*You are currently looking at **version 1.0** of this notebook. To download notebooks and datafiles, as well as get help on Jupyter notebooks in the Coursera platform, visit the [Jupyter Notebook FAQ (https://www.coursera.org/learn/python-machine-learning/resources/bANLa)](https://www.coursera.org/learn/python-machine-learning/resources/bANLa) course resource.*

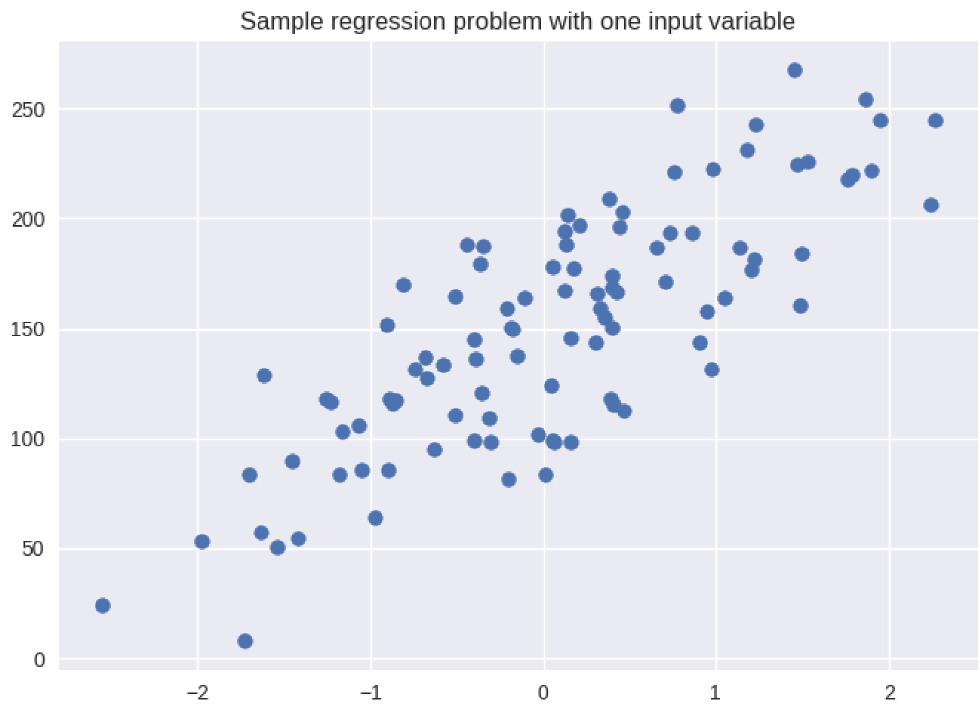
Applied Machine Learning: Module 4 (Supervised Learning, Part II)

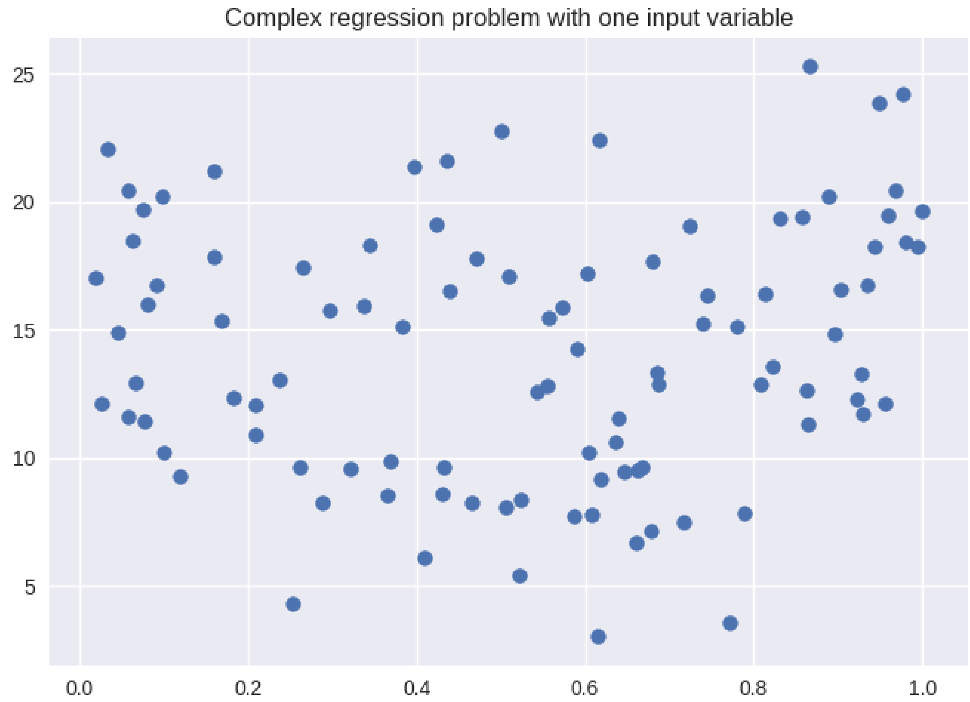
Preamble and Datasets

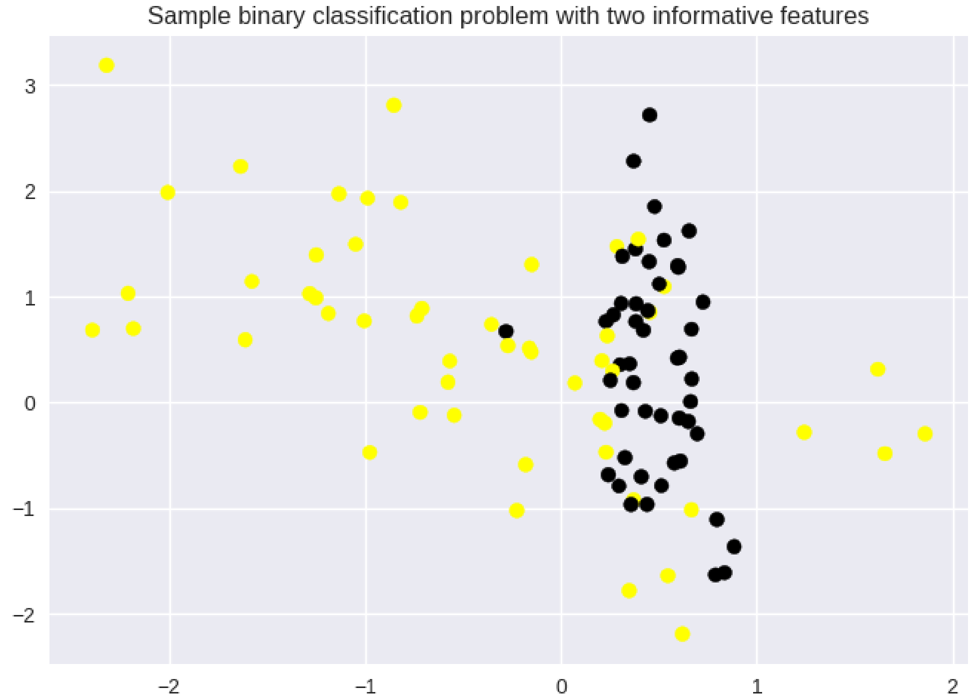
In [1]:

```
%matplotlib notebook
import numpy as np
import pandas as pd
import seaborn as sn
import matplotlib.pyplot as plt

from sklearn.model_selection import train_test_split
from sklearn.datasets import make_classification, make_blobs
from matplotlib.colors import ListedColormap
from sklearn.datasets import load_breast_cancer
from adspy_shared_utilities import load_crime_dataset


cmap_bold = ListedColormap(['#FFFF00', '#00FF00', '#0000FF','#000000'])

# fruits dataset
fruits = pd.read_table('fruit_data_with_colors.txt')

feature_names_fruits = ['height', 'width', 'mass', 'color_score']
X_fruits = fruits[feature_names_fruits]
y_fruits = fruits['fruit_label']
target_names_fruits = ['apple', 'mandarin', 'orange', 'lemon']

X_fruits_2d = fruits[['height', 'width']]
y_fruits_2d = fruits['fruit_label']

# synthetic dataset for simple regression
from sklearn.datasets import make_regression
plt.figure()
plt.title('Sample regression problem with one input variable')
X_R1, y_R1 = make_regression(n_samples = 100, n_features=1,
                            n_informative=1, bias = 150.0,
                            noise = 30, random_state=0)
plt.scatter(X_R1, y_R1, marker= 'o', s=50)
plt.show()

# synthetic dataset for more complex regression
from sklearn.datasets import make_friedman1
plt.figure()
plt.title('Complex regression problem with one input variable')
X_F1, y_F1 = make_friedman1(n_samples = 100, n_features = 7,
                           random_state=0)

plt.scatter(X_F1[:, 2], y_F1, marker= 'o', s=50)
plt.show()

# synthetic dataset for classification (binary)
plt.figure()
plt.title('Sample binary classification problem with two informative features')
X_C2, y_C2 = make_classification(n_samples = 100, n_features=2,
                                n_redundant=0, n_informative=2,
                                n_clusters_per_class=1, flip_y = 0.1,
                                class_sep = 0.5, random_state=0)
plt.scatter(X_C2[:, 0], X_C2[:, 1], marker= 'o',
           c=y_C2, s=50, cmap=cmap_bold)
plt.show()

# more difficult synthetic dataset for classification (binary)
# with classes that are not linearly separable
```

```
X_D2, y_D2 = make_blobs(n_samples = 100, n_features = 2,

                        centers = 8, cluster_std = 1.3,
                        random_state = 4)
y_D2 = y_D2 % 2
plt.figure()
plt.title('Sample binary classification problem with non-linearly separable classes')
plt.scatter(X_D2[:,0], X_D2[:,1], c=y_D2,
           marker= 'o', s=50, cmap=cmap_bold)
plt.show()

# Breast cancer dataset for classification
cancer = load_breast_cancer()
(X_cancer, y_cancer) = load_breast_cancer(return_X_y = True)

# Communities and Crime dataset
(X_crime, y_crime) = load_crime_dataset()
```



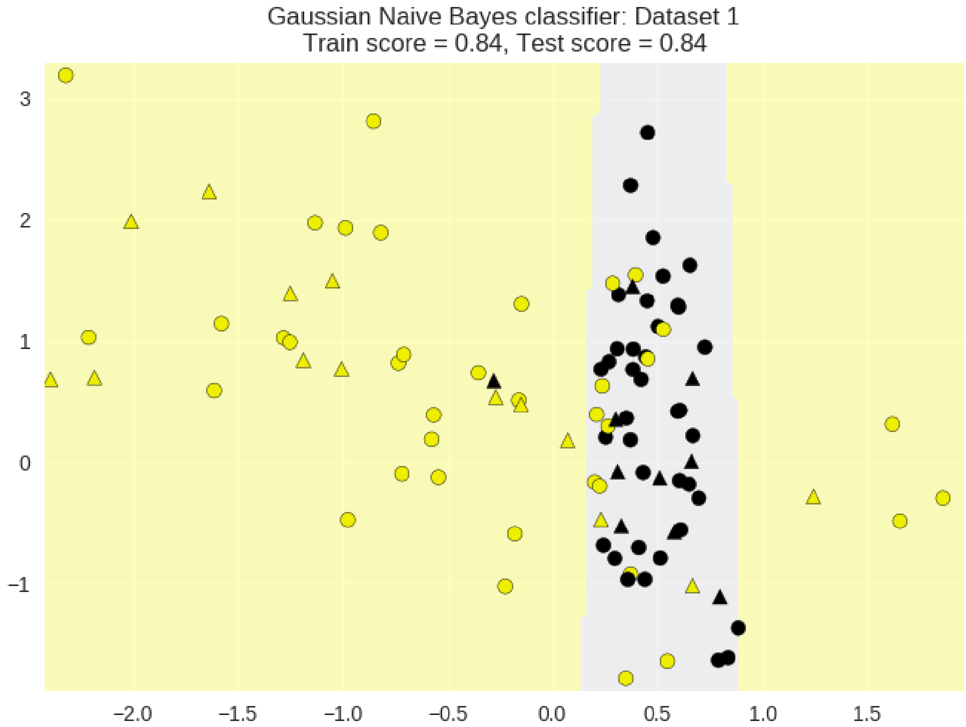

Complex regression problem with one input variable
25
20
15
10
5
0.0
0.2
0.4
0.6
0.8
1.0


Sample binary classification problem with two informative features
3
2
1
0
−1
−2
−2
−1
0
1
2

Naive Bayes classifiers

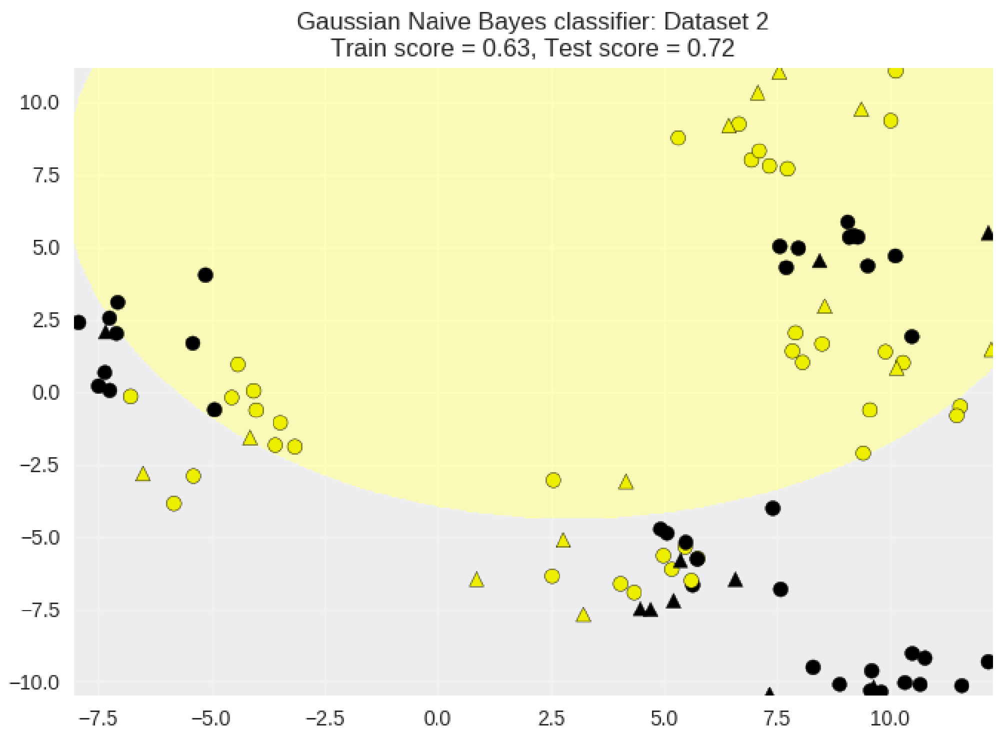
In [2]:

```
from sklearn.naive_bayes import GaussianNB
from adspy_shared_utilities import plot_class_regions_for_classifier

X_train, X_test, y_train, y_test = train_test_split(X_C2, y_C2, random_state=0)

nbclf = GaussianNB().fit(X_train, y_train)
plot_class_regions_for_classifier(nbclf, X_train, y_train, X_test, y_test,
                                  'Gaussian Naive Bayes classifier: Dataset 1')
```



In [3]:

```
X_train, X_test, y_train, y_test = train_test_split(X_D2, y_D2,
                                                   random_state=0)

nbclf = GaussianNB().fit(X_train, y_train)
plot_class_regions_for_classifier(nbclf, X_train, y_train, X_test, y_test,
                                 'Gaussian Naive Bayes classifier: Dataset 2')
```



Application to a real-world dataset

In [4]:

```
X_train, X_test, y_train, y_test = train_test_split(X_cancer, y_cancer, random_state = 0)

nbclf = GaussianNB().fit(X_train, y_train)
print('Breast cancer dataset')
print('Accuracy of GaussianNB classifier on training set: {:.2f}'
     .format(nbclf.score(X_train, y_train)))
print('Accuracy of GaussianNB classifier on test set: {:.2f}'
     .format(nbclf.score(X_test, y_test)))
```

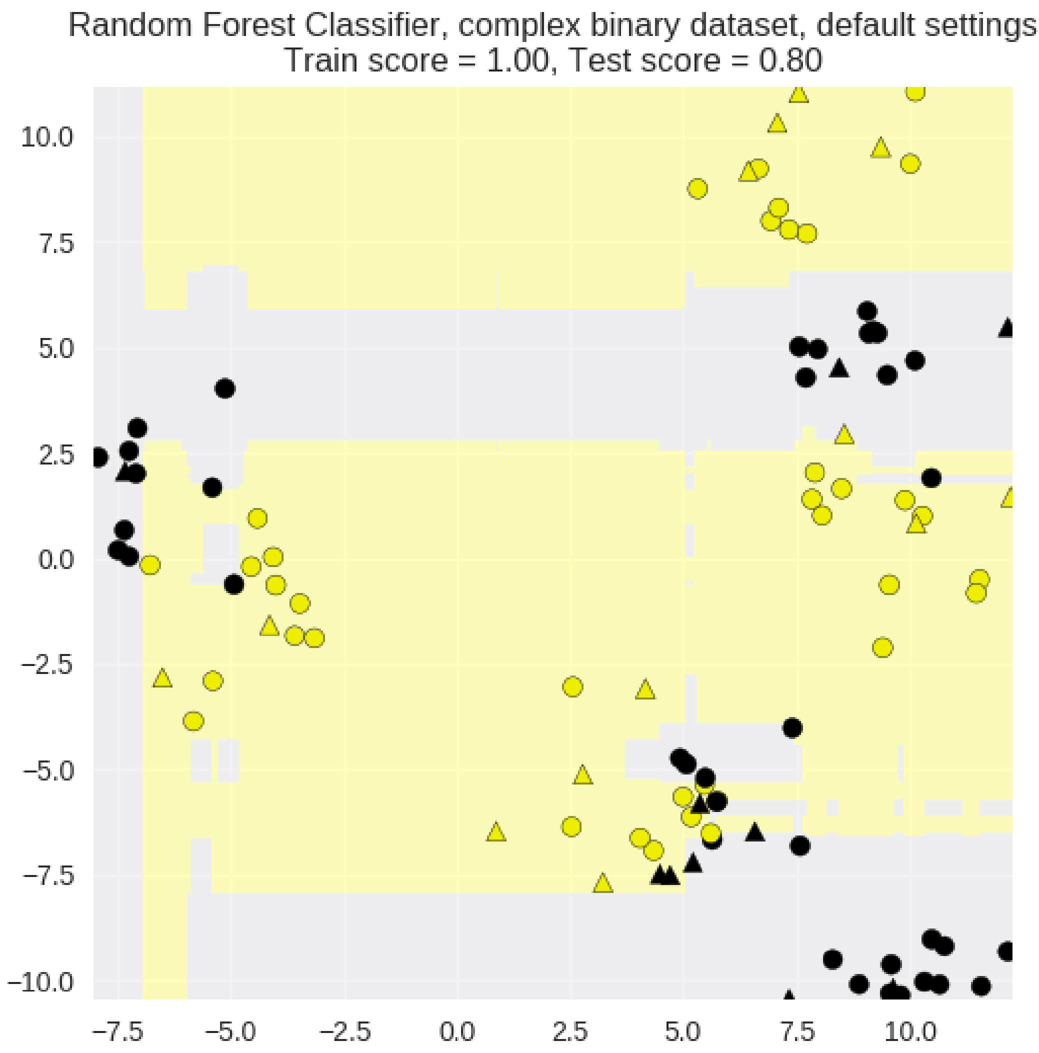
```
Breast cancer dataset
Accuracy of GaussianNB classifier on training set: 0.95
Accuracy of GaussianNB classifier on test set: 0.94
```

Ensembles of Decision Trees

Random forests

In [5]:

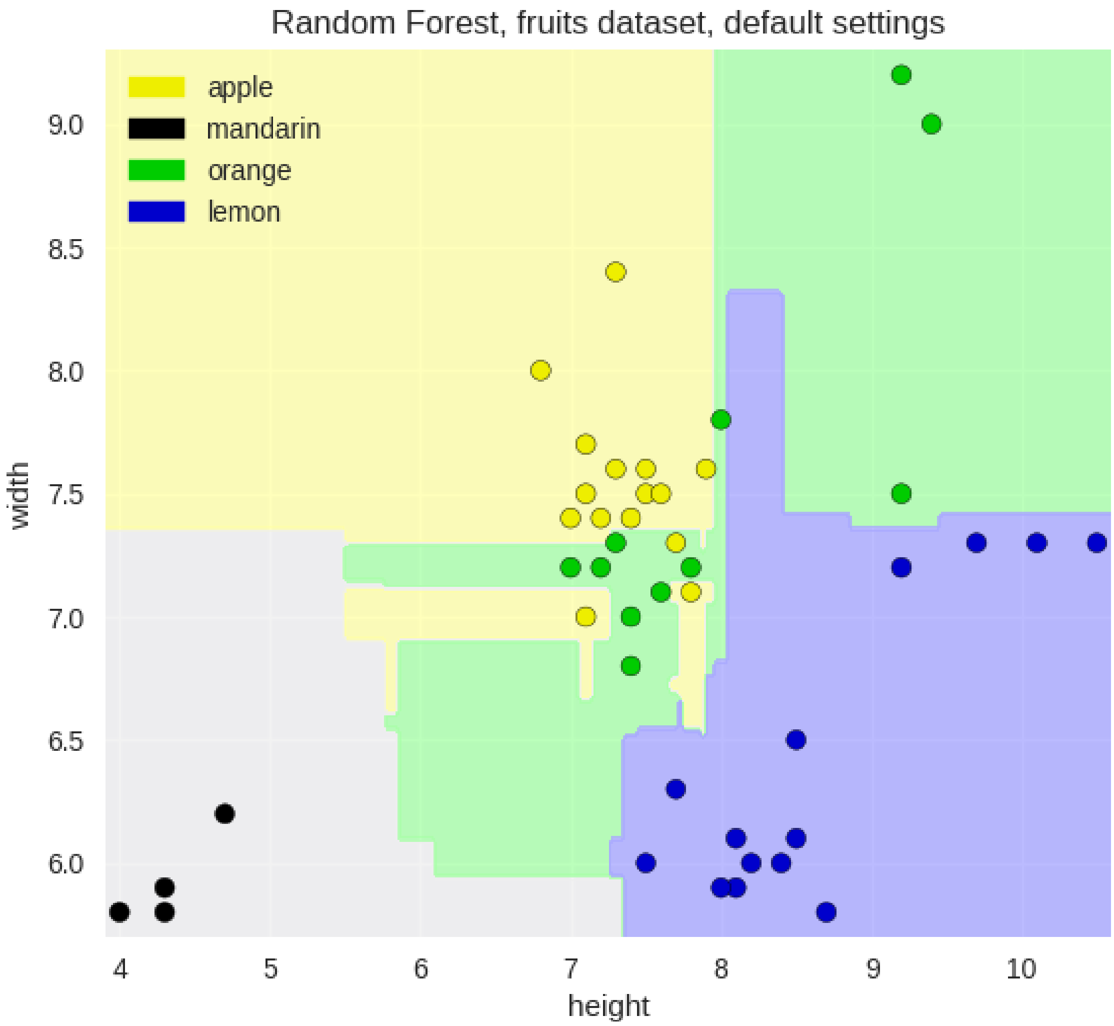
```
from sklearn.ensemble import RandomForestClassifier
from sklearn.model_selection import train_test_split
from adspy_shared_utilities import plot_class_regions_for_classifier_subplot

X_train, X_test, y_train, y_test = train_test_split(X_D2, y_D2,
                                                    random_state = 0)
fig, subaxes = plt.subplots(1, 1, figsize=(6, 6))

clf = RandomForestClassifier().fit(X_train, y_train)
title = 'Random Forest Classifier, complex binary dataset, default settings'
plot_class_regions_for_classifier_subplot(clf, X_train, y_train, X_test,
                                          y_test, title, subaxes)

plt.show()
```

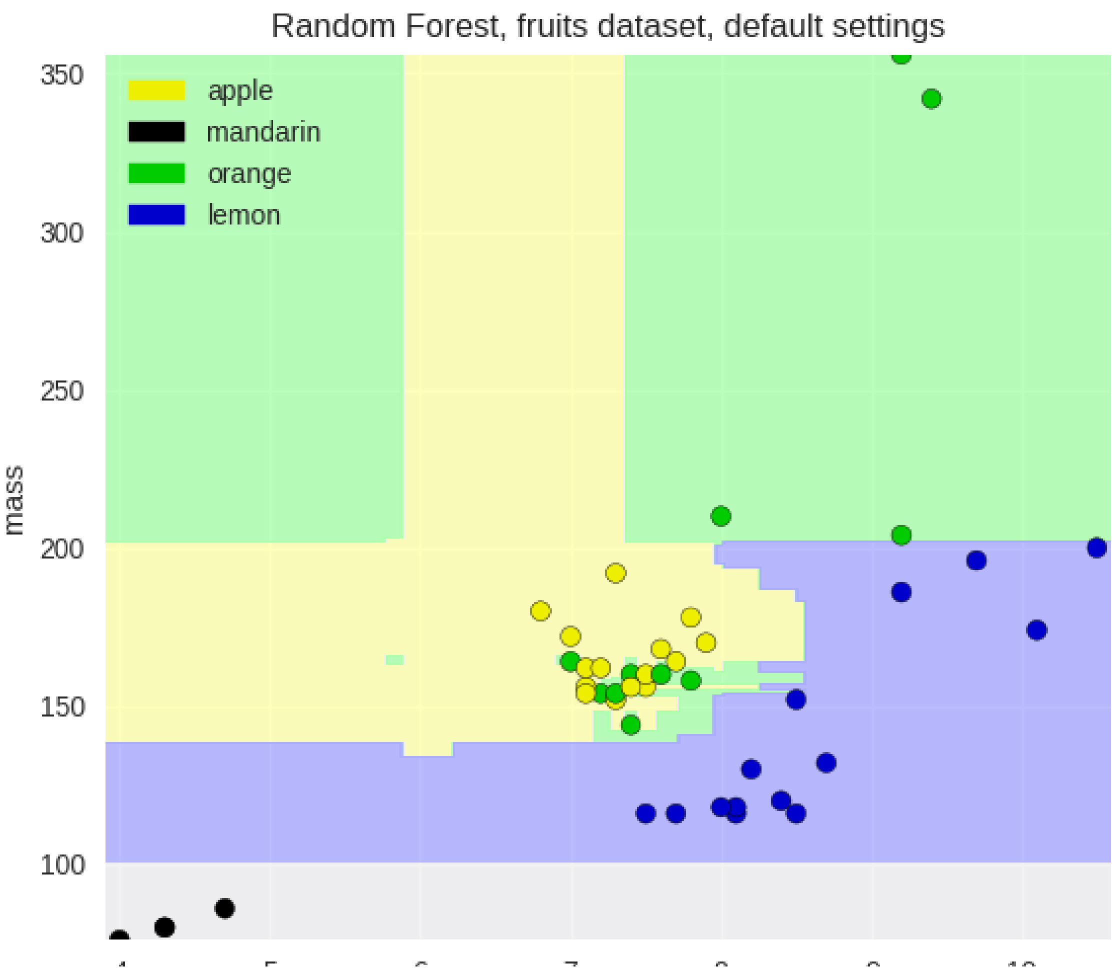


Random forest: Fruit dataset

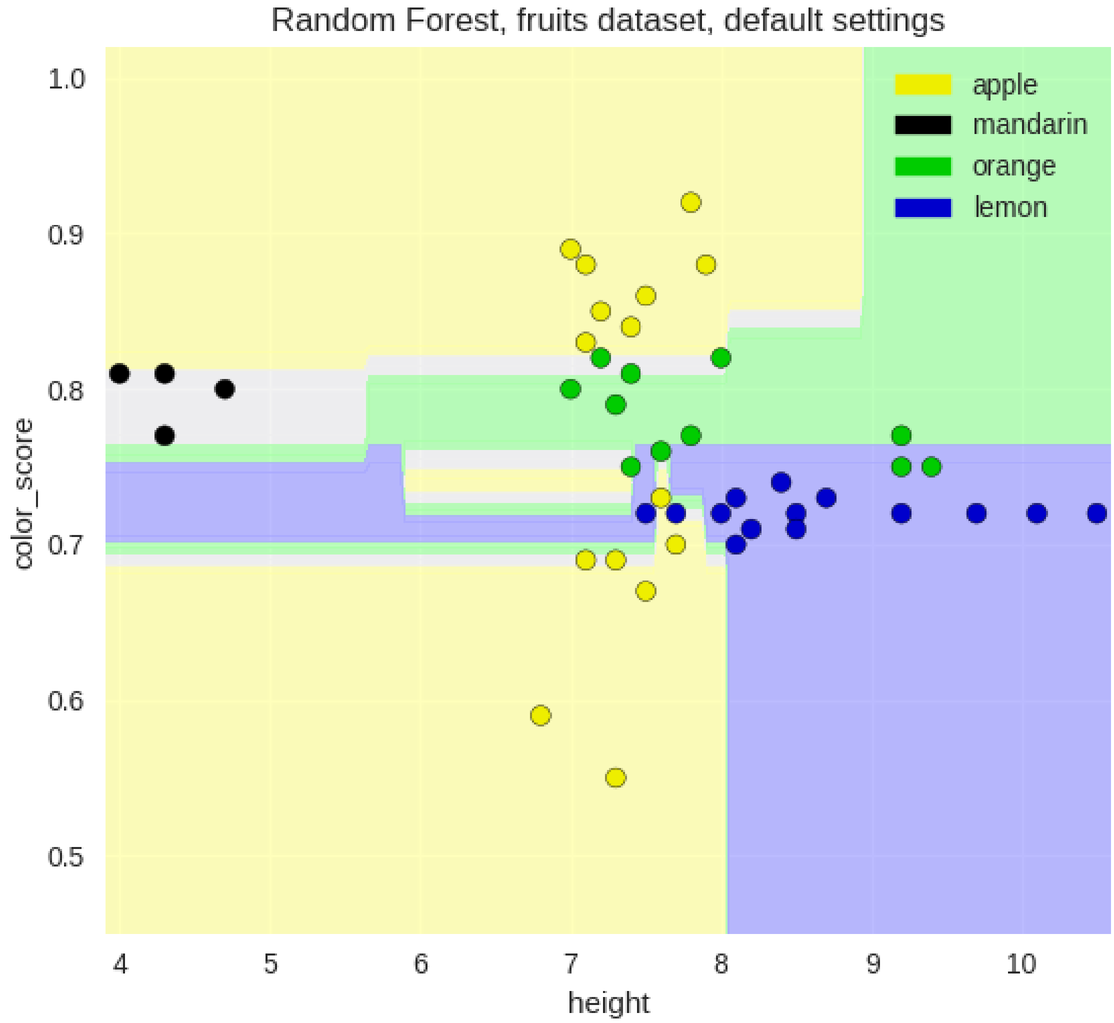
In [6]:

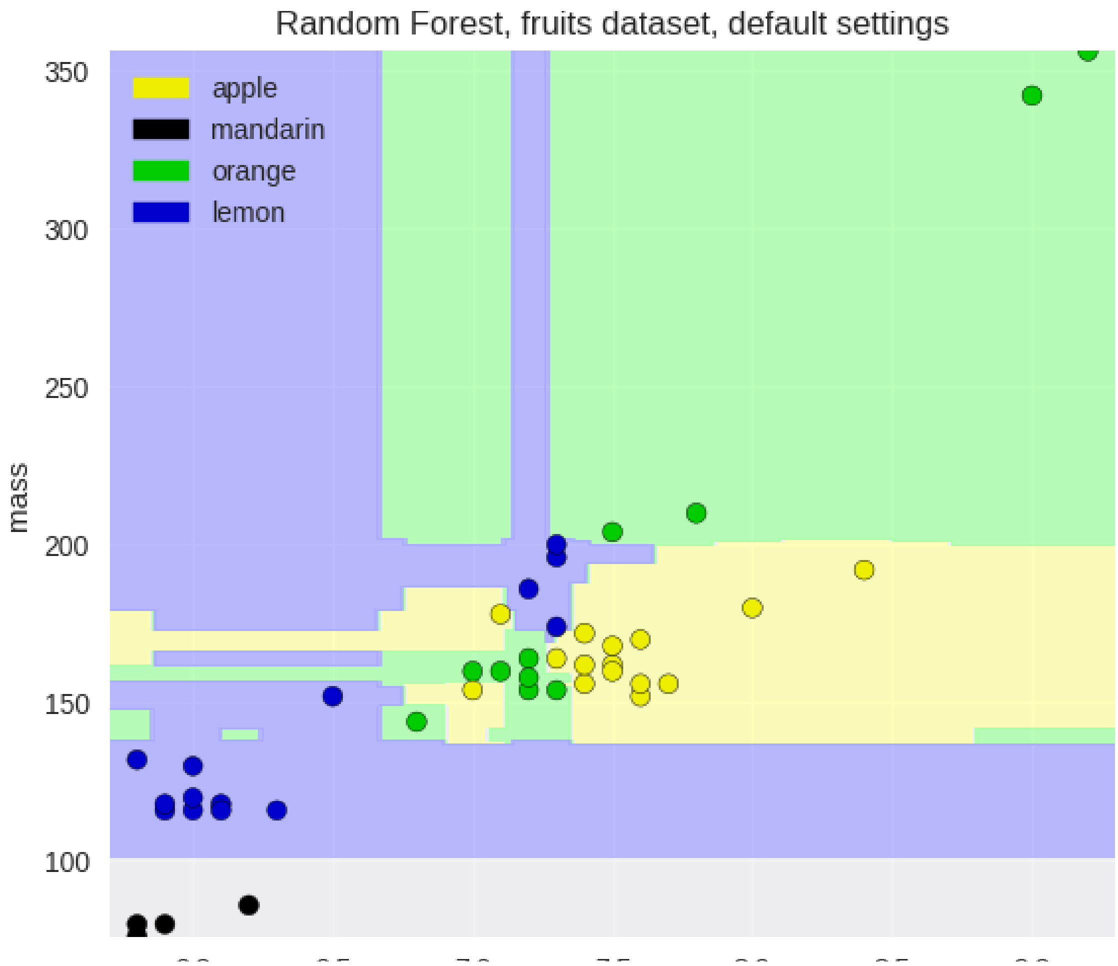
```
from sklearn.ensemble import RandomForestClassifier
from sklearn.model_selection import train_test_split
from adspy_shared_utilities import plot_class_regions_for_classifier_subplot

X_train, X_test, y_train, y_test = train_test_split(X_fruits.as_matrix(),
                                                    y_fruits.as_matrix(),
                                                    random_state = 0)
fig, subaxes = plt.subplots(6, 1, figsize=(6, 32))

title = 'Random Forest, fruits dataset, default settings'
pair_list = [[0,1], [0,2], [0,3], [1,2], [1,3], [2,3]]

for pair, axis in zip(pair_list, subaxes):
    X = X_train[:, pair]
    y = y_train

    clf = RandomForestClassifier().fit(X, y)
    plot_class_regions_for_classifier_subplot(clf, X, y, None,
                                              None, title, axis,
                                              target_names_fruits)

    axis.set_xlabel(feature_names_fruits[pair[0]])
    axis.set_ylabel(feature_names_fruits[pair[1]])

plt.tight_layout()
plt.show()

clf = RandomForestClassifier(n_estimators = 10,
                             random_state=0).fit(X_train, y_train)

print('Random Forest, Fruit dataset, default settings')
print('Accuracy of RF classifier on training set: {:.2f}'
     .format(clf.score(X_train, y_train)))
print('Accuracy of RF classifier on test set: {:.2f}'
     .format(clf.score(X_test, y_test)))
```


Random Forest, fruits dataset, default settings
apple
mandarin
orange
lemon
width
9.0
8.5
8.0
7.5
7.0
6.5
6.0
4
5
6
7
8
9
10
height

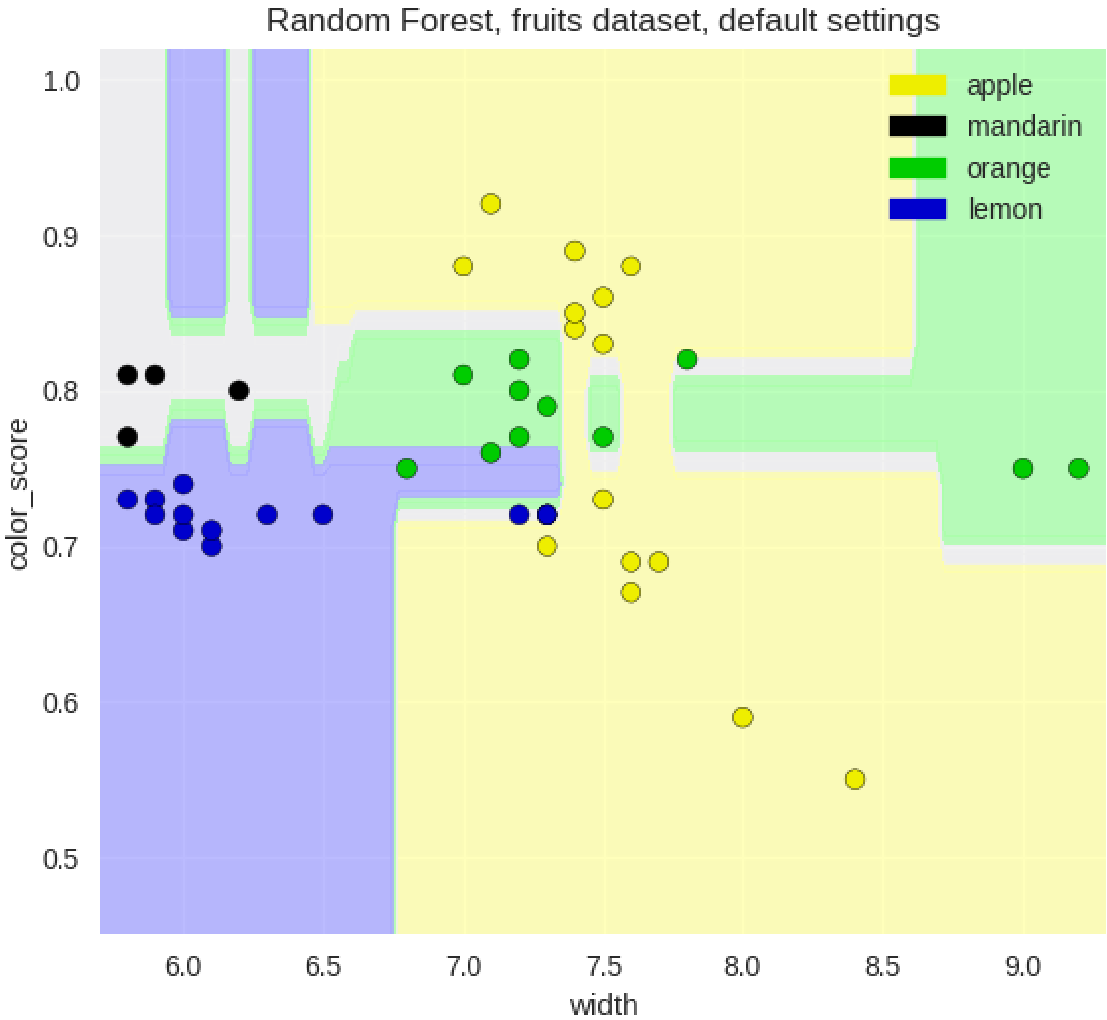

Random Forest, fruits dataset, default settings
apple
mandarin
orange
lemon
mass
350
300
250
200
150
100

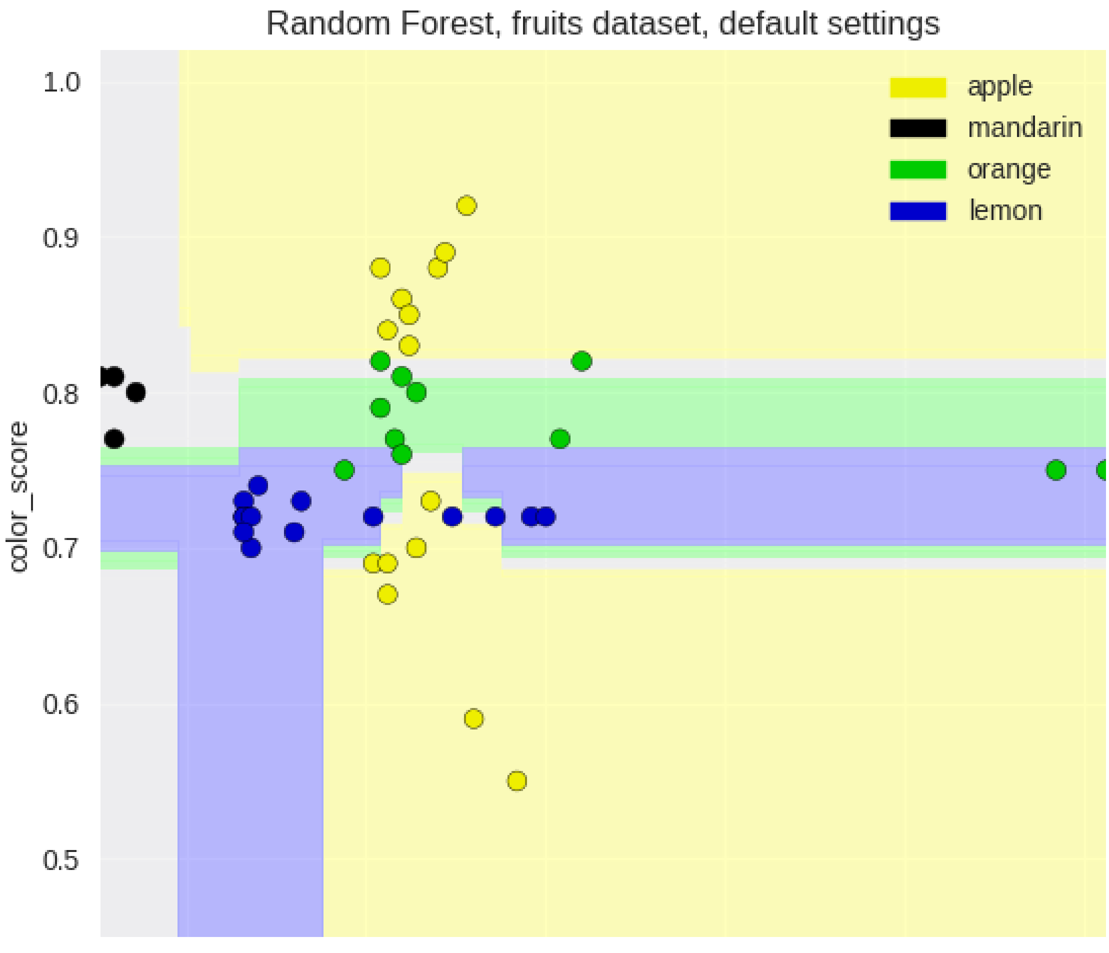

4
5
6
7
8
9
10
height


Random Forest, fruits dataset, default settings
apple
mandarin
orange
lemon
1.0
0.9
0.8
0.7
0.6
0.5
color_score
4
5
6
7
8
9
10
height


Random Forest, fruits dataset, default settings
apple
mandarin
orange
lemon
350
300
250
200
150
100
mass

6.0 6.5 7.0 7.5 8.0 8.5 9.0
width






```
Random Forest, Fruit dataset, default settings
Accuracy of RF classifier on training set: 1.00
Accuracy of RF classifier on test set: 0.80
```

Random Forests on a real-world dataset

In [7]:

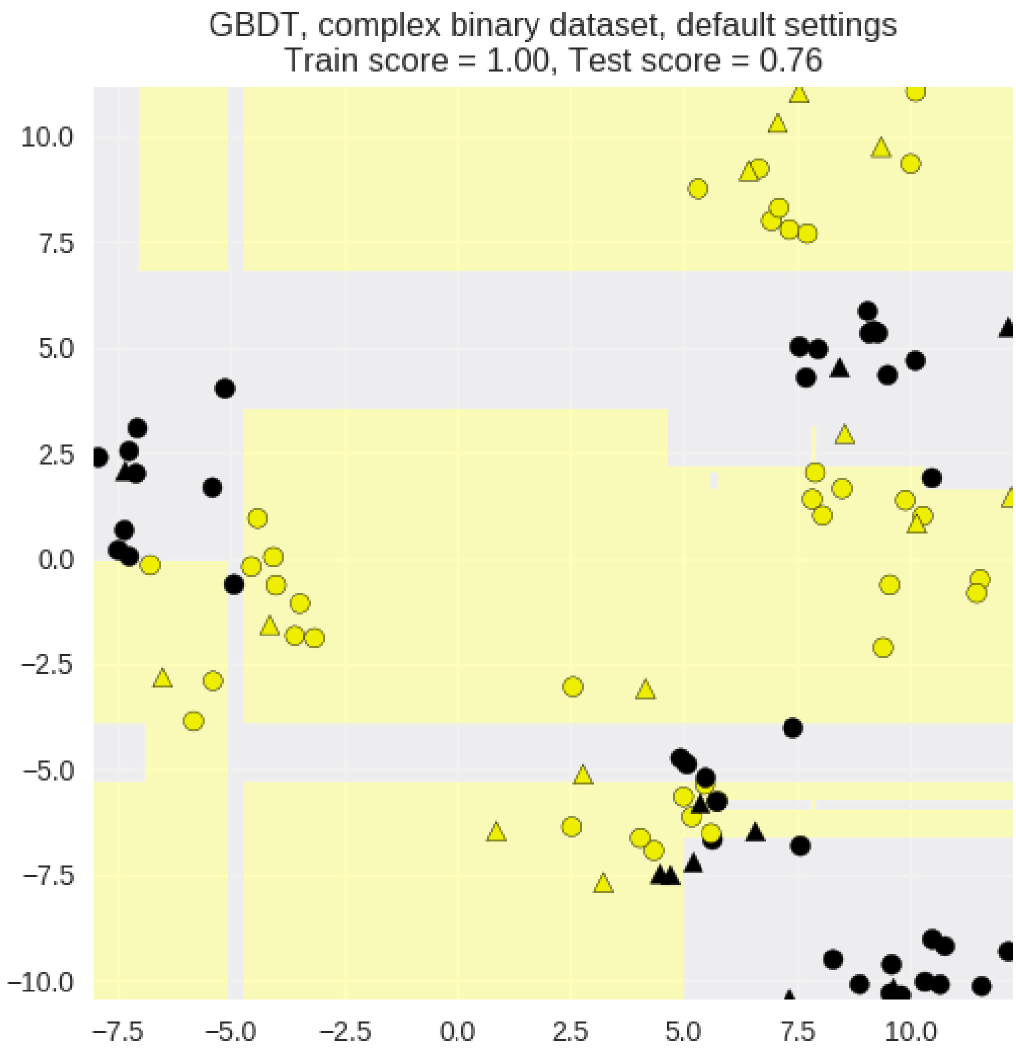
```
from sklearn.ensemble import RandomForestClassifier

X_train, X_test, y_train, y_test = train_test_split(X_cancer, y_cancer, random_state = 0)

clf = RandomForestClassifier(max_features = 8, random_state = 0)
clf.fit(X_train, y_train)

print('Breast cancer dataset')
print('Accuracy of RF classifier on training set: {:.2f}'
     .format(clf.score(X_train, y_train)))
print('Accuracy of RF classifier on test set: {:.2f}'
     .format(clf.score(X_test, y_test)))
```

```
Breast cancer dataset
Accuracy of RF classifier on training set: 1.00
Accuracy of RF classifier on test set: 0.99
```

Gradient-boosted decision trees

In [8]:

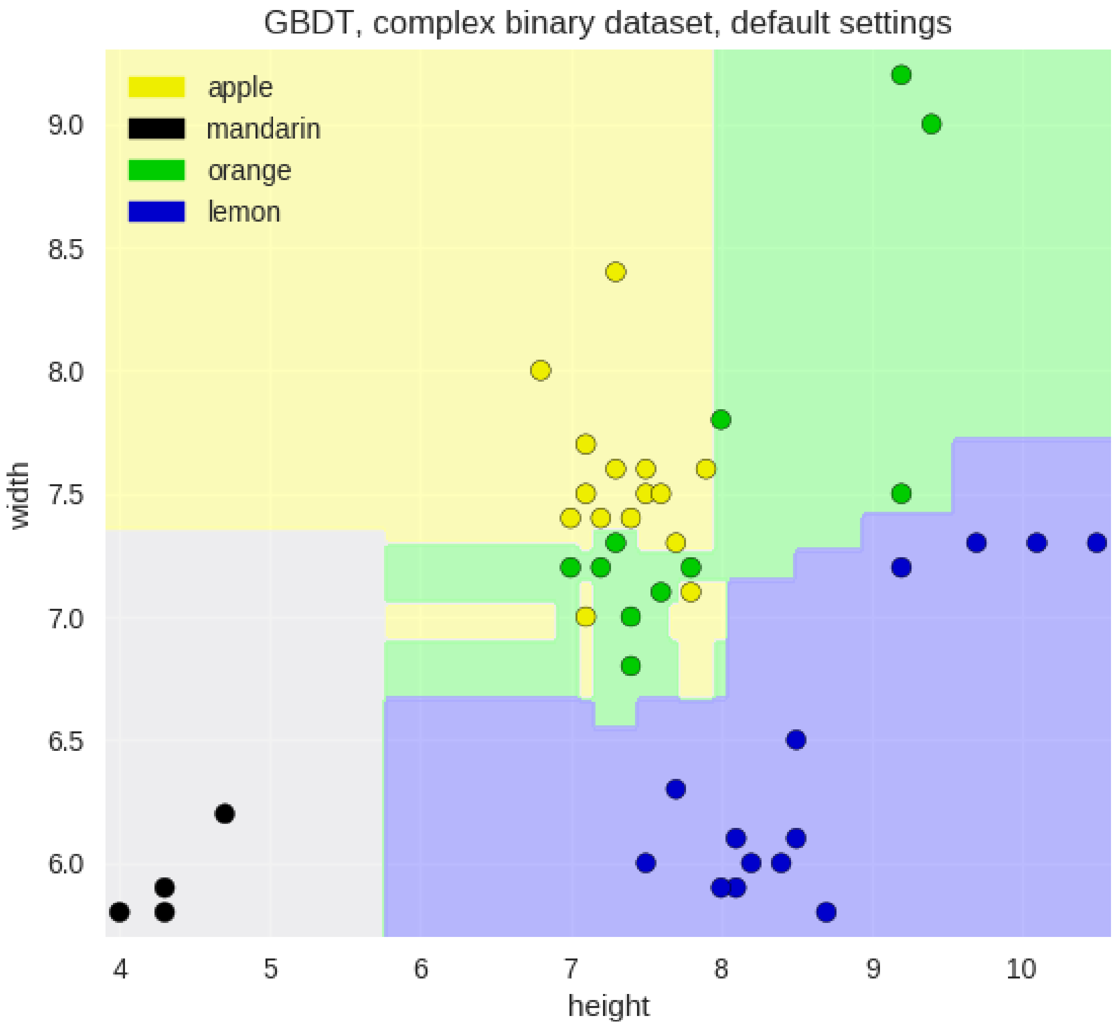
```
from sklearn.ensemble import GradientBoostingClassifier
from sklearn.model_selection import train_test_split
from adspy_shared_utilities import plot_class_regions_for_classifier_subplot

X_train, X_test, y_train, y_test = train_test_split(X_D2, y_D2, random_state = 0)
fig, subaxes = plt.subplots(1, 1, figsize=(6, 6))

clf = GradientBoostingClassifier().fit(X_train, y_train)
title = 'GBDT, complex binary dataset, default settings'
plot_class_regions_for_classifier_subplot(clf, X_train, y_train, X_test,
                                          y_test, title, subaxes)

plt.show()
```

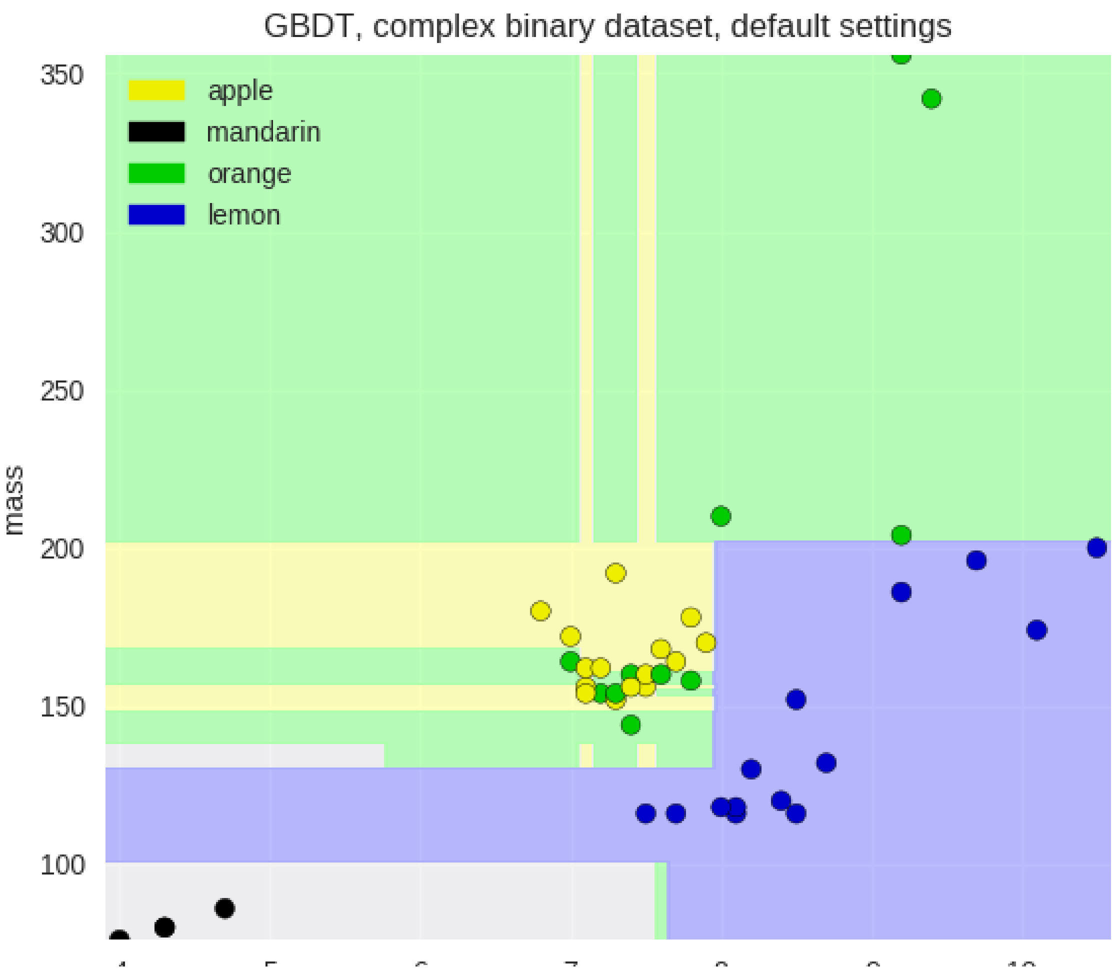


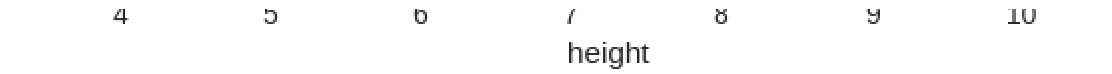
Gradient boosted decision trees on the fruit dataset

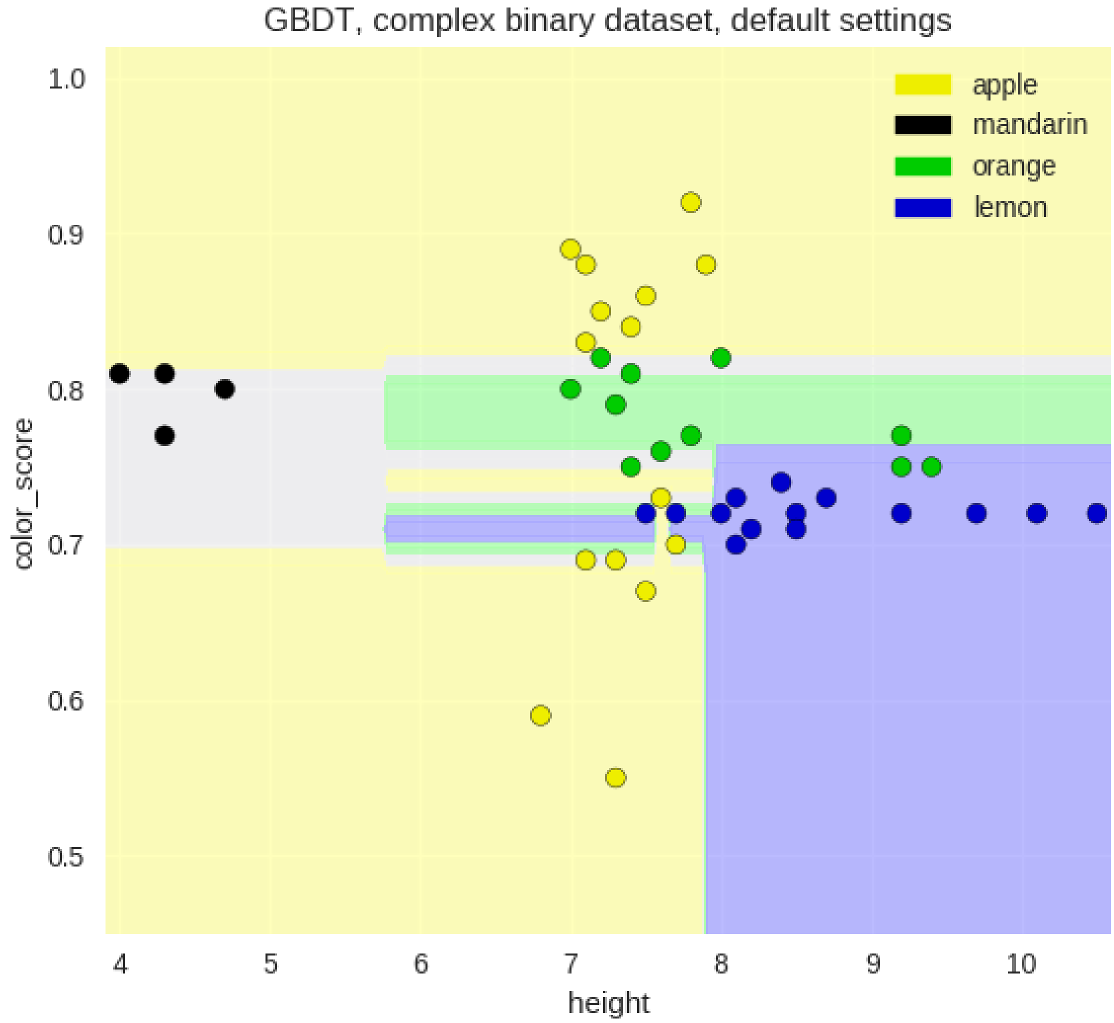
In [9]:

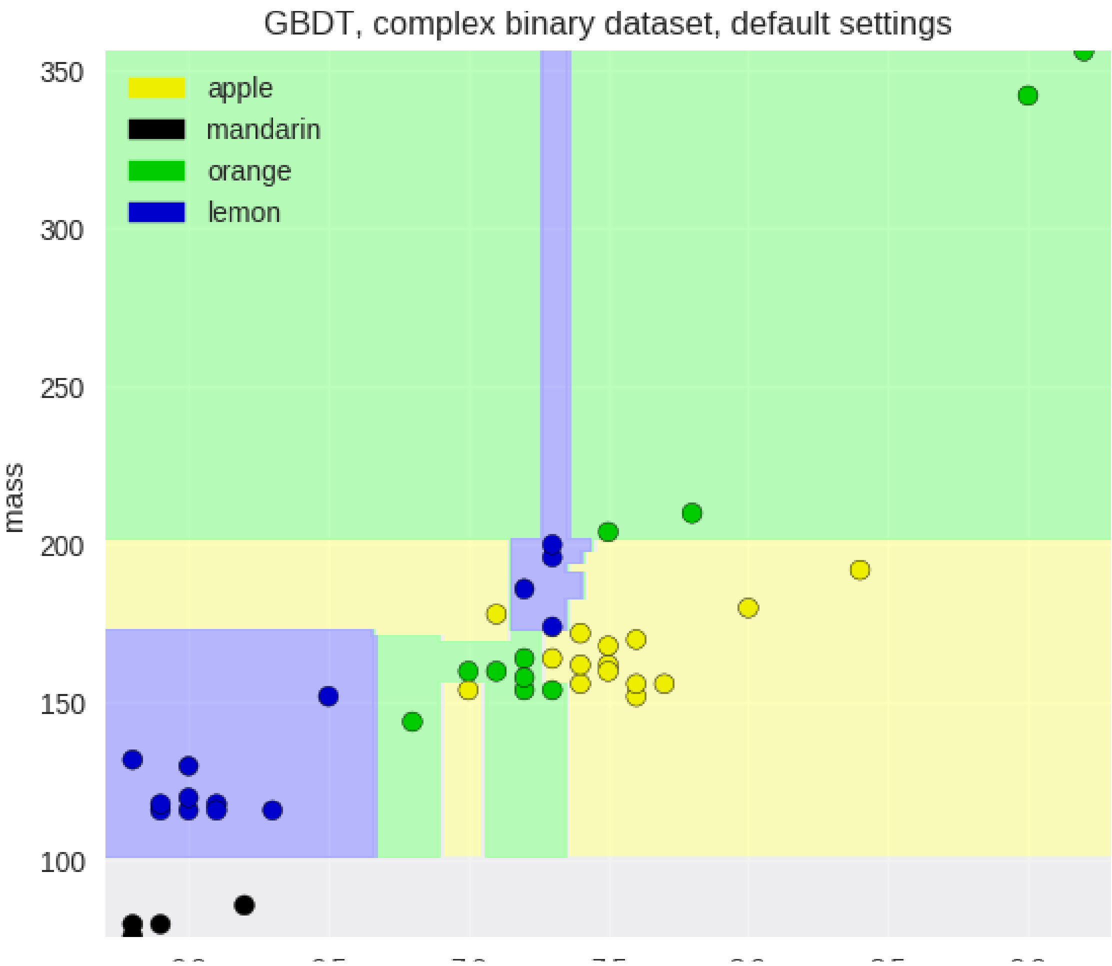
```
X_train, X_test, y_train, y_test = train_test_split(X_fruits.as_matrix(),
                                                     y_fruits.as_matrix(),
                                                     random_state = 0)
fig, subaxes = plt.subplots(6, 1, figsize=(6, 32))

pair_list = [[0,1], [0,2], [0,3], [1,2], [1,3], [2,3]]

for pair, axis in zip(pair_list, subaxes):
    X = X_train[:, pair]
    y = y_train

    clf = GradientBoostingClassifier().fit(X, y)
    plot_class_regions_for_classifier_subplot(clf, X, y, None,
                                             None, title, axis,
                                             target_names_fruits)

    axis.set_xlabel(feature_names_fruits[pair[0]])
    axis.set_ylabel(feature_names_fruits[pair[1]])

plt.tight_layout()
plt.show()
clf = GradientBoostingClassifier().fit(X_train, y_train)

print('GBDT, Fruit dataset, default settings')
print('Accuracy of GBDT classifier on training set: {:.2f}'
     .format(clf.score(X_train, y_train)))
print('Accuracy of GBDT classifier on test set: {:.2f}'
     .format(clf.score(X_test, y_test)))
```


GBDT, complex binary dataset, default settings
apple
mandarin
orange
lemon
width
9.0
8.5
8.0
7.5
7.0
6.5
6.0
4
5
6
7
8
9
10
height

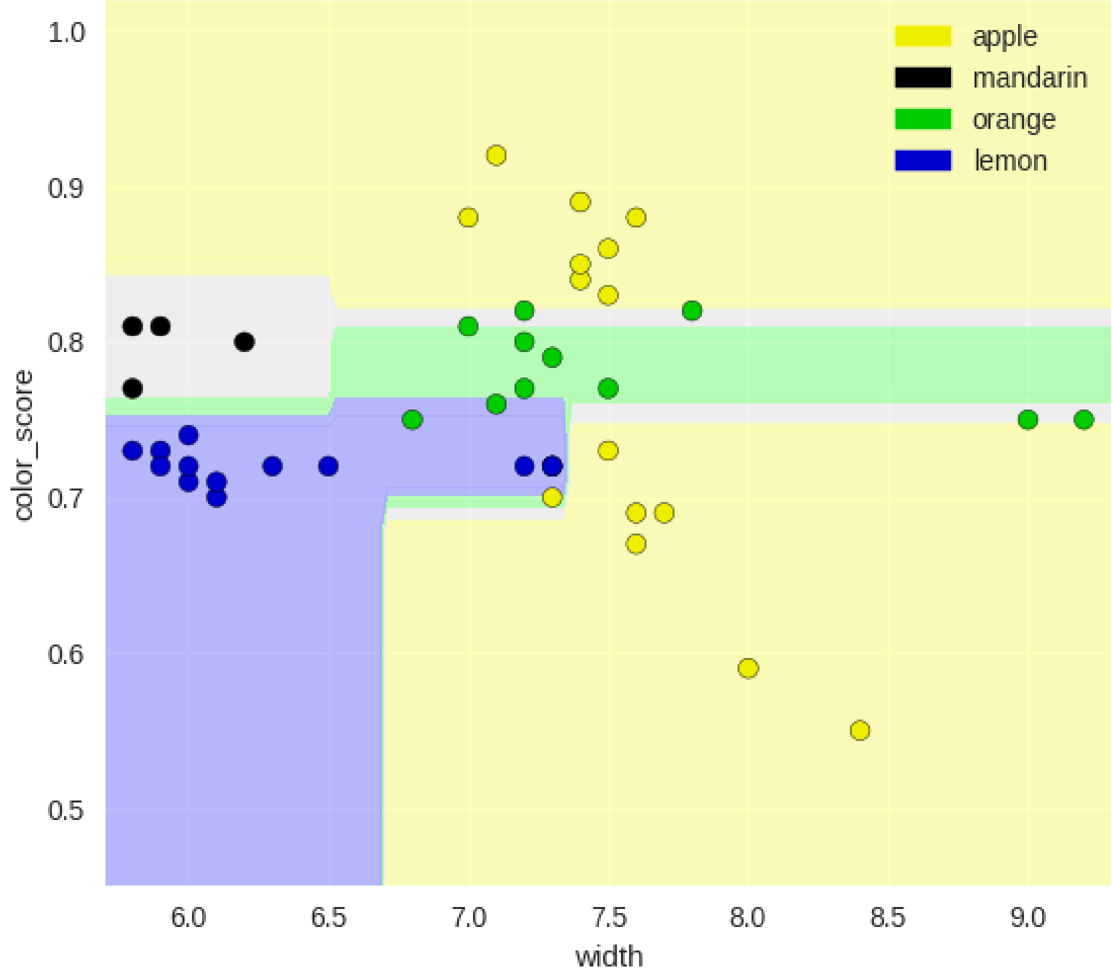

GBDT, complex binary dataset, default settings
apple
mandarin
orange
lemon
mass
350
300
250
200
150
100


height

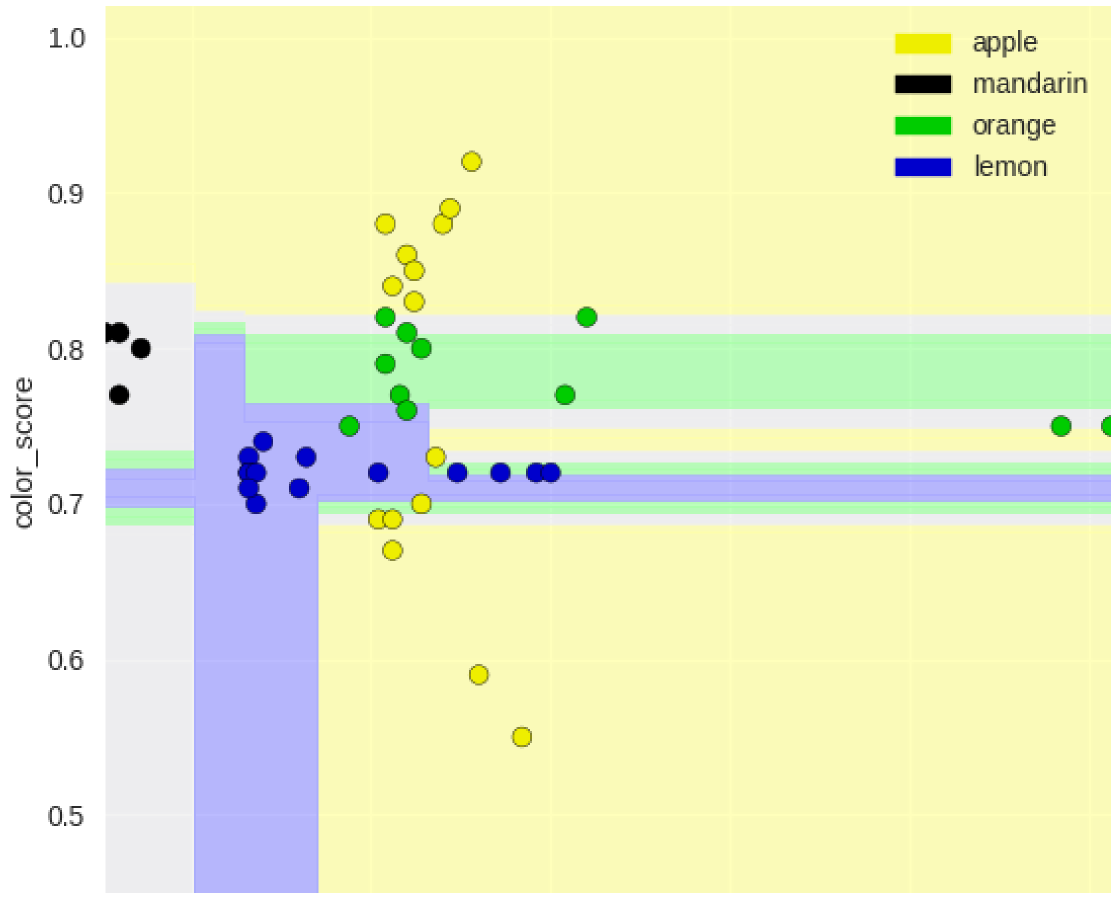

GBDT, complex binary dataset, default settings
apple
mandarin
orange
lemon
color_score
height


GBDT, complex binary dataset, default settings
apple
mandarin
orange
lemon
mass

GBDT, complex binary dataset, default settings



GBDT, complex binary dataset, default settings




```
GBDT, Fruit dataset, default settings
Accuracy of GBDT classifier on training set: 1.00
Accuracy of GBDT classifier on test set: 0.80
```

Gradient-boosted decision trees on a real-world dataset

In [10]:

```
from sklearn.ensemble import GradientBoostingClassifier

X_train, X_test, y_train, y_test = train_test_split(X_cancer, y_cancer, random_state = 0)

clf = GradientBoostingClassifier(random_state = 0)
clf.fit(X_train, y_train)

print('Breast cancer dataset (learning_rate=0.1, max_depth=3)')
print('Accuracy of GBDT classifier on training set: {:.2f}'
     .format(clf.score(X_train, y_train)))
print('Accuracy of GBDT classifier on test set: {:.2f}\n'
     .format(clf.score(X_test, y_test)))

clf = GradientBoostingClassifier(learning_rate = 0.01, max_depth = 2, random_state = 0)
clf.fit(X_train, y_train)

print('Breast cancer dataset (learning_rate=0.01, max_depth=2)')
print('Accuracy of GBDT classifier on training set: {:.2f}'
     .format(clf.score(X_train, y_train)))
print('Accuracy of GBDT classifier on test set: {:.2f}'
     .format(clf.score(X_test, y_test)))
```

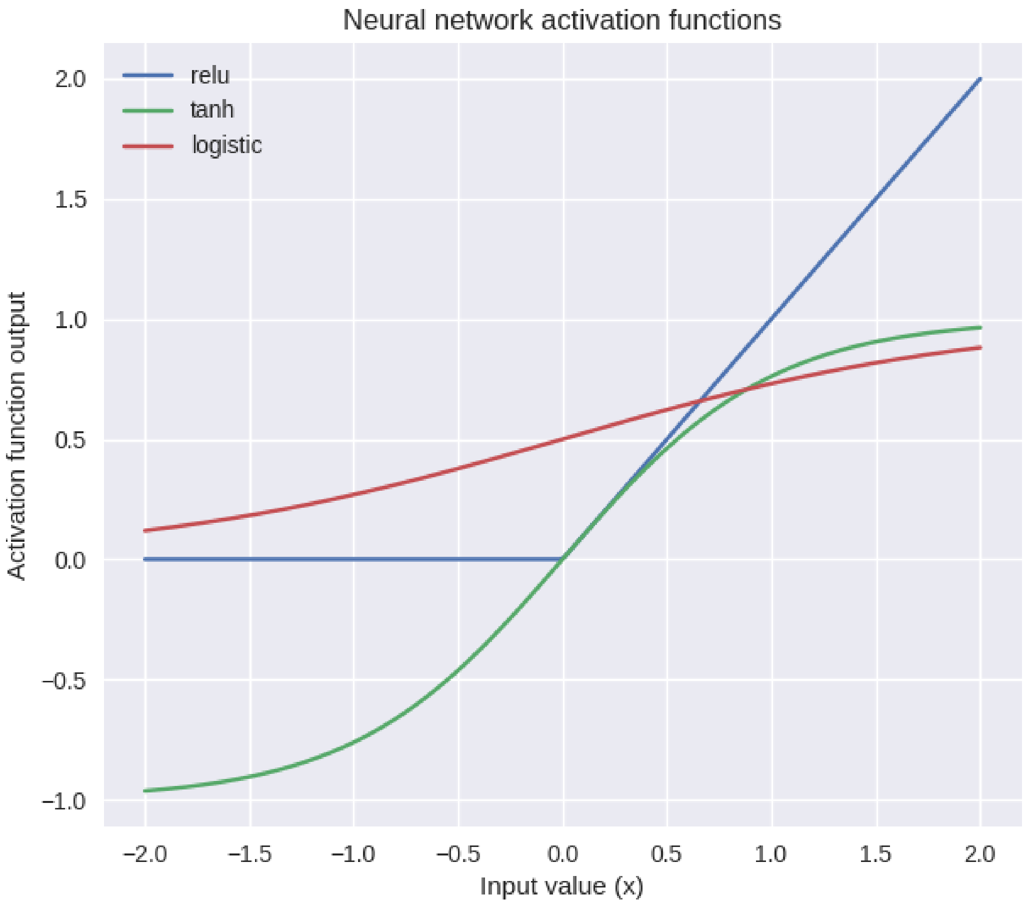
```
Breast cancer dataset (learning_rate=0.1, max_depth=3)
Accuracy of GBDT classifier on training set: 1.00
Accuracy of GBDT classifier on test set: 0.96

Breast cancer dataset (learning_rate=0.01, max_depth=2)
Accuracy of GBDT classifier on training set: 0.97
Accuracy of GBDT classifier on test set: 0.97
```

Neural networks

Activation functions

In [11]:

```
xrange = np.linspace(-2, 2, 200)

plt.figure(figsize=(7,6))

plt.plot(xrange, np.maximum(xrange, 0), label = 'relu')
plt.plot(xrange, np.tanh(xrange), label = 'tanh')
plt.plot(xrange, 1 / (1 + np.exp(-xrange)), label = 'logistic')
plt.legend()
plt.title('Neural network activation functions')
plt.xlabel('Input value (x)')
plt.ylabel('Activation function output')

plt.show()
```



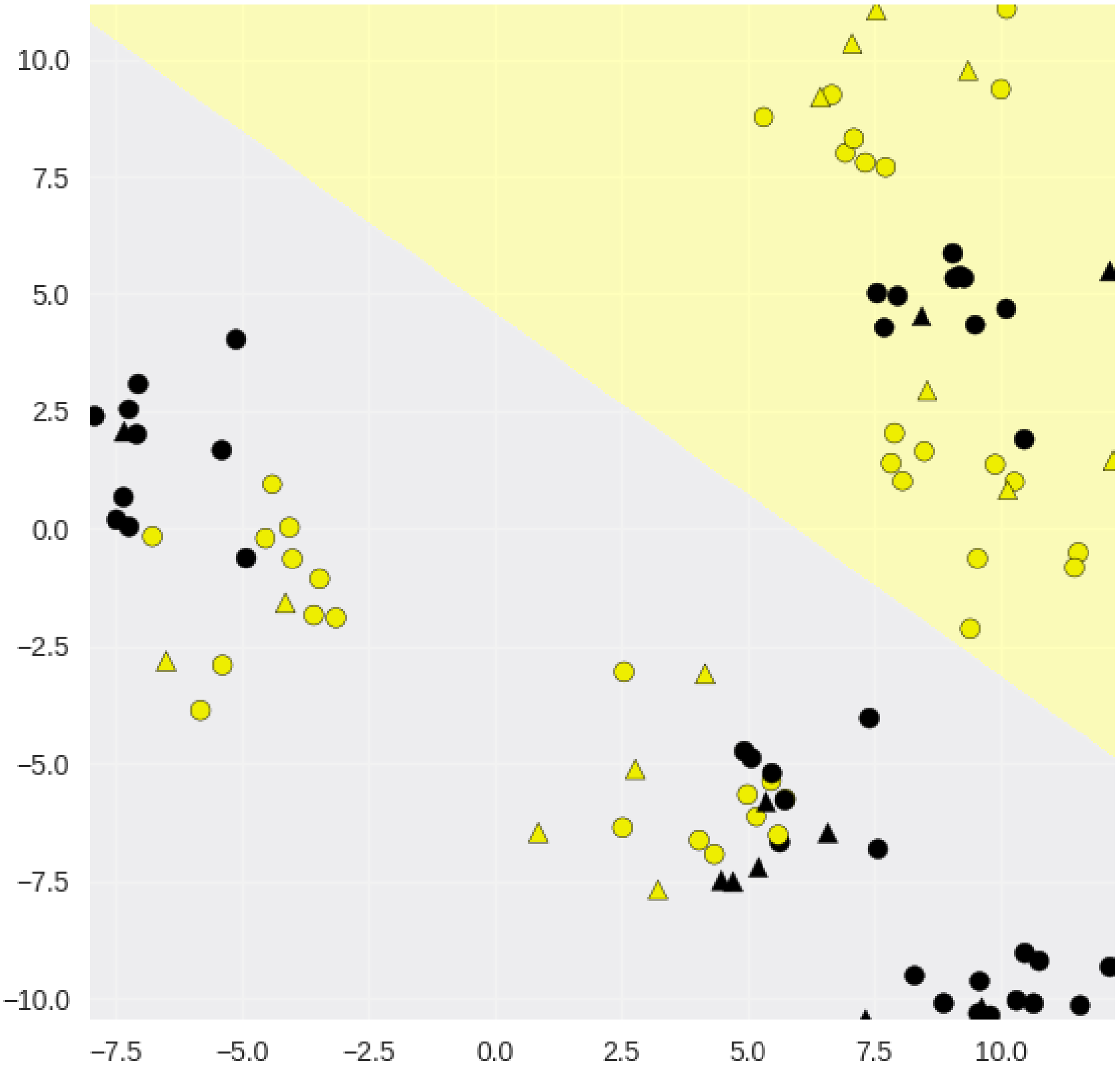
Neural networks: Classification

Synthetic dataset 1: single hidden layer

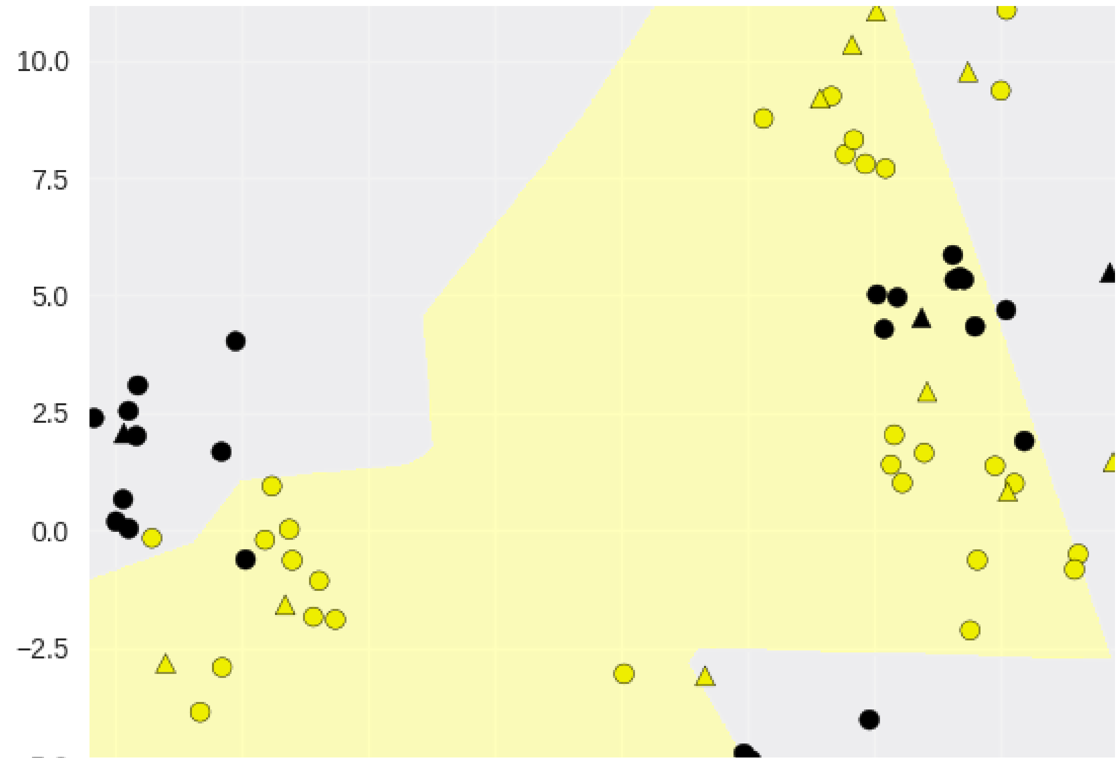
In [12]:

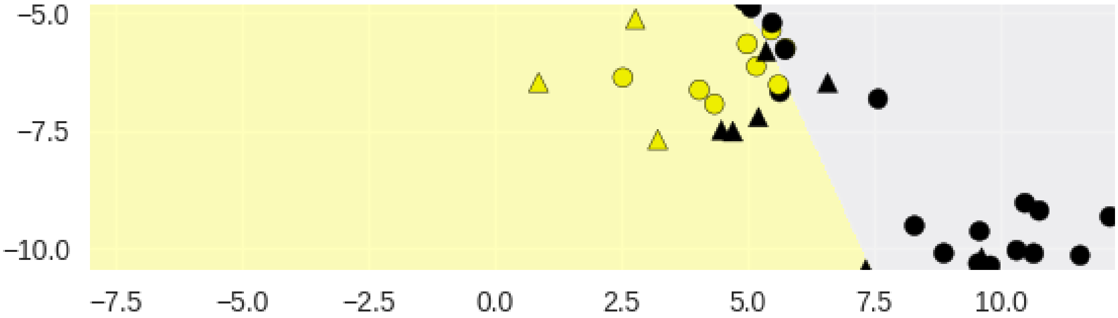
```
from sklearn.neural_network import MLPClassifier
from adspy_shared_utilities import plot_class_regions_for_classifier_subplot

X_train, X_test, y_train, y_test = train_test_split(X_D2, y_D2, random_state=0)

fig, subaxes = plt.subplots(3, 1, figsize=(6,18))

for units, axis in zip([1, 10, 100], subaxes):
    nnclf = MLPClassifier(hidden_layer_sizes = [units], solver='lbfgs',
                          random_state = 0).fit(X_train, y_train)

    title = 'Dataset 1: Neural net classifier, 1 layer, {} units'.format(units)

    plot_class_regions_for_classifier_subplot(nnclf, X_train, y_train,
                                              X_test, y_test, title, axis)
    plt.tight_layout()
```

Dataset 1: Neural net classifier, 1 layer, 1 units
Train score = 0.61, Test score = 0.64

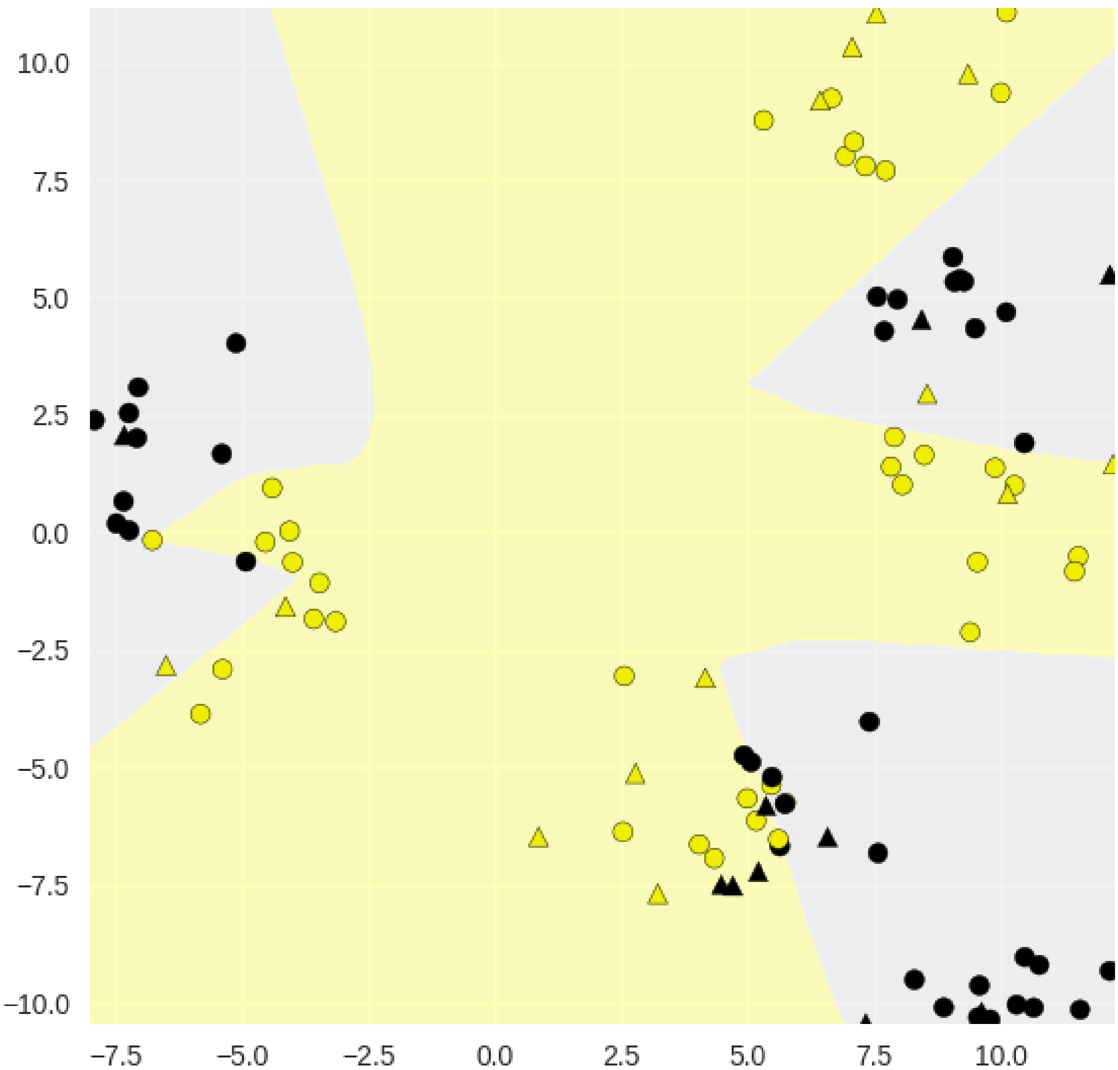


Dataset 1: Neural net classifier, 1 layer, 10 units
Train score = 0.77, Test score = 0.64





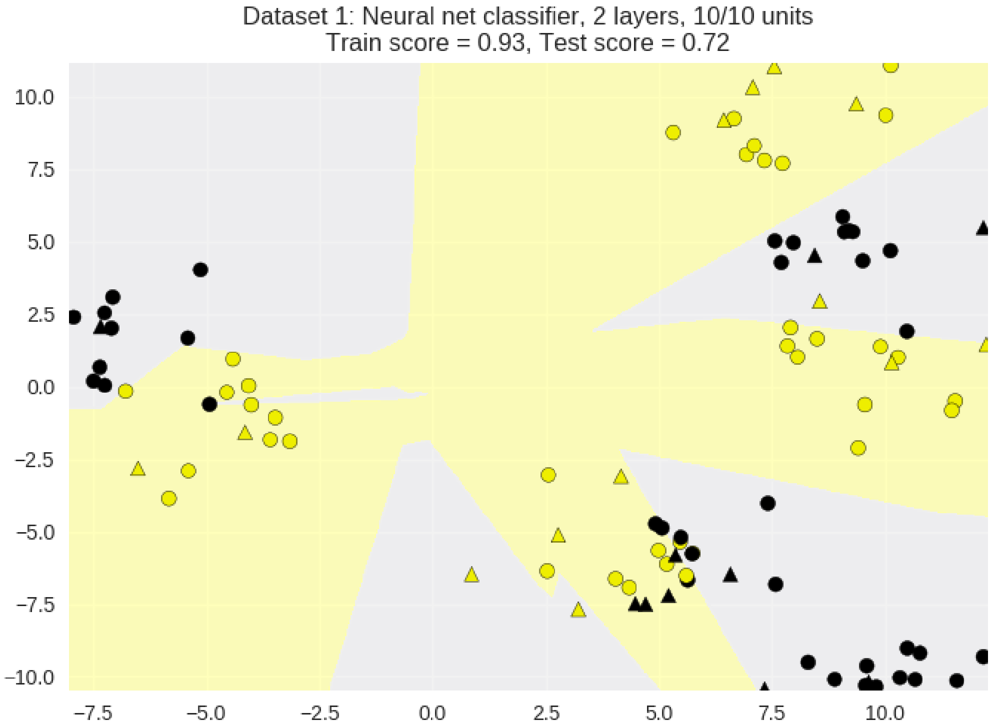
Dataset 1: Neural net classifier, 1 layer, 100 units
Train score = 0.93, Test score = 0.76



Synthetic dataset 1: two hidden layers

In [13]:

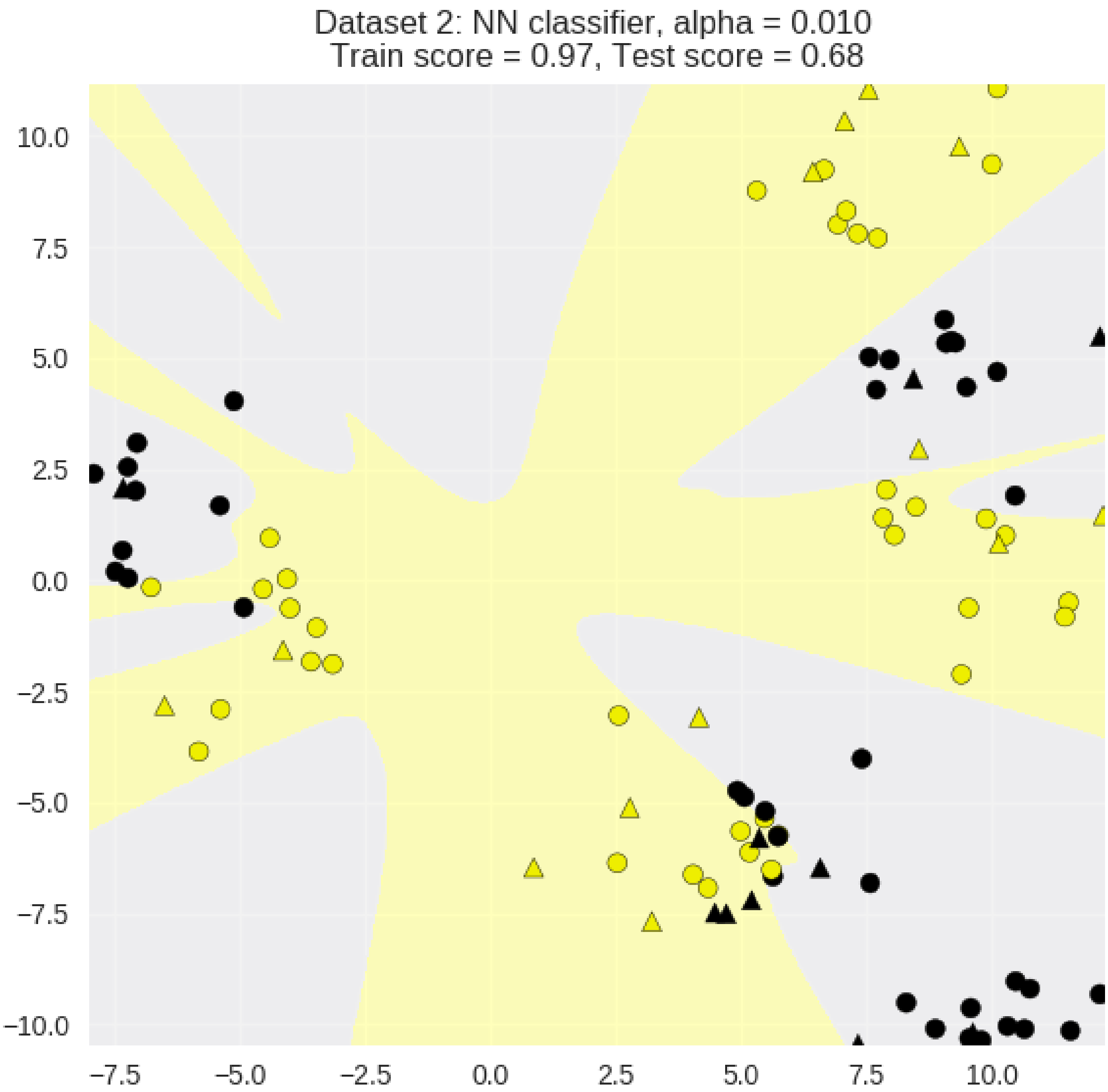
```
from adspy_shared_utilities import plot_class_regions_for_classifier

X_train, X_test, y_train, y_test = train_test_split(X_D2, y_D2, random_state=0)

nnclf = MLPClassifier(hidden_layer_sizes = [10, 10], solver='lbfgs',
                     random_state = 0).fit(X_train, y_train)

plot_class_regions_for_classifier(nnclf, X_train, y_train, X_test, y_test,
                                 'Dataset 1: Neural net classifier, 2 layers, 10/10 units')
```

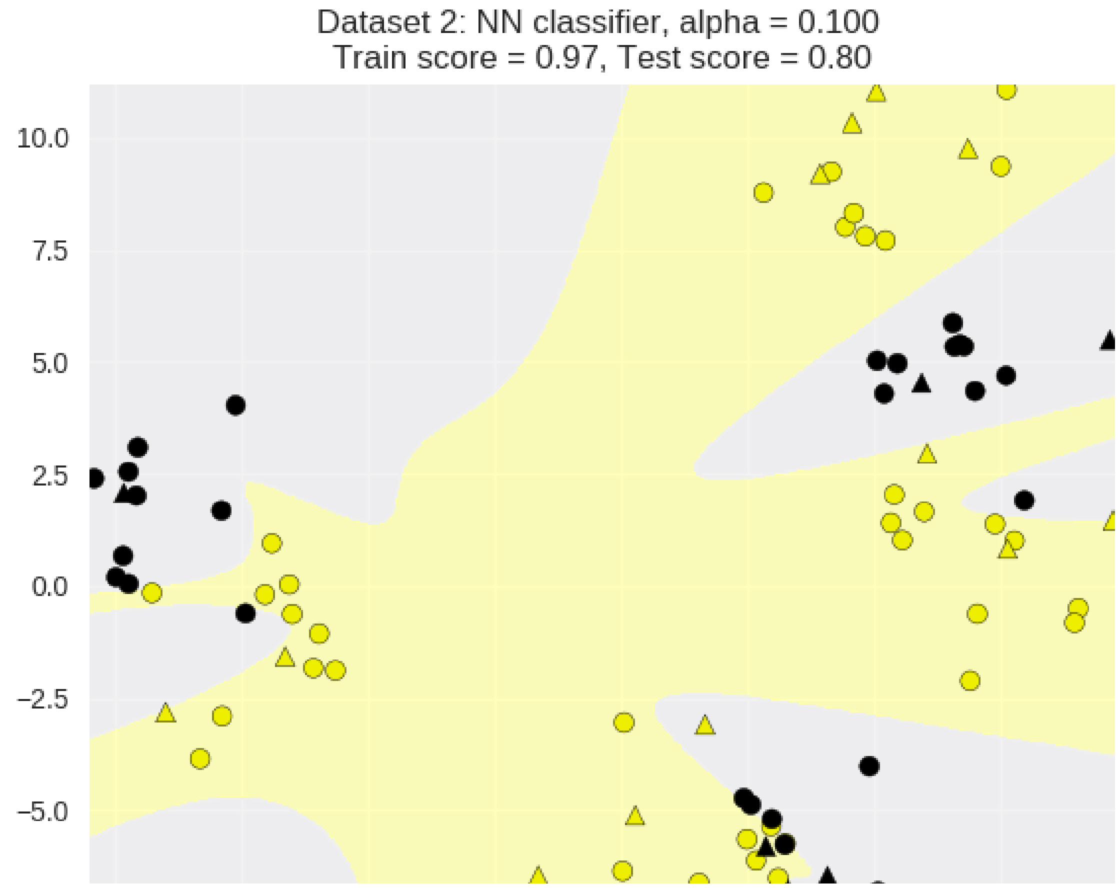


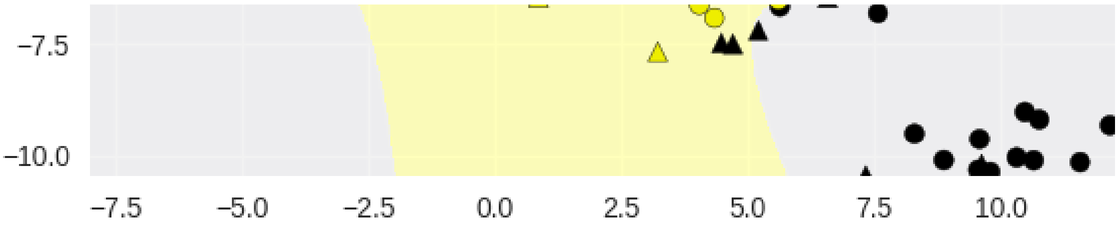
Regularization parameter: alpha

In [14]:

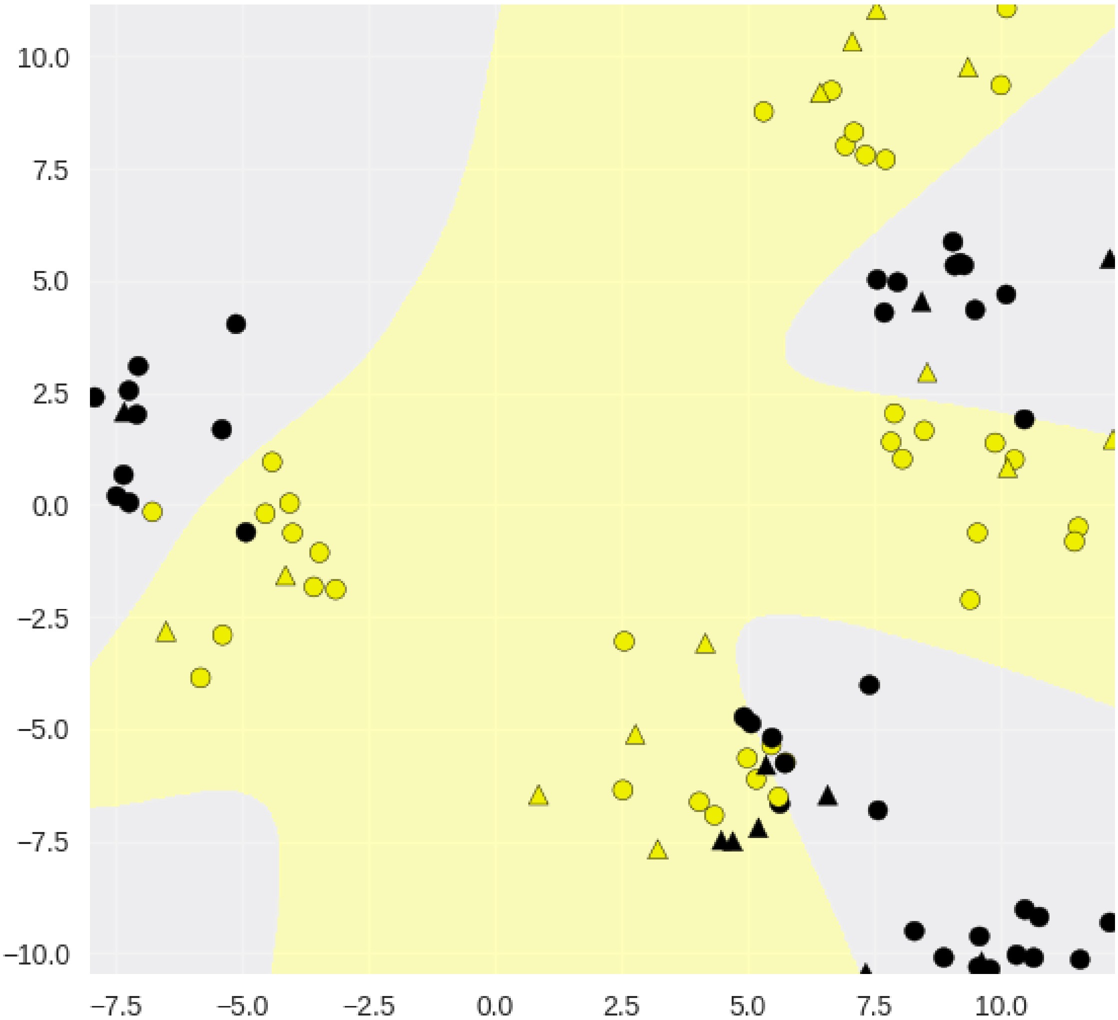
```
X_train, X_test, y_train, y_test = train_test_split(X_D2, y_D2, random_state=0)

fig, subaxes = plt.subplots(4, 1, figsize=(6, 23))

for this_alpha, axis in zip([0.01, 0.1, 1.0, 5.0], subaxes):
    nnclf = MLPClassifier(solver='lbfgs', activation = 'tanh',
                         alpha = this_alpha,
                         hidden_layer_sizes = [100, 100],
                         random_state = 0).fit(X_train, y_train)

    title = 'Dataset 2: NN classifier, alpha = {:.3f} '.format(this_alpha)

    plot_class_regions_for_classifier_subplot(nnclf, X_train, y_train,
                                             X_test, y_test, title, axis)
    plt.tight_layout()
```


Dataset 2: NN classifier, alpha = 0.010
Train score = 0.97, Test score = 0.68
10.0
7.5
5.0
2.5
0.0
−2.5
−5.0
−7.5
−10.0
−7.5
−5.0
−2.5
0.0
2.5
5.0
7.5
10.0

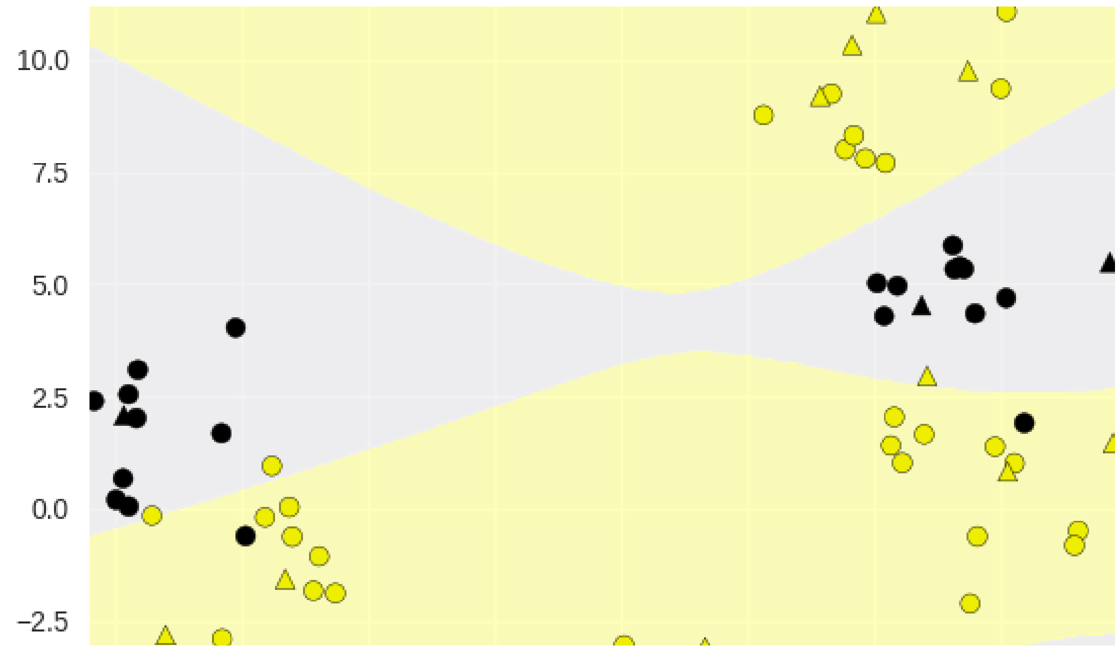

Dataset 2: NN classifier, alpha = 0.100
Train score = 0.97, Test score = 0.80
10.0
7.5
5.0
2.5
0.0
−2.5
−5.0

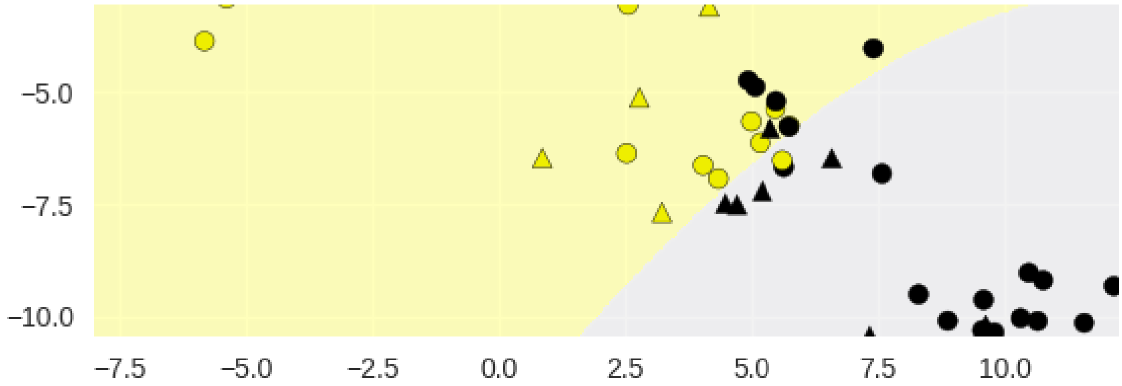


Dataset 2: NN classifier, alpha = 1.000
Train score = 0.89, Test score = 0.80



Dataset 2: NN classifier, alpha = 5.000
Train score = 0.87, Test score = 0.92

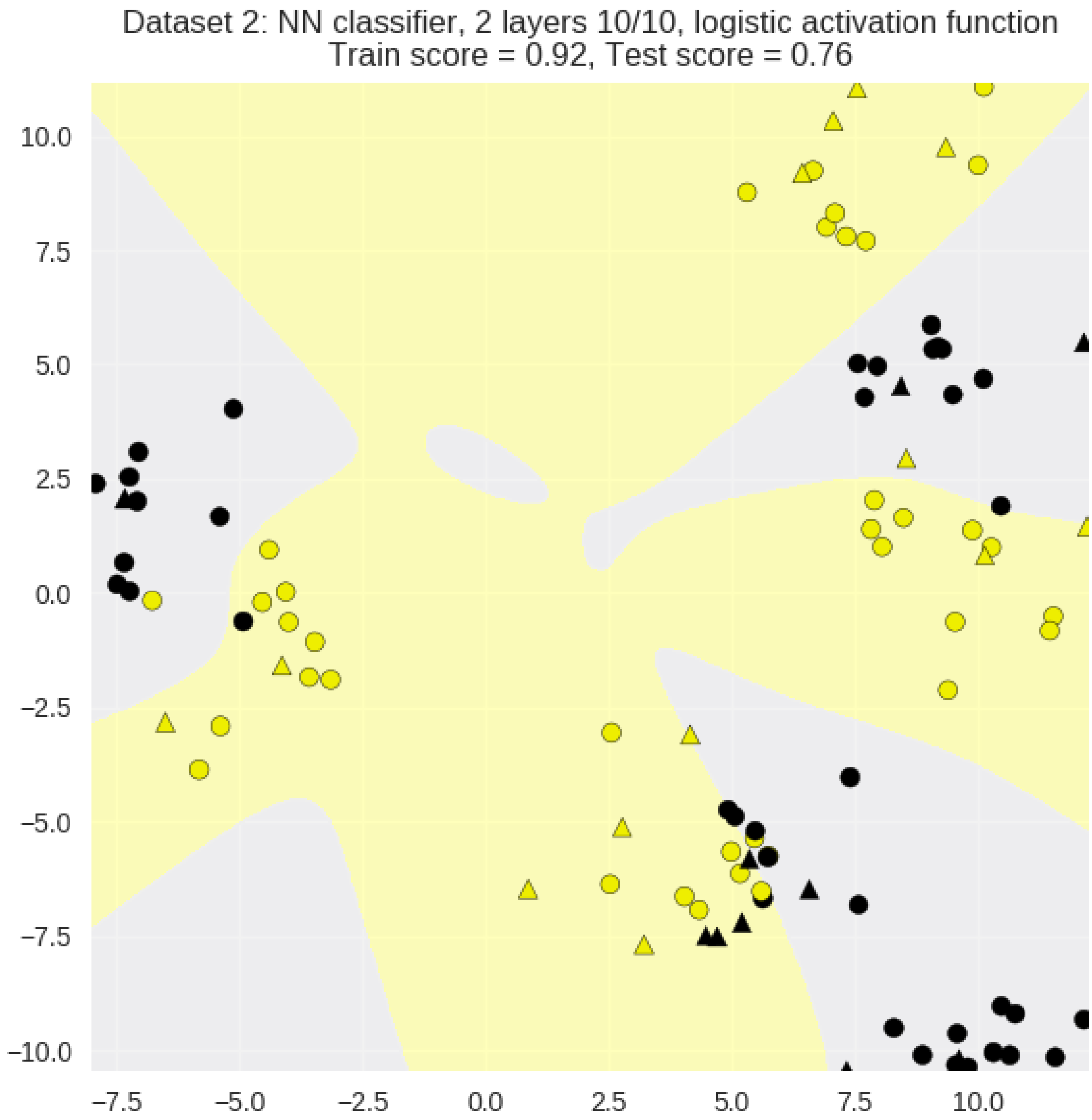


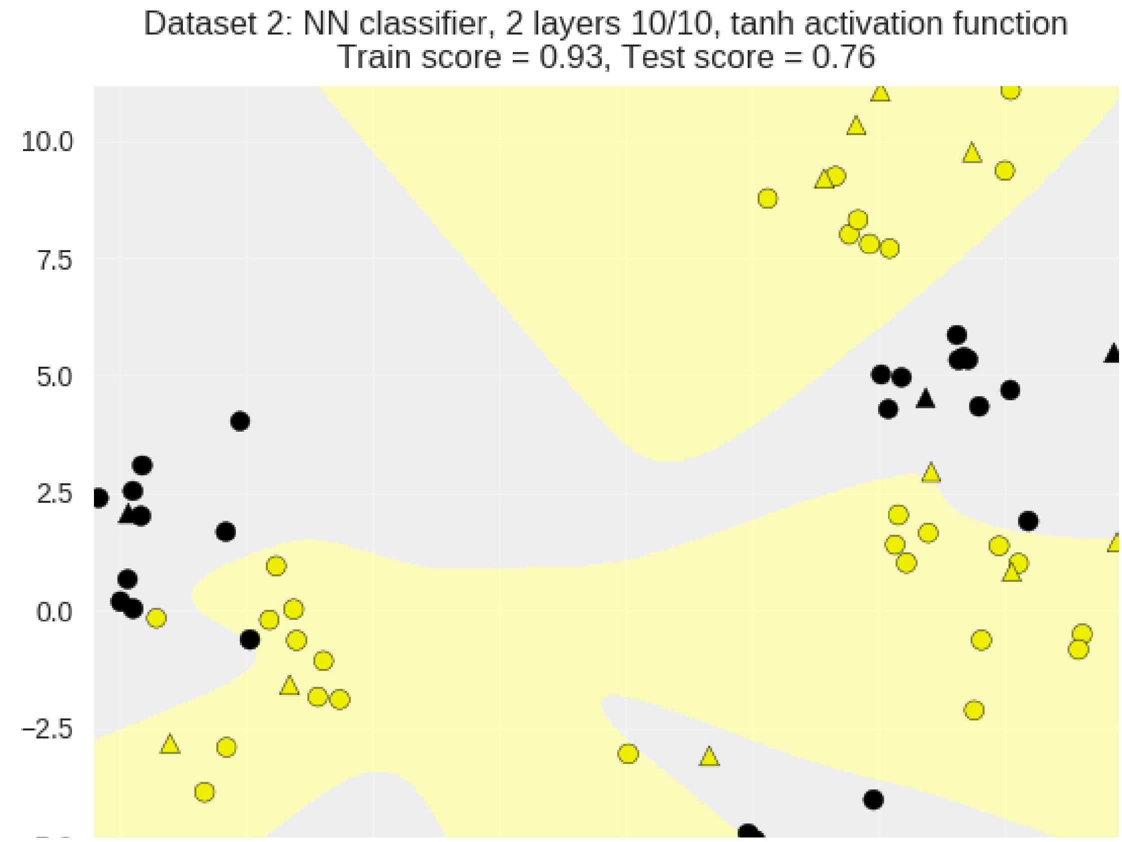


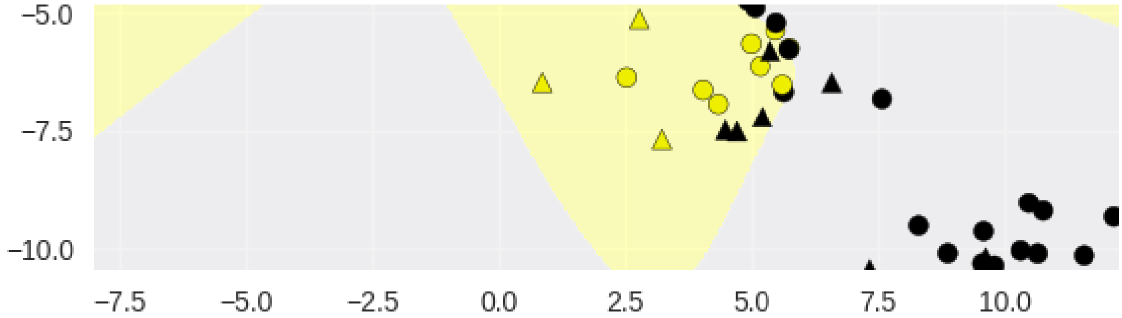
The effect of different choices of activation function

In [15]:

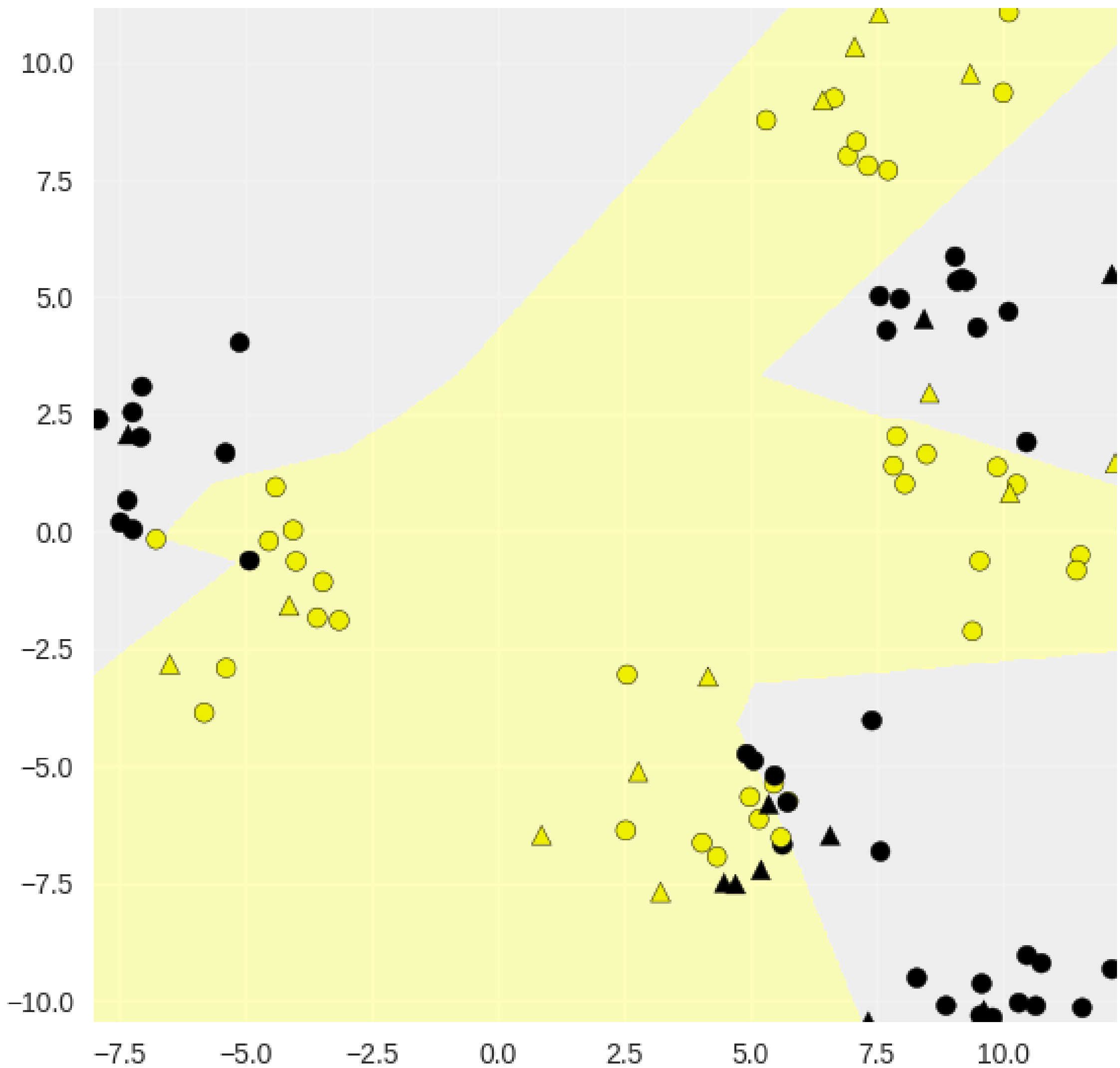
```
X_train, X_test, y_train, y_test = train_test_split(X_D2, y_D2, random_state=0)

fig, subaxes = plt.subplots(3, 1, figsize=(6,18))

for this_activation, axis in zip(['logistic', 'tanh', 'relu'], subaxes):
    nnclf = MLPClassifier(solver='lbfgs', activation = this_activation,
                         alpha = 0.1, hidden_layer_sizes = [10, 10],
                         random_state = 0).fit(X_train, y_train)

    title = 'Dataset 2: NN classifier, 2 layers 10/10, {} \
activation function'.format(this_activation)

    plot_class_regions_for_classifier_subplot(nnclf, X_train, y_train,
                                             X_test, y_test, title, axis)
    plt.tight_layout()
```


Dataset 2: NN classifier, 2 layers 10/10, logistic activation function
Train score = 0.92, Test score = 0.76
10.0
7.5
5.0
2.5
0.0
−2.5
−5.0
−7.5
−10.0
−7.5
−5.0
−2.5
0.0
2.5
5.0
7.5
10.0


Dataset 2: NN classifier, 2 layers 10/10, tanh activation function
Train score = 0.93, Test score = 0.76
10.0
7.5
5.0
2.5
0.0
−2.5



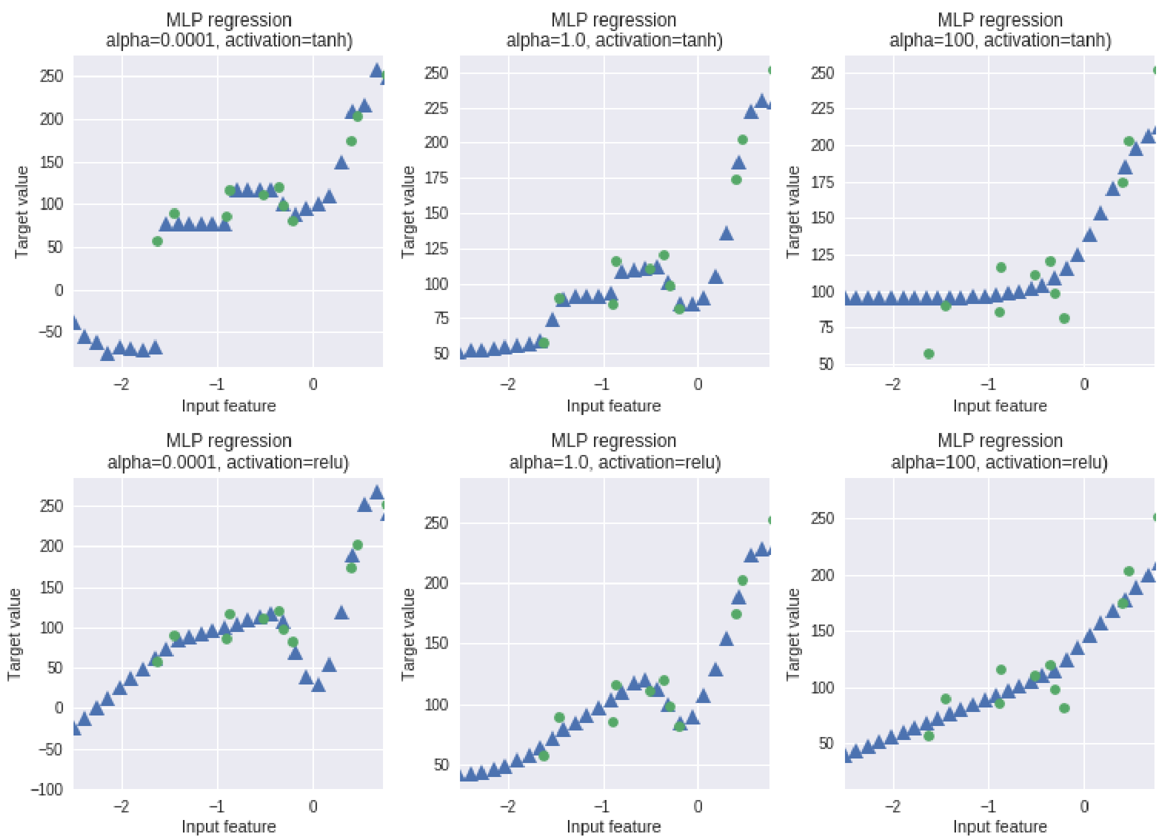
Dataset 2: NN classifier, 2 layers 10/10, relu activation function
Train score = 0.91, Test score = 0.76



Neural networks: Regression

In [16]:

```
from sklearn.neural_network import MLPRegressor

fig, subaxes = plt.subplots(2, 3, figsize=(11,8), dpi=70)

X_predict_input = np.linspace(-3, 3, 50).reshape(-1,1)

X_train, X_test, y_train, y_test = train_test_split(X_R1[0::5], y_R1[0::5], random_state =

for thisaxisrow, thisactivation in zip(subaxes, ['tanh', 'relu']):
    for thisalpha, thisaxis in zip([0.0001, 1.0, 100], thisaxisrow):
        mlpreg = MLPRegressor(hidden_layer_sizes = [100,100],
                             activation = thisactivation,
                             alpha = thisalpha,
                             solver = 'lbfgs').fit(X_train, y_train)
        y_predict_output = mlpreg.predict(X_predict_input)
        thisaxis.set_xlim([-2.5, 0.75])
        thisaxis.plot(X_predict_input, y_predict_output,
                     '^', markersize = 10)
        thisaxis.plot(X_train, y_train, 'o')
        thisaxis.set_xlabel('Input feature')
        thisaxis.set_ylabel('Target value')
        thisaxis.set_title('MLP regression\nalpha={}, activation={})'
                          .format(thisalpha, thisactivation))
        plt.tight_layout()
```



Application to real-world dataset for classification

In [17]:

```
from sklearn.neural_network import MLPClassifier
from sklearn.preprocessing import MinMaxScaler


scaler = MinMaxScaler()

X_train, X_test, y_train, y_test = train_test_split(X_cancer, y_cancer, random_state = 0)
X_train_scaled = scaler.fit_transform(X_train)
X_test_scaled = scaler.transform(X_test)

clf = MLPClassifier(hidden_layer_sizes = [100, 100], alpha = 5.0,
                   random_state = 0, solver='lbfgs').fit(X_train_scaled, y_train)

print('Breast cancer dataset')
print('Accuracy of NN classifier on training set: {:.2f}'
     .format(clf.score(X_train_scaled, y_train)))
print('Accuracy of NN classifier on test set: {:.2f}'
     .format(clf.score(X_test_scaled, y_test)))
```

```
Breast cancer dataset
Accuracy of NN classifier on training set: 0.98
Accuracy of NN classifier on test set: 0.97
```