TASK

Supervised Learning – Logistic Regression

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Introduction

WELCOME TO THE SUPERVISED LEARNING – LOGISTIC REGRESSION TASK!

We have worked with regression models and have been able to make predictions for the datasets for which the dependent variable is numerical. In this task, we are going to predict the outcome for datasets whose dependent variable is categorical.

CLASSIFICATION PROBLEMS

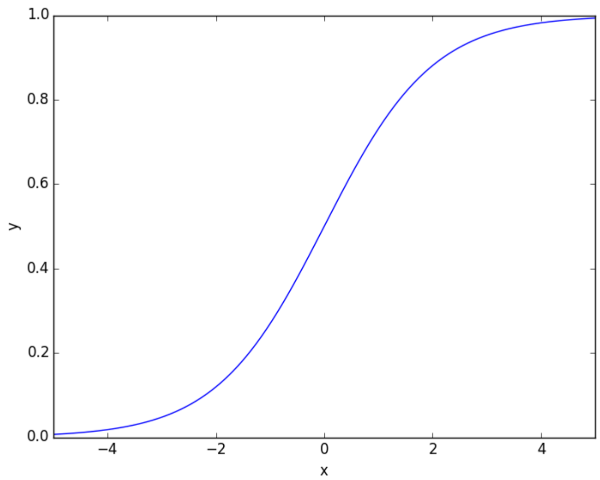
The linear regression models discussed in the previous tasks assumed that the dependent variable **Y** is a **continuous numerical value**. However, it is very common in machine learning for problems instead to be with **categorical variables**. These variables take on distinct non-continuous values that correspond to a particular set of categories. For example, recall the previous compulsory exercise where the nurses could either work in a 'Hospital' or 'Office' position, and these positions were represented as the values 0 and 1. This is an example of a categorical variable, where the category is usually encoded as a numeric value.

Predicting categorical variables is called **classification**. Classification problems are very common, perhaps even more so than problems suited for regression.

Classification involves predicting the probability of each of the categories for a given observation and assigning the observation to the category with the highest probability. For example, a classifier might take an hourly wage and the number of years of practice of an employee and predict the probability that they are a hospital nurse and the probability that they are an office nurse. The model would then typically return either the probabilities or the category with the highest probability.

LOGISTIC REGRESSION

One approach to classification is logistic regression. Logistic regression is a common way of doing binary classification, which is classifying into two categories. It works by using the logistic function. This function, also called the sigmoid function, is an S-shaped curve that maps input values x to output values y.



Logistic regression is similar to linear regression, however, the output is not continuous along a line, but a value between 0 and 1. That value can then be interpreted as the probability that the instance belongs to a certain category.

To give you an example, consider this sample of the Iris dataset:

SepalLength	SepalWidth	PetalLength	PetalWidth	Species
5.3	3.7	1.5	0.2	Iris-setosa
5	3.3	1.4	0.2	Iris-setosa
7	3.2	4.7	1.4	Iris-versicolour
6.4	3.2	4.5	1.5	Iris-versicolour

Our input values are the length and width of both the petal and sepal. The output will be the probability of the instance of being either a setosa or versicolour type.

The model will calculate the probability that a sample (consisting of a set of these measurements, or 'features') belongs to each category using a simple formula:

$$\mathbf{p(Species) = \beta_0 + \beta_1 SepalLength + \beta_2 SepalWidth + \beta_3 PetalLength + \beta_4 PetalWidth}$$

Let's say we fit the model and it predicts the following output:

setosa	versicolour
0.4	0.6
0.7	0.3
0.2	0.8
0.9	0.1

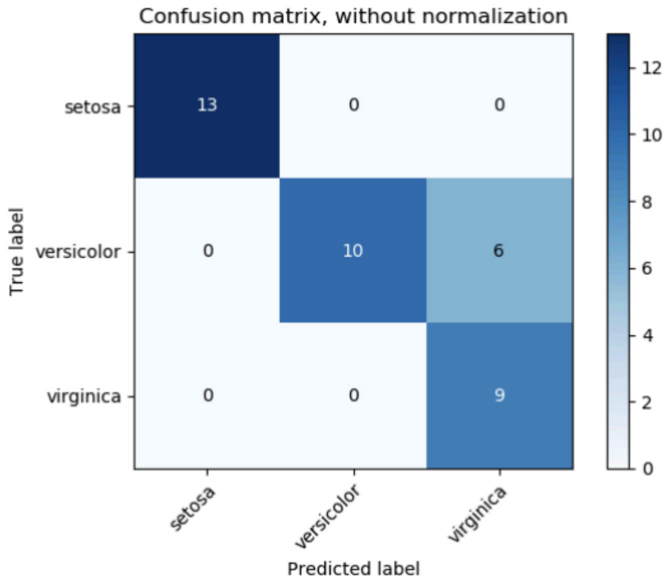
This table shows that the first observation is predicted with a 40% probability to be of the species setosa, and with a 60% probability to be the species versicolour. The prediction for the first instance is thus that it's a member of the category versicolour.

EVALUATING CLASSIFICATION

In the tasks on regression, we evaluated our models by looking at the deviation of the predictions from the gold standard and computing the error. This works for continuous outcomes but not for categorical ones. Outcomes of classifiers are instead evaluated in different ways.

Confusion matrix

A confusion matrix is an NxN table that summarises a classification model's predictions. One axis of a confusion matrix is the label that the model predicted, and the other axis is the actual label. N represents the number of classes. In a binary classification problem N=2. In the complete Iris dataset with three classes, N=3. Here is a sample confusion matrix for the iris classification problem:



The confusion matrix is a great way to see where the weaknesses of the classifier lie. In this example, we see that the model never classifies setosa instances as versicolour or vice versa, but on six occasions it classified versicolour instances as virginica instances, suggesting that those two types are, in the eyes of the system, harder to distinguish.

While the confusion matrix gives insights into the behaviour of the classifier, we need evaluation metrics to make claims about whether the model did well or not compared to other models. To understand the most common evaluation metrics, let's go over a story.

> A shop owner employs a security guard to keep a lookout for shoplifters. If the guard sees someone slip any merchandise into their pockets, he approaches the person he suspects of shoplifting, retrieves the stolen items, and escorts the shoplifter out of the shop. Unfortunately, looks can be deceiving, and the security guard sometimes makes mistakes and confronts people who may have only been putting their mobile phone back in their pocket. This makes innocent customers very upset and the shop owner gets angry. Practised shoplifters also sometimes deceive the security guard and slip past him unnoticed with stolen goods, which also makes the shop owner angry as he is losing money. The security guard lets regular customers who do not shoplift pass peacefully out of

the shop.

This story highlights two types of errors the security guard can make: accusing an innocent person of shoplifting and missing an actual shoplifting event.

If we state that:

- 'Shoplifter' is the positive class
- 'Not a shoplifter' is the negative class

Then we can summarise our 'shoplifting prediction' model using a 2x2 confusion matrix with the following four possible outcomes:

True Positive (TP):

- Reality: A person stole an item
- Guard said: 'Shoplifter.'
- Outcome: The owner is happy

False Positive (FP):

- Reality: Regular customer, not stealing
- Guard said: 'Shoplifter.'
- Outcome: The owner is angry

False Negative (FN):

- Reality: A person stole an item
- Guard said: 'Not a shoplifter.'
- Outcome: The owner is angry

True Positive (TP): True Negative TN

- Reality: Regular customer, not stealing
- Guard said: 'Not a shoplifter.'
- Outcome: The owner is happy

Correct predictions occur both for true positive predictions, where the model correctly predicts a positive (shoplifting) event, and true negative predictions, where the model correctly predicts a negative event (not shoplifting).

Incorrect predictions occur when the model predicts a false positive or a false negative. False positive predictions occur when the model predicts the positive class, but the reality is the negative class – i.e., a regular customer is accused of shoplifting. False negative predictions occur when the model predicts the negative class, but the reality is a positive class – i.e., the guard thinks a shoplifter is a regular customer and lets them pass.

For a multi-class classification problem that deals with more than two classes (e.g., setosa, versicolour, and virginica), a confusion matrix is made for each class (i.e., setosa vs not-setosa, versicolour vs not-versicolour, and virginica vs not-virginica) and evaluation metrics can be computed for each class and then averaged to get a sense of overall performance.

This brings us to common evaluation metrics, which are calculated using the number of TPs, FPs, TNs, and FNs in the confusion table.

Accuracy

Accuracy is one metric for evaluating classification models. Informally, accuracy is the fraction of predictions our model got right. Formally, accuracy has the following definition:

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

Thus, in the shoplifter example, accuracy is the number of correct predictions (both shoplifter and not a shoplifter) out of all the predictions made. For the iris example discussed earlier, the number of correct predictions is the squares along the diagonal in the confusion matrix coloured darker blue, and the total number of predictions is the number of observations in the test set, i.e., the total of all the numbers in the confusion matrix.

Note that if a class is very rare, the value of TP will be low. This means that a model that does not predict a positive for any of the test items will have high accuracy. After all, the TN value will be high enough to offset the cost of the false negatives. For this reason, accuracy is often not the only measure you will want to use.

Precision

Precision is the proportion of predictions of the positive class that is correct. Precision is defined as follows:

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

In our shoplifter example, this metric tells us: 'Of all the predictions that a person was a shoplifter (i.e., positive predictions), what proportion of these were correct?'

Recall

Recall is a measure of how many instances of a class the model was able to recognise. Recall is defined as follows:

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

Again in terms of our shoplifter example, this metric tells us: 'Of all actual shoplifters in the shop, what proportion of them were spotted by the security guard?'

F1 score

Precision and recall often form a trade-off: A model which predicts the category 'shoplifter' very often is likely to identify all shoplifters (= high recall), but is also likely to predict 'shoplifter' labels for a lot of customers that are not shoplifters (= low precision). In contrast, a model which is very careful about which customers it predicts to be shoplifters will have high precision but low recall, i.e., it is likely to let a lot of shoplifters exit the shop unconfronted, but won't misclassify many innocent customers as shoplifters. It is, therefore, useful to have a measure that is high for models that have both decent recall and decent precision. The most common is the F1 score.

The F1 score is the weighted average of precision and recall, and is defined as follows:

$$F1 = 2 \times \frac{precision \times recall}{precision + recall}$$

Instructions

- Read through this **blog** and the **Logistic_Regression.ipynb** file that comes with this task as guides to applying logistic regression.

- Read this **article** from DataCamp to learn about preprocessing categorical variables.

Practical Task

Follow these steps:

- Begin by reading the Iris dataset (`Iris.csv`) into a Jupyter notebook and name it **iris_logistic_regression.ipynb**.

- The dataset consists of three classes of irises. The objective is to create a classifier that will predict whether an iris belongs to the '`Iris-setosa`' class or not.

  This means that we have two classes: '`Iris-setosa`' and `not-`'`Iris-setosa`' (which includes '`Iris-versicolour`' and '`Iris-virginica`').

  - Identify your independent variable **x**.
  - Encode your dependent variable **y** such that '`Iris-setosa`' is encoded

Split the target variable into 2 groups.

as `0`, and '`Iris-versicolour`' and '`Iris-virginica`' are both encoded as `1`. (`0` corresponds to the `'Iris-setosa`' class, and `1` corresponds to the `not-`'`Iris-setosa`' class.)

- Split the data into a training and test set.
- Use **sklearn**'s logistic regression function to fit a model and make predictions on the test set.
- Use **sklearn** to generate a confusion matrix, which compares the predicted labels to the actual labels (gold labels).
- Analyse the confusion matrix and provide a prediction, in a comment, on whether the model is likely to have higher precision, higher recall, or similar precision and recall.
- Write your **own code** to calculate the accuracy, precision, and recall, and check whether your prediction was right.

- (**Optional**) Repeat this task but change it so that we only have all three categories '`Iris-setosa`', '`Iris-versicolour`', and '`Iris-virginica`' corresponding to the numeric values 0, 1, and 2 respectively; this will now be a three-class problem. Observe how this changes the confusion matrix.

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