# hw1-yuquan-cai-q1

March 7, 2025

```python
[105]: import pandas as pd
       import numpy as np
       import matplotlib.pyplot as plt
```

## 0.1  1. Load data

1. Load provided `Iris.csv` file.
2. Change the Species columns to numeric label `0, 1, 2` and output a numpy.ndarray in shape (`num_data, 1`).
3. Convert `SepalLengthCm, SepalWidthCm` column into numpy.ndarray in shape (`num_data, 2`).

1.1 Load provided `Iris.csv` file. Show the first 10 lines (1 points.)

```python
[106]: #######################
       # Write your code here #
       data = pd.read_csv("C:/Users\Quan\GitHub\CUHKSZ-DDA3020\Assignment 01/raw_data/
        ↪Iris.csv")
       data.head(10)
       #######################
```

```
[106]:    Id  SepalLengthCm  SepalWidthCm  PetalLengthCm  PetalWidthCm      Species
       0   1            5.1           3.5            1.4           0.2  Iris-setosa
       1   2            4.9           3.0            1.4           0.2  Iris-setosa
       2   3            4.7           3.2            1.3           0.2  Iris-setosa
       3   4            4.6           3.1            1.5           0.2  Iris-setosa
       4   5            5.0           3.6            1.4           0.2  Iris-setosa
       5   6            5.4           3.9            1.7           0.4  Iris-setosa
       6   7            4.6           3.4            1.4           0.3  Iris-setosa
       7   8            5.0           3.4            1.5           0.2  Iris-setosa
       8   9            4.4           2.9            1.4           0.2  Iris-setosa
       9  10            4.9           3.1            1.5           0.1  Iris-setosa
```

1.2 Change the Species columns to numeric label `0, 1, 2` and output a numpy.ndarray in shape (`num_data, 1`). Show data every 10 lines. (2 points)

```python
[107]: #######################
       # Write your code here #
```

```
data["Species"] = data["Species"].apply(lambda x: 0 if x == "Iris-setosa" else␣
  ↪1 if x == "Iris-versicolor" else 2)
y = data["Species"].to_numpy()
y = y.reshape(-1, 1)
y[::10]
#######################
```

[107]: 
```
array([[0],
       [0],
       [0],
       [0],
       [0],
       [1],
       [1],
       [1],
       [1],
       [1],
       [2],
       [2],
       [2],
       [2],
       [2]])
```

1.3 Convert `SepalLengthCm` and `SepalWidthCm` columns to ndarray in shape `[num_data, 2]`. Convert numeric label column to ndarray in shape `[num_data, 1]`. Print these two ndarray (1 point).

[108]: 
```
#######################
# Write your code here #
data_ndarray = data[["SepalLengthCm", "SepalWidthCm"]].to_numpy()
data_ndarray.reshape(-1, 2)
print(data_ndarray)
print(y)
#######################
```

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[[5.1 3.5]
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## 0.2   2. Softmax, Cost, and Derivative Functions

2.1 Develop softmax function and try to output softmax function output of this example (3 points).
Softmax function

$$\hat{y}_c = \frac{\exp(z_c)}{\sum_{j=1}^{C} \exp(z_j)}, \text{ where } c \text{ is class index and } C \text{ is the number of classes.}$$

```python
[109]: def softmax(z):
           """
           Calculating softmax function.
           Args:
               z: (numpy.ndarray in shape [num_data, num_classes]) logit
           Returns:
               pred: (numpy.ndarray in shape [num_data, num_classes]) predict value
           """
           ######################
           # Write your code here #
           exp_zc = np.exp(z)
           pred = exp_zc / np.sum(exp_zc, axis=1, keepdims=True)
           ######################

           return pred

       test_z = np.array([[1, 1, 1],
                          [1, 3, 5],
                          [-1, 0, 1]])

       softmax(test_z)
```

```
[109]: array([[0.33333333, 0.33333333, 0.33333333],
              [0.01587624, 0.11731043, 0.86681333],
              [0.09003057, 0.24472847, 0.66524096]])
```

2.2 Develop cost function of multi-class logistic regression and try to output cost function output of this example (3 points). Cost function

$$\mathcal{L} = -\frac{1}{N} \sum_{i=1}^{N} \sum_{c=1}^{C} y_{ic} \log(\hat{y}_{ic}), \text{ where } N \text{ is the number of data}$$

(Hint: convert label ndarray to the same shape of predicted ndarray, e.g.

$$\begin{bmatrix} 0 \\ 1 \\ 2 \\ 1 \\ 0 \end{bmatrix} \Rightarrow \begin{bmatrix} 1 & 0 & 0 \\ 0 & 1 & 0 \\ 0 & 0 & 1 \\ 0 & 1 & 0 \\ 1 & 0 & 0 \end{bmatrix}$$

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```
[110]: def cost_function(pred, label):
           """
           Calculating cost function.
           Args:
               pred: (numpy.ndarray in shape [num_data, num_classes]) predict value
        →after softmax
           Returns:
               loss: (numpy.ndarray)
           """
           #######################
           # Write your code here #
           data_num = label.shape[0]
           type_num = np.max(label) + 1
           label = label.transpose()
           label_one_hot = np.eye(type_num)[label]

           loss = -np.sum(label_one_hot * np.log(pred)) / data_num
           #######################
           return loss

       test_pred = np.array([[0.1, 0.2, 0.7],
                             [0.2, 0.6, 0.2],
                             [0.2, 0.1, 0.7]])
       test_label = np.array([[2], [1], [0]])
       cost_function(test_pred, test_label)
```

[110]: np.float64(0.8256461600462744)

2.3 Develop gradient calculation of multi-class logistic regression and try to output gradient of given example. You're required to derive the derivatives $\frac{\partial \mathcal{L}}{\partial \mathbf{w}}$ by yourself and write it in your writing problems. Assume all $x_0 = 1$, predicted values should be $\hat{y}_i = \text{Softmax}\left(\mathbf{x}_i^T \mathbf{w}\right)$ (3 points for coding, 3 points for mathematical derivation).

```
[111]: def get_gradient(X, y, y_pred):
           """
           Calculate gradient for gradient descent.
           Args:
               X: (numpy.ndarray in shape [num_data, 3])
               y: (numpy.ndarray in shape [num_data, 1])
               y_pred: (numpy.ndarray in shape [num_data, num_classes])
           Return:
               gradient: (numpy.ndarray in [3, 3]) gradient of w
           """
           #######################
           # Write your code here #
           N = X.shape[0]
           C = y_pred.shape[1]   # number of classes
```

```python
        y_one_hot = np.zeros_like(y_pred)
        for i in range(N):
            y_one_hot[i, y[i]] = 1

        gradient = np.dot(X.T, (y_pred - y_one_hot)) / N

        #######################
    return gradient

test_X = np.array([[1, 1, 2],
                   [1, 2, 3],
                   [1, 3, 4],
                   [1, 4, 5]])
test_y = np.array([[0], [1], [1], [2]])
test_y_pred = np.array([[0.1, 0.2, 0.7],
                        [0.2, 0.4, 0.4],
                        [0.2, 0.3, 0.5],
                        [0.3, 0.4, 0.3]])
get_gradient(test_X, test_y, test_y_pred)
```

```
[111]: array([[-0.05 , -0.175,  0.225],
              [ 0.325, -0.375,  0.05 ],
              [ 0.275, -0.55 ,  0.275]])
```

## 0.3  3. Gradient Descent

3.1 Convert data according to assumption of $x_0 = 1$. (1 point)

```python
[112]: #######################
       # Write your code here #
       X = np.hstack((np.ones((data_ndarray.shape[0], 1)), data_ndarray))
       print(X)
       #######################
```

```
[[1.  5.1 3.5]
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 [1.  4.6 3.1]
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 [1.  4.4 2.9]
 [1.  4.9 3.1]
 [1.  5.4 3.7]
 [1.  4.8 3.4]
 [1.  4.8 3. ]
```

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[1.   5.8 4. ]
[1.   5.7 4.4]
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```

3.2 Initialize value of **w** and start up gradient descent. Record cost function value iteration by iteration. (3 points)

```python
[113]: def gradient_descent(X, y, lr, epoch):
           np.random.seed(42) # set random seed to control initialized value
           w = np.random.rand(3, 3)
```

```python
    ##########################
    # Write your code here #
    for i in range(epoch):
        y_pred = softmax(X @ w)
        gradient = get_gradient(X, y, y_pred)
        w -= lr * gradient
        cost = cost_function(y_pred, y)
        cost_record.append(cost)
        print(f"[Epoch {i}] Cost function = {cost}")
    ##########################

    return w

epoch = 10000
lr = 0.1
cost_record = []
w = gradient_descent(X, y, lr, epoch)
```

```
[Epoch 0] Cost function = 1.4264728216843992
[Epoch 1] Cost function = 1.3192481221359094
[Epoch 2] Cost function = 1.2950487037227485
[Epoch 3] Cost function = 1.2799895636445147
[Epoch 4] Cost function = 1.2671271578474355
[Epoch 5] Cost function = 1.2549975939033138
[Epoch 6] Cost function = 1.2432597310293731
[Epoch 7] Cost function = 1.2317865042125327
[Epoch 8] Cost function = 1.2205417715760947
[Epoch 9] Cost function = 1.2095118698594853
[Epoch 10] Cost function = 1.1986915818471295
[Epoch 11] Cost function = 1.1880778943309023
[Epoch 12] Cost function = 1.1776685426489333
[Epoch 13] Cost function = 1.1674613378087462
[Epoch 14] Cost function = 1.1574540580485617
[Epoch 15] Cost function = 1.1476443659765407
[Epoch 16] Cost function = 1.1380298182085815
[Epoch 17] Cost function = 1.1286078584087529
[Epoch 18] Cost function = 1.1193758308808017
[Epoch 19] Cost function = 1.110330986368553
[Epoch 20] Cost function = 1.10147049326914
[Epoch 21] Cost function = 1.0927914460635377
[Epoch 22] Cost function = 1.0842908751476887
[Epoch 23] Cost function = 1.0759657556020854
[Epoch 24] Cost function = 1.0678130161537884
[Epoch 25] Cost function = 1.059829547576737
[Epoch 26] Cost function = 1.0520122108868686
[Epoch 27] Cost function = 1.044357845095166
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[Epoch 28] Cost function = 1.0368632746124258
[Epoch 29] Cost function = 1.0295253162291522
[Epoch 30] Cost function = 1.022340785693315
[Epoch 31] Cost function = 1.0153065038624047
[Epoch 32] Cost function = 1.0084193024373718
[Epoch 33] Cost function = 1.0016760292751952
[Epoch 34] Cost function = 0.995073553287712
[Epoch 35] Cost function = 0.9886087689330786
[Epoch 36] Cost function = 0.9822786003107834
[Epoch 37] Cost function = 0.9760800048720375
[Epoch 38] Cost function = 0.9700099767596313
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[Epoch 57] Cost function = 0.8754482905377453
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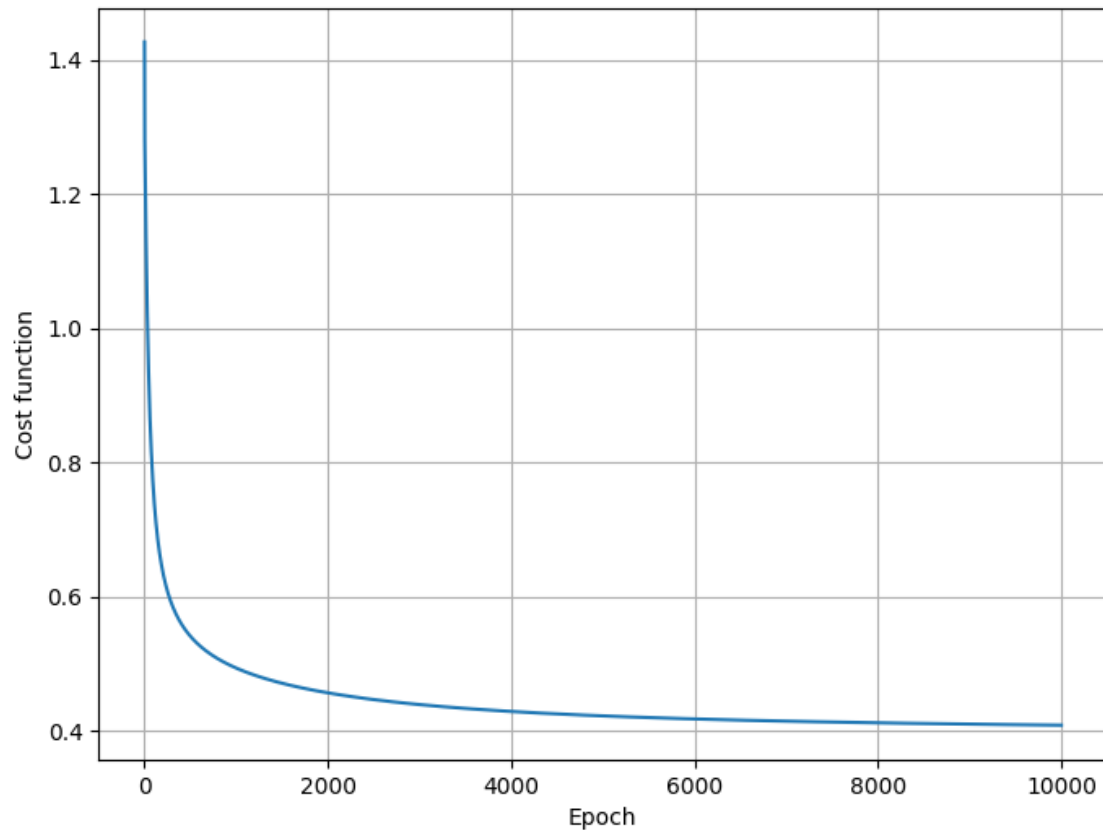
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```

3.3 Plot cost function v.s. epoch curve. (1 point)

```python
[114]:  #########################
        # Write your code here #
        plt.figure(figsize=(8, 6))
        plt.plot(range(len(cost_record)), cost_record)
        plt.xlabel("Epoch")
        plt.ylabel("Cost function")
        plt.grid(True)
        plt.show()
        #########################
```

## 0.4  4. Plot result

4.1 Plot scatters using ground-truth label. (2 points)

```
[115]: ########################
       # Write your code here #
       species = data["Species"]
       colors = ['r', 'g', 'b']
       labels = ['Iris-setosa', 'Iris-versicolor', 'Iris-virginica']

       plt.figure(figsize=(8, 6))

       for label in range(3):
           plt.scatter(data.loc[species == label, "SepalLengthCm"], data.loc[species
        ↪== label, "SepalWidthCm"], color=colors[label], label=labels[label])

       plt.xlabel("Sepal Length")
       plt.ylabel("Sepal Width")
       plt.legend()
       plt.show()
```
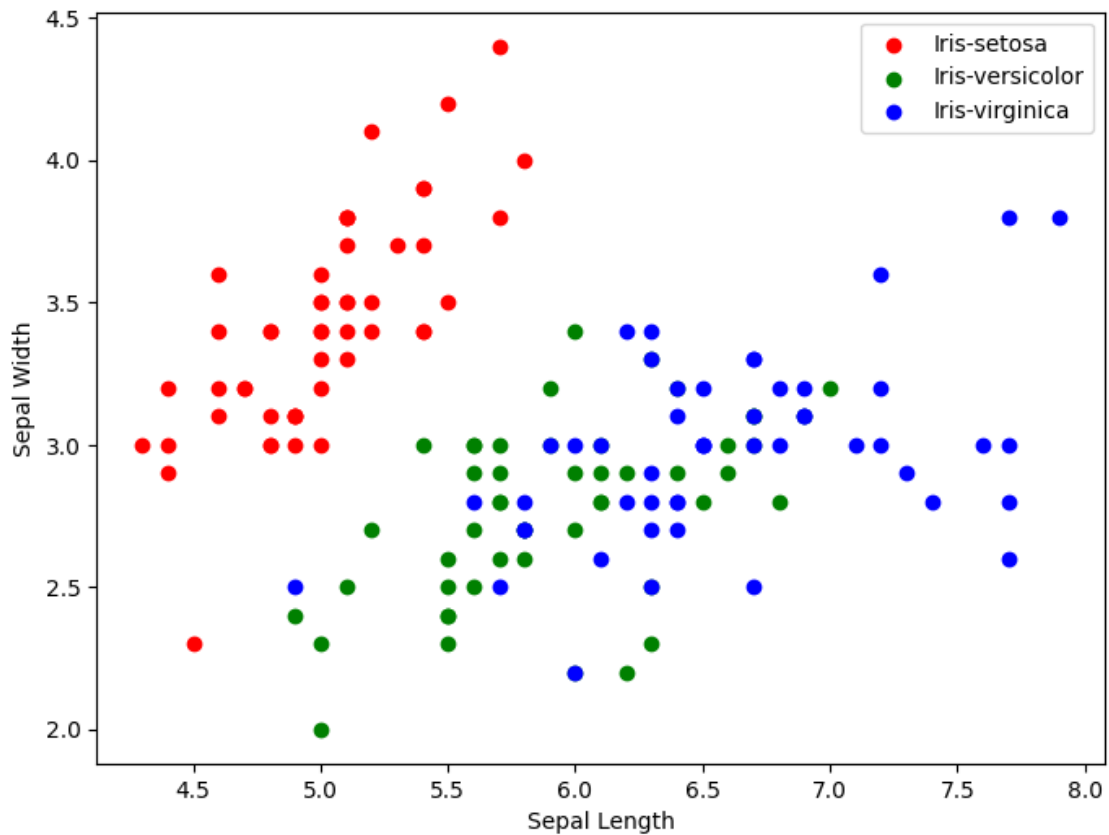
4.1 Plot scatters using predicted label. (2 points)

```
[116]:  ########################
        # Write your code here #
        colors = ['r', 'g', 'b']
        labels = ['Iris-setosa', 'Iris-versicolor', 'Iris-virginica']

        y_pred = softmax(X @ w)
        species_pred = np.argmax(y_pred, axis=1)

        plt.figure(figsize=(8, 6))

        for label in range(3):
            plt.scatter(data.loc[species_pred == label, "SepalLengthCm"], data.
         ↪loc[species_pred == label, "SepalWidthCm"], color=colors[label],␣
         ↪label=labels[label])

        plt.xlabel("Sepal Length")
```

```
plt.ylabel("Sepal Width")
plt.legend()
plt.show()
########################
```