Learning From Data
Lecture 1: Introduction

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TBSI

September 17, 2022

Today's Lecture

- About This Class
- What is Machine Learning?
- Course Preview: a Brief History of Machine Learning

About this Class

Course Goal

- In-depth understanding of key concepts, algorithms for machine learning.
- Practical applications of learning from data.

Course Material

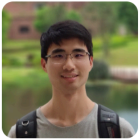
The primary course materials are the lecture slides.

Reference Text :

- (Recommended) Machine Learning Lecture Notes by Andrew Ng: https://github.com/mxc19912008/Andrew-Ng-Machine-Learning-Notes
- Pattern Recognition and Machine Learning, 2nd Edition, by Christopher Bishop

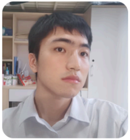
Staffs

Yang Li
Instructor



Weida Wang
TA

Dexu Kong
TA



Zhiyuan Peng
TA

Wanda Li
TA

Office hours

Name	Time	Location
Yang	Friday 2:00-4:00pm	Info Building 1108a
Zhiyuan	Tuesday 3:00-5:00pm	Info Building, 11th floor common area)
Weida	Wednesday 4:00-6:00pm	(same as above)
Dexu	Thursday 7:00-9:00pm	(same as above)

Grading

Your overall grade will be determined roughly as follows:

ACTIVITIES	PERCENTAGES
Midterm	15 %
Final Project	25 %
Problem sets (written & programming)	60 %

Homework advice

- Form study groups (2-3 people) to discuss homework problems. Do homework **independently**, indicate your study group members on your submitted file.
- Use "Online Learning" Q&A discussion board!
- Come to office hours
- Attend recitations

Class Policy

Late homeworks

- **2 free chances** to turn in a late homework assignment (except for the final project).
- Late homework must be handed in within 3 days of the deadline.

Class Policy

How to give credits

- Write your collaborators' names in the homework *(this includes receiving/giving explicit help from/to others on any part of the homework)*
- Note any online resource (e.g. wiki, github, stackoverflow) you've used for the assignment

Homework plagiarism (copying) is not tolerated!

Ask for help early and often!

Final Group Project

Apply recent machine learning techniques on real-world problems, or explore theoretical problems related to learning from data.

Previous class projects

- Camera lens super-resolution (Dinjian Jin& Xiangyu Chen)

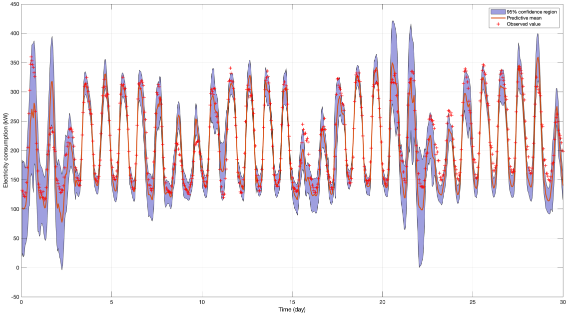
Comparison between two super-resolution models: SRGAN and VDSR

Final Group Project

Apply recent machine learning techniques on real-world problems, or explore theoretical problems related to learning from data.

Previous class projects

- A Gaussian Process Regression Based Approach for Predicting Building Cooling and Heating Consumption (Xiaoting Wang & Yiqian Wu)



1-month prediction of electricity consumption

Final Group Project

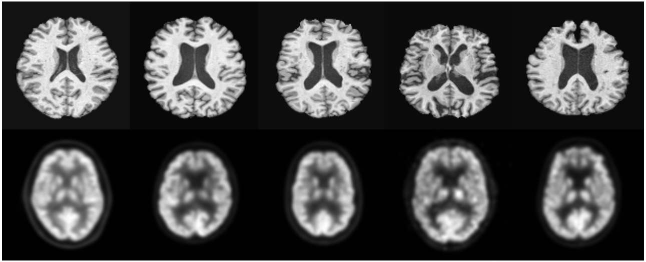
Apply recent machine learning techniques on real-world problems, or explore theoretical problems related to learning from data.

Previous class projects

- Missing Data Imputation for Multi-Modal Brain Images (Wangbin Sun)

MRI

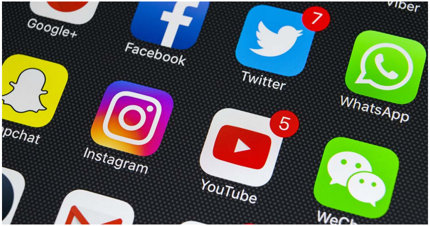
PET

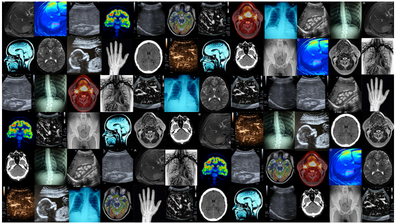


MRI (top) and PET (bottom) scans of normal and Alzheimer patient brains

Section I: What is Machine Learning?

The age of big data





How does a computer program learn “knowledge” from data ? *i.e. machine learning*

What is Machine Learning?

Design programs that can ...

learn from data

(pattern)

- discover characteristics of data
- find new insights

- make decisions based on environment feedback.

What is Machine Learning?

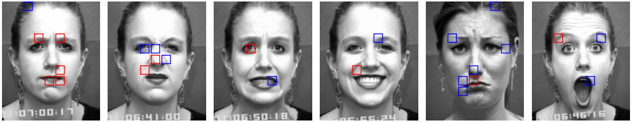
Design programs that can

- learn rules from data for some **task**
- adapt to changes
- improve **performance** with **experience**.

(from "Machine Learning Theory" by Avrim Blum)

Machine Learning Tasks

- Classification

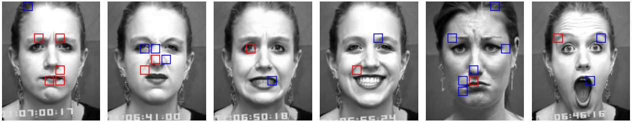


(a) Ang (b) Dis (c) Fea (d) Hap (e) Sad (f) Sur

Facial expression recognization (Liu et al. CVPR 2014)

Machine Learning Tasks

- Classification



(a) Ang (b) Dis (c) Fea (d) Hap (e) Sad (f) Sur

Facial expression recognization (Liu et al. CVPR 2014)

"The voice quality of this phone is amazing." (Positive)

"The earphone broke in two days." (Negative)

Product review sentiment classification

Machine Learning Tasks

- Regression

Highway travel time prediction

Machine Learning Tasks

- Regression

Highway travel time prediction

Algorithmic trading: forecast close price, highs and lows

Machine Learning Tasks

- Data denoising

Machine Learning Tasks

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- Pattern recognition (e.g. spam filter)

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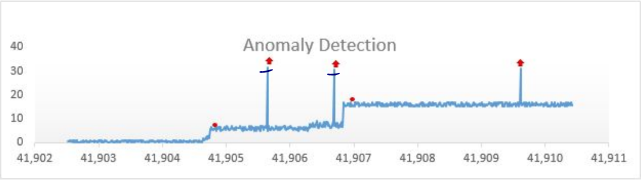
- Anomaly detection: finding abnormal operational activity for network security.



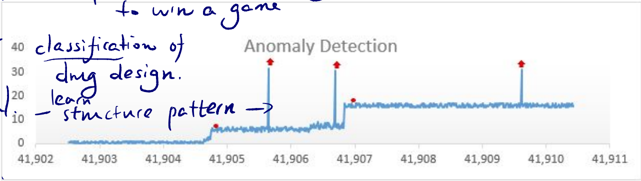
Machine Learning Tasks

- Data denoising

- Pattern recognition (e.g. spam filter)

- Anomaly detection: finding abnormal operational activity for network security.

- AI playing games. – sequential decision making to win a game
- drug discovery. – classification of drug design.
- find best material. – learn structure pattern →
- data generation.



Can you name some other tasks?

Machine Learning Experience

- **Dataset**: a collection of input, $X = \{x^{(1)}, \ldots, x^{(m)}\}$ and optionally, the corresponding output (**labels**) $Y = \{y^{(1)}, \ldots, y^{(m)}\}$
- Each input (data point) $x^{(i)}$ is represented by n **features**

Machine Learning Experience

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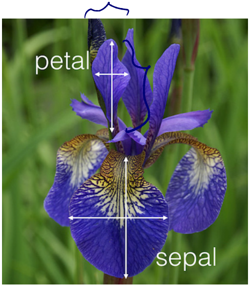
Example: features of an iris flower

sepal length	sepal width	petal length	petal width $n=4.$	spieces
5.1	3.5	1.4	0.2 $x^{(1)}$	Setosa $y^{(1)}=1$
4.9	3.0	1.4	0.2	Setosa
6.4	3.5	4.5	1.2	Versicolor
5.9	3.0	5.0	1.8	Virginica
⋮	⋮	⋮	⋮	⋮



Machine Learning Performance

- Quantitatively evaluate the ability of a machine learning algorithm for a given task, e.g.
  - Mean square error (MSE): $\frac{1}{m}\sum_{i=1}^{m}(y^{(i)} - f(x^{(i)}))^2$
  - Mean absolute error (MAE): $\frac{1}{m}\sum_{i=1}^{m}\mathbf{1}\{y^{(i)} \neq f(x^{(i)})\}$

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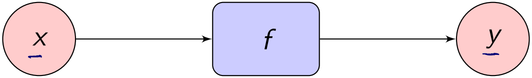
- Must perform well on new, previously unseen input!
  - Separate **test dataset** from training data

Different Types of Learning

Supervised learning

Given some input and output (label) training data, learn the **machine** f from training data model/program



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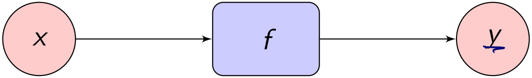


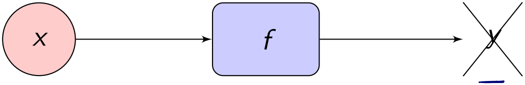
Supervised learning tasks: e.g. $y \in \{1, 2, 3\}$

- Classification: y is discrete   e.g. $y \in \mathbb{R}^d$
- Regression: y is continuous (predict stock market closing price, image captioning, automated video transcription)

Different Types of Learning

Unsupervised learning

No labels are given in prior, find hidden structure or pattern from the data



Different Types of Learning

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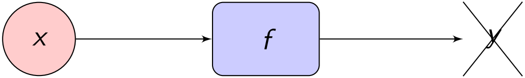


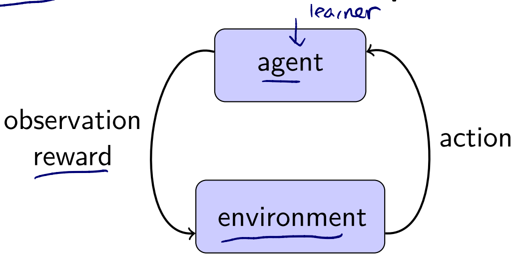
Unsupervised learning tasks:

- Data clustering
- Anomaly detection

Different Types of Learning

Reinforcement learning

The learning machine is presented in an interactive manner to a dynamic environment, and need to make **sequential decisions**



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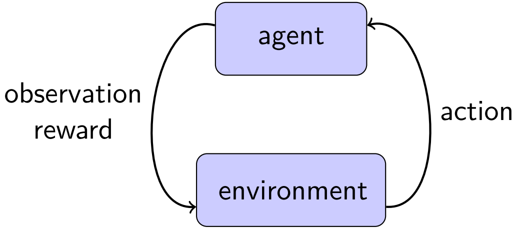

- Robotics (self-driving car)
- AI for sequntial decision making (AlphaGo)
- Intelligent control system

Inference vs Prediction

Given training data of x and y,

Inference

knowing the structure of f, find good models to describe f. i.e. model the data generation process

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Prediction

given **future** data samples of x, predict the corresponding output data y using $\boxed{f}$.

Inference vs Prediction

Given training data of x and y,

Inference

knowing the structure of f, find good models to describe f. i.e. model the data generation process $\leftarrow$ *focus of statistics*

Prediction

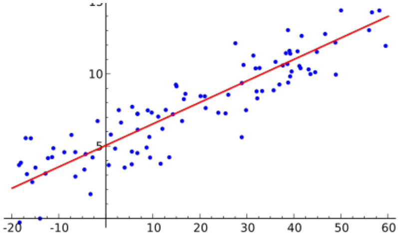
given **future** data samples of x, predict the corresponding output data y using f. $\leftarrow$ *focus of machine learning*

A Brief History of Machine Learning

Development of Statistical Methods (<1950)

- (1805): Adrien-Marie Legendre proposed the **least squares** method for data fitting. **(e.g. linear regression)**

$$f(x) = b + w_1 x_1 + w_2 x_2 = w^T x + b$$



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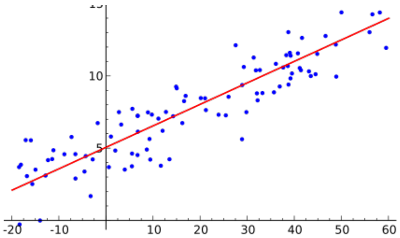

Learn model f by minimizing the **loss function** (MSE):

$$J(w, b) = \frac{1}{2} \sum_{i=1}^{m} (f(x^{(i)}) - y^{(i)})^2$$

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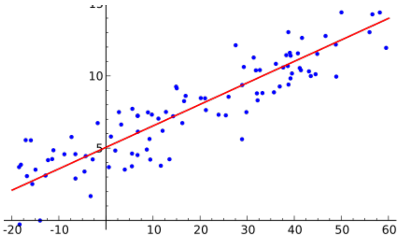


Learn model f by minimizing the **loss function** (MSE):

$$J(w, b) = \frac{1}{2} \sum_{i=1}^{m} (f(x^{(i)}) - y^{(i)})^2$$

Can be generalize to nonlinear least squares

Development of Statistical Methods (<1950)

- (1812): Pierre-Simon Laplace defined **Bayes Theorem**, based on earlier works of Thomas Bayes.

likelihood

$$\underbrace{P(X|Y)}_{\text{posterior}} = \frac{P(Y|X)P(X)}{P(Y)}$$

Development of Statistical Methods (<1950)

- (1812): Pierre-Simon Laplace defined **Bayes Theorem**, based on earlier works of Thomas Bayes.

$$P(X|Y) = \frac{P(Y|X)P(X)}{P(Y)}$$

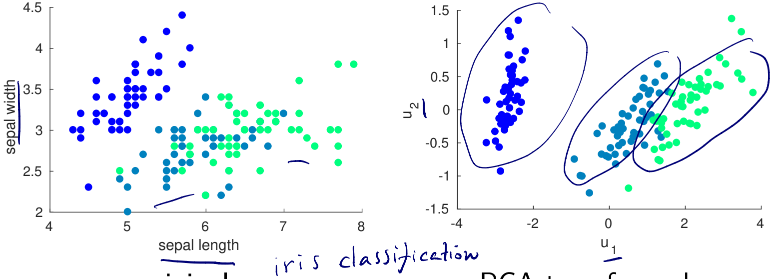
The foundation of **Bayesian estimation**, a core approach in estimating model parameters from data.

Development of Statistical Methods (<1950)

- (1901): Karl Pearson invented **principal component analysis** (PCA), a classic tool in exploratory data analysis and dimension reduction.

PCA

Convert observations of possibly correlated variables into a set of *linearly uncorrelated variables* called **principal components**.

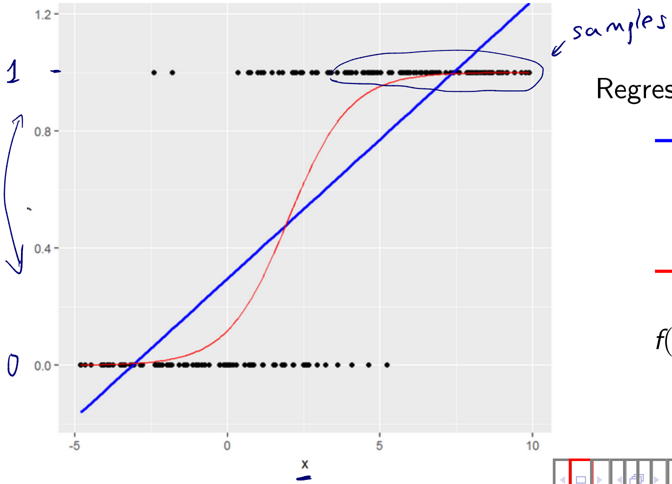


original

PCA transformed

Development of Statistical Methods (<1950)

- (1935): Ronald A. Fisher fit the **Probit** model using maximal likelihood estimation for binary classification problem (a.k.a. **Logistic Regression**)



Regression model

linear

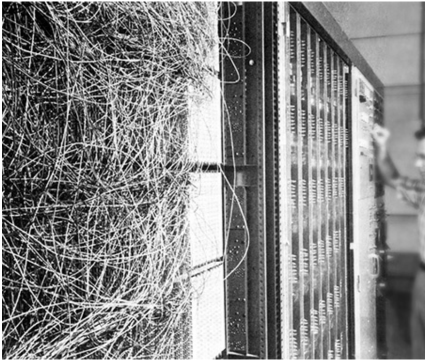
$$f(x) = w^T x + b$$

logistic

$$f(x) = \frac{1}{1 + e^{-z(w^T x + b)}}$$

Simple Learning Algorithms (1950)

- (1957): Frank Rosenblatt invented the **Perceptron** algorithm, the first artificial nueral network

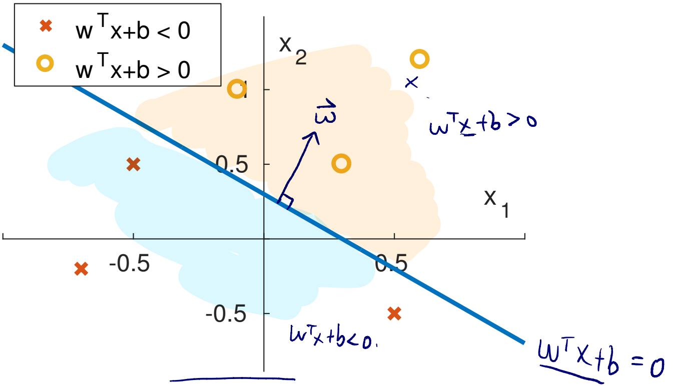


Hardware implementation: Mark I Perceptron

The perceptron learning algorithm

Given x, predict $y \in \{0, 1\}$

$$f(x) = \begin{cases} 1 & \text{if } w^T x + b \geq 0 \\ 0 & \text{otherwise} \end{cases} \triangleq 1\{w^T x + b \geq 0\}$$



The perceptron learning algorithm

Training a perceptron

For each x, compare y and the prediction $f(x) = \begin{cases} 1 & \text{if } w^T x + b > 0 \\ 0 & \text{o.w} \end{cases}$

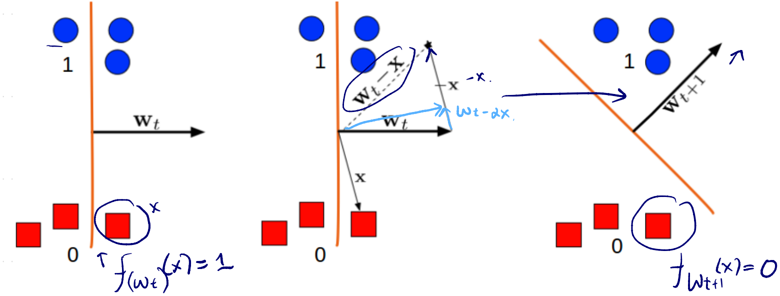
- When prediction is correct: $w_{t+1} = w_t$
- When prediction is incorrect: $\alpha \in \mathbb{R}$
  - $y=0$ predicted "1": $w_{t+1} := w_t - \alpha x$
  - $y=1$ predicted "0": $w_{t+1} := w_t + \alpha x$

The perceptron learning algorithm

Training a perceptron

For each x, compare y and the prediction $f(x)$

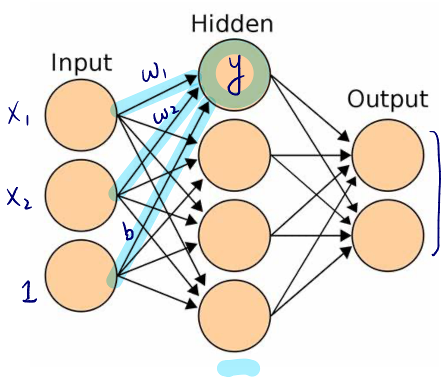
- When prediction is correct: $w_{t+1} = w_t$
- When prediction is incorrect: $0 < \alpha << 1$
  - $y = 0$ predicted "1": $w_{t+1} := w_t - \alpha x$ let $\alpha = 1$
  - predicted "0": $w_{t+1} := w_t + \alpha x$



Simple Learning Algorithms (1960s)

- Rise of **Connectionism**: an approach to explain mental phenomena using artificial neural networks (ANN)

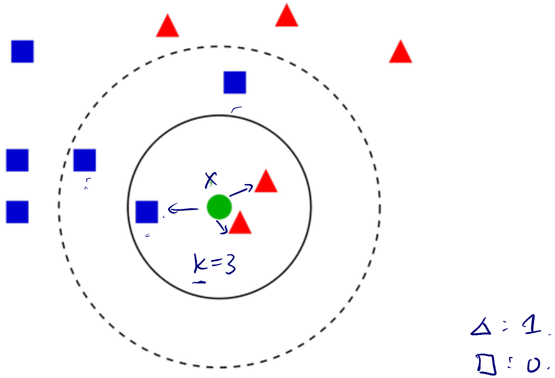
Learning always involves modifying the connection weights



ANN with a hidden layer

Simple Learning Algorithms (1960s)

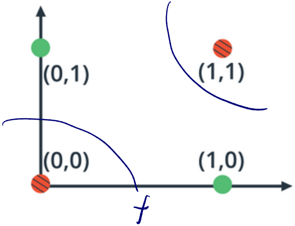
- (1967): Cover and Hart invented **Nearest Neighbor Classification** and the start of Pattern Recognition *One of the first non-parametric learning algorithms*



When k=3, target is classified as 1; When k=5, target is classified as 0

The "AI Winter"(1970s)

- (1969): Minsky and Papert's 1969 book *Perceptrons* presented limitations to what perceptrons could do
  - Single-layer network can not solve the XOR problem
  - Difficult to update weights in neural networks with multiple hidden layers



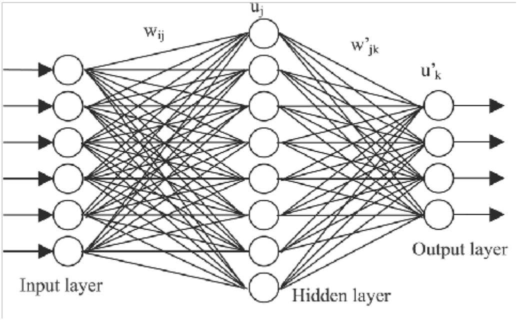
The XOR problem

Virtually no research at all was done in connectionism for 10 years

Rediscovery of Backpropagation (1980s)

- (1976) David Rumelhart, Geoff Hinton and Ronald J. Williams rediscovered of **Backpropagation** (first proposed by Linnainmaa in 1970) *an efficient way to calculate the derivative of the loss function with respect to the weights of the network*

Allows efficient training of **multi-layer perceptrons**.

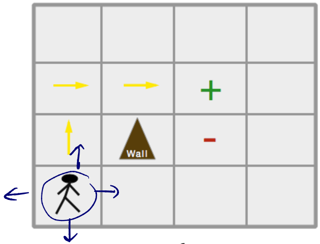


Many hidden units increase expressiveness of ANNs

Rediscovery of Backpropagation (1980s)

- (1989) Christopher Watkins proposed **Q-learning**, fundation of modern **Reinforcement Learning**

maze.



Q-learning

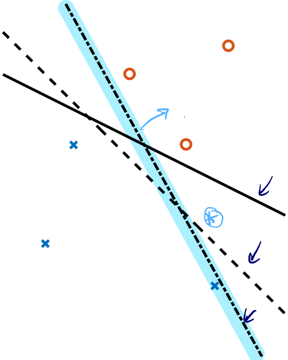
Given any **Markov decision process**, learn a policy, which tells an agent what action to take under what circumstances (states).

States set: {free, wall, goal, }
Action set: {Left, Right, Top, Down}

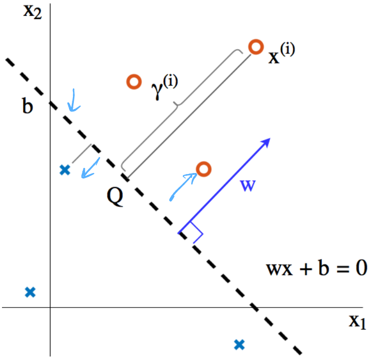
Rise of Data Driven Methods (1990s)

- (1992): Corinna Cortes and Vladimir Vapnik discovered **Support Vector Machine**

Single-layer perceptron may have infinite solutions



Support Vector Classifier



Give accuracy comparable to neural networks with elaborated features in a handwriting task

Kernel Methods (2000s)

Kernel method: learn feature representations of data from pairwise similarity, defined by some (family of) kernel functions

- (1998) **Kernel principal component analysis** (kernel PCA) was proposed by Schölkopf
- (2010) Radio Basis Function (RBF) kernel for SVM proposed by Yin-Wen Chang et. al.

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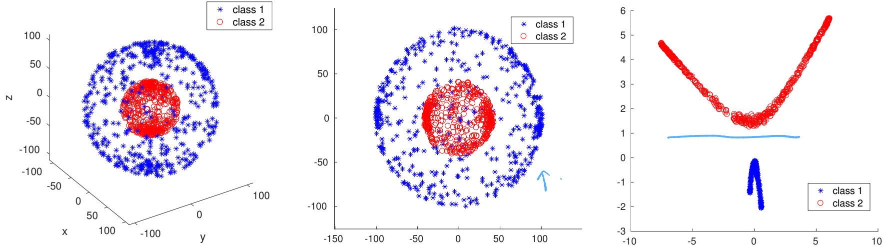


original data   linear PCA   Gassian-kernel PCA

Deep Neural Networks (2010s-Present)

Notable events and achievements in computer vision and NLP:

- (2006) First GPU-implementation CNN by K. Chellapilla et al.
- (2009) Nvidia GPUs were used for deep learning, drastically speedup training
- (2012) ImageNet dataset by Feifei Li's team, greatly facilitated vision recognition research
- (2013) Word2Vec word embedding model BERT released by Google
- (2014) Generative Adversarial Network (GAN) was invented by Ian Goodfellow and his colleagues
- (2016) Further development in CNN: e.g. ResNet (image classification) and UNet (semantic segmentation)
- (2020) language model GPT-3 generates human-like text

Deep Neural Networks (2010s-Present)

Deep reinforcement learning demonstrates human-level game play

Screenshots of Atari 2600 Challenge

- (2013) AI plays Atari games
- (2016) AlphaGo beats human at Go
- (2018) AlphaStar reaches grandmaster level at Starcraft

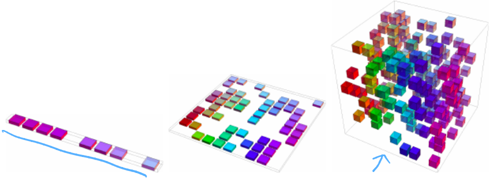
Challenges in Deep Learning

- Overfitting
- Lack of interpretability
- Vulnerbility to adversarial attack
- Highly dependent on data (GPT-3 is the current largest deep neural network with 175,000,000,000 parameters)

Machine Learning Research

Important Challenges in Machine Learning Research

Curse of dimensionality

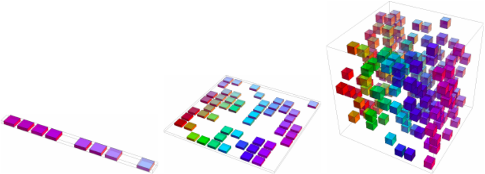


In high dimensional space, the possible configuration of x is much larger than the number of training examples.

- **Semi-supervised learning**: learn from a small set of labeled data and a rich set of unlabeled data.

Important Challenges in Machine Learning Research

Curse of dimensionality



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- **Semi-supervised learning**: learn from a small set of labeled data and a rich set of unlabeled data.
- **Active learning**: a type of semi-supervised learning that interactively queries the user to obtain labels at new datapoints.

Important Challenges in Machine Learning Research

Curse of dimensionality

In high dimensional space, the possible configuration of x is much larger than the number of training examples.

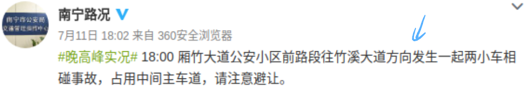
- **Semi-supervised learning**: learn from a small set of labeled data and a rich set of unlabeled data.
- **Active learning**: a type of semi-supervised learning that interactively queries the user to obtain labels at new datapoints.
- **Deep convolutional neural networks** : learn efficient representations from data with multiple levels of abstraction

Heterogeneous learning

Real world applications encounter a lot of **heterogeneities** in data representations and tasks.

e.g. Road traffic status are partially observed by heterogeneous sources:

- Static sensors
- Mobile sensors
- Real-time social media content related to traffic condition
- Accident report
- ...



Transfer learning, domain adaption, and multi-modal learning are motivated by this challenge.

Machine learning theories

Provides theoretical supports on why machine learning algorithms work, improves learning performances, and discovers potential pitfalls.

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- How data quality affects learning performance
- How auxiliary information (unlabeled data, similar tasks) improves the ability to learn from new things
- Understand deep neural networks through information theory

...

Summary

Machine learning: learn rules from data, adapt to changes and improves performance with experience.

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Machine learning: learn rules from data, adapt to changes and improves performance with experience.

- Machine learning themes in history
  - Statistical methods
  - Perceptrons and ANN
  - SVM, kernel methods, ensemble methods
  - Deep neural networks

Next Lecture: Linear Space Methods

- Linear Regression
- Logistic Regression
- Optimization methods