

An Introduction To Machine Learning¹

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"Computers are able to see, hear and learn.
Welcome to the future."

Dave Waters

"This is nothing. In a few years, that bot will move
so fast you'll need a strobe light to see it.
Sweet dreams..."

Elon Musk

"Machine intelligence is the last invention
that humanity will ever need to make."

Nick Bostrom

¹Available @ <https://github.com/a-mhamdi/isetbz/>



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- 1 An overview
- 2 Supervised Learning
- 3 Unsupervised Learning
- 4 Artificial Neural Network
- 5 ML Landscape through Quizzes



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Trends



“Numbers represent search interest relative to the highest point on the chart for the given region and time.

- A value of 100 is the peak popularity for the term;
- A value of 50 means that the term is half as popular;
- A score of 0 means there was not enough data for this term.”

Global Data Traffic



Update on the internet in real time is available [here](#).

Top Uses



Literature Review (1/3)

“The field of machine learning is concerned with the question of how to construct computer programs that automatically improve with experience.”

Mitchell, T. (1997) *Machine Learning*. McGraw-Hill International Editions. McGraw-Hill.

Literature Review (2/3)

“Machine learning (ML) is a scientific discipline that concerns developing learning capabilities in computer systems. Machine learning is one of central areas of Artificial Intelligence (AI). It is an interdisciplinary area that combines results from statistics, logic, robotics, computer science, computational intelligence, pattern recognition, data mining, cognitive science, and more.”

Wojtusiak, J. (2012) [Machine learning](#). In *Encyclopedia of the Sciences of Learning*, pages 2082–2083. Springer US.

Literature Review (3/3)

“Machine learning is an evolving branch of computational algorithms that are designed to emulate human intelligence by learning from the surrounding environment. They are considered the working horse in the new era of the so-called big data. Techniques based on machine learning have been applied successfully in diverse fields ranging from pattern recognition, computer vision, spacecraft engineering, finance, entertainment, and computational biology to biomedical and medical applications. [...] The ability of machine learning algorithms to learn from current context and generalize into unseen tasks would allow improvements in both the safety and efficacy of radiotherapy practice leading to better outcomes.”

El Naqa, I. and Murphy, M. J. (2015) *What Is Machine Learning?*, pages 3–11. Springer International Publishing.

Debrief

Arthur Samuel (1959)

Machine Learning: Field of study that gives computers the ability to learn without being explicitly programmed.

Tom Mitchell (1998)

Well-posed Learning Problem: A computer is said to learn from experience \mathcal{E} with respect to some task \mathcal{T} and some performance measure \mathcal{P} , if its performance on \mathcal{T} , as measured by \mathcal{P} , improves with experience \mathcal{E} .

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Task #1

Suppose your email program watches which emails you do or do not mark as spam, and based on that learns how to better filter spam. What is the task \mathcal{T} in this setting?

- ➊ Classifying emails as spam or not spam;
- ➋ Watching you label emails as spam or not spam;
- ➌ The number (or fraction) of emails correctly classified as spam/not spam;
- ➍ None of the above-this not a machine learning problem.

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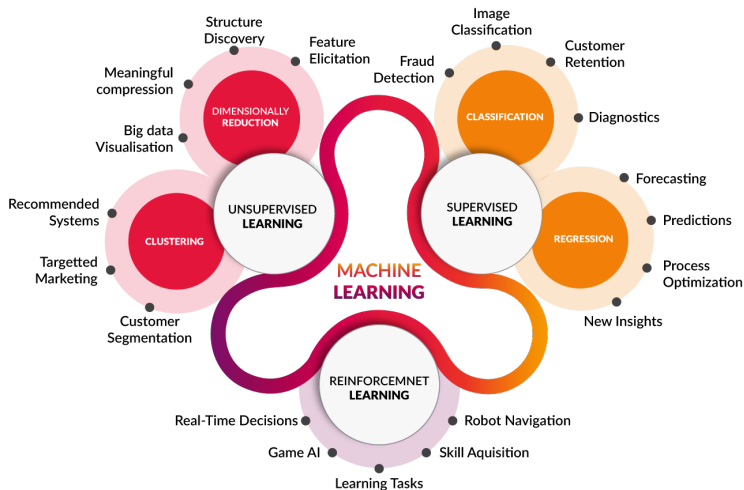
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Overall Methodology

- 1 Define the problem;
- 2 Gather dataset;
- 3 Choose measure of success;
- 4 Decide evaluation protocol;
- 5 Prepare the data;
- 6 Develop a model;
- 7 Iterate models.

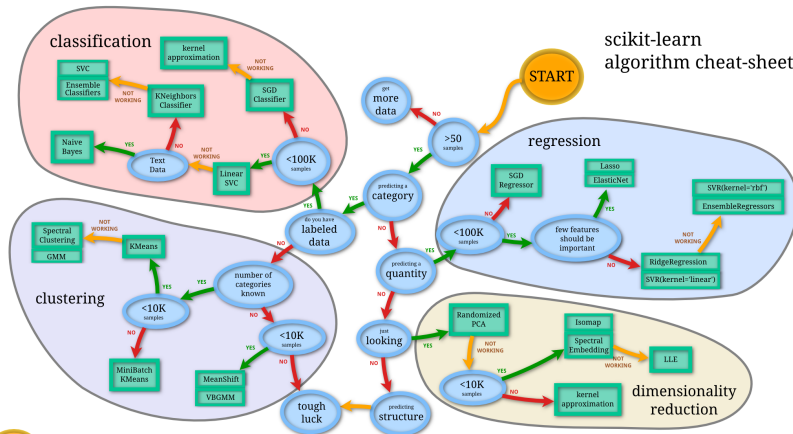


<https://www.cognub.com/index.php/cognitive-platform/>



<https://vitalflux.com/great-mind-maps-for-learning-machine-learning/>

scikit-learn algorithm cheat-sheet



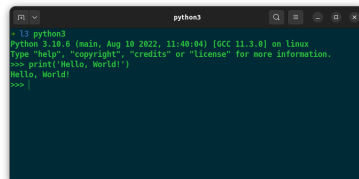
https://scikit-learn.org/stable/tutorial/machine_learning_map/index.html

Regression | Classification | Clustering



<https://github.com/MathWorks-Teaching-Resources/Machine-Learning-for-Regression>

Programming Language

A terminal window titled "python3" with a dark blue background. The text inside the terminal is as follows:

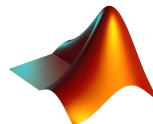
```
* l3 python3
Python 3.10.6 (main, Aug 10 2022, 11:40:04) [GCC 11.3.0] on linux
Type "help", "copyright", "credits" or "license" for more information.
>>> print('Hello, World!')
Hello, World!
>>> |
```

Development Environments



▲ \$ docker compose up

▼ \$ docker compose down



Required Packages



Valid only for...

- A full list is available @ <https://pypi.org/>

Numpy



Matplotlib



Pandas



Scikit – learn



Keras



```
$ pip install virtualenv
$ virtualenv - -version
$ virtualenv «virtualenv_name»
$ source «virtualenv_name»/bin/activate # ACTIVATE
$ deactivate # DEACTIVATE
```

```
> pip install virtualenv
> virtualenv - -version
> virtualenv «virtualenv_name»
> «virtualenv_name»\Scripts\activate :: ACTIVATE
> deactivate :: DEACTIVATE
```





Source Control Management (SCM)

a-mhamdi/mlpy: The repo

github.com/a-mhamdi/mlpy

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Go to file Add file Code

a-mhamdi ref. to mlpy @ dockerhub ✓ 27a84b2 32 minutes ago 34 commits

.github/workflows	ref. to mlpy @ dockerhub	32 minutes ago
codes	update codes folder	last month
.gitignore	Docker config for machine learning image	2 months ago
Dockerfile	rm +platforms support	4 days ago
LICENSE	Initial commit	2 months ago
Makefile	change repo's name & references	15 days ago
README.md	ref. to mlpy @ dockerhub	32 minutes ago

About

The repository contains the Dockerfile I use to create an image where students can run the labs of Machine Learning.

Readme MIT license 0 stars 1 watching 0 forks

Releases

No releases published Create a new release

<https://github.com/a-mhamdi/mlpy>



Continuous Integration (CI)

The screenshot shows the Docker Hub interface for the repository 'abmhamdi/mlpy'. The page includes a search bar, navigation tabs (General, Tags, Builds, Collaborators, Webhooks, Settings), and a description of the repository as 'Machine Learning Labs @ ISETBZ'. It also displays Docker commands for pushing a new tag, a table of tags and scans, and information about automated builds.

abmhamdi / mlpy

Description
Machine Learning Labs @ ISETBZ
Last pushed: 18 minutes ago

Docker commands
To push a new tag to this repository,
`docker push abmhamdi/mlpy:tagname`

Tags and scans
This repository contains 1 tag(s).
VULNERABILITY SCANNING - DISABLED [Enable](#)

Tag	OS	Type	Pulled	Pushed
latest		Image	—	18 minutes ago

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Automated Builds
Manually pushing images to Hub? Connect your account to GitHub or Bitbucket to automatically build and tag new images whenever your code is updated, so you can focus your time on creating.
Available with Pro, Team and Business subscriptions.
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<https://hub.docker.com/r/abmhamdi/mlpy>



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Workflow in Machine Learning



Data Preprocessing

- ▶ Raw data is often messy and may need to be cleaned and formatted before it can be used for machine learning.
(This may involve removing missing or invalid data, handling outliers, and encoding categorical variables.)
- ▶ Normalizing the data can help to scale the features so that they are on the same scale.
(This can be important for algorithms that use distance measures, as features on different scales can dominate the distance measure.)
- ▶ Preprocessing techniques such as feature selection and feature extraction can help to reduce the dimensionality of the data.
(This may improve the performance of the model and reduce the risk of overfitting.)
- ▶ Preprocessing techniques such as feature selection can help to identify the most important features in the data.
(This can make the model more interpretable and easier to understand.)

Feature Scaling

Normalisation (*MinMaxScaler*)

$$X \triangleq \frac{X - \min(X)}{\max(X) - \min(X)}$$

▲ No assumption on data distribution

Standardisation (*StandardScaler*)

$$X \triangleq \frac{X - \mu}{\sigma}$$

▲ More recommended when following normal distribution

Data Preprocessing Template

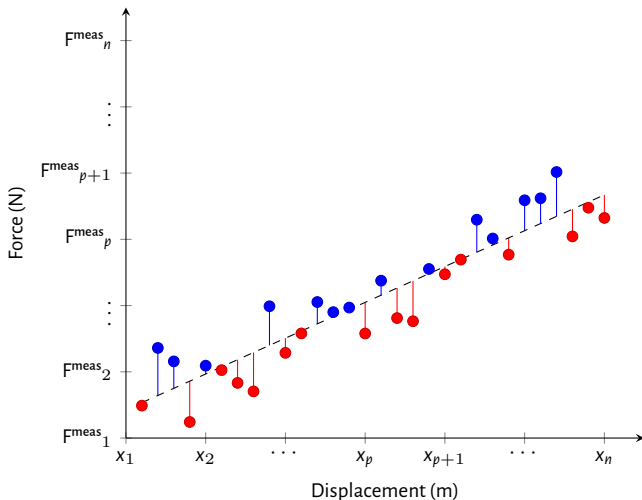
```
[ ]: from sklearn.preprocessing import StandardScaler
```

```
[ ]: sc = StandardScaler()  
X_train = sc.fit_transform(X_train)  
X_test = sc.transform(X_test)
```



The notebook is available at <https://github.com/a-mhamdi/isetbz/>
→ Artificial Intelligence → Codes → Python → data-preprocessing.ipynb

This kind of supervised learning deals with labelled data. A subset of this data is used later to predict in continuous form. Regression problems involve tasks where the outputs form generally a set of real numbers. They often follow linear formats.



Consider the example of a spring. Our main goal is to determine the stiffness k of this spring, given some experimental data. The mathematical model (*Hooke's law*):

$$F = kx \quad (1)$$

Restoring force is proportional to displacement.

Table: Measurements of couple (x_i, F_{meas_i})

x_i	x_1	\dots	x_p	\dots	x_n
F_{meas_i}	F_{meas_1}	\dots	F_{meas_p}	\dots	F_{meas_n}

$$\begin{aligned} F_{\text{meas}_i} &= F_i + \varepsilon_i \\ &= kx_i + \varepsilon_i, \end{aligned} \quad (2)$$

where F_i denotes the unknown real value of the force applied to the spring. In order to estimate the stiffness value k , we can consider the quadratic criterion:

$$\begin{aligned} \mathcal{J} &= \sum_{i=1}^n \varepsilon_i^2 \\ &= \sum_{i=1}^n (F_{\text{meas}_i} - kx_i)^2 \end{aligned}$$

$$\frac{\partial \mathcal{J}}{\partial k} = 0 \quad (3)$$

$$2 \sum_{i=1}^n (F^{\text{meas}}_i - kx_i) \sum_{i=1}^n \frac{\partial (F^{\text{meas}}_i - kx_i)}{\partial k} = 0$$

$$\sum_{i=1}^n (F^{\text{meas}}_i - kx_i) \sum_{i=1}^n x_i = 0$$

$$\sum_{i=1}^n F^{\text{meas}}_i x_i = k \sum_{i=1}^n x_i^2 \iff \hat{k} = \frac{\sum_{i=1}^n F^{\text{meas}}_i x_i}{\sum_{i=1}^n x_i^2}$$

Simple Linear Regression

CODE SNIPPET

Training the Simple Linear Regression model on the Training set

```
[ ]: from sklearn.linear_model import LinearRegression
```

```
[ ]: lr = LinearRegression()  
      lr.fit(X_train, y_train)
```

```
[ ]: LinearRegression()
```

Predicting the Test set results

```
[ ]: y_pred = lr.predict(X_test)
```



The notebook is available at <https://github.com/a-mhamdi/isetbz/>
→ Artificial Intelligence → Codes → simple-linear-regression.ipynb

Multiple Linear Regression

CODE SNIPPET

Training the multiple linear regression model on the training set

```
[ ]: from sklearn.linear_model import LinearRegression
```

```
[ ]: lr = LinearRegression()  
     lr.fit(X_train, y_train)
```

```
[ ]: LinearRegression()
```

Making predictions using the X test set and comparison

```
[ ]: y_pred = lr.predict(X_test)
```



The notebook is available at <https://github.com/a-mhamdi/isetbz/>
→ Artificial Intelligence → Codes → multiple-linear-regression.ipynb

Consider the following multivariate equation:

$$y = \theta_1 x_{(1)} + \theta_2 x_{(2)} + \cdots + \theta_m x_{(m)} \quad (4)$$

For a particular single measurement, eq. (4) can be updated as

$$y_k = \theta_1 x_{(1,k)} + \theta_2 x_{(2,k)} + \cdots + \theta_m x_{(m,k)} + \varepsilon_k \quad (5)$$

We denote hereafter by θ the vector $\begin{bmatrix} \theta_1 \\ \theta_2 \\ \vdots \\ \theta_n \end{bmatrix}$. The function y_k becomes:

$$y_k = \underbrace{[x_{(1,k)}, x_{(2,k)}, \cdots, x_{(m,k)}]}_{x_k^T} \theta + \varepsilon_k \quad (6)$$

We assume that we have n measurements for y . Then we can transform the previous equation into

$$y = X\theta + \varepsilon, \quad (7)$$

where $y^T = [y_1, y_2, \cdots, y_n]$, $X = \begin{bmatrix} x_1^T \\ x_2^T \\ \vdots \\ x_n^T \end{bmatrix}$, and $\varepsilon^T = [\varepsilon_1, \varepsilon_2, \cdots, \varepsilon_n]$.

The regressor is given by

$$\hat{\theta} = (X^T X)^{-1} X^T y$$



$X^T X$ is not invertible (singular/degenerate)

▼ Redundant Features

Some features are linearly dependant, i.e, \exists some $x_p \propto$ some x_l .

▼ Too many features

Fewer observations compared to the number of features, i.e, $m \geq n$.

- ▲ Delete some features
- ▲ Add extra observations

GRADIENT DESCENT

The linear regression is given by:

$$y_k = \underbrace{\left[x_{(1,k)}, x_{(2,k)}, \dots, x_{(m,k)} \right]}_{\underbrace{x_k^T}_{h_\theta(x_k)}} \theta + \varepsilon_k \quad (8)$$

$$\theta_0 \triangleq \theta_0 + \alpha \frac{1}{n} \sum_{k=1}^n (y_k - h_\theta(x_k)) x_{(0,k)}$$

$$\theta_1 \triangleq \theta_1 + \alpha \frac{1}{n} \sum_{k=1}^n (y_k - h_\theta(x_k)) x_{(1,k)}$$

$$\vdots$$

$$\theta_m \triangleq \theta_m + \alpha \frac{1}{n} \sum_{k=1}^n (y_k - h_\theta(x_k)) x_{(m,k)}$$

The parameter α is the learning rate.

Polynomial Regression

CODE SNIPPET

```
[ ]: from sklearn.preprocessing import PolynomialFeatures
```

```
[ ]: poly_reg = PolynomialFeatures(degree=4)
      X_poly = poly_reg.fit_transform(X)
      print(X_poly[:5])
      lr_2 = LinearRegression()
      lr_2.fit(X_poly, y)
```



The notebook is available at <https://github.com/a-mhamdi/isetbz/>
→ Artificial Intelligence → Codes → Python → polynomial-regression.ipynb

Task #2

The yield y of a chemical process is a random variable whose value is considered to be a linear function of the temperature x . The following data of corresponding values of x and y is found:

Temperature in °C (x)	0	25	50	75	100
Yield in grams (y)	14	38	54	76	95

The linear regression model $y = \theta_0 + \theta_1 x$ is used. Determine the values of θ_0 , θ_1 .

- ① Using normal equation,
- ② Using gradient descent for 5 iterations.

$$y = \begin{bmatrix} 14 \\ 38 \\ 54 \\ 76 \\ 95 \end{bmatrix} \quad \text{and} \quad X = \begin{bmatrix} 1 & 0 \\ 1 & 25 \\ 1 & 50 \\ 1 & 75 \\ 1 & 100 \end{bmatrix} \quad \Rightarrow \quad X^T X = \begin{bmatrix} 5 & 250 \\ 250 & 18750 \end{bmatrix}$$

$$\hat{\theta} = \begin{bmatrix} \hat{\theta}_0 \\ \hat{\theta}_1 \end{bmatrix} = \begin{bmatrix} 15.4 \\ 0.8 \end{bmatrix}$$

```
import matplotlib.pyplot as plt
import numpy as np

X = np.array([[1,0], [1,25], [1,50], [1,75], [1,100]], dtype=np.float32)
y = np.array([[14], [38], [54], [76], [95]])

# NORMAL EQUATION
XtX = X.T.dot(X)
invXtX = np.linalg.inv(XtX)
t_ne = invXtX.dot(np.matmul(X.T, y))
print(t_ne)
X[:,1] = (X[:,1]-X[:,1].min())/X[:,1].max()
y = (y-y.min())/y.max()

# GRADIENT DESCENT
t_gd = np.array([[1], [1]])
alpha = .1
vect = np.zeros(shape=(2, 1001))
vect[:,0] = t_gd[[0,1],[0]]
lost = []
for k in range(1000):
    eps = y-np.matmul(X, t_gd)
    lost.append(1/(2*len(y))*eps.T.dot(eps)[[0],[0]][0])
    t_gd = t_gd+alpha*1/len(y)*np.matmul((eps).T, X).T
```

```
vect[:,k+1] = t_gd[[0,1],[0]]
```

```
print(vect[:, -1])  
plt.plot(vect[0, :], label=r'$\hat{\theta}_0$')  
plt.plot(vect[1, :], label=r'$\hat{\theta}_1$')  
plt.legend(); plt.grid(); plt.show()  
  
plt.plot(loss); plt.grid(); plt.show()
```


F1-Score, Accuracy, Recall and **Precision** are calculated as follow:

$$f1 - score = \frac{2}{\frac{1}{Recall} + \frac{1}{Precision}}$$

f1 - score denotes the Harmonic Mean of Recall & Precision

$$Accuracy = \frac{TP + TN}{TP + FP + TN + FN}$$

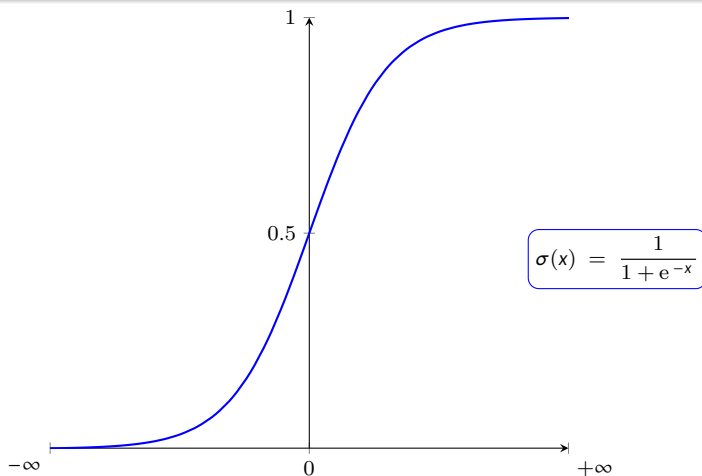
It denotes the ratio of how much we got right over all cases. Recall, on the other hand, designates the ratio of how much positives do we got right over all actual positive cases.

$$Recall = \frac{TP}{TP + FN}$$

Precision, at last, is how much positives we got right over all positive predictions. It is given by:

$$Precision = \frac{TP}{TP + FP}$$

Logistic or S-shaped function σ



- ▲ σ squashes range of distance from $]-\infty, +\infty[$ to $[0, 1]$
- ▲ σ is differentiable and easy to compute: $\dot{\sigma} = \sigma \times (1 - \sigma)$

Decision boundary

$$y = \sigma \left(\theta_1 x_{(1)} + \theta_2 x_{(2)} + \cdots + \theta_m x_{(m)} \right)$$

$$y = \frac{1}{1 + e^{-\theta^T x}}$$

Hypothesis:

Considering $h_{\theta}(x) = \frac{1}{1 + e^{-\theta^T x}}$ yields $h_{\theta}(x_k) = \frac{1}{1 + e^{-\theta^T x_k}}$

GRADIENT DESCENT

⋮

$$\theta_m \triangleq \theta_m + \alpha \frac{1}{n} \sum_{k=1}^n (y_k - h_{\theta}(x_k)) x_{(m,k)}$$

Logistic Regression

CODE SNIPPET

Training the logistic regressor

```
[ ]: from sklearn.linear_model import LogisticRegression
```

```
[ ]: clf = LogisticRegression(random_state=123)  
      clf.fit(X_train, y_train)
```

```
[ ]: LogisticRegression(random_state=123)
```

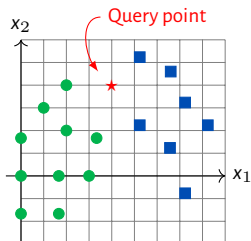
Predicting the test set results

```
[ ]: y_pred = clf.predict(X_test)
```



The notebook is available at <https://github.com/a-mhamdi/isetbz/>
→ Artificial Intelligence → Codes → Python → logistic-regression.ipynb

k -Nearest Neighbors (1/5)



► Evelyn Fix and Joseph Hodges, 1951

► Thomas Cover, 1966

Algorithm Summary Construction

1: **procedure** HOW DOES k -NN WORK? (Finding Nearest Neighbors)

Input: A query point;

Output: Assign a class label to that point.

2: Define how many neighbors will be checked to classify the specific query point;

3: Compute the distance $d(x; y)$ of the query point to other data points;

4: Count the number of the data points in each category;

5: Assign the query point to the class with most frequent neighbors.

6: **end procedure**

k -Nearest Neighbors (2/5)

Minkowski distance

$$d(x; y) = \left(\sum_{i=1}^n |y_i - x_i|^p \right)^{1/p}$$

Manhattan distance ($p=1$)

$$d(x; y) = \sum_{i=1}^n |y_i - x_i|$$

Euclidean distance ($p=2$)

$$d(x; y) = \sqrt{\sum_{i=1}^n (y_i - x_i)^2}$$

Task #3

Let be the following coordinate points:

$A(1, 6)$; $B(2, 6)$; $C(3, 1)$; $D(4, 2)$; $E(6, 0)$; $F(7, 5)$; $G(7, 3)$; $H(10, 3)$; $I(-4, -1)$

Using the Euclidean distance, what are the two closest neighbors of point $P(5, 5)$?

$$d(A; P) = \sqrt{17} \approx 4.12 \quad d(B; P) = \sqrt{10} \approx 3.16 \quad d(C; P) = \sqrt{20} \approx 4.47$$

$$d(D; P) = \sqrt{10} \approx 3.16 \quad d(E; P) = \sqrt{26} \approx 5.1 \quad d(F; P) = \sqrt{4} = 2$$

$$d(G; P) = \sqrt{8} \approx 2.83 \quad d(H; P) = \sqrt{29} \approx 5.38 \quad d(I; P) = \sqrt{117} \approx 10.82$$

k-Nearest Neighbors (3/5)

```
from math import sqrt
def dds(a, b): # `a` and `b` are coordinates of some point
    d_squared = (a-5)**2+(b-5)**2
    return (d_squared, sqrt(d_squared))

dds(1, 6) # Point `A`
dds(2, 6) # Point `B`
```

k -Nearest Neighbors (4/5)

Task #4^a

^aFrom Prof. Winston's book

We try to predict the color of a fruit according to its width (w) and height (h). The following training data is available:

Fruit	F_1	F_2	F_3	F_4	F_5	F_6	F_7	F_8
w	2	5	2	6	1	4	2	6
h	6	6	5	5	2	2	1	1
Color	Red	Yellow	Orange	Purple	Red	Blue	Violet	Green

The goal here is to study the influence of neighbors on the color property of a fruit. Let U be the new fruit of width $w = 1$ and height $h = 4$

- ❶ What is its color if we consider 1 neighbor?
- ❷ What is its color if we consider 3 neighbors?
- ❸ Rather than majority voting, we would like to consider the vote of neighbors weighted by the distance. Each neighbor votes according to a weight inversely proportional to the square of its distance: $\frac{1}{d^2}$. We take 3 neighbors, what is the color of U ? Compare your results to those in question 2.

k-Nearest Neighbors (5/5)

$$d(U; F_1) = \sqrt{5} \approx 2.24 \quad d(U; F_2) = \sqrt{20} \approx 4.47 \quad d(U; F_3) = \sqrt{2} \approx 1.41$$

$$d(U; F_4) = \sqrt{26} \approx 5.1 \quad d(U; F_5) = \sqrt{4} = 2 \quad d(U; F_6) = \sqrt{13} \approx 3.6$$

$$d(U; F_7) = \sqrt{10} \approx 3.16 \quad d(U; F_8) = \sqrt{34} \approx 5.83$$

- ① Color of U is Orange because $d(U; F_3)$ is the smallest.
- ② Color of U is Red: F_1 and F_5 (+2 to Red class), F_3 (+1 to Orange class)
- ③ Color of U is Orange

$$S(\text{Red}) = \frac{1}{d^2(U; F_1)} + \frac{1}{d^2(U; F_5)} = 0.45$$

$$S(\text{Orange}) = \frac{1}{d^2(U; F_3)} = 0.5$$

```
from math import sqrt
def dds(w, h): # `w` and `h` are width and height of some fruit
    d_squared = (w-1)**2+(h-4)**2
    return (d_squared, sqrt(d_squared))
```

```
dds(2, 6) # Fruit `F_1`
```

```
dds(5, 6) # Fruit `F_2`
```

Importing the classifier

```
[ ]: from sklearn.neighbors import KNeighborsClassifier
```

Training the K-NN model on the training set

```
[ ]: clf = KNeighborsClassifier(n_neighbors, metric, p)
      clf.fit(X_train, y_train)
```

Predicting the test set results

```
[ ]: y_pred = clf.predict(X_test)
```



The notebook is available at <https://github.com/a-mhamdi/isetbz/>
→ Artificial Intelligence → Codes → Python → k -nearest-neighbors.ipynb

Rule of Thumb to Choose k

k is even if the number of classes is odd

k is odd if the number of classes is even

k is an important hyperparameter that can affect the performance of the model.

- 1 Larger values of k will result in a smoother decision boundary, which can lead to a more generalized model.
- 2 Smaller values of k will result in a more complex decision boundary, which can lead to a model that is more prone to overfitting.
- 3 The optimal value of K may depend on the specific dataset and the characteristics of the data.

Outroduction

Method		Pros		Cons
<i>Logistic Regression</i>	▲	Probabilistic	▼	Almost linearly separable data
<i>K-NN</i>	▲	Simple	▼	Number of neighbors k Detecting outliers ²
	▲	Fast	▼	
	▲	Efficient		

²Points that differ significantly from the rest of the data points.



- 1 An overview
- 2 Supervised Learning
- 3 Unsupervised Learning**
- 4 Artificial Neural Network
- 5 ML Landscape through Quizzes

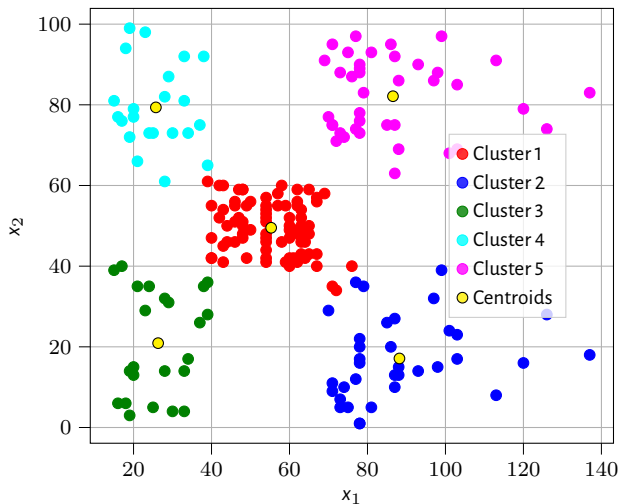
K-Means Clustering (1/3)

The algorithm **K-Means** allows to display regularities or patterns in unlabeled data.

- ▶ The term 'means' refers to averaging the data when computing each centroid;
- ▶ A centroid is the arithmetic mean of all the data points belonging to a particular cluster.

This technique identifies a certain number of centroids within a data set. The algorithm then allocates every data point to the nearest cluster as it attempts to keep the clusters as small as possible. At the same time, *K*-Means attempts to keep the other clusters as different as possible.

K-Means Clustering (2/3)



K-Means Clustering (3/3)

Algorithm Summary Construction

1: **procedure** HOW DOES K-MEANS WORK? (Discovering similarities)

Input: Unlabeled data sets;

Output: Grouping into clusters.

2: Define how many clusters will be used to group the data sets;

3: Initialize all the coordinates of the k cluster centers

4: **repeat**

5: Assign each point to its nearest cluster;

6: Update the centroids coordinates;

7: **until** No changes to the centers of the clusters

8: Assign new cases to one of the clusters

9: **end procedure**

Task #5^a

"From 'Machine Learning' course on 'Coursera'"

Of the following examples, which would you address using an unsupervised learning algorithms? (*Check all that apply.*)

- ❶ Given email labeled as spam/not spam, learn a spam filter
- ❷ Given a set of news articles found on the web, group them into set of articles about the same story
- ❸ Given a database of customer data, automatically discover market segments and group customers into different market segments
- ❹ Given a dataset of patients diagnosed as either having diabetes or not, learn to classify new patients as having diabetes or not.

Task #5^a

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Of the following examples, which would you address using an unsupervised learning algorithms? (*Check all that apply.*)

- ❶ Given email labeled as spam/not spam, learn a spam filter
- ❷ Given a set of news articles found on the web, group them into set of articles about the same story
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- ❹ Given a dataset of patients diagnosed as either having diabetes or not, learn to classify new patients as having diabetes or not.

Task #6^a

^aCredit: Shokoufeh Mirzaei, PhD

Use K-Means algorithm to cluster the following eight points into three clusters:

A(2, 10); B(2, 5); C(8, 4); D(5, 8); E(7, 5); F(6, 4); G(1, 2) and H(4, 9).

- ▶ Initial cluster centers are: $\alpha(2, 10)$; $\beta(5, 8)$ and $\gamma(1, 2)$
- ▶ The distance between two points: $M(x_m, y_m)$ and $N(x_n, y_n)$ is defined as

$$d(M; N) = |x_m - x_n| + |y_m - y_n|$$

Task #6^a

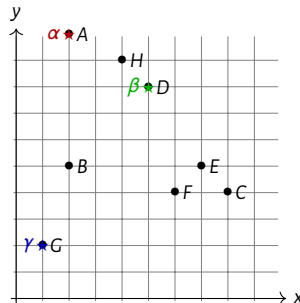
^aCredit: Shokoufeh Mirzaei, PhD

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Task #6^a

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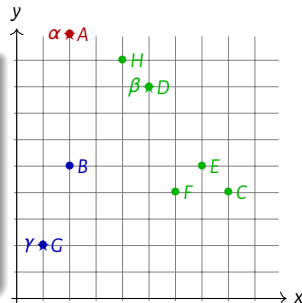
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Point	$\alpha(2, 10)$	$\beta(5, 8)$	$\gamma(1, 2)$	#
$A(2, 10)$	0	5	9	1
$B(2, 5)$	5	6	4	3
$C(8, 4)$	12	7	9	2
$D(5, 8)$	5	0	10	2
$E(7, 5)$	10	5	9	2
$F(6, 4)$	10	5	7	2
$G(1, 2)$	9	10	0	3
$H(4, 9)$	3	2	10	2



Task #6^a^aCredit: Shokoufeh Mirzaei, PhD

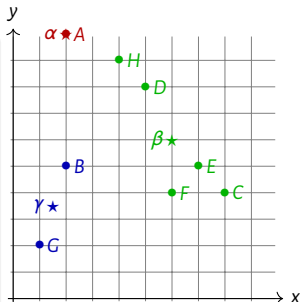
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$F(6, 4)$	10	5	7	2
$G(1, 2)$	9	10	0	3
$H(4, 9)$	3	2	10	2

 $\alpha(2, 10)$ $\beta(6, 6)$ $\gamma(1.5, 3.5)$ 

Task #6^a^aCredit: Shokoufeh Mirzaei, PhD

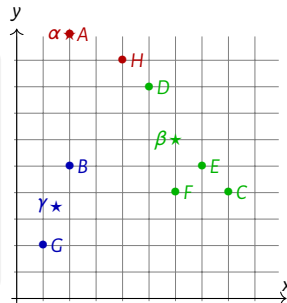
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Point	$\alpha(2, 10)$	$\beta(6, 6)$	$\gamma(1.5, 3.5)$	#
A(2, 10)	0	8	7	1
B(2, 5)	5	5	2	3
C(8, 4)	12	4	7	2
D(5, 8)	5	3	8	2
E(7, 5)	10	2	7	2
F(6, 4)	10	2	5	2
G(1, 2)	9	9	2	3
H(4, 9)	3	5	8	1



Task #6^a^aCredit: Shokoufeh Mirzaei, PhD

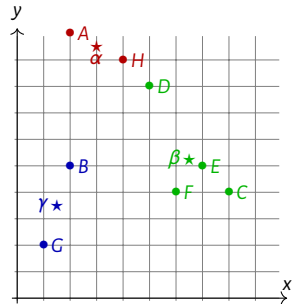
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 $\alpha(3, 9.5)$ $\beta(6.5, 5.25)$ $\gamma(1.5, 3.5)$ 

Task #6^a^aCredit: Shokoufeh Mirzaei, PhD

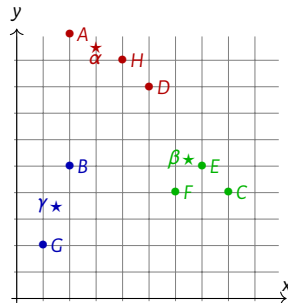
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Point	$\alpha(3, 9.5)$	$\beta(6.5, 5.25)$	$\gamma(1.5, 3.5)$	#
A(2, 10)	1.5	9.25	7	1
B(2, 5)	5.5	4.75	2	3
C(8, 4)	10.5	2.75	7	2
D(5, 8)	3.5	4.25	8	1
E(7, 5)	8.5	0.75	7	2
F(6, 4)	8.5	1.75	5	2
G(1, 2)	9.5	8.75	2	3
H(4, 9)	1.5	6.25	8	1



Task #6^a^aCredit: Shokoufeh Mirzaei, PhD

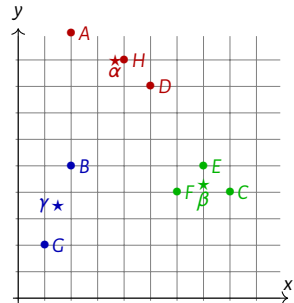
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 $\alpha(3.67, 9)$ $\beta(7, 4.3)$ $\gamma(1.5, 3.5)$ 

Task #6^a^aCredit: Shokoufeh Mirzaei, PhD

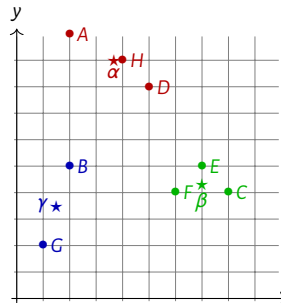
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Point	$\alpha(3.67, 9)$	$\beta(7, 4.3)$	$\gamma(1.5, 3.5)$	#
A(2, 10)	2.67	10.7	7	1
B(2, 5)	5.67	5.7	2	3
C(8, 4)	9.33	1.3	7	2
D(5, 8)	2.33	5.7	8	1
E(7, 5)	7.33	0.7	7	2
F(6, 4)	7.33	1.3	5	2
G(1, 2)	9.67	8.3	2	3
H(4, 9)	0.33	7.7	8	1



Task #6^a^aCredit: Shokoufeh Mirzaei, PhD

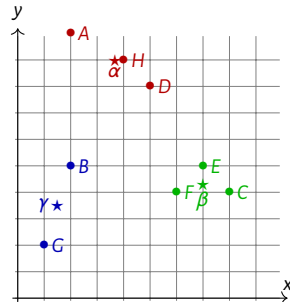
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 $\alpha(3.67, 9)$ $\beta(7, 4.3)$ $\gamma(1.5, 3.5)$ 

K-Means

CODE SNIPPET

Import KMeans class

```
[ ]: from sklearn.cluster import KMeans
```

Training the K-Means model on the dataset

```
[ ]: kmeans = KMeans(n_clusters, init, random_state)
     y_pred = kmeans.fit_predict(X)
```



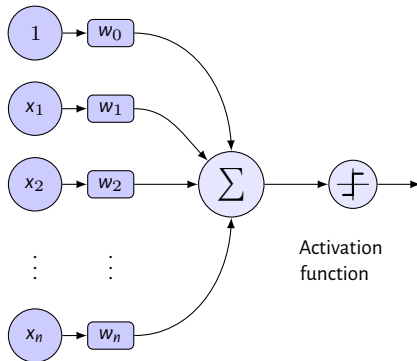
The notebook is available at <https://github.com/a-mhamdi/isetbz/>
→ Artificial Intelligence → Codes → Python → k-means-clustering.ipynb



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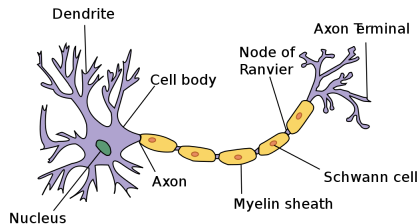
Fundamental unit of a neural network (1/3)

Artificial neuron



Inputs Weights

Biological neuron

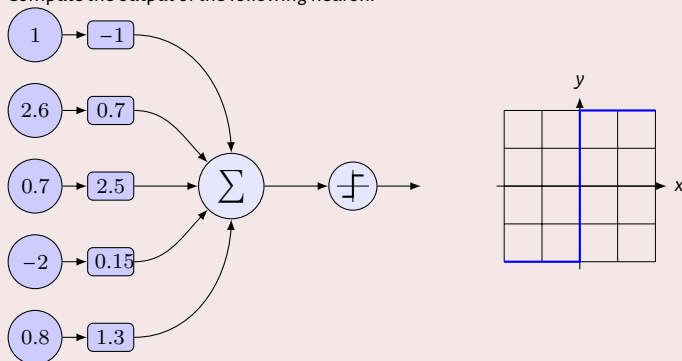


https://id.wikipedia.org/wiki/Sel_saraf

Fundamental unit of a neural network (2/3)

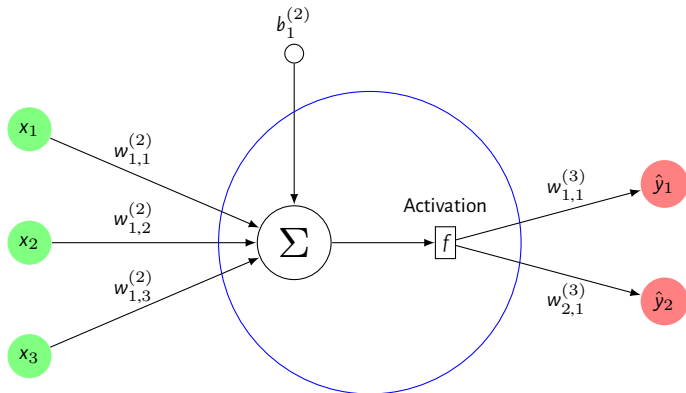
Task #7

Compute the output of the following neuron.

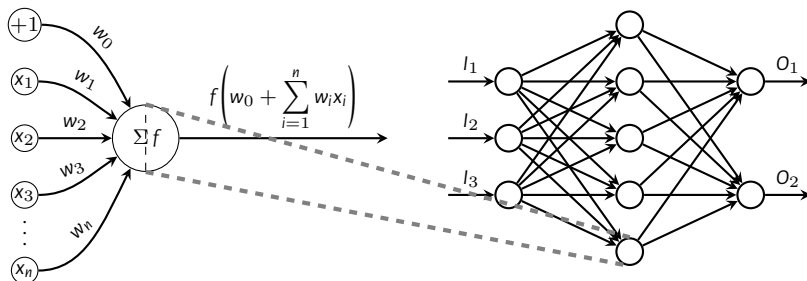


$$y = \text{sign}(1 \times -1 + 2.6 \times 0.7 + 0.7 \times 2.5 - 2 \times 0.15 + 0.8 \times 1.3) = 1$$

Fundamental unit of a neural network (3/3)



Multilayer Perceptron (MLP)

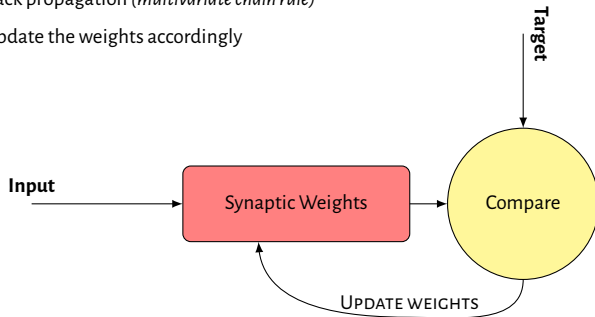


Task #8

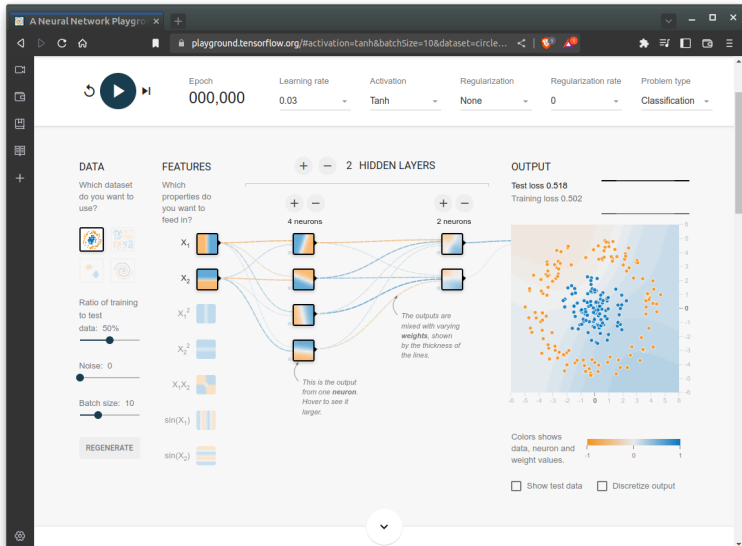
For the above structure, determine how many parameters are to be adjusted.

$$\text{Params \#} = 5 \times 3 + 5 + 2 \times 5 + 2 = 32$$

- ✓ Design a structure
- ✓ Specify a loss function to minimize
- ✓ Optimize using gradient descent
 - ① Feedforward propagation (*matrix multiplication and point-wise activation*)
 - ② Back propagation (*multivariate chain rule*)
 - ③ Update the weights accordingly



Tinker with a neural network



<https://playground.tensorflow.org/>

ANN

CODE SNIPPET

```
[ ]: from keras.models import Sequential  
     from keras.layers import Dense
```

```
[ ]: clf = Sequential()  
     ndim = X_train.shape[1]  
     clf.add(Dense(units=8, activation="relu", input_dim=ndim))  
     clf.add(Dense(units=4, activation="relu"))  
     clf.add(Dense(units=4, activation="relu"))  
     clf.add(Dense(units=1, activation="sigmoid"))
```

```
[ ]: clf.compile(optimizer="adam", loss="binary_crossentropy",  
               metrics=["accuracy"])
```

```
[ ]: clf.fit(X_train, y_train, batch_size=16, epochs=32);
```



The notebook is available at <https://github.com/a-mhamdi/isetbz/>
→ Artificial Intelligence → Codes → Python → artificial-neural-network.ipynb



List of available optimizers

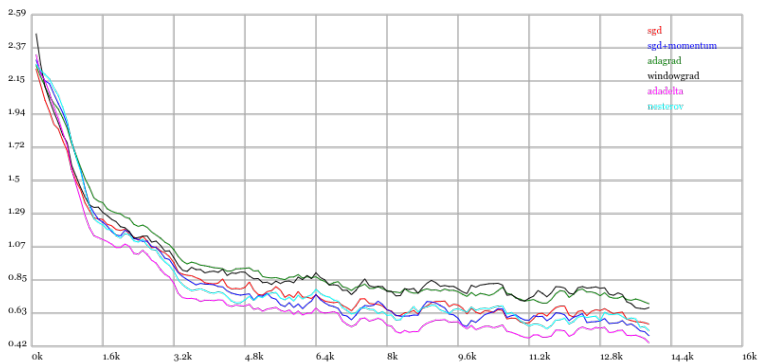
Here is a list of some common optimizers for artificial neural networks:

$$\Delta \hat{\Theta} \triangleq \mathcal{F} \left(\nabla \underbrace{\mathcal{J}(\hat{\Theta})}_{\text{Loss Function}} \right) \equiv \hat{\Theta} \triangleq \hat{\Theta} + \mathcal{F}(\nabla \mathcal{J}(\hat{\Theta})) \quad \nabla \mathcal{J}(\hat{\Theta}) = \begin{bmatrix} \frac{\partial \mathcal{J}}{\partial \hat{\theta}_0} \\ \vdots \\ \frac{\partial \mathcal{J}}{\partial \hat{\theta}_n} \end{bmatrix}$$

SGD
SGD+MOMENTUM
ADAGRAD

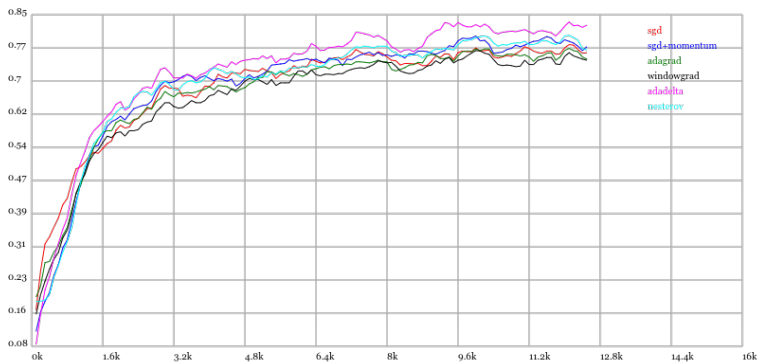
WINDOWGRAD
ADADELTA
NESTEROV

Effect of optimizer on loss values



<https://cs.stanford.edu/people/karpathy/convnetjs/demo/trainers.html>

Effect of optimizer on testing accuracy values



<https://cs.stanford.edu/people/karpathy/convnetjs/demo/trainers.html>



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MCQ (1/8)

1 What is Machine Learning (ML)?

- × The selective acquisition of knowledge through the use of computer programs
- × The selective acquisition of knowledge through the use of manual programs
- ✓ The autonomous acquisition of knowledge through the use of computer programs
- × The autonomous acquisition of knowledge through the use of manual programs

2 Successful applications of ML

- × Learning to recognize spoken words
- × Learning to drive an autonomous vehicle
- × Learning to classify new astronomical structures
- × Learning to play world-class backgammon
- ✓ All of the above

3 Features of Machine Learning are ...

- ✓ Automation
- ✓ Improved customer experience
- ✓ Business intelligence

4 ... is the machine learning algorithm that can be used with labeled data.

- ✓ Regression algorithm
- × Clustering algorithm
- × Association algorithm

MCQ (2/8)

- 5 Replace missing values with mean/median/mode helps to handle missing or corrupted data in a dataset. True/False?
- ✓ True
 - × False
- 6 Which among the following algorithms are used in Machine learning?
- ✓ Naïve Bayes
 - ✓ Support Vector Machines
 - ✓ k -Nearest Neighbors
- 7 The term machine learning was coined by ...
- × James Gosling
 - ✓ Arthur Samuel
 - × Guido van Rossum
 - × None of the above
- 8 The Real-world machine learning use cases are
- ✓ Digital assistants
 - ✓ Chatbots
 - ✓ Fraud detection

MCQ (3/8)

9 Machine learning approaches can be traditionally categorized into ... categories.

- ✓ 3
- × 4
- × 7
- × 9

10 ... is a part of machine learning that works with neural networks.

- × Artificial intelligence
- ✓ Deep learning
- × All of the above
- × None of the above

11 The supervised learning problems can be grouped as ...

- × Regression problems
- × Classification problems
- ✓ All of the above
- × None of the above

12 The unsupervised learning problems can be grouped as ...

- × Clustering
- × Association
- ✓ All of the above
- × None of the above

MCQ (4/8)

- 13 Overfitting is a type of modelling error which results in the failure to predict future observations effectively or fit additional data in the existing model. Yes/No?
- ☐ Probably
 - ☒ Yes
 - ☐ No
 - ☐ Can not say
- 14 ... is the scenario when the model fails to decipher the underlying trend in the input data.
- ☒ Underfitting
 - ☐ Overfitting
 - ☐ All of the above
 - ☐ None of the above
- 15 The categories in which Machine learning approaches can be traditionally categorized are ...
- ☐ Supervised learning
 - ☐ Unsupervised learning
 - ☐ Reinforcement learning
 - ☒ All of the above
- 16 In general, to have a well-defined learning problem, we must identify which of the following
- ☐ The class of tasks
 - ☐ The measure of performance to be improved
 - ☐ The source of experience
 - ☒ All of the above

MCQ (5/8)

- 17 The average positive difference between computed and desired outcome values
- × Root Mean Squared Error
 - × Mean Squared Error
 - × Mean Absolute Error
 - ✓ Mean Positive Error
- 18 ... is used as an input to the machine learning model for training and prediction purposes.
- × Target variable
 - ✓ Feature vector
 - × All of the above
 - × None of the above
- 19 Simple regression assumes a ... relationship between the input attribute and output attribute.
- ✓ linear
 - × quadratic
 - × reciprocal
 - × inverse
- 20 The correlation between the number of years an employee has worked for a company and the salary of the employee is 0.75. What can be said about employee salary and years worked?
- × There is no relationship between salary and years worked.
 - ✓ Individuals that have worked for the company the longest have higher salaries.
 - × Individuals that have worked for the company the longest have lower salaries.
 - × The majority of employees have been with the company a long time.

MCQ (6/8)

- 21 Which machine learning models are trained to make a series of decisions based on the rewards and feedback they receive for their actions?
- × Supervised learning
 - × Unsupervised learning
 - ✓ Reinforcement learning
 - × All of the above
- 22 Which of the following is not a type of supervised learning?
- × Classification
 - × Regression
 - ✓ Clustering
 - × None of the above
- 23 As the amount of training data increases
- × Training error usually increases and generalization error usually increases
 - ✓ Training error usually increases and generalization error usually decreases
 - × Training error usually decreases and generalization error usually decreases
 - × Training error usually decreases and generalization error usually increases
- 24 Which of the following are not classification tasks?
- × Find the gender of a person by analyzing his writing style
 - × Detect Pneumonia from Chest X-ray images
 - ✓ Predict the price of a house based on floor area, number of rooms, etc.
 - × Predict whether there will be abnormally heavy rainfall next year

MCQ (7/8)

- 25 Which of the following is a categorical feature?
- × Height of a person
 - × Price of petroleum
 - × Amount of rainfall in a day
 - ✓ Mother tongue of a person
- 26 What is the use of validation dataset in Machine Learning?
- × To train the machine learning model.
 - ✓ To tune the hyperparameters of the machine learning model
 - × To evaluate the performance of the machine learning model
 - × None of the above
- 27 Which of the following criteria is typically used for optimizing in linear regression.
- × Maximize the number of points it touches.
 - × Minimize the number of points it touches.
 - ✓ Minimize the squared distance from the points.
 - × Minimize the maximum distance of a point from a line.
- 28 For two runs of K-Mean clustering, is it expected to get same clustering results?
- × Yes
 - ✓ No

MCQ (8/8)

- 29 Logistic Regression is used for ...
- × regression purposes
 - ✓ classification purposes
 - × all of the above
 - × none of the above
- 30 Which of the following methods do we use to best fit the data in Logistic Regression?
- × Least Squared Error
 - ✓ Maximum Likelihood
 - × Jaccard distance
- 31 When there is noise in data, which of the following options would improve the performance of the k -NN algorithm?
- ✓ Increase the value of k
 - × Decrease the value of k
 - × Changing value of k will not change the effect of the noise
 - × None of these

Some Useful Links

- 1 <https://setosa.io/ev/>
- 2 <https://karpathy.ai/>
- 3 <http://yann.lecun.com/>
- 4 <https://www.hackingnote.com/>
- 5 <https://machinelearningmastery.com/>
- 6 <https://stanford.edu/~shervine/teaching/>
- 7 <https://www.ibm.com/downloads/cas/GB8ZMQZ3>
- 8 <https://colah.github.io/posts/2014-03-NN-Manifolds-Topology/>

Further Reading (1/2)

- [Bur19] A. Burkov. *The Hundred-Page Machine Learning Book*. Andriy Burkov, Jan. 1, 2019. 160 pp.
- [Bur20] A. Burkov. *Machine Learning Engineering*. True Positive Inc., Sept. 8, 2020. 310 pp.
- [DFO20] M. P. Deisenroth, A. A. Faisal, and C. S. Ong. *Mathematics for Machine Learning*. Cambridge University Pr., Apr. 1, 2020. 398 pp.
- [ENM15] I. El Naqa and M. J. Murphy. "What Is Machine Learning?" In: *Machine Learning in Radiation Oncology: Theory and Applications*. Ed. by I. El Naqa, R. Li, and M. J. Murphy. Cham: Springer International Publishing, 2015, pp. 3–11. DOI: 10.1007/978-3-319-18305-3_1.
- [Fla12] P. Flach. "References". In: *Machine Learning: The Art and Science of Algorithms that Make Sense of Data*. Cambridge University Press, Sept. 2012, pp. 367–382. DOI: 10.1017/CB09780511973000.017.
- [GBC16] I. Goodfellow, J. Bengio, and A. Courville. *Deep Learning*. MIT Press Ltd, Nov. 18, 2016. 800 pp.
- [Gé19] A. Géron. *Hands-on Machine Learning with Scikit-Learn, Keras, and TensorFlow*. O'Reilly Media, Oct. 15, 2019. 819 pp.
- [HYU21] T. J. Hui (York University). *Machine Learning Fundamentals*. Cambridge University Press, Nov. 25, 2021. 420 pp.
- [Jia22] H. Jiang. *Machine Learning Fundamentals*. Cambridge University Pr., Jan. 31, 2022.
- [JPM21] L. M. John Paul Mueller. *Machine Learning For Dummies*. Wiley John + Sons, Apr. 8, 2021. 464 pp.

- [Mit97] T. Mitchell. *Machine Learning*. McGraw-Hill International Editions. McGraw-Hill, 1997.
- [Pra18] M. L. de Prado. *Advances in Financial Machine Learning*. John Wiley & Sons Inc, May 4, 2018. 400 pp.
- [SG16] A. C. M. Sarah Guido. *Introduction to Machine Learning with Python*. O'Reilly Media, July 31, 2016.
- [Woj12] J. Wojtusiak. “Machine Learning”. In: *Encyclopedia of the Sciences of Learning*. Springer US, 2012, pp. 2082–2083. DOI: 10.1007/978-1-4419-1428-6_1927.