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CSC 448: Machine Learning, Fall 2020

Term Project

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# Description

This is a multi-part project to build a machine learning library from scratch using Python. The library is called ML.py. Included with the library are sample scripts demonstrating the usage of the various components of the library.

# Usage

## Setup & Requirements

For the ML.py library to be useable, a few dependencies must be met. These dependencies are given in requirements.txt which is located in the root project directory. Installation is accomplished using the following pip command:

pip3 install -r requirements.txt

A [Python virtual environment](https://docs.python.org/3/tutorial/venv.html) can be used to help simplify dependency and package management across multiple applications. When using a Python virtual environment, dependencies are installed into the virtual environment and not into your system-wide Python installation.

## Importing the ML Library

The ML library is implemented in ML.py. To use this library in your own code you must first import it. For example, to use the Perceptron class and plot\_decision\_regions helper function the following import statement would be used:

from ML import Perceptron, plot\_decision\_regions

# Perceptron

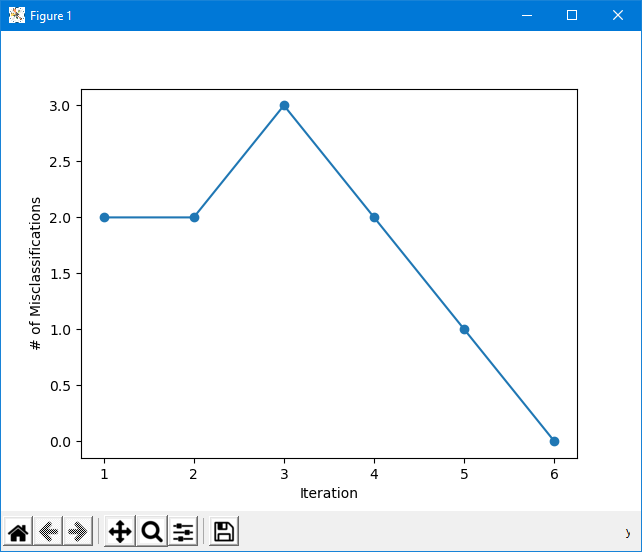
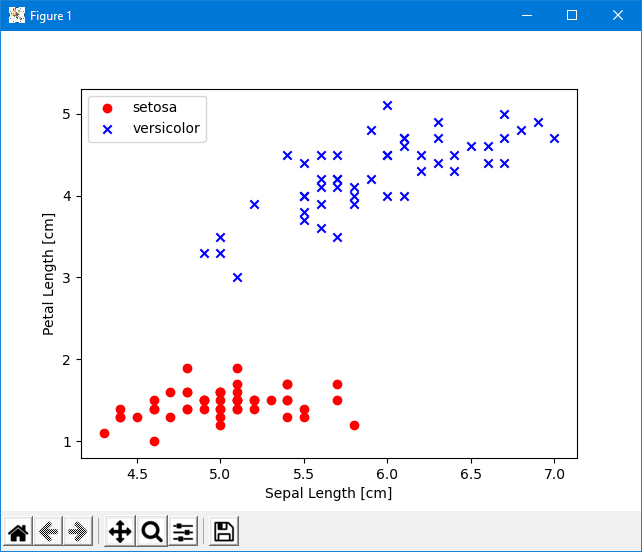
## Description

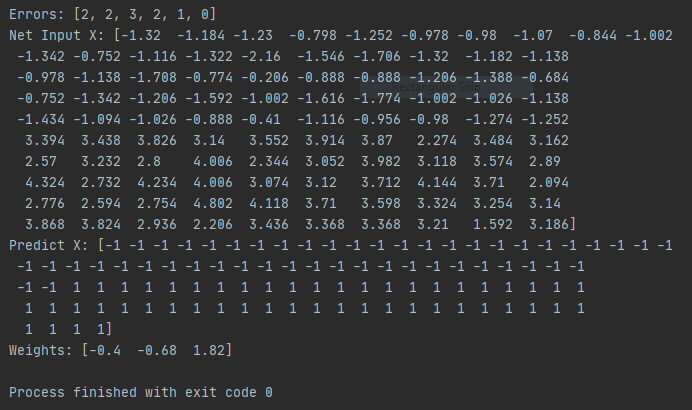
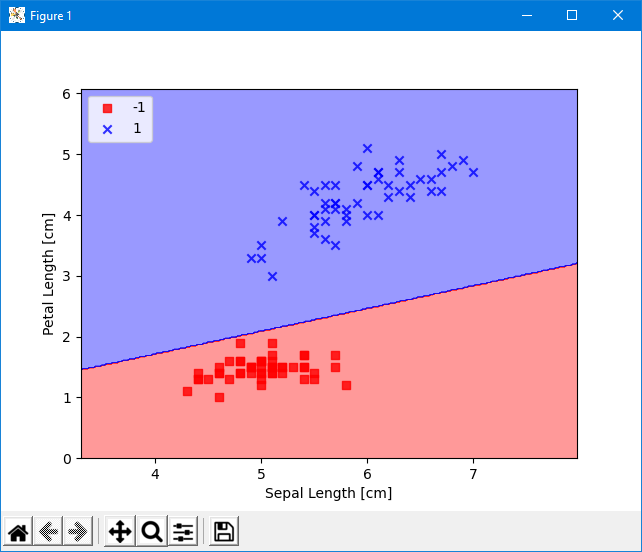
A [perceptron](https://en.wikipedia.org/wiki/Perceptron#Learning_algorithm) is a linear classifier that maps real-valued inputs to a binary output, or label. This means that in order for a perceptron to converge (classify all inputs correctly), the data must be linearly separable. Linearly separable means that it is possible to separate positive and negative examples with a hyperplane. At a high level the perceptron works by iterating over the training data, calculating the predicted values, calculating the error between the predicted values and the expected values, and finally updating the weights and bias in order to improve the error on the next iteration.

## Usage

A file called perceptron.py has been included that demonstrates the usage of the Perceptron class included with the ML.py library. This file also demonstrates the usage of the decision boundary visualization module. The demonstration uses data from the famous [Iris Data Set](https://archive.ics.uci.edu/ml/datasets/iris) for machine learning.

To run the sample code first make sure that all of the dependencies are installed. Next, open a terminal and run python3 perceptron.py in the root directory of the project. The program will get the sepal length and petal length for the Iris-setosa and Iris-versicolor data. It will then show a scatter plot of this data to illustrate that the data is separable. Next, the program will instantiate a perceptron using the ML library and train the perceptron on the sample data. The features used to train the Perceptron are sepal length and petal length. A graph will be displayed that plots the number of misclassifications that occurred during training. Finally, the program will use the plot\_decision\_regions function from the ML library to plot the decision surface. The decision surface shows the partition between the two classes of objects (Iris-setosa and Iris-versicolor). Example screenshots of the expected output are provided below.





## Files & Functions

### perceptron.py

This file contains code that demonstrates the usage of the Perceptron class.

### ML.py

CLASSES

class Perceptron(learning\_rate=0.01, iterations=10)

|

| init(self, learning\_rate=0.01, iterations=10)

| Initialize the Perceptron.

| Args:

| learning\_rate Float: used to scale the weight array

| iterations Int: number of iterations for fitting data to labels

|

| fit(self, X, y)

| Fit training data.

| Args:

| X : Training vectors, X.shape : [#samples, #features]

| y : Target values, y.shape : [#samples]

|

| net\_input(self, X)

| Calculate the net input.

| Args:

| X : Training vectors, X.shape : [#samples, #features]

| Returns:

| Float: the dot product (X.w) plus the bias

|

| predict(self, X)

| Return the class label after unit step

| Args:

| X : Training vectors, X.shape : [#samples, #features]

| Returns:

| Int: the predicted class label (1 or -1)

|

| errors

| This is the getter for the error array. Using a getter prevents the caller

| from changing the array.

| Returns:

| list: the array of errors in each iteration

|

| weight

| This is the getter for the weight array. Using a getter prevents the caller

| from changing the array.

| Returns:

| numpy.ndarray: the current weight array

## Testing

The Perceptron class was tested using the famous [Iris Data Set](https://archive.ics.uci.edu/ml/datasets/iris) for machine learning. The expected output of perceptron.py is given above and was checked against the output of Dr. Karlsson’s program as given in the Perceptron assignment PDF to ensure correctness. Additional tests were done using different pairs and triples in the Iris Data Set. The Perceptron was also tested using all four features in the Iris Data Set to ensure that it is generic enough to accept any number of features, however; it should be noted that when using more than two features from the Iris Data Set the data seems to be inseparable.

# Regression Models

## Linear Regression Model

### Description

Linear regression is a useful tool for modeling linear relationships between data. The linear regression model included with the ML.py library uses naïve batch [gradient descent](https://towardsdatascience.com/batch-mini-batch-stochastic-gradient-descent-7a62ecba642a) to predict a y-value for some given x-value. Since all linear regression problems are convex regardless of the input data, gradient descent can be used without worrying about “getting stuck” in a local minimum. The linear regression model works by iterating over the training data, calculating the predicted y-value, computing the partial derivatives of mean squared error with respect to the slope and y-intercept, and finally updating the weights associated with the slope and y-intercept in order to improve the error on the next iteration. Calculations are performed over the entire **X** and **y** vectors as opposed to each row of the vectors individually. This is where the term batch gradient descent comes from. Currently, the model only works for *d=1* dimensional data (i.e. **X** has one *x* value per row).

### Usage

A file called linearRegression.py has been included. This file demonstrates the usage of the LinearRegression class from the ML.py library. The demonstration uses data from the famous [Iris Data Set](https://archive.ics.uci.edu/ml/datasets/iris) for machine learning as well as from a [fish market dataset](https://www.kaggle.com/aungpyaeap/fish-market). The [scikit-learn linear regression model](https://scikit-learn.org/stable/auto_examples/linear_model/plot_ols.html) is used to check the accuracy of the ML.py linear regression model.

To run the sample code first make sure that all of the dependencies are installed. Next, open a terminal and run python3 linearRegression.py in the root directory of the project. Example screenshots of the expected output are provided below.

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### Files & Functions

#### linearRegression.py

This file contains code that demonstrates the usage of the LinearRegression class.

#### ML.py

class LinearRegression(builtins.object)

| LinearRegression(learning\_rate=0.05, iterations=1000)

|

| This is the linear regression implementation for the ML library.

|

| Methods defined here:

|

| \_\_init\_\_(self, learning\_rate=0.05, iterations=1000)

| Initialize the linear regression module.

|

| Args:

| learning\_rate (float, optional): used to scale the weight array. Defaults to 0.05.

| iterations (int, optional): number of gradient descent iterations. Defaults to 1000.

|

| fit(self, X, Y)

| Fit training data. Since all linear regression problems are

| convex regardless of the input data, we can use gradient descent

| without worrying about getting stuck in a local minimum.

|

| Args:

| X : X training vector (independent variables)

| Y : Y training vector (dependent variables)

|

| predict(self, X\_test)

| Return the predicted Y values.

|

| Args:

| X\_test : X test vector

|

| Returns:

| Y\_pred : Y prediction vector

|

| ----------------------------------------------------------------------

| Data descriptors defined here:

|

| \_\_dict\_\_

| dictionary for instance variables (if defined)

|

| \_\_weakref\_\_

| list of weak references to the object (if defined)

### Testing

The LinearRegression class was tested using the famous [Iris Data Set](https://archive.ics.uci.edu/ml/datasets/iris) for machine learning as well as a [fish market dataset](https://www.kaggle.com/aungpyaeap/fish-market). The expected output of linearRegression.py is given above. Part of the above output is the output of the scikit-learn linear regression model, which was used to check the correctness of the ML.py linear regression model. In addition to performing visual checks of scatter plots and regression lines, mean squared error, mean absolute error, and mean root squared error were compared.

## Logistic Regression Model

### Description

[Logistic regression](https://en.wikipedia.org/wiki/Logistic_regression) is used to make binary predictions about the likelihood that data belongs to some class. The example below uses logistic regression to predict whether datapoints from the Iris dataset belong to the Iris-setosa class or the Iris-versicolor class. For each datapoint, the likelihood of that datapoint belonging to some class is calculated. This results in a probability, which is then rounded to either 0 or 1. The value of 0 or 1 can then be mapped to a label. Logistic regression works by using a sigmoid function to construct a hypothesis class, which is then used for classifying data. The specific sigmoid function used is the logistic function . If *X* is the input data such that each column of *X* is associated with some feature, then Z is the result of applying weights to the data associated with each feature in *X*. The logistic function has the advantage of being convex, so gradient descent can be used to find the global minimum.

### Usage

A file called logisticRegression.py has been included. This file demonstrates the usage of the LogisticRegression class from the ML.py library. The demonstration uses data from the famous [Iris Data Set](https://archive.ics.uci.edu/ml/datasets/iris) for machine learning as well as from a [fish market dataset](https://www.kaggle.com/aungpyaeap/fish-market). The [scikit-learn logistic regression model](https://scikit-learn.org/stable/modules/generated/sklearn.linear_model.LogisticRegression.html) is used to check the accuracy of the ML.py logistic regression model.

To run the sample code first make sure that all of the dependencies are installed. Next, open a terminal and run python3 logisticRegression.py in the root directory of the project. Example screenshots of the expected output are provided below.

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### Files & Functions

#### logisticRegression.py

This file contains code that demonstrates the usage of the LogisticRegression class.

#### ML.py

class LogisticRegression(builtins.object)

| LogisticRegression(learning\_rate=0.01, iterations=10)

|

| This is the logistic regression implementation for the ML library.

|

| Methods defined here:

|

| \_\_init\_\_(self, learning\_rate=0.01, iterations=10)

| Initialize the logistic regression module.

|

| Args:

| learning\_rate (float, optional): used to scale the weight array. Defaults to 0.01.

| iterations (int, optional): number of gradient descent iterations. Defaults to 10.

|

| fit(self, X, Y)

| Fit training data.

|

| Args:

| X: X training vector (independent variables)

| Y : Y training vector (dependent variables)

|

| predict(self, X\_test)

| Return the predicted Y values.

|

| Args:

| X\_test: X\_test : X test vector

|

| Returns:

| Y\_pred : Y prediction vector

|

| ----------------------------------------------------------------------

| Data descriptors defined here:

|

| \_\_dict\_\_

| dictionary for instance variables (if defined)

|

| \_\_weakref\_\_

| list of weak references to the object (if defined)

### Testing

The LogisticRegression class was tested using the famous [Iris Data Set](https://archive.ics.uci.edu/ml/datasets/iris) for machine learning as well as a [fish market dataset](https://www.kaggle.com/aungpyaeap/fish-market). The expected output of logisticRegression.py is given above. Part of the above output is the output of the scikit-learn logistic regression model, which was used to check the correctness of the ML.py logistic regression model.

# Hypothesis Classes of Low VC Dimension

## Axis-Aligned Rectangles

### Description

Axis-aligned rectangles are a type of low VC dimension hypothesis class that work by using training data to form a bounding box separating positively labelled points from negatively labelled points. Test data is then classified based on whether or not the data point is within the axis-aligned rectangle. Data points within the axis-aligned rectangle are labelled positively and those outside of the axis-aligned rectangle are labelled negatively. If the input data is linearly separable, the dimensions of the axis-aligned rectangle are very simple to compute. For each column (feature) in **X**, the min and max of that column are points on the perimeter of the bounding box. If the data is not linearly separable, the axis-aligned rectangle will be resized to minimize the total number of misclassifications.

### Usage

A file called axisAlignedRectangle.py has been included. This file demonstrates the usage of the AxisAlignedRectangles class from the ML.py library. The demonstration uses data from the famous [Iris Data Set](https://archive.ics.uci.edu/ml/datasets/iris) for machine learning as well as from a [fish market dataset](https://www.kaggle.com/aungpyaeap/fish-market). The [scikit-learn AdaBoostClassifier](https://scikit-learn.org/stable/modules/generated/sklearn.ensemble.AdaBoostClassifier.html) is used to boost the performance of the low VC dimension classifier and enable easy comparisons with other types of classifiers.

To run the sample code first make sure that all of the dependencies are installed. Next, open a terminal and run python3 axisAlignedRectangle.py in the root directory of the project. Example screenshots of the expected output are provided below.

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### Files & Functions

#### axisAlignedRectangle.py

This file contains code that demonstrates the usage of the AxisAlignedRectangles class.

#### ML.py

class AxisAlignedRectangles(sklearn.base.BaseEstimator, sklearn.base.ClassifierMixin)

| AxisAlignedRectangles(iterations=10)

|

| This is the axis-aligned rectangle low vc dimension learner implementation

| for the ML library.

|

| Args:

| BaseEstimator : Base class for all estimators in scikit-learn,

| used for compatibility with the sci-kit-learn AdaBoostClassifier

| ClassifierMixin : Mixin class for all classifiers in scikit-learn,

| used for compatibility with the sci-kit-learn AdaBoostClassifier

|

| Method resolution order:

| AxisAlignedRectangles

| sklearn.base.BaseEstimator

| sklearn.base.ClassifierMixin

| builtins.object

|

| Methods defined here:

|

| \_\_init\_\_(self, iterations=10)

| Initialize the axis-aligned rectangle low vc dimension learner.

|

| Args:

| iterations: number of iterations for reducing size of axis-aligned rectangle, defaults to 10

|

| fit(self, X, y, sample\_weight=None)

| Fit training data.

|

| Args:

| X : X training vector

| y : y label vector

| sample\_weight (optional): Required for compatibility with the scikit-learn Adaboost module. Defaults to None.

|

| Returns:

| self : Required for compatibility with the scikit-learn Adaboost module.

|

| predict(self, X)

| Return the predicted Y values.

|

| Args:

| X : X test vector

|

| Returns:

| Y\_pred : Y prediction vector

|

| ----------------------------------------------------------------------

| Methods inherited from sklearn.base.BaseEstimator:

|

| \_\_getstate\_\_(self)

|

| \_\_repr\_\_(self, N\_CHAR\_MAX=700)

| Return repr(self).

|

| \_\_setstate\_\_(self, state)

|

| get\_params(self, deep=True)

| Get parameters for this estimator.

|

| Parameters

| ----------

| deep : bool, default=True

| If True, will return the parameters for this estimator and

| contained subobjects that are estimators.

|

| Returns

| -------

| params : mapping of string to any

| Parameter names mapped to their values.

|

| set\_params(self, \*\*params)

| Set the parameters of this estimator.

|

| The method works on simple estimators as well as on nested objects

| (such as pipelines). The latter have parameters of the form

| ``<component>\_\_<parameter>`` so that it's possible to update each

| component of a nested object.

|

| Parameters

| ----------

| \*\*params : dict

| Estimator parameters.

|

| Returns

| -------

| self : object

| Estimator instance.

|

| ----------------------------------------------------------------------

| Data descriptors inherited from sklearn.base.BaseEstimator:

|

| \_\_dict\_\_

| dictionary for instance variables (if defined)

|

| \_\_weakref\_\_

| list of weak references to the object (if defined)

|

| ----------------------------------------------------------------------

| Methods inherited from sklearn.base.ClassifierMixin:

|

| score(self, X, y, sample\_weight=None)

| Return the mean accuracy on the given test data and labels.

|

| In multi-label classification, this is the subset accuracy

| which is a harsh metric since you require for each sample that

| each label set be correctly predicted.

|

| Parameters

| ----------

| X : array-like of shape (n\_samples, n\_features)

| Test samples.

|

| y : array-like of shape (n\_samples,) or (n\_samples, n\_outputs)

| True labels for X.

|

| sample\_weight : array-like of shape (n\_samples,), default=None

| Sample weights.

|

| Returns

| -------

| score : float

| Mean accuracy of self.predict(X) wrt. y.

### Testing

The AxisAlignedRectangles class was tested using the famous [Iris Data Set](https://archive.ics.uci.edu/ml/datasets/iris) for machine learning as well as a [fish market dataset](https://www.kaggle.com/aungpyaeap/fish-market). The expected output of axisAlignedRectangle.py is given above. The [scikit-learn AdaBoostClassifier](https://scikit-learn.org/stable/modules/generated/sklearn.ensemble.AdaBoostClassifier.html) was used to enable easy testing because it allows a [base estimator](https://scikit-learn.org/stable/developers/develop.html) (i.e. low VC dimension learner) to be passed in as a parameter. This enabled comparisons to be made between the axis-aligned rectangle classifier and the built-in scikit-learn decision stump classifier. The results of the comparison are reflected in the output shown above.

## Decision Stump

### Description

[Decision stumps](https://en.wikipedia.org/wiki/Decision_stump) are a type of low VC dimension hypothesis class and can be thought of as a one-level decision tree. A decision stump works by selecting a single feature from a set of training data and attaching a threshold to that feature. The decision stump then uses that feature-threshold pair to label the test data. The ML.py decision stump selects the feature-threshold pair that yields the smallest error over the training data. Part of this selection process includes attaching an inequality lambda to the feature-threshold pair. The inequality lambda can be greater-than or less-than and is essential for predicting labels. The reasoning for this is that the feature-threshold pair alone do not provide enough information to make a comparison. We must also know whether the value of the feature should be above or below the threshold.

### Usage

A file called decisionStump.py has been included. This file demonstrates the usage of the DecisionStump class from the ML.py library. The demonstration uses data from the famous [Iris Data Set](https://archive.ics.uci.edu/ml/datasets/iris) for machine learning as well as from a [fish market dataset](https://www.kaggle.com/aungpyaeap/fish-market). The [scikit-learn AdaBoostClassifier](https://scikit-learn.org/stable/modules/generated/sklearn.ensemble.AdaBoostClassifier.html) is used to boost the performance of the low VC dimension classifier and enable easy comparisons with other types of classifiers.

To run the sample code first make sure that all of the dependencies are installed. Next, open a terminal and run python3 decisionStump.py in the root directory of the project. Example screenshots of the expected output are provided below.

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### Files & Functions

#### decisionStump.py

This file contains code that demonstrates the usage of the DecisionStump class.

#### ML.py

class DecisionStump(sklearn.base.BaseEstimator, sklearn.base.ClassifierMixin)

| This is the decision stump low vc dimension learner implementation

| for the ML library.

|

| Args:

| BaseEstimator : Base class for all estimators in scikit-learn,

| used for compatibility with the sci-kit-learn AdaBoostClassifier

| ClassifierMixin : Mixin class for all classifiers in scikit-learn,

| used for compatibility with the sci-kit-learn AdaBoostClassifier

|

| Method resolution order:

| DecisionStump

| sklearn.base.BaseEstimator

| sklearn.base.ClassifierMixin

| builtins.object

|

| Methods defined here:

|

| \_\_init\_\_(self)

| Initialize the decision stump low vc dimension learner.

|

| fit(self, X, y, sample\_weight=None)

| Fit training data.

|

| Args:

| X : X training vector

| y : y label vector

| sample\_weight (optional): Required for compatibility with the scikit-learn Adaboost module. Defaults to None.

|

| Returns:

| self : Required for compatibility with the scikit-learn Adaboost module.

|

| predict(self, X)

| Return the predicted Y values.

|

| Args:

| X : X test vector

|

| Returns:

| Y\_pred : Y prediction vector

|

| ----------------------------------------------------------------------

| Methods inherited from sklearn.base.BaseEstimator:

|

| \_\_getstate\_\_(self)

|

| \_\_repr\_\_(self, N\_CHAR\_MAX=700)

| Return repr(self).

|

| \_\_setstate\_\_(self, state)

|

| get\_params(self, deep=True)

| Get parameters for this estimator.

|

| Parameters

| ----------

| deep : bool, default=True

| If True, will return the parameters for this estimator and

| contained subobjects that are estimators.

|

| Returns

| -------

| params : mapping of string to any

| Parameter names mapped to their values.

|

| set\_params(self, \*\*params)

| Set the parameters of this estimator.

|

| The method works on simple estimators as well as on nested objects

| (such as pipelines). The latter have parameters of the form

| ``<component>\_\_<parameter>`` so that it's possible to update each

| component of a nested object.

|

| Parameters

| ----------

| \*\*params : dict

| Estimator parameters.

|

| Returns

| -------

| self : object

| Estimator instance.

|

| ----------------------------------------------------------------------

| Data descriptors inherited from sklearn.base.BaseEstimator:

|

| \_\_dict\_\_

| dictionary for instance variables (if defined)

|

| \_\_weakref\_\_

| list of weak references to the object (if defined)

|

| ----------------------------------------------------------------------

| Methods inherited from sklearn.base.ClassifierMixin:

|

| score(self, X, y, sample\_weight=None)

| Return the mean accuracy on the given test data and labels.

|

| In multi-label classification, this is the subset accuracy

| which is a harsh metric since you require for each sample that

| each label set be correctly predicted.

|

| Parameters

| ----------

| X : array-like of shape (n\_samples, n\_features)

| Test samples.

|

| y : array-like of shape (n\_samples,) or (n\_samples, n\_outputs)

| True labels for X.

|

| sample\_weight : array-like of shape (n\_samples,), default=None

| Sample weights.

|

| Returns

| -------

| score : float

| Mean accuracy of self.predict(X) wrt. y.

### Testing

The DecisionStump class was tested using the famous [Iris Data Set](https://archive.ics.uci.edu/ml/datasets/iris) for machine learning as well as a [fish market dataset](https://www.kaggle.com/aungpyaeap/fish-market). The expected output of decisionStump.py is given above. The [scikit-learn AdaBoostClassifier](https://scikit-learn.org/stable/modules/generated/sklearn.ensemble.AdaBoostClassifier.html) was used to enable easy testing because it allows a [base estimator](https://scikit-learn.org/stable/developers/develop.html) (i.e. low VC dimension learner) to be passed in as a parameter. This enabled comparisons to be made between the ML.py decision stump classifier and the built-in scikit-learn decision stump classifier. The results of the comparison are reflected in the output shown above.

# Visualization Modules

## Decision Boundary

### Description

The plot\_decision\_regions function is used to display the decision regions of a classifier. The decision regions of the classifier are the partitions between different classes of data. The plot below shows the output of this function.

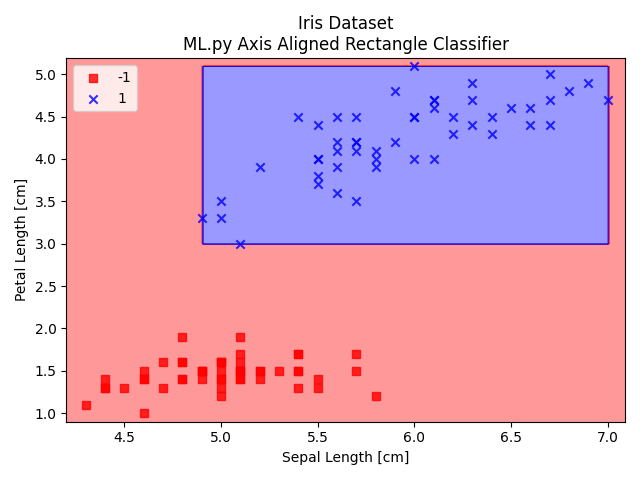


Figure : Setosa (-1) is represented by red squares. Versicolor (1) is represented by blue crosses.

### Usage

The plot\_decision\_regions function can be imported from the ML.py library using the following import statement:

from ML import plot\_decision\_regions

Several of the included demo scripts use the plot\_decision\_regions function including perceptron.py and axisAlignedRectangle.py.

### Files & Functions

#### ML.py

FUNCTIONS

plot\_decision\_regions(X, y, classifier, resolution=0.02, x\_label='', y\_label='', title='')

This is a helper function to plot the decision regions of the classifier. This shows the partition(s) between the

different classes of objects.

Args:

X : Training vectors, X.shape : [#samples, #features]

y : Target values, y.shape : [#samples]

classifier : the classification algorithm

resolution (float, optional) : the resolution of the meshgrid

x\_label (string, optional) : the x label for the plot

y\_label (string, optional) : the y label for the plot

title (string, optional) : the title for the plot

## Regression Line

### Description

Regression lines help to visualize the relationship between x, y points. Regression lines are typically added to a scatter plot so that the relationship between the points and the line is clear. The line is a result of linear regression and the equation of the regression line is used to approximate the corresponding y-value for a given x-value.

### Usage

The plot\_regression\_line function can be imported from the ML.py library using the following import statement:

from ML import plot\_regression\_line

The linearRegression.py demo script uses this function to display the results of linear regression, as shown below.

Chart, scatter chart

Description automatically generated

Figure : Sample Regression Line

### Files & Functions

#### ML.py

FUNCTIONS

plot\_regression\_line(y\_predicted, x\_actual, y\_actual, x\_label='', y\_label='', title='', line\_color='red', x\_range=None, y\_range=None)

This function plots the linear regression line.

A linear regression line has an equation of the form Y = a + bX.

X is the explanatory variable and Y is the dependent variable.

The slope of the line is b, and a is the intercept.

Args:

y\_predicted : the y values predicted by the linear regression learner

x\_actual : the actual x values

y\_actual : the actual y values

x\_label (str, optional): Horizontal axis label. Defaults to "".

y\_label (str, optional): Vertical axis label. Defaults to "".

title (str, optional): Plot title. Defaults to "".

line\_color (str, optional): Plot line color. Defaults to 'red'.

x\_range (tuple, optional): x range of graph

y\_range (tuple, optional): y range of graph

## Scatter Plots

### Description

Scatter plots are helpful tools to observe the relationship between different variables. Scatter plots can also be used to help make determinations about whether data is separable or inseparable.

### Usage

Matplotlib contains a function called [matplotlib.pyplot.scatter](https://matplotlib.org/3.3.2/api/_as_gen/matplotlib.pyplot.scatter.html) that will display a scatter plot. Usage of this function is described in the Matplotlib documentation and demonstrated in each of the demo scripts included with the project.

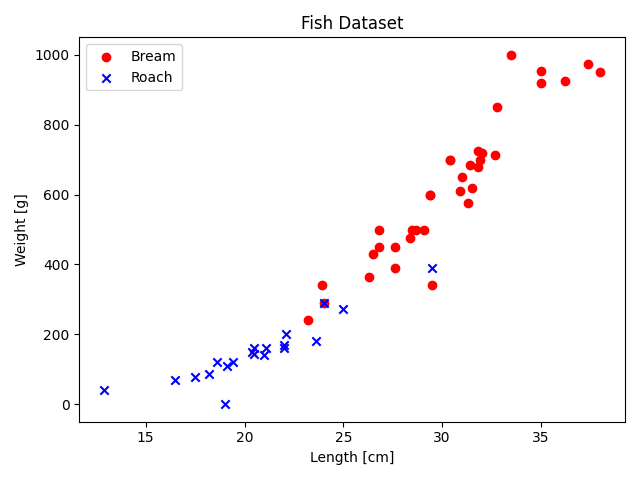


Figure : Sample scatter plot using data from the Fish Market dataset.