Homework 12: Classification

Reading:

- Classification (https://www.inferentialthinking.com/chapters/17/classification.html)

Please complete this notebook by filling in the cells provided. Before you begin, execute the following cell to load the provided tests. Each time you start your server, you will need to execute this cell again to load the tests.

Homework 12 is due **Thursday, 4/30 at 11:59pm**. You will receive an early submission bonus point if you turn in your final submission by Wednesday, 4/29 at 11:59pm. Start early so that you can come to office hours if you're stuck. Check the website for the office hours schedule. Late work will not be accepted as per the policies (http://data8.org/sp20/policies.html) of this course.

Directly sharing answers is not okay, but discussing problems with the course staff or with other students is encouraged. Refer to the policies page to learn more about how to learn cooperatively.

For all problems that you must write out explanations and sentences for, you **must** provide your answer in the designated space. Moreover, throughout this homework and all future ones, please be sure to not re-assign variables throughout the notebook! For example, if you use `max_temperature` in your answer to one question, do not reassign it later on.

In [1]:
```
# Don't change this cell; just run it.

import numpy as np
from datascience import *

# These lines do some fancy plotting magic.
import matplotlib
%matplotlib inline
import matplotlib.pyplot as plt
plt.style.use('fivethirtyeight')
import warnings
warnings.simplefilter('ignore', FutureWarning)

from client.api.notebook import Notebook
ok = Notebook('hw12.ok')
```

```
=====================================================================
Assignment: Homework 12: Classification
OK, version v1.14.19
=====================================================================
```

```
---------------------------------------------------------------------
----
LoadingException                          Traceback (most recent call l
ast)
<ipython-input-1-f0cdafd032eb> in <module>
     13
     14 from client.api.notebook import Notebook
---> 15 ok = Notebook('hw12.ok')

/opt/anaconda3/lib/python3.7/site-packages/client/api/notebook.py in __
init__(self, filepath, cmd_args, debug, mode)
     13         ok_logger = logging.getLogger('client')   # Get top-lev
el ok logger
     14         ok_logger.setLevel(logging.DEBUG if debug else logging.
ERROR)
---> 15         self.assignment = load_assignment(filepath, cmd_args)
     16         # Attempt a login with enviornment based tokens
     17         login_with_env(self.assignment)

/opt/anaconda3/lib/python3.7/site-packages/client/api/assignment.py in
load_assignment(filepath, cmd_args)
     22     if cmd_args is None:
     23         cmd_args = Settings()
---> 24     return Assignment(cmd_args, **config)
     25
     26 def _get_config(config):

/opt/anaconda3/lib/python3.7/site-packages/client/sources/common/core.p
y in __call__(cls, *args, **kargs)
    185                 raise ex.SerializeException('__init__() missing
expected '
    186                                             'argument {}'.format(attr))
--> 187         obj.post_instantiation()
    188         return obj
    189

/opt/anaconda3/lib/python3.7/site-packages/client/api/assignment.py in
post_instantiation(self)
    151     def post_instantiation(self):
    152         self._print_header()
--> 153         self._load_tests()
    154         self._load_protocols()
    155         self.specified_tests = self._resolve_specified_tests(

/opt/anaconda3/lib/python3.7/site-packages/client/api/assignment.py in
_load_tests(self)
    205
    206         if not self.test_map:
--> 207             raise ex.LoadingException('No tests loaded')
    208
    209     def dump_tests(self):

LoadingException: No tests loaded
```

1. Bay Area School Coordinates with Classification

Welcome to Homework 12! This homework is about k-Nearest Neighbors classification (kNN). Since this topic is covered in depth in Project 3, the purpose of this homework is to reinforce the basics of this method. You can and should reuse a lot of code that you wrote for Project 3 for this homework, or use code from this homework on Project 3!

Our Dearest Neighbors

Carol is trying classify students as either attendees of UC Berkeley or as attendees of Leland Stanford Junior College. To classify the students, Carol has access to the coordinates of the location they live during the school year. First, load in the `coordinates` table.

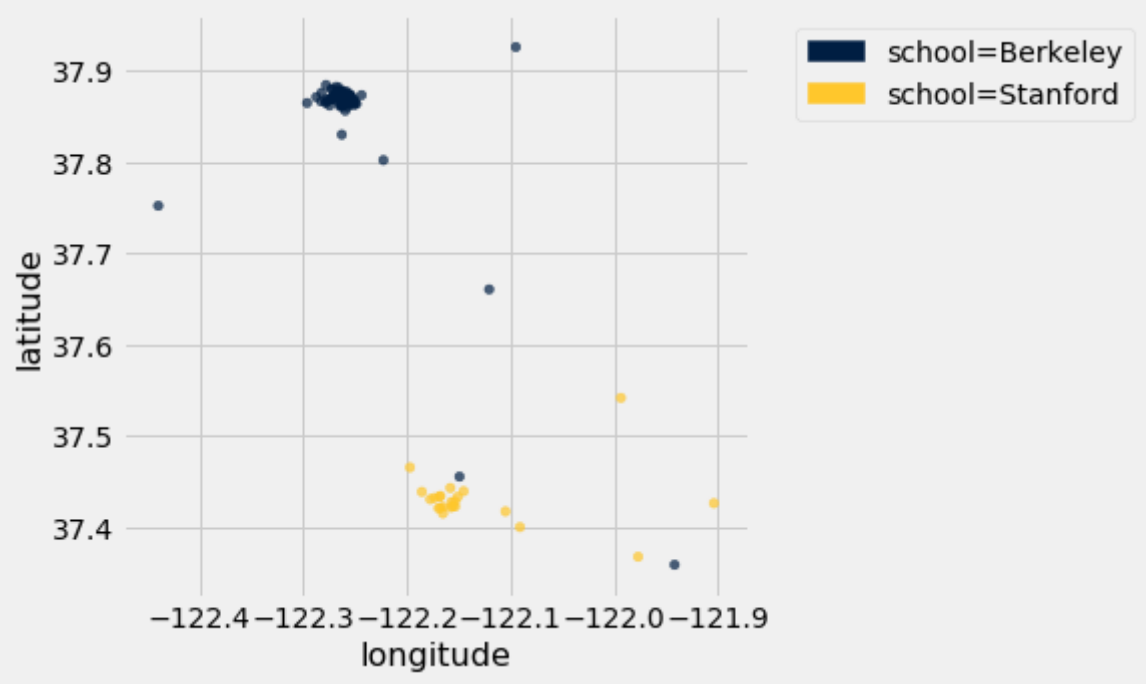
In [2]:
```
# Just run this cell!
coordinates = Table.read_table('coordinates.csv')
coordinates.show(5)
```

latitude	longitude	school
37.8693	-122.255	Berkeley
37.8651	-122.256	Berkeley
37.8661	-122.254	Berkeley
37.868	-122.26	Berkeley
37.8683	-122.257	Berkeley

... (95 rows omitted)

As usual, let's investigate our data visually before performing any kind of numerical analysis.

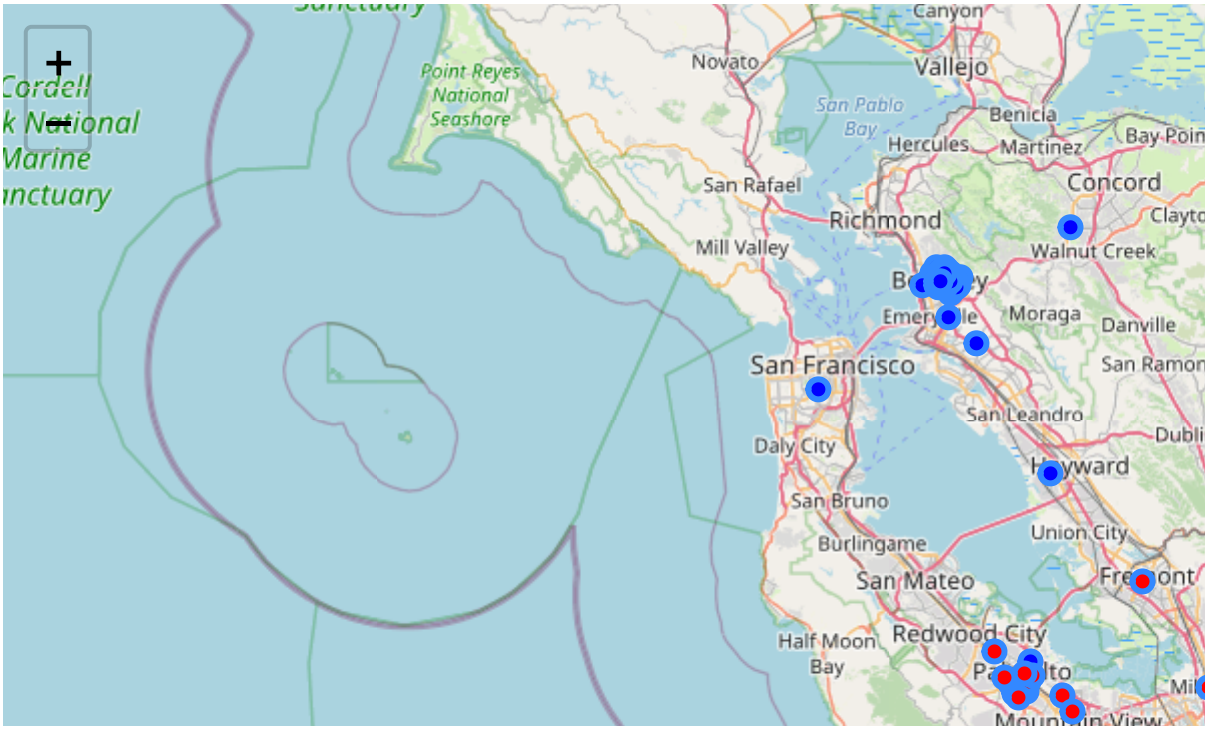
In [3]:
```
# Just run this cell!
coordinates.scatter("longitude", "latitude", group="school")
```



The locations of the points on this scatter plot might be familiar - run the following cell to see what they correspond to.

In [4]:
```
# Just run this cell!
colors = {"Berkeley":"blue", "Stanford":"red"}
t = Table().with_columns("lat", coordinates.column(0),
                                        "lon", coordinates.column(1),
                                        "color", coordinates.apply(colors.
get, 2)
                         )
Circle.map_table(t, radius=5, fill_opacity=1)
```

Out[4]:



Question 1

Let's begin implementing the k-Nearest Neighbors algorithm. Define the `distance` function, which takes in two arguments: an array of numerical features, and a different array of numerical features. The function should return the Euclidean distance (https://en.wikipedia.org/wiki/Euclidean_distance) between the two arrays. Euclidean distance is often referred to as the straight-line distance formula that you may have learned previously.

```
BEGIN QUESTION
name: q1_1
manual: false
```

In [5]:
```
def distance(arr1, arr2):
    # BEGIN SOLUTION
    return np.sqrt(sum((arr1-arr2)**2))
    # END SOLUTION

# Don't change/delete the code below in this cell
distance_example = distance(make_array(1, 2, 3), make_array(4, 5, 6))
distance_example
```

Out[5]: 5.196152422706632

In [6]:
```
# TEST
type(distance_example) in set([float, np.float32, np.float64])
```

Out[6]: True

In [7]:
```
# TEST
np.round(distance_example, 3) == 5.196
```

Out[7]: True

Splitting the dataset

We'll do 2 different kinds of things with the `coordinates` dataset:

1. We'll build a classifier using coordinates for which we know the associated label; this will teach it to recognize labels of similar coordinate values. This process is known as *training*.
2. We'll evaluate or *test* the accuracy of the classifier we build on data we haven't seen before.

For reasons discussed in lecture and the textbook, we want to use separate datasets for these two purposes. So we split up our one dataset into two.

Question 2

Next, let's split our dataset into a training set and a test set. Since `coordinates` has 100 rows, let's create a training set with the first 75 rows and a test set with the remaining 25 rows. Remember that assignment to each group should be random, so we should shuffle the table first.

Hint: as a first step we can shuffle all the rows, then use the `tbl.take` function to split up the rows for each table

```
BEGIN QUESTION
name: q1_2
manual: false
```

In [8]:
```
shuffled_table = coordinates.sample(with_replacement=False) # SOLUTION
train = shuffled_table.take(np.arange(0, 75)) # SOLUTION
test = shuffled_table.take(np.arange(75, 100)) # SOLUTION

print("Training set:\t",   train.num_rows, "examples")
print("Test set:\t",       test.num_rows, "examples")
train.show(5), test.show(5);
```

```
Training set:    75 examples
Test set:        25 examples
```

latitude	longitude	school
37.8805	-122.273	Berkeley
37.4228	-122.156	Stanford
37.8685	-122.272	Berkeley
37.4261	-121.904	Stanford
37.8638	-122.249	Berkeley

... (70 rows omitted)

latitude	longitude	school
37.8672	-122.264	Berkeley
37.3587	-121.942	Berkeley
37.8697	-122.274	Berkeley
37.4171	-122.105	Stanford
37.8744	-122.255	Berkeley

... (20 rows omitted)

In [9]:
```
# TEST
# Double check that you have the correct number of rows for the `train`
 table.
train.num_rows == 75
```

Out[9]: True

In [10]:
```
# TEST
# Double check that you have the correct number of rows for the `test` t
able.
test.num_rows == 25
```

Out[10]: True

In [11]:
```
# TEST
train.num_rows + test.num_rows == coordinates.num_rows
```

Out[11]: True

Question 3

Assign `features` to an array of the labels of the features from the `coordinates` table.

Hint: which of the column labels in the `coordinates` table are the features, and which of the column labels correspond to the class we're trying to predict?

```
BEGIN QUESTION
name: q1_3
manual: false
```

In [12]:
```
features = make_array("latitude", "longitude") # SOLUTION
features
```

Out[12]:
```
array(['latitude', 'longitude'], dtype='<U9')
```

In [13]:
```
# TEST
sorted(features) == ['latitude', 'longitude']
```

Out[13]:
```
True
```

Question 4

Now define the `classify` function. This function should take in a `row` from a table like `test` and classify it based on the data in `train` using the `k` -Nearest Neighbors based on the correct `features` .

Hint: use the `row_to_array` function we defined for you to convert rows to arrays of features so that you can use the `distance` function you defined earlier.

Hint 2: the skeleton code we provided iterates through each row in the training set

```
BEGIN QUESTION
name: q1_4
manual: false
```

In [14]:
```
def row_to_array(row, features):
    arr = make_array()
    for feature in features:
        arr = np.append(arr, row.item(feature))
    return arr

def classify(row, k, train):
    test_row_features_array = row_to_array(row, features)
    distances = make_array()
    for train_row in train.rows:
        train_row_features_array = row_to_array(train_row, features) # SOLUTION
        row_distance = distance(test_row_features_array, train_row_features_array) # SOLUTION
        distances = np.append(distances, row_distance) # SOLUTION
    train_with_distances = train.with_column("Distances", distances) # SOLUTION
    nearest_neighbors = train_with_distances.sort("Distances").take(np.arange(k)) # SOLUTION
    most_common_label = nearest_neighbors.group("school").sort("count", descending=True).column("school").item(0) # SOLUTION
    return most_common_label # SOLUTION

# Don't modify/delete the code below
first_test = classify(test.row(0), 5, train)
first_test
```

Out[14]: 'Berkeley'

In [15]:
```
# TEST
type(first_test) == str
```

Out[15]: True

In [16]:
```
# TEST
sorted_coordinates = coordinates.sort("school")
classify(sorted_coordinates.row(85), 3, sorted_coordinates.take(np.arange(50, 100))) == 'Stanford'
```

Out[16]: True

Question 5

Define the function `three_classify` that takes a `row` from `test` as an argument and classifies the row based on using 3-Nearest Neighbors. Use this function to find the `accuracy` of a 3-NN classifier on the `test` set. `accuracy` should be a proportion (not a percentage) of the schools that were correctly predicted.

Hint: you should be using a function you just created!

Note: Usually before using a classifier on a test set, we'd classify first on a "validation" set, which we then can modify our training set again if need be, before actually testing on the test set. You don't need to do that for this question, but you will learn about this more in Data 100.

```
BEGIN QUESTION
name: q1_5
manual: false
```

In [17]:
```
def three_classify(row):
    # BEGIN SOLUTION
    return classify(row, 3, train)
    # END SOLUTION

test_with_prediction = test.with_column("prediction", test.apply(three_c
lassify))
labels_correct = test_with_prediction.column("school") == test_with_pred
iction.column("prediction") # SOLUTION
accuracy = np.count_nonzero(labels_correct) / len(labels_correct) # SOLU
TION
accuracy
```

Out[17]: 0.96

In [18]:
```
# TEST
sorted_coordinates = coordinates.sort("school")
classify(sorted_coordinates.row(29), 3, train) == three_classify(sorted_
coordinates.row(29))
```

Out[18]: True

In [19]:
```
# TEST
# You should expect to see really high accuracy
0.90 <= accuracy <= 1
```

Out[19]: True

Question 6

There are 77 rows of Berkeley students and 23 rows of Stanford students in the `coordinates` table. If we used the entire `coordinates` table as the train set, what is the smallest value of k would ensure that a k-Nearest Neighbor classifier would always predict Berkeley as the class? Assign the value to `k`.

```
BEGIN QUESTION
name: q1_6
manual: false
```

In [20]:
```
k = 47 # SOLUTION
k
```

Out[20]: 47

In [21]:
```
# TEST
# `k` should be an int
type(k) == int
```

Out[21]: True

In [22]:
```
# HIDDEN TEST
k == 47
```

Out[22]: True

Question 7

Why do we divide our data into a training and test set? Should we use our test set to find the best possible number of neighbors for a k-NN classifer? What is the point of a test set, and why do we only want to use the test set once? Explain.

```
BEGIN QUESTION
name: q1_7
manual: true
```

SOLUTION: We divide our data into a training and test set, so we can use the training set in order to build our classifier, and the test-set is used to see if your model will be able to generalize to data you have never seen before. As such, you should not use your test set to tune your parameters/find the best possible number of neighbors for a k-NN classifier. Otherwise, you are biasing your classifier and it may learn how to get a good accuracy on your training/test set, but not generalize to data you have never seen before. Ideally, this is why you should only use the test set once. (You'll learn more about this in depth if you decide to take Data 100)

Question 8

Why do we use an odd-numbered `k` in k-NN? Explain.

```
BEGIN QUESTION
name: q1_8
manual: true
```

SOLUTION: We use an odd-numbered `k` in k-NN in order to avoid having ties; using an odd-numbered `k` guarantees a majority.

Question 9

Thomas has devised a scheme for splitting up the test and training set. For each row from `coordinates`:

- Rows for Stanford students have a 50% chance of being placed in the train set and 50% chance of placed in the test set.
- Rows for Berkeley students have a 80% chance of being placed in the train set and 20% chance of placed in the test set.

Given that a row is in the test set, what is the probability that it corresponds to a Stanford student? Assign that probability to `prob_furd`.

Hint: Remember that there are 77 Berkeley students and 23 Stanford students in `coordinates`

Hint 2: Thomas' last name is Bayes

```
BEGIN QUESTION
name: q1_9
manual: false
```

In [23]:
```
prob_furd = (.23 * .5) / ((.23 * .5) + (.77 * .2)) # SOLUTION
prob_furd
```

Out[23]:
```
0.4275092936802974
```

In [24]:
```
# TEST
type(prob_furd) in set([float, np.float32, np.float64])
```

Out[24]:
```
True
```

In [25]:
```
# TEST
# Should be a decimal, not a percentage
0 <= prob_furd <= 1
```

Out[25]:
```
True
```

In [26]:
```
# HIDDEN TEST
np.round(prob_furd, 3) == 0.428
```

Out[26]:
```
True
```

(OPTIONAL, NOT IN SCOPE): k-NN for Non-Binary Classification

THIS IS NOT IN SCOPE/IS OPTIONAL. There are no autograder tests for this/code for you to write. It just relies on the function `classify` in Question 4.

In this class, we have taught you how to use the kNN algorithm to classify data as one of two classes. However, much of the data you will encounter in the real world will not fall nicely into one of two categories.

How can we classify data with non-binary classes? It turns out we can still use kNN! That is, we find the distance between a point and all its neighbors, find the nearest neighbors, and take a majority vote among the neighbors to determine this point's class.

The only difference is that now the neighboring points have more than two possible classes. This does introduce difficulty because now we have no way of guaranteeing that we will not encounter ties between classes. In the case that we do encounter a tie, we can just arbitrarily choose one of the classes.

In fact, you don't even have to modify the code you wrote before at all to enable multi-class classification!

Let's add some more data to our train table, this time for another class of students, students at San Jose Community College (SJCC).

In [27]:
```
coordinates_multi = coordinates.with_rows([
                                [37.304346, -121.915401, "SJCC"],
                                [37.316275, -121.913879, "SJCC"],
                                [37.409435, -121.951379, "SJCC"],
                                [37.349387, -121.960771, "SJCC"],
                                [37.329083, -121.928479, "SJCC"],
                                [37.313017, -121.866730, "SJCC"],
                                [37.346525, -121.894767, "SJCC"],
                                [37.364157, -121.955717, "SJCC"],
                                [37.383362, -121.925776, "SJCC"],
                                [37.329545, -121.880639, "SJCC"]
])
```

In [28]:
```
classify(coordinates_multi.row(0), 5, coordinates_multi)
```

Out[28]:
```
'Berkeley'
```

In [29]:
```
classify(coordinates_multi.row(91), 5, coordinates_multi)
```

Out[29]:
```
'Stanford'
```

In [30]:
```
classify(coordinates_multi.row(105), 5, coordinates_multi)
```

Out[30]:
```
'SJCC'
```

Our classifier can classify rows as belonging to one of three classes!

Classification is one of the most important fields in statistics, data science, and machine learning. There are thousands of different classification algorithms and modifications of algorithms! There are many that you'll learn if you continue down the path of becoming a data scientist!

2. Final-Semester Survey

You can find the end of semester feedback form here (https://docs.google.com/forms/d/e/1FAIpQLSeVRzkHTsNIrnblaYCopJViaFDro1HfemS4y79Q_oZPxUcEvg/viewfo usp=sf_link). Please take some time to fill the survey out! Data 8 is still a relatively new class, and your feedback helps the class get better every semester!

As incentive, if 80% of the course fills out this feedback form **and** the official Berkeley Course Evaluations (which will be released sometime in the next couple of weeks) for Data 8, everyone will receive two points of extra credit!

Question 1. Fill out the end of semester feedback form linked above. Once you have submitted, a secret word will be displayed. Set `secret_word` to the secret string at the end of the form.

```
BEGIN QUESTION
name: q2_1
manual: false
```

In [31]:
```
secret_word = "bayes" # SOLUTION
```

In [32]:
```
# TEST
len(secret_word) > 0
```

Out[32]:
```
True
```

In [33]:
```
# HIDDEN TEST
secret_word == "bayes"
```

Out[33]:
```
True
```

3. Submission

Once you're finished, select "Save and Checkpoint" in the File menu and then execute the `submit` cell below. The result will contain a link that you can use to check that your assignment has been submitted successfully. If you submit more than once before the deadline, we will only grade your final submission. If you mistakenly submit the wrong one, you can head to okpy.org (https://okpy.org/) and flag the correct version. To do so, go to the website, click on this assignment, and find the version you would like to have graded. There should be an option to flag that submission for grading!

In [34]:
```
_ = ok.submit()
```

```
---------------------------------------------------------------------------
NameError                                 Traceback (most recent call last)
<ipython-input-34-cc46ca874451> in <module>
----> 1 _ = ok.submit()

NameError: name 'ok' is not defined
```

In [35]:
```
# For your convenience, you can run this cell to run all the tests at once!
import os
print("Running all tests...")
_ = [ok.grade(q[:-3]) for q in os.listdir("tests") if q.startswith('q') and len(q) <= 10]
print("Finished running all tests.")
```

```
Running all tests...
Finished running all tests.
```