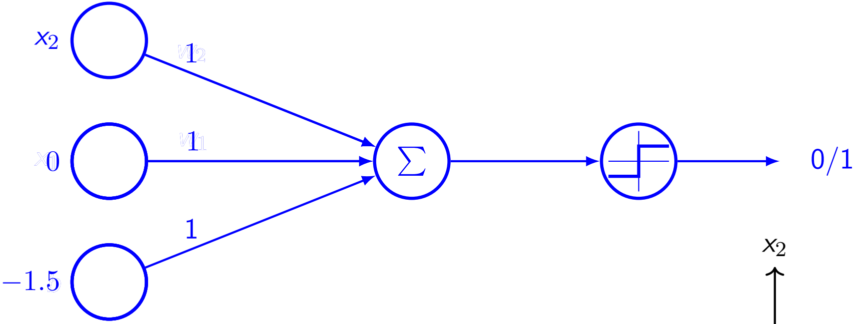

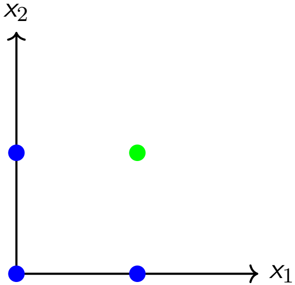

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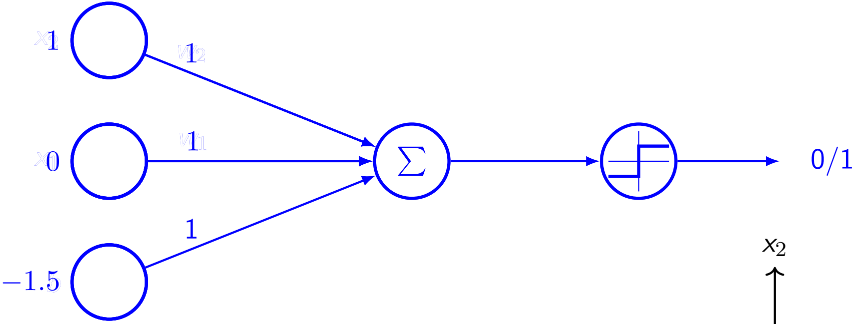

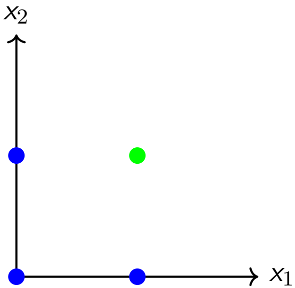

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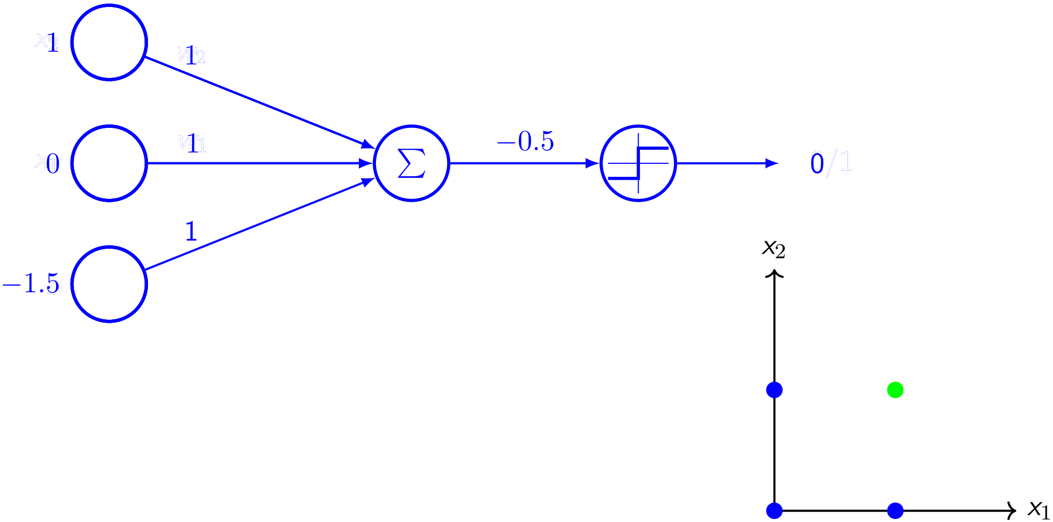

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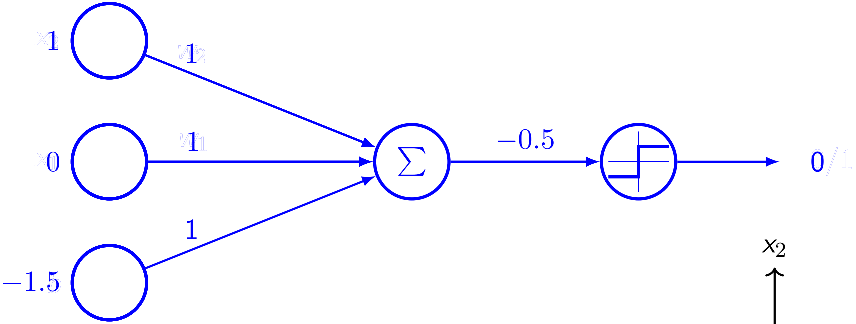
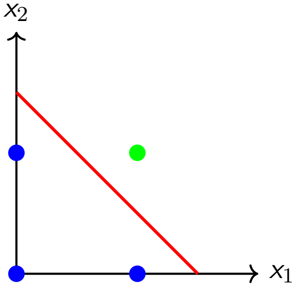
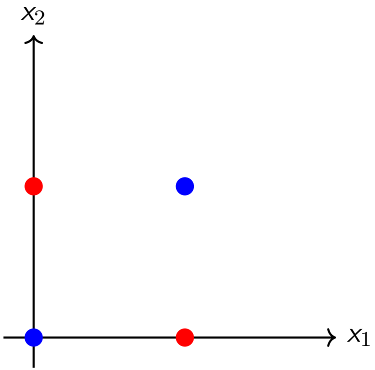




Example NN: XOR gate



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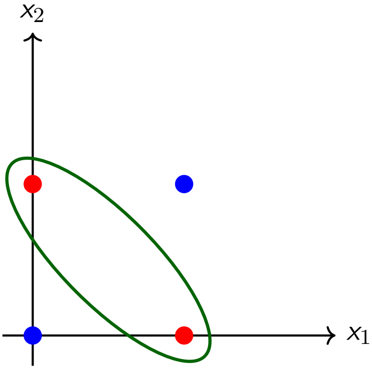

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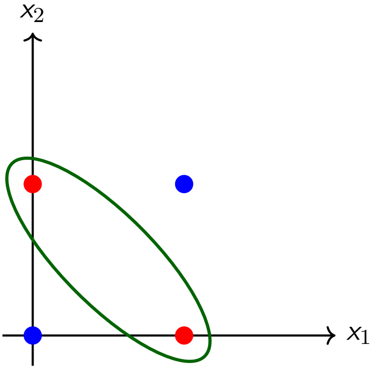
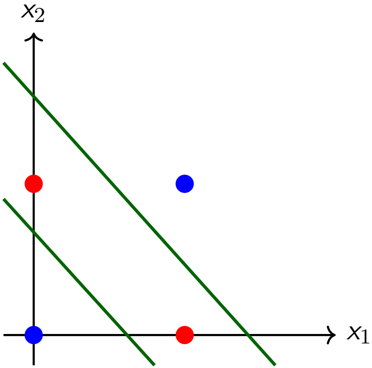




Distributed representation

- Each input should be represented by many features
- Each feature should be involved in the representation of many possible inputs
- Example: car, flower, birds — red, green, blue
  - 9 neurons
  - For each combination of color and object
- Distributed neurons
  - 3 Neurons for color
  - 3 Neurons for object
  - Total 6 neurons

Popularization of Neural Network

- Most of the theory of neural network was developed in the 1980s
- Started gaining popularity around 2012
  - Geoffrey Hinton and Alex Krizhevsky winning the ImageNet competition where they beat the nearest competitor by a huge margin (2012)

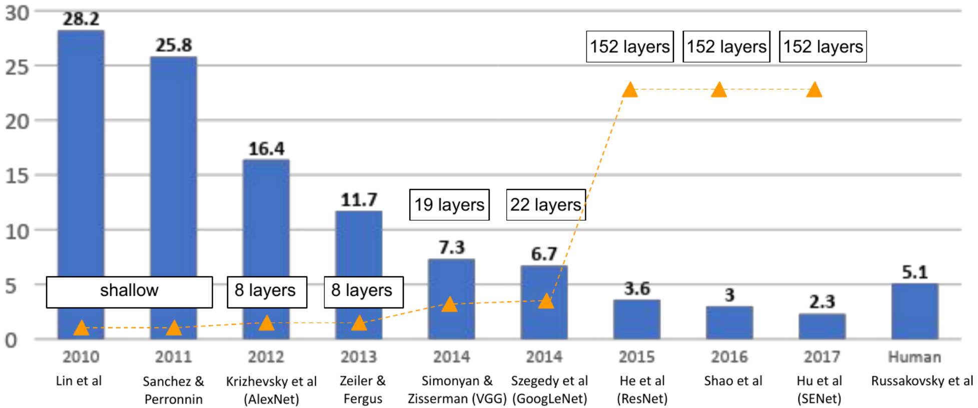


Image source: Jiajun et al. CS230 slides

Popularity

- Increase data size
  - Computing resources are available
  - Accepting performance 5000 labeled example per category
  - 10 million for human performance
- Increasing model size
- Increasing accuracy, complexity, real world impact
- Used by many companies
  - Google, Microsoft, Facebook, IBM, Baidu, Apple, Adobe, Nvidia, NEC, etc.
- Availability of good commercial & open-source tools
  - Theano, Torch, DistBelief, Caffe, TensorFlow, Keras, etc.

DL Trend

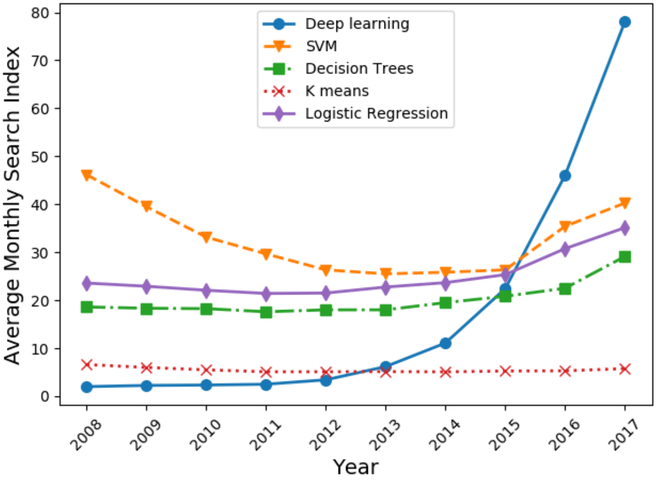


Image source: Internet

Search trend in Google

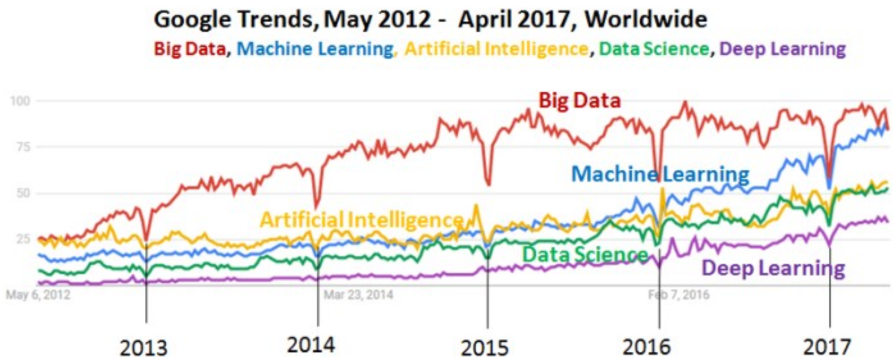
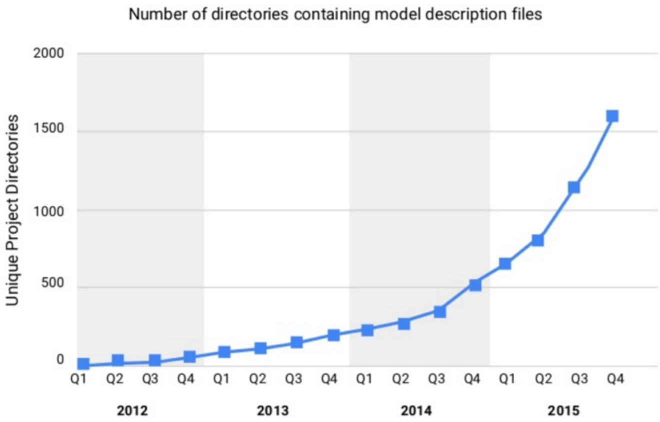


Image source: Internet

AI/DL in Google



Across many products/areas

- Apps
- Maps
- Photos
- Gmail
- Speech
- Android
- YouTube
- Translation
- Robotics Research
- Image Understanding
- Natural Language Understanding
- Drug Discovery

Google

Image source: Internet

Ethics

- Bias and fairness - bias arises due to training data
- Explainability - generation of interpretable description
- Weaponizing AI - most successful technologies have been applied directly or indirectly towards war
- Concentrating power - no idea of effects of large scale adoptation of AI on society
- Existential risk - risk due to technology advancement
- This list is not exhaustive!!

Artificial Intelligence is the New Electricity - Andrew Ng

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Thank you!