

# 15B-Classification-II-Demo

October 31, 2016

## 1 Classification in Practice

Today we'll look at two classification methods in practice: Decision Trees, and k-Nearest Neighbors.

### 1.1 $k$ -Nearest Neighbors

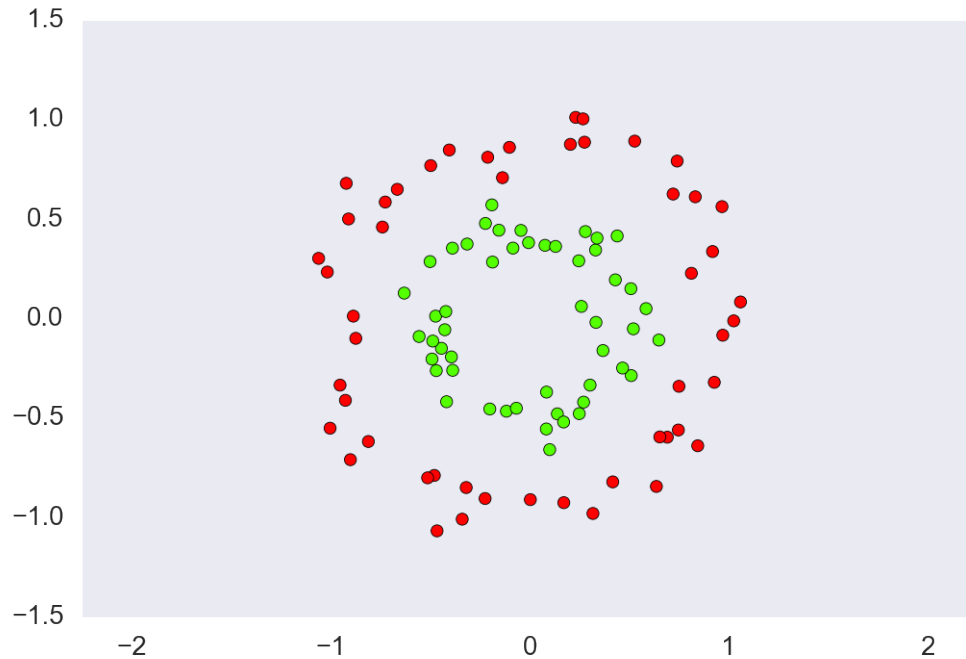
First we'll generate some synthetic data to work with.

```
In [85]: X, y = datasets.make_circles(noise=.1, factor=.5, random_state=1)
         print('Shape of data: {}'.format(X.shape))
         print('Unique labels: {}'.format(np.unique(y)))
```

```
Shape of data: (100, 2)
Unique labels: [0 1]
```

Here is what the data looks like:

```
In [86]: plt.prism() # this sets a nice color map
         plt.scatter(X[:, 0], X[:, 1], c=y)
         _ = plt.axis('equal')
```



Recall that we always want to test on data separate from our training data.  
So we will take the first 50 examples for training and the rest for testing.

```
In [87]: X_train = X[:50]
         y_train = y[:50]
         X_test = X[50:]
         y_test = y[50:]

In [88]: plt.subplot(121)
         plt.scatter(X_train[:, 0], X_train[:, 1], c=y_train, )
         plt.axis('equal')
         plt.title('Training Data')
         plt.subplot(122)
         plt.scatter(X_test[:, 0], X_test[:, 1], c=y_test)
         plt.title('Test Data')
         _=plt.axis('equal')
```



For our first example, we will classify the points (in the two classes) using a k-nn classifier:  
<http://scikit-learn.org/stable/modules/generated/sklearn.neighbors.NearestNeighbors.html#sklearn.neighbors.NearestNeighbors>  
 We will specify that  $k = 5$ , i.e., we will classify based on the majority vote of the 5 nearest neighbors.

```
In [89]: k = 5
         knn = KNeighborsClassifier(n_neighbors=k)
```

In the context of supervised learning, the `scikit-learn fit()` function corresponds to **training** and the `predict()` function corresponds to **testing**.

```
In [90]: knn.fit(X_train,y_train)
         y_pred_test = knn.predict(X_test)
         print('Accuracy on test data: {}'.format(knn.score(X_test, y_test)))
```

Accuracy on test data: 0.72

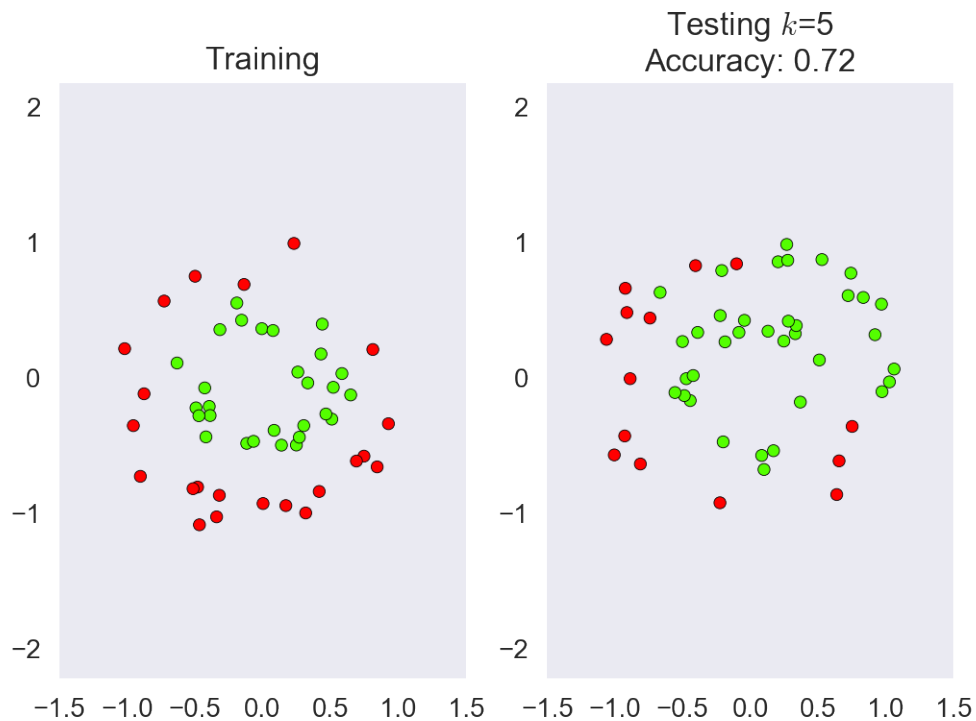
Just for kicks we can see how the classifier does on the training data, although that's not as important as the test data.

```
In [91]: y_pred_train = knn.predict(X_train)
         print('Accuracy on training data: {}'.format(knn.score(X_train, y_train)))
```

Accuracy on training data: 0.94

Now let's visualize the results.

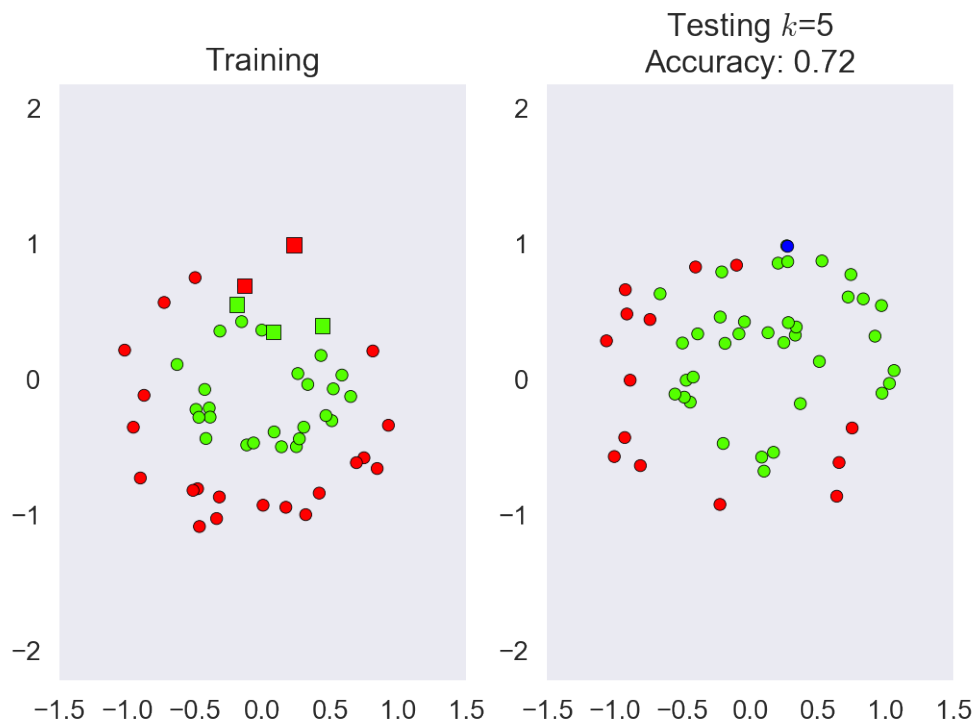
```
In [92]: plt.subplot(121)
plt.scatter(X_train[:, 0], X_train[:, 1], c=y_train)
plt.axis('equal')
plt.title('Training')
plt.subplot(122)
plt.scatter(X_test[:, 0], X_test[:, 1], c=y_pred_test)
plt.title('Testing $k$={}\nAccuracy: {}'.format(k,knn.score(X_test, y_test))
_=plt.axis('equal')
```



Let's look at one of the points that the classifier got wrong:

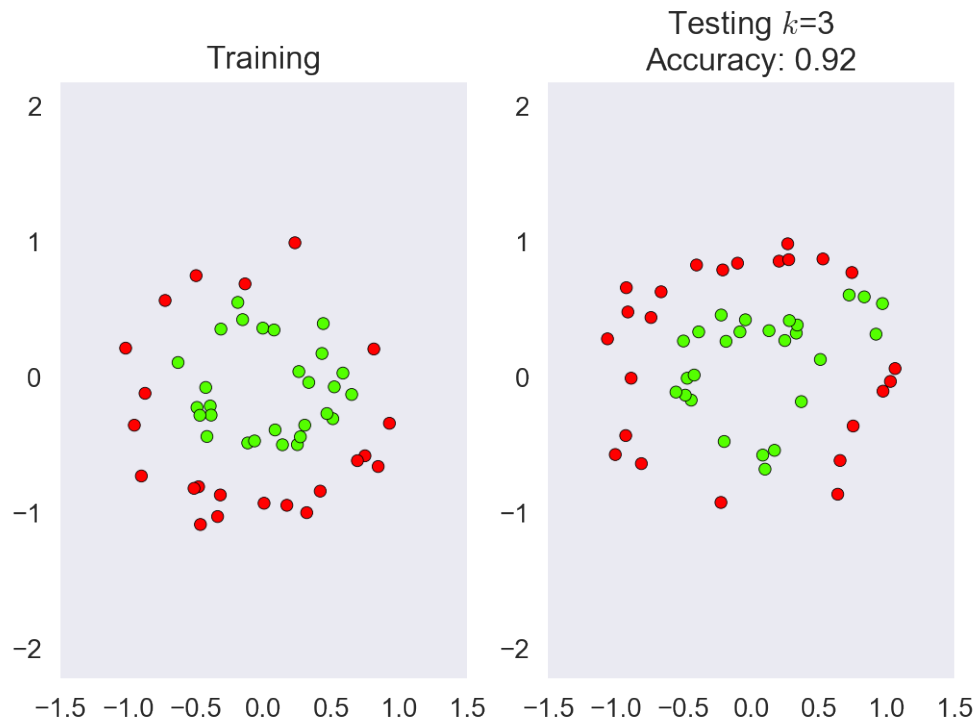
```
In [93]: test_point = np.argmax(X_test[:,1])
X_test[test_point]
neighbors = knn.kneighbors([X_test[test_point]])[1]
plt.subplot(121)
plt.scatter(X_train[:, 0], X_train[:, 1], c=y_train,)
plt.scatter(X_train[neighbors,0], X_train[neighbors,1], c = y_train[neighb
plt.axis('equal')
plt.title(r'Training')
plt.subplot(122)
plt.scatter(X_test[:, 0], X_test[:, 1], c=y_pred_test)
plt.scatter(X_test[test_point,0], X_test[test_point,1], c='b')
```

```
plt.title('Testing $k$={}\nAccuracy: {}'.format(k,knn.score(X_test, y_test))
_ = plt.axis('equal')
```



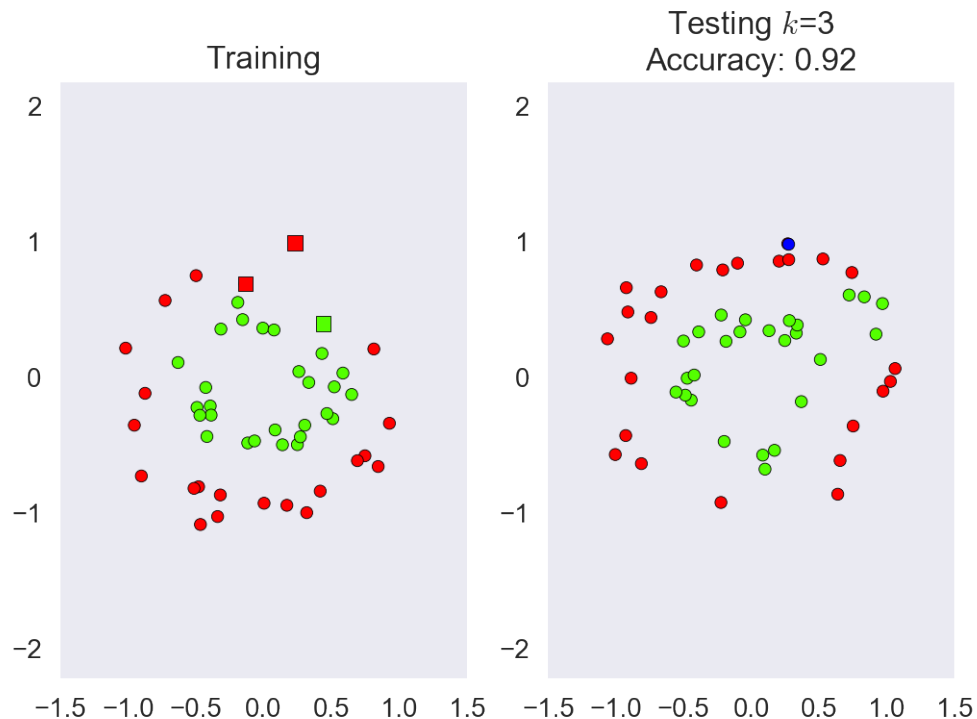
For comparison purposes, let's try  $k = 3$ .

```
In [94]: k = 3
knn = KNeighborsClassifier(n_neighbors=k)
knn.fit(X_train,y_train)
y_pred_test = knn.predict(X_test)
plt.subplot(121)
plt.scatter(X_train[:, 0], X_train[:, 1], c=y_train, )
plt.axis('equal')
plt.title(r'Training')
plt.subplot(122)
plt.scatter(X_test[:, 0], X_test[:, 1], c=y_pred_test)
plt.title('Testing $k$={}\nAccuracy: {}'.format(k,knn.score(X_test, y_test))
_ = plt.axis('equal')
```



And let's look at the same individual point as before:

```
In [95]: test_point = np.argmax(X_test[:,1])
         X_test[test_point]
         neighbors = knn.kneighbors([X_test[test_point]])[1]
         plt.subplot(121)
         plt.scatter(X_train[:, 0], X_train[:, 1], c=y_train,)
         plt.scatter(X_train[neighbors,0], X_train[neighbors,1], c = y_train[neighbors])
         plt.axis('equal')
         plt.title(r'Training')
         plt.subplot(122)
         plt.scatter(X_test[:, 0], X_test[:, 1], c=y_pred_test)
         plt.scatter(X_test[test_point,0], X_test[test_point,1], c='b')
         plt.title('Testing $k$={}\nAccuracy: {}'.format(k,knn.score(X_test, y_test)))
         _=plt.axis('equal')
```



## 1.2 Decision Tree

Next, we'll use a decision tree on the same data set.

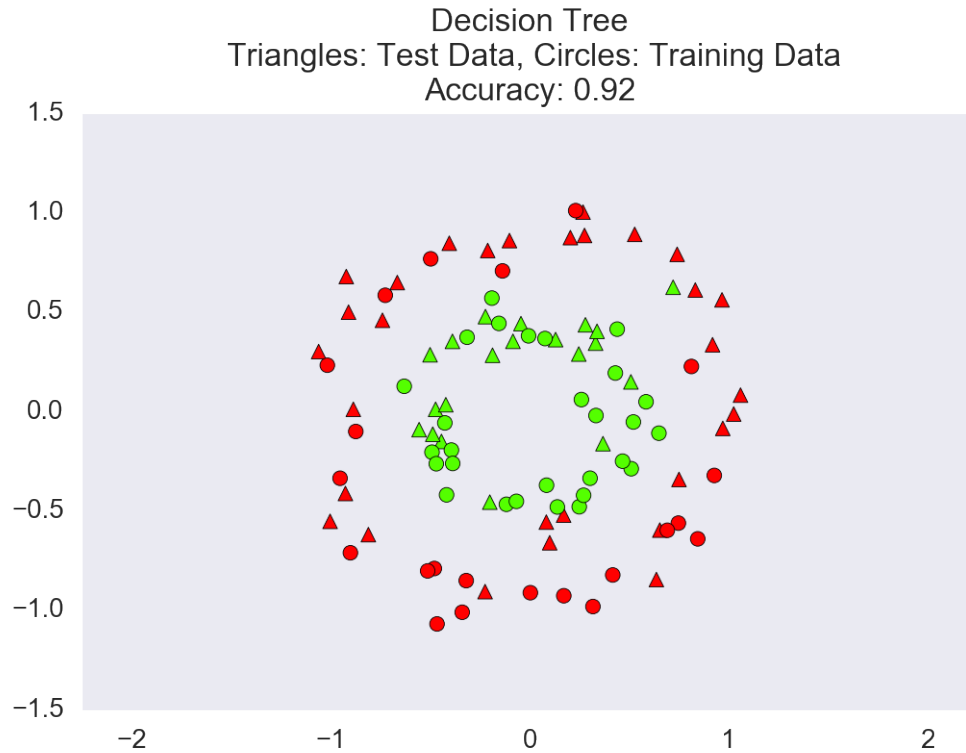
<http://scikit-learn.org/stable/modules/tree.html>

```
In [96]: dtc = tree.DecisionTreeClassifier()

        dtc.fit(X_train,y_train)
        y_pred_test = dtc.predict(X_test)
        print('DT validation accuracy on test cycles: ', dtc.score(X_test, y_test))
        y_pred_train = dtc.predict(X_train)
        print('DT validation accuracy on training cycles: ', dtc.score(X_train, y_train))
```

```
DT validation accuracy on test cycles:  0.92
DT validation accuracy on training cycles:  1.0
```

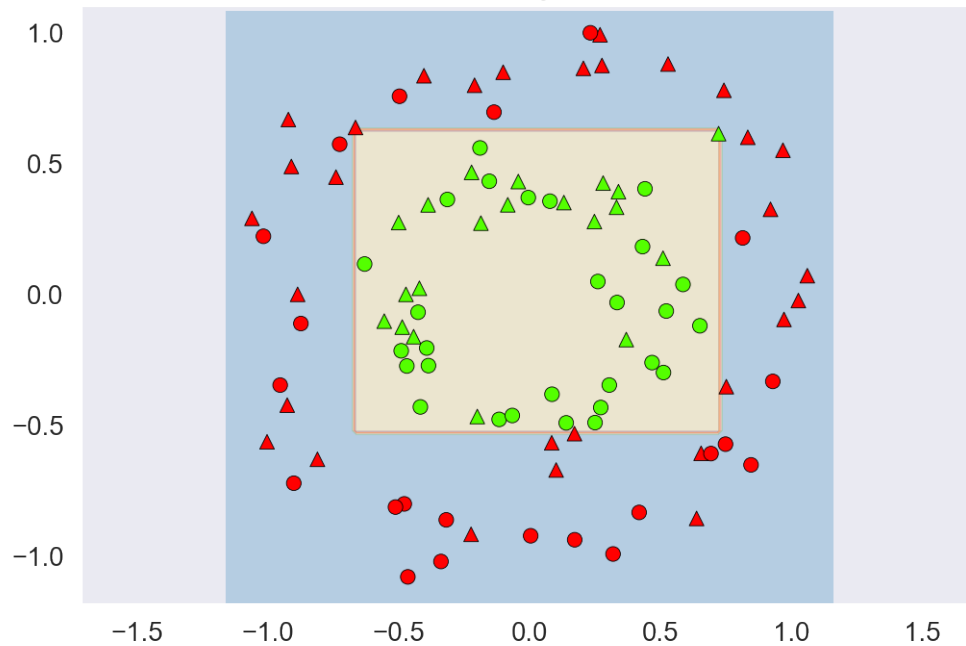
```
In [97]: plt.scatter(X_test[:, 0], X_test[:, 1], c=y_pred_test, marker='^',s=30)
        plt.scatter(X_train[:, 0], X_train[:, 1], c=y_train, s=30)
        plt.axis('equal')
        _=plt.title('Decision Tree\n Triangles: Test Data, Circles: Training Data')
```



```
In [98]: x_min, x_max = X[:, 0].min() - .1, X[:, 0].max() + .1
y_min, y_max = X[:, 1].min() - .1, X[:, 1].max() + .1
plot_step = 0.02
xx, yy = np.meshgrid(np.arange(x_min, x_max, plot_step),
                     np.arange(y_min, y_max, plot_step))
Z = dtc.predict(np.c_[xx.ravel(), yy.ravel()])
Z = Z.reshape(xx.shape)
cs = plt.contourf(xx, yy, Z, cmap=plt.cm.Paired,alpha=0.3)
plt.scatter(X_test[:, 0], X_test[:, 1], c=y_pred_test, marker='^',s=30)
plt.scatter(X_train[:, 0], X_train[:, 1], c=y_train, s=30)
plt.axis('equal')
plt.xlim((x_min, x_max))
plt.ylim((y_min, y_max))
_=plt.title('Decision Tree\n Triangles: Test Data, Circles: Training Data')
```



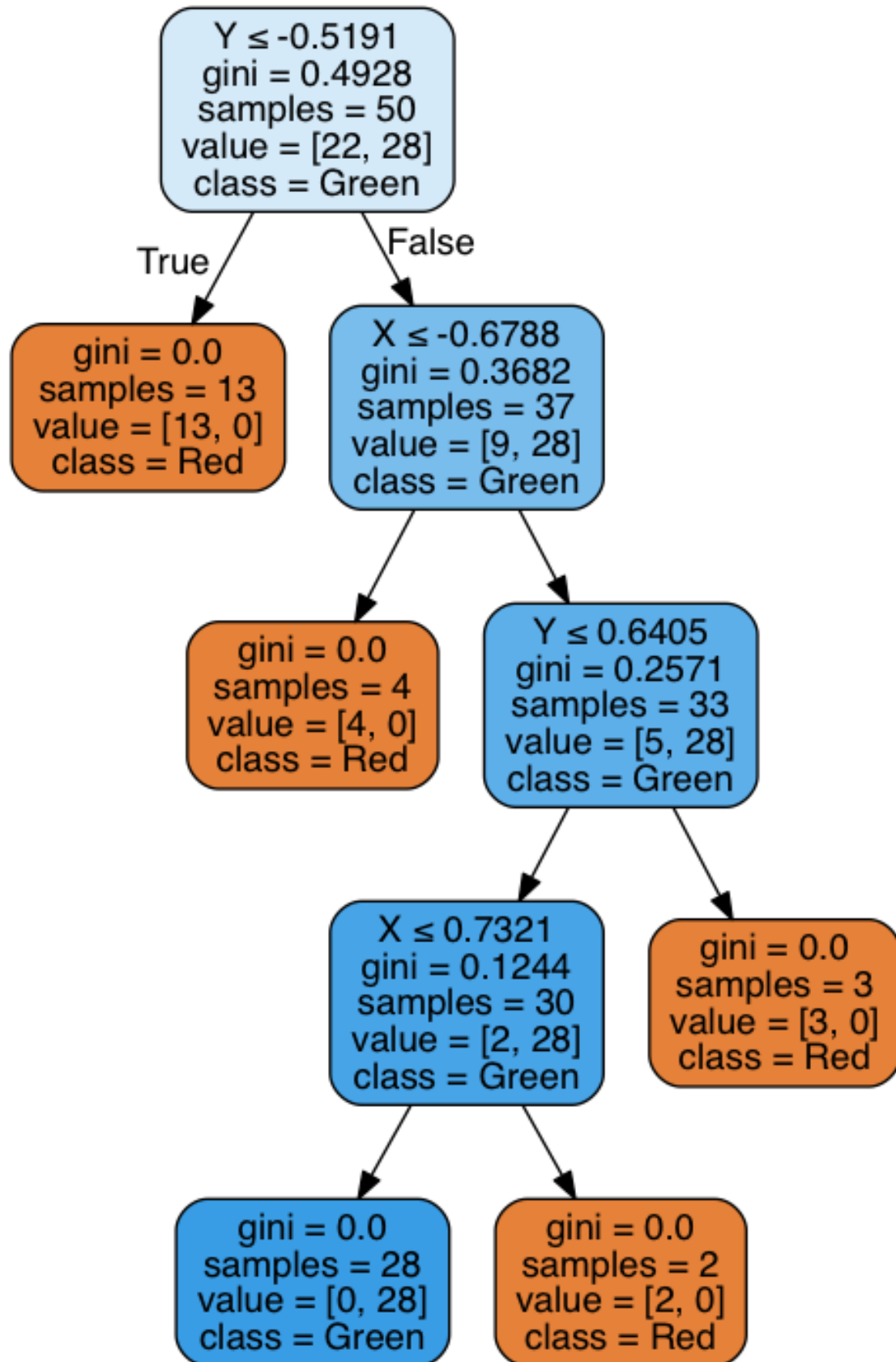
Decision Tree  
 Triangles: Test Data, Circles: Training Data  
 Accuracy: 0.92



```
In [99]: dot_data = tree.export_graphviz(dtc, out_file=None,
      feature_names=['X', 'Y'],
      class_names=['Red', 'Green'],
      filled=True, rounded=True,
      special_characters=True)

import pydotplus
graph = pydotplus.graph_from_dot_data(dot_data)
graph.write_pdf("dt.pdf")
Image(graph.create_png())
```

Out [99]:



### 1.3 “Real” data: the IRIS dataset

This is a famous dataset used by Ronald Fisher in a classic 1936 paper on classification.  
<https://archive.ics.uci.edu/ml/datasets/Iris>



By [http://www.swlearning.com/quant/kohler/stat/biographical\\_sketches/Fisher\\_3.jpeg](http://www.swlearning.com/quant/kohler/stat/biographical_sketches/Fisher_3.jpeg),  
Public Domain, <https://commons.wikimedia.org/w/index.php?curid=4233489>  
Quoting from Wikipedia:

The data set consists of 50 samples from each of three species of Iris (Iris setosa, Iris virginica and Iris versicolor). Four features were measured from each sample: the length and the width of the sepals and petals, in centimetres. Based on the combination of these four features, Fisher developed a linear discriminant model to distinguish the species from each other.

```
In [101]: iris = datasets.load_iris()
```

```
In [102]: X = iris.data  
          y = iris.target
```



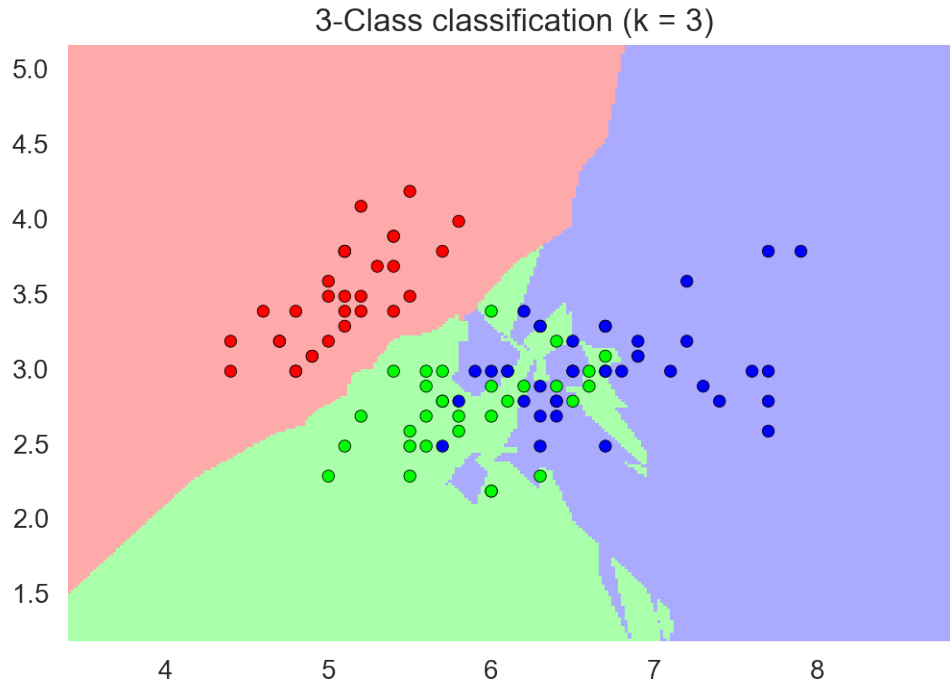
Accuracy of KNN test set: 0.94

```
In [107]: # Create color maps
from matplotlib.colors import ListedColormap
cmap_light = ListedColormap(['#FFAAAA', '#AAFFAA', '#AAAAFF'])
cmap_bold = ListedColormap(['#FF0000', '#00FF00', '#0000FF'])

# we will use only the first two (of four) features, so we can visualize
X = X_train[:, :2]
h = .02 # step size in the mesh
k = 3
knn = KNeighborsClassifier(n_neighbors=k)
knn.fit(X, y_train)
# Plot the decision boundary. For that, we will assign a color to each
# point in the mesh [x_min, x_max]x[y_min, y_max].
x_min, x_max = X[:, 0].min() - 1, X[:, 0].max() + 1
y_min, y_max = X[:, 1].min() - 1, X[:, 1].max() + 1
xx, yy = np.meshgrid(np.arange(x_min, x_max, h),
                     np.arange(y_min, y_max, h))
Z = knn.predict(np.c_[xx.ravel(), yy.ravel()])

# Put the result into a color plot
Z = Z.reshape(xx.shape)
plt.figure()
plt.pcolormesh(xx, yy, Z, cmap=cmap_light)

# Plot also the training points
plt.scatter(X[:, 0], X[:, 1], c=y_train, cmap=cmap_bold)
plt.xlim(xx.min(), xx.max())
plt.ylim(yy.min(), yy.max())
_ = plt.title("3-Class classification (k = {})".format(k))
```



```
In [108]: dtc = tree.DecisionTreeClassifier()
          dtc.fit(X_train,y_train)
          y_pred_test = dtc.predict(X_test)
          print("Accuracy of DTC test set:", dtc.score(X_test, y_test))
```

Accuracy of DTC test set: 0.9

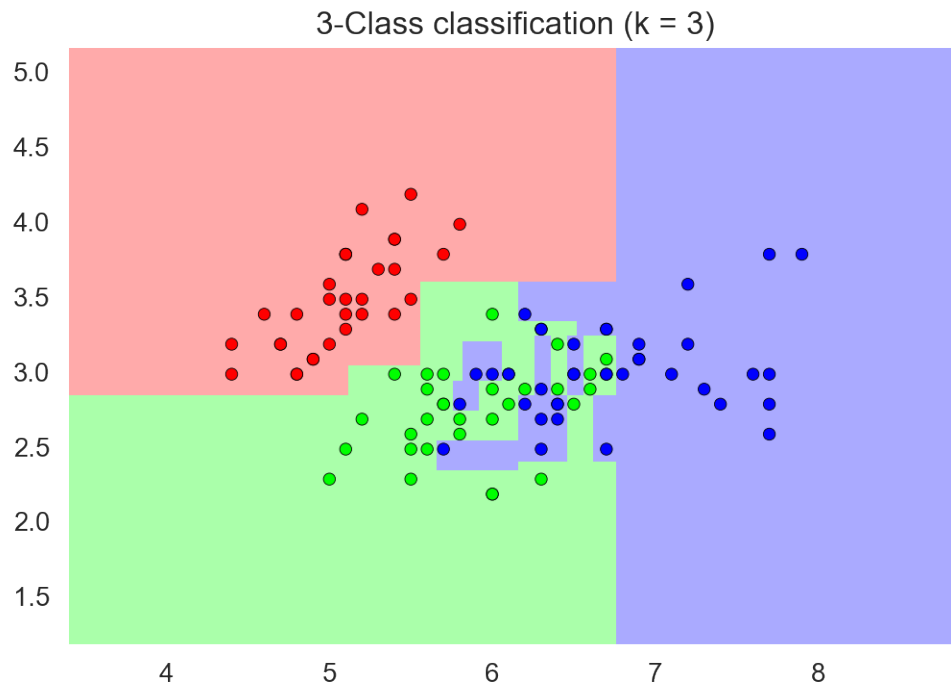
```
In [109]: # we will use only the first two (of four) features, so we can visualize
          X = X_train[:, :2]
          h = .02 # step size in the mesh
          dtc.fit(X, y_train)
          # Plot the decision boundary. For that, we will assign a color to each
          # point in the mesh [x_min, x_max]x[y_min, y_max].
          x_min, x_max = X[:, 0].min() - 1, X[:, 0].max() + 1
          y_min, y_max = X[:, 1].min() - 1, X[:, 1].max() + 1
          xx, yy = np.meshgrid(np.arange(x_min, x_max, h),
                               np.arange(y_min, y_max, h))
          Z = dtc.predict(np.c_[xx.ravel(), yy.ravel()])

          # Put the result into a color plot
          Z = Z.reshape(xx.shape)
          plt.figure()
          plt.pcolormesh(xx, yy, Z, cmap=cmap_light)
```

```

# Plot also the training points
plt.scatter(X[:, 0], X[:, 1], c=y_train, cmap=cmap_bold)
plt.xlim(xx.min(), xx.max())
plt.ylim(yy.min(), yy.max())
_ = plt.title("3-Class classification (k = {})".format(k))

```



## 1.4 “Really Real” Data: MNIST dataset

<http://yann.lecun.com/exdb/mnist/>

NIST used to be called the “National Bureau of Standards.” These are the folks who bring you the reference meter, reference kilogram, etc.

NIST constructed datasets for machine learning of handwritten digits. These were collected from Census Bureau employees and also from high-school students.

```

In [132]: digits = datasets.load_digits()
          X_digits, y_digits = digits.data, digits.target

          print ('Data shape: {}'.format(X_digits.shape))
          print ('Data labels: {}'.format(y_digits))
          print ('Unique labels: {}'.format(digits.target_names))
          X_digits, y_digits = utils.shuffle(X_digits, y_digits, random_state=1)

Data shape: (1797, 64)
Data labels: [0 1 2 ..., 8 9 8]
Unique labels: [0 1 2 3 4 5 6 7 8 9]

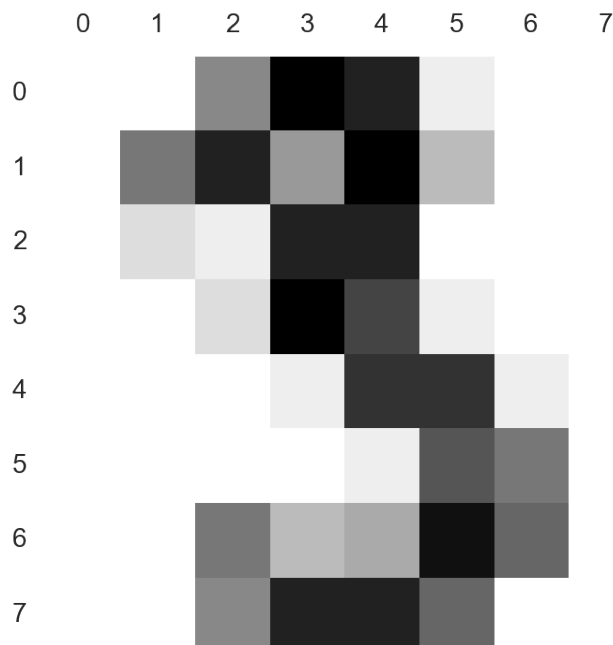
```

```
In [133]: digits.images[3]
```

```
Out[133]: array([[ 0.,  0.,  7., 15., 13.,  1.,  0.,  0.],
 [ 0.,  8., 13.,  6., 15.,  4.,  0.,  0.],
 [ 0.,  2.,  1., 13., 13.,  0.,  0.,  0.],
 [ 0.,  0.,  2., 15., 11.,  1.,  0.,  0.],
 [ 0.,  0.,  0.,  1., 12., 12.,  1.,  0.],
 [ 0.,  0.,  0.,  0.,  1., 10.,  8.,  0.],
 [ 0.,  0.,  8.,  4.,  5., 14.,  9.,  0.],
 [ 0.,  0.,  7., 13., 13.,  9.,  0.,  0.]])
```

```
In [134]: plt.gray()
plt.rc('axes', grid=False)
_=plt.matshow(digits.images[3], cmap=plt.cm.gray_r)
```

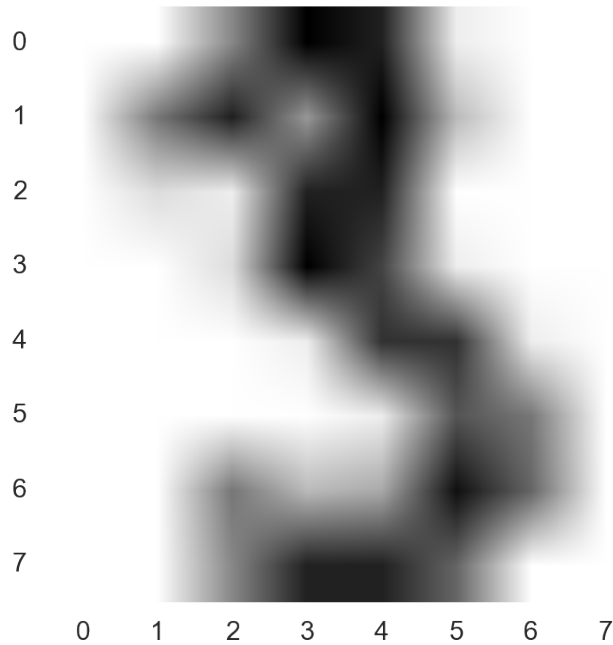
```
<matplotlib.figure.Figure at 0x11a54eda0>
```



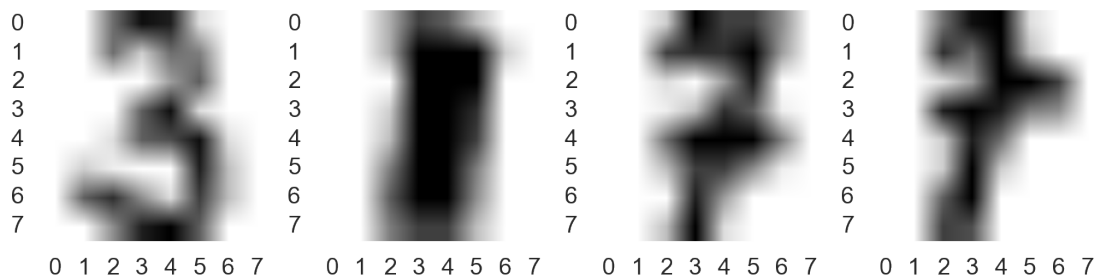
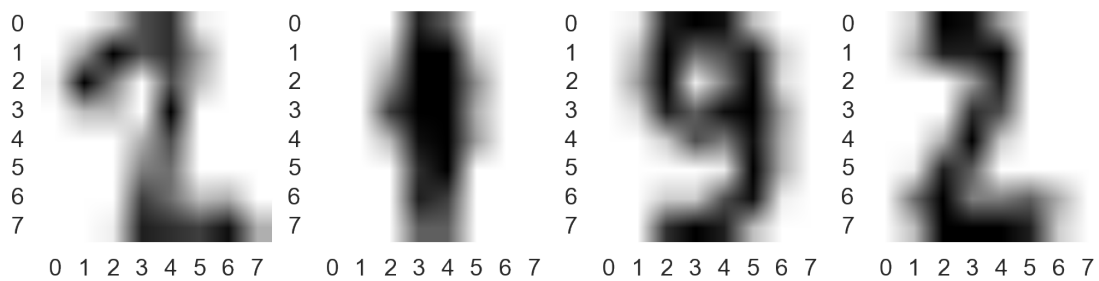
Notice that this is an  $8 \times 8$  image. However we just treat it as a vector of length 64.  
It is easier to visualize if we blur the pixels a little bit.

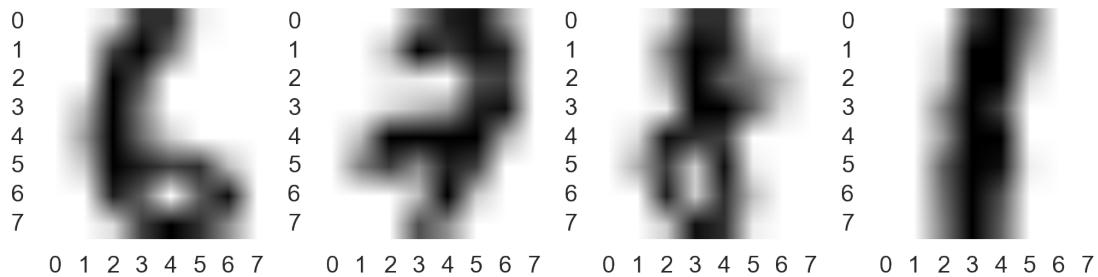
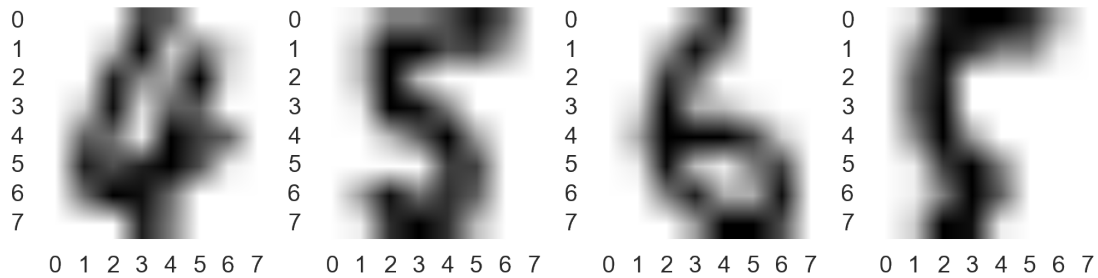
```
In [135]: plt.rc('image', cmap='binary', interpolation='bilinear')
plt.rc('axes', grid=False)
plt.figure(figsize=(4,4))
_=plt.imshow(digits.images[3])
```





```
In [136]: for t in range(4):
           plt.figure(figsize=(8,2))
           for j in range(4):
               plt.subplot(1, 4, 1 + j)
               plt.imshow(X_digits_test[4*t + j].reshape(8, 8))
```





This time we will use all classes, but only a small training set.  
 This points out one issue of KNN: it can be slow on a large training set (why?).  
 To do model selection, we also create a test set to adjust k.

```
In [137]: step = 1000;
          X_digits_train = X_digits[:step]
          y_digits_train = y_digits[:step]
          X_digits_test = X_digits[step:len(y_digits)]
          y_digits_test = y_digits[step:len(y_digits)]
```

Again using the k-NN classifier:

```
In [138]: knn_digits = KNeighborsClassifier(n_neighbors=20)
          _=knn_digits.fit(X_digits_train, y_digits_train)

In [139]: knn_digits = KNeighborsClassifier(n_neighbors=3)
          knn_digits.fit(X_digits_train, y_digits_train)
          y_digits_test_pred = knn_digits.predict(X_digits_test)
          print("KNN test accuracy on MNIST digits: ", knn_digits.score(X_digits_test, y_digits_test))
```

```
KNN test accuracy on MNIST digits: 0.984943538269
```

Looking at the nearest neighbors of some points (for k=3):

```
In [140]: neighbors = knn_digits.kneighbors(X_digits_test, n_neighbors=3, return_di
          print(type(neighbors))
          print(neighbors.shape)
```

```
<class 'numpy.ndarray'>
(797, 3)
```

Let's take a look at them...

```
In [141]: plt.rc("image", cmap="binary") # this sets a black on white colormap
          # plot X_digits_valid[0]
          for t in range(3):
              plt.figure(figsize=(8,2))
              plt.subplot(1, 4, 1)
              plt.imshow(X_digits_test[t].reshape(8, 8))
              plt.title("Query")
              # plot three nearest neighbors from the training set
              for i in [0, 1, 2]:
                  plt.subplot(1, 4, 2 + i)
                  plt.title("neighbor {}".format(i))
                  plt.imshow(X_digits_train[neighbors[t, i]].reshape(8, 8))
```

