Setup

In [ ]:
```
import numpy as np
import matplotlib.pyplot as plt
import matplotlib.colors
import pandas as pd
from sklearn.model_selection import train_test_split
from sklearn.metrics import accuracy_score, mean_squared_error, log_loss
from tqdm import tqdm_notebook
import seaborn as sns
import imageio
from IPython.display import HTML


from sklearn.preprocessing import OneHotEncoder
from sklearn.datasets import make_blobs
```

In [ ]:
```
my_cmap = matplotlib.colors.LinearSegmentedColormap.from_list("", ["red","yell
```

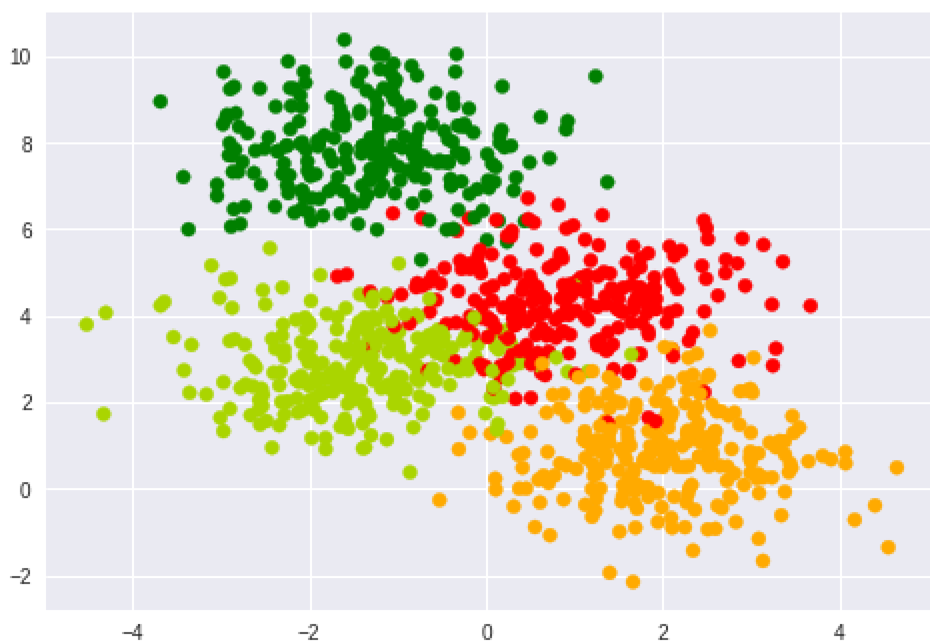
In [ ]:
```
np.random.seed(0)
```

Generate data

In [ ]:
```
data, labels = make_blobs(n_samples=1000, centers=4, n_features=2, random_stat
print(data.shape, labels.shape)
```

```
(1000, 2) (1000,)
```

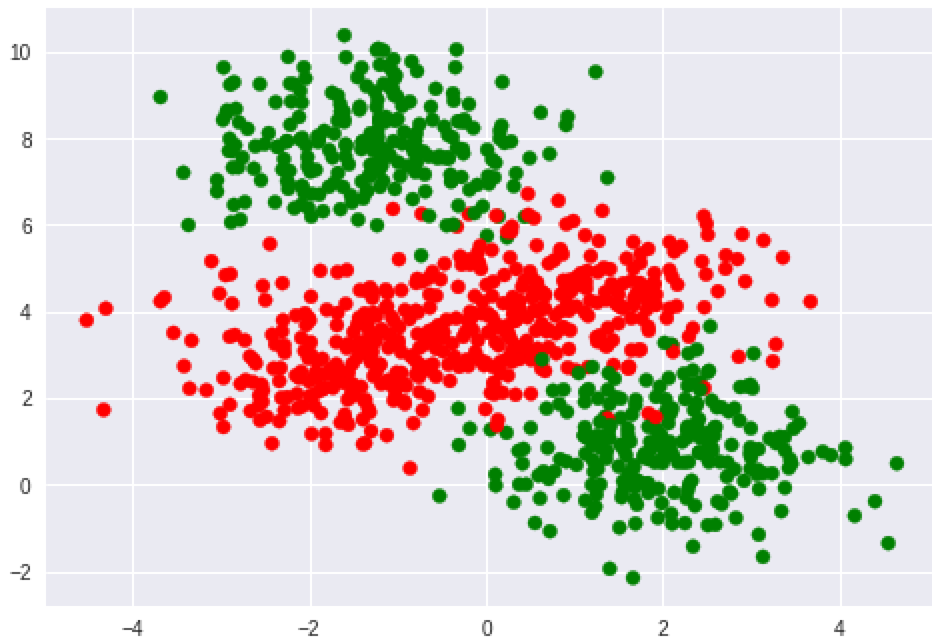
In [ ]:
```
plt.scatter(data[:,0], data[:,1], c=labels, cmap=my_cmap)
plt.show()
```



In [ ]:
```
labels_orig = labels
```

```
labels = np.mod(labels_orig, 2)
```

In [ ]:
```
plt.scatter(data[:,0], data[:,1], c=labels, cmap=my_cmap)
plt.show()
```



In [ ]:
```
X_train, X_val, Y_train, Y_val = train_test_split(data, labels, stratify=label
print(X_train.shape, X_val.shape)
```

```
(750, 2) (250, 2)
```

```
# This is formatted as code
```

FeedForward Network

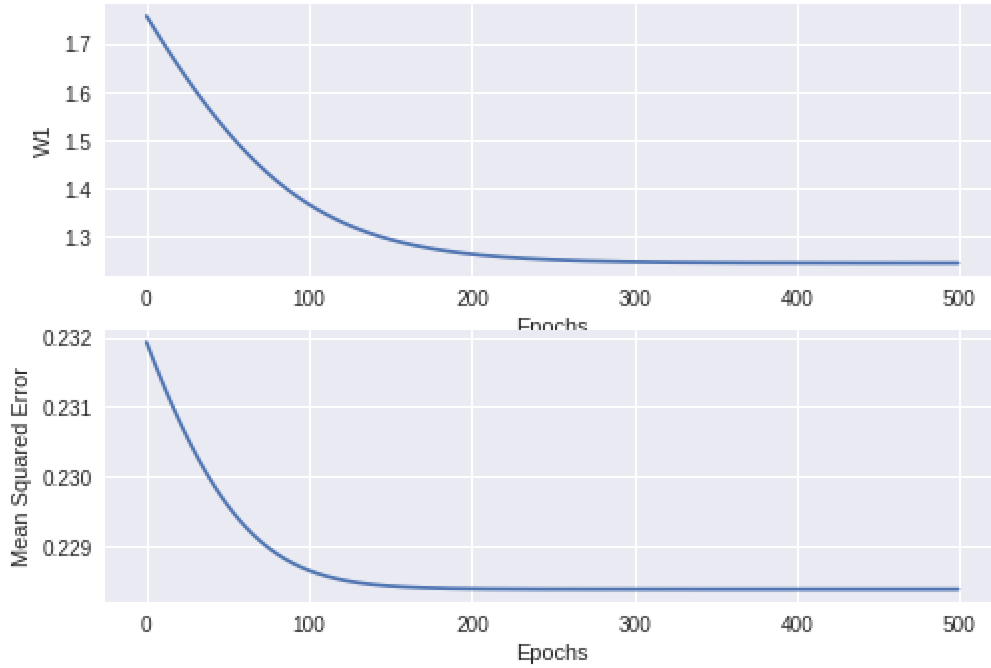
In [ ]:
```
class FFNetworkW1:

  def __init__(self):
    self.w1 = np.random.randn()
    self.w2 = np.random.randn()
    self.w3 = np.random.randn()
    self.w4 = np.random.randn()
    self.w5 = np.random.randn()
    self.w6 = np.random.randn()
    self.b1 = 0
    self.b2 = 0
    self.b3 = 0

  def sigmoid(self, x):
    return 1.0/(1.0 + np.exp(-x))

  def forward_pass(self, x):
    self.x1, self.x2 = x
    self.a1 = self.w1*self.x1 + self.w2*self.x2 + self.b1
    self.h1 = self.sigmoid(self.a1)
    self.a2 = self.w3*self.x1 + self.w4*self.x2 + self.b2
    self.h2 = self.sigmoid(self.a2)
```

```
    self.a3 = self.w5*self.h1 + self.w6*self.h2 + self.b3
    self.h3 = self.sigmoid(self.a3)
    return self.h3

  def grad(self, x, y):
    self.forward_pass(x)
    self.dw1 = (self.h3-y) * self.h3*(1-self.h3) * self.w5 * self.h1*(1-self.h1


  def fit(self, X, Y, epochs=1, learning_rate=1, display_loss=False):

    if display_loss:
      loss = {}
      w1 = {}

    for i in tqdm_notebook(range(epochs), total=epochs, unit="epoch"):
      dw1, dw2, dw3, dw4, dw5, dw6, db1, db2, db3 = [0]*9
      for x, y in zip(X, Y):
        self.grad(x, y)
        dw1 += self.dw1

      m = X.shape[0]
      self.w1 -= learning_rate * dw1 / m

      if display_loss:
        w1[i] = self.w1
        Y_pred = self.predict(X)
        loss[i] = mean_squared_error(Y_pred, Y)


    if display_loss:
      plt.tight_layout()

      plt.subplot(2,1,1)
      plt.plot(w1.values())
      plt.xlabel('Epochs')
      plt.ylabel('W1')

      plt.subplot(2,1,2)
      plt.plot(loss.values())
      plt.xlabel('Epochs')
      plt.ylabel('Mean Squared Error')

      plt.show()

  def predict(self, X):
    Y_pred = []
    for x in X:
      y_pred = self.forward_pass(x)
      Y_pred.append(y_pred)
    return np.array(Y_pred)
```

In [ ]:

```
ffnw1 = FFNetworkW1()
ffnw1.fit(X_train, Y_train, epochs=500, learning_rate=1, display_loss=True)
```

```
HBox(children=(IntProgress(value=0, max=500), HTML(value='')))
```



In [ ]:
```
class FirstFFNetwork:

  def __init__(self):
    np.random.seed(0)
    self.w1 = np.random.randn()
    self.w2 = np.random.randn()
    self.w3 = np.random.randn()
    self.w4 = np.random.randn()
    self.w5 = np.random.randn()
    self.w6 = np.random.randn()
    self.b1 = 0
    self.b2 = 0
    self.b3 = 0

  def sigmoid(self, x):
    return 1.0/(1.0 + np.exp(-x))

  def forward_pass(self, x):
    self.x1, self.x2 = x
    self.a1 = self.w1*self.x1 + self.w2*self.x2 + self.b1
    self.h1 = self.sigmoid(self.a1)
    self.a2 = self.w3*self.x1 + self.w4*self.x2 + self.b2
    self.h2 = self.sigmoid(self.a2)
    self.a3 = self.w5*self.h1 + self.w6*self.h2 + self.b3
    self.h3 = self.sigmoid(self.a3)
    return self.h3

  def grad(self, x, y):
    self.forward_pass(x)

    self.dw5 = (self.h3-y) * self.h3*(1-self.h3) * self.h1
    self.dw6 = (self.h3-y) * self.h3*(1-self.h3) * self.h2
    self.db3 = (self.h3-y) * self.h3*(1-self.h3)

    self.dw1 = (self.h3-y) * self.h3*(1-self.h3) * self.w5 * self.h1*(1-self.h
    self.dw2 = (self.h3-y) * self.h3*(1-self.h3) * self.w5 * self.h1*(1-self.h
    self.db1 = (self.h3-y) * self.h3*(1-self.h3) * self.w5 * self.h1*(1-self.h
```

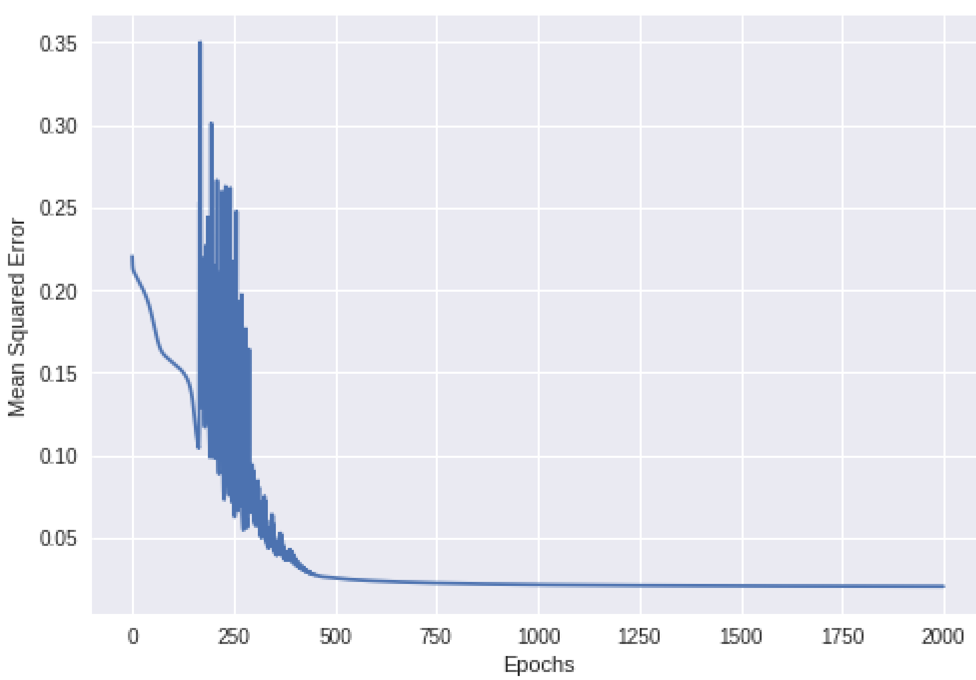
```
    self.dw3 = (self.h3-y) * self.h3*(1-self.h3) * self.w6 * self.h2*(1-self.h
    self.dw4 = (self.h3-y) * self.h3*(1-self.h3) * self.w6 * self.h2*(1-self.h
    self.db2 = (self.h3-y) * self.h3*(1-self.h3) * self.w6 * self.h2*(1-self.h


  def fit(self, X, Y, epochs=1, learning_rate=1, initialise=True, display_loss

    # initialise w, b
    if initialise:
      np.random.seed(0)
      self.w1 = np.random.randn()
      self.w2 = np.random.randn()
      self.w3 = np.random.randn()
      self.w4 = np.random.randn()
      self.w5 = np.random.randn()
      self.w6 = np.random.randn()
      self.b1 = 0
      self.b2 = 0
      self.b3 = 0

    if display_loss:
      loss = {}

    for i in tqdm_notebook(range(epochs), total=epochs, unit="epoch"):
      dw1, dw2, dw3, dw4, dw5, dw6, db1, db2, db3 = [0]*9
      for x, y in zip(X, Y):
        self.grad(x, y)
        dw1 += self.dw1
        dw2 += self.dw2
        dw3 += self.dw3
        dw4 += self.dw4
        dw5 += self.dw5
        dw6 += self.dw6
        db1 += self.db1
        db2 += self.db2
        db3 += self.db3

      m = X.shape[0]
      self.w1 -= learning_rate * dw1 / m
      self.w2 -= learning_rate * dw2 / m
      self.w3 -= learning_rate * dw3 / m
      self.w4 -= learning_rate * dw4 / m
      self.w5 -= learning_rate * dw5 / m
      self.w6 -= learning_rate * dw6 / m
      self.b1 -= learning_rate * db1 / m
      self.b2 -= learning_rate * db2 / m
      self.b3 -= learning_rate * db3 / m

      if display_loss:
        Y_pred = self.predict(X)
        loss[i] = mean_squared_error(Y_pred, Y)

      if display_weight:
        weight_matrix = np.array([[0, self.b3, self.w5, self.w6, 0, 0], [self.
        weight_matrices.append(weight_matrix)

    if display_loss:
      plt.plot(loss.values())
      plt.xlabel('Epochs')
      plt.ylabel('Mean Squared Error')
```

```
      plt.show()

  def predict(self, X):
    Y_pred = []
    for x in X:
      y_pred = self.forward_pass(x)
      Y_pred.append(y_pred)
    return np.array(Y_pred)

  def predict_h1(self, X):
    Y_pred = []
    for x in X:
      y_pred = self.forward_pass(x)
      Y_pred.append(self.h1)
    return np.array(Y_pred)

  def predict_h2(self, X):
    Y_pred = []
    for x in X:
      y_pred = self.forward_pass(x)
      Y_pred.append(self.h2)
    return np.array(Y_pred)

  def predict_h3(self, X):
    Y_pred = []
    for x in X:
      y_pred = self.forward_pass(x)
      Y_pred.append(self.h3)
    return np.array(Y_pred)
```

In [ ]:

```
weight_matrices = []
ffn = FirstFFNetwork()
ffn.fit(X_train, Y_train, epochs=2000, learning_rate=5, display_loss=True, disp
```

```
HBox(children=(IntProgress(value=0, max=2000), HTML(value='')))
```

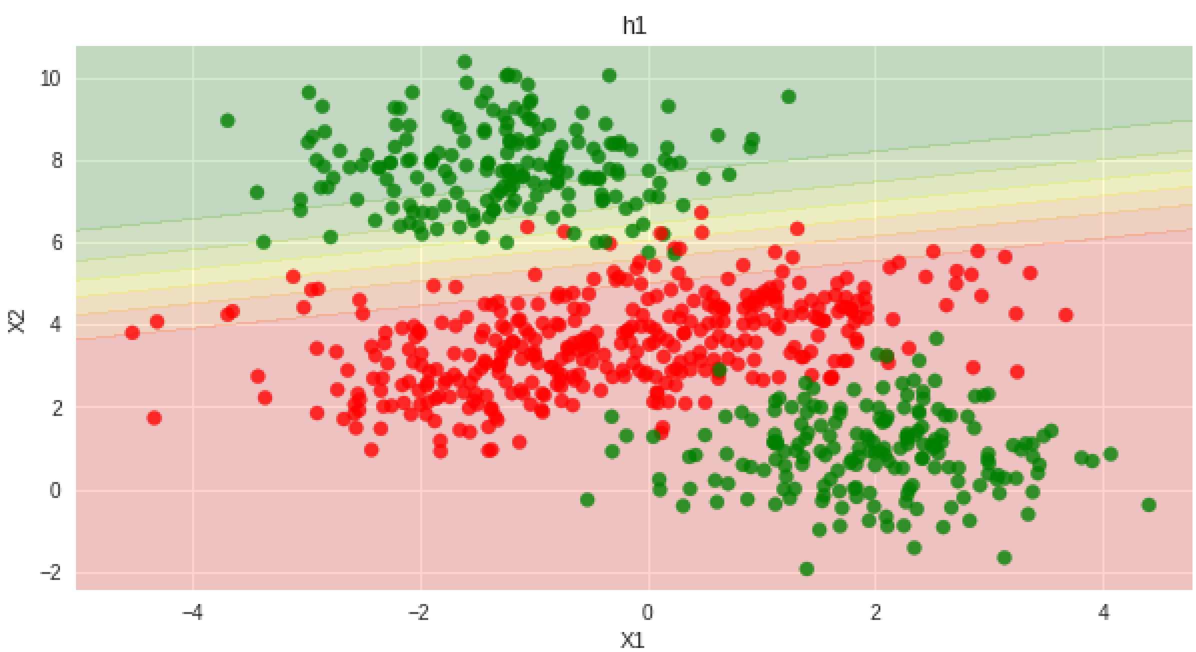


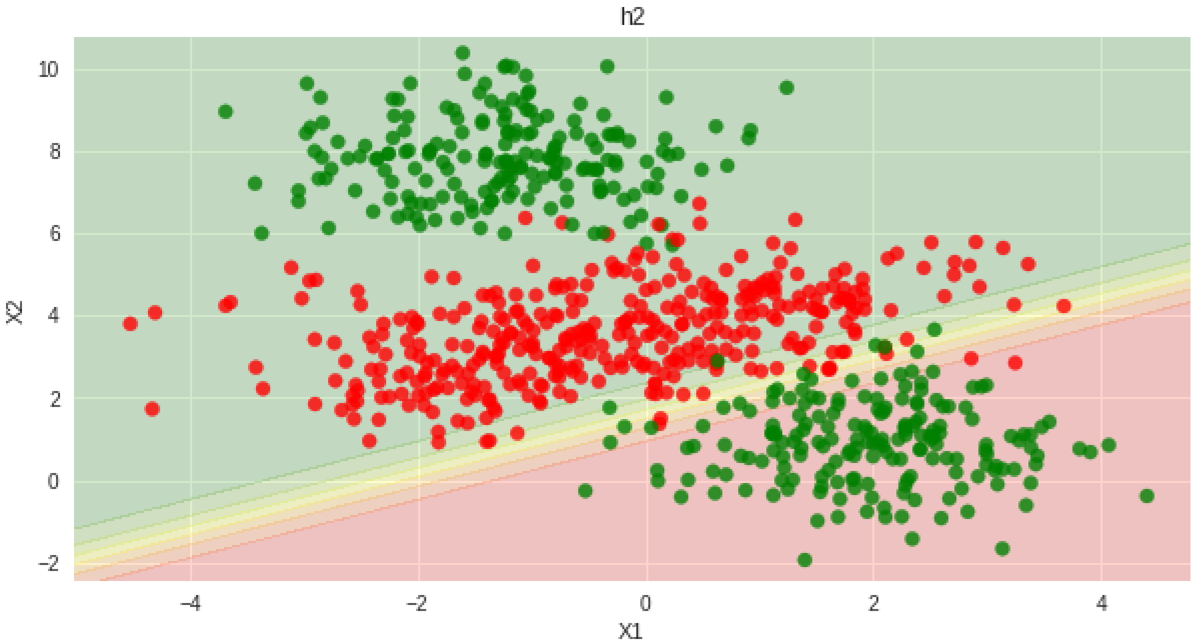
In [ ]:

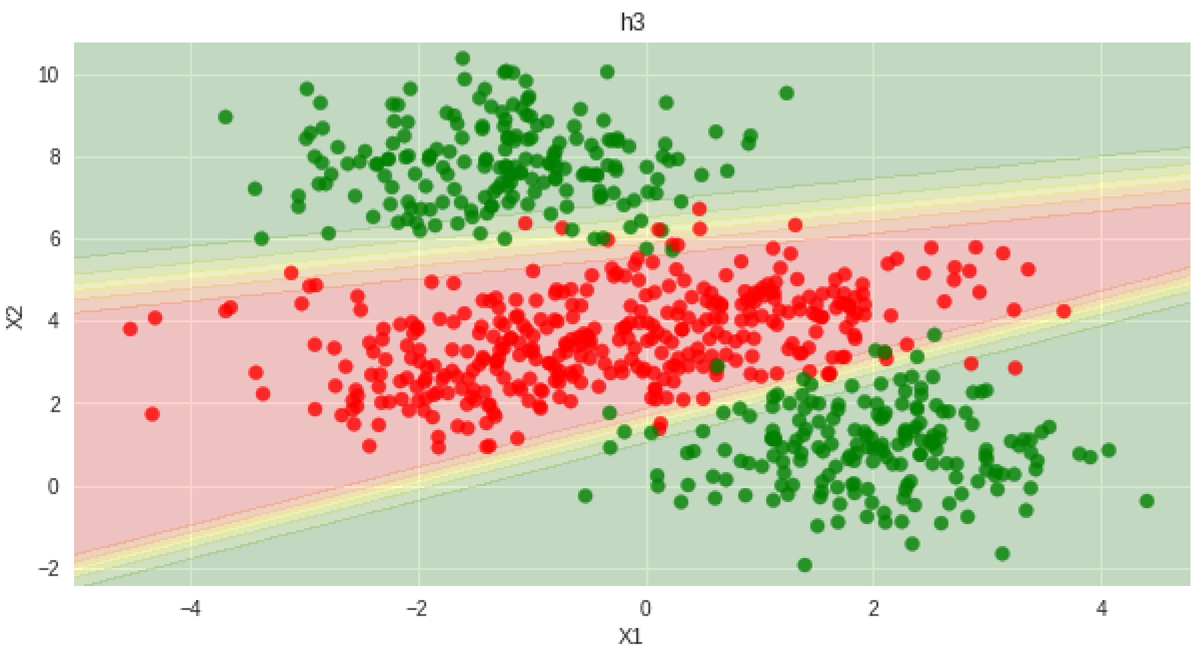
```
def make_meshgrid(x, y, h=.2):
    x_min, x_max = x.min() - 0.5, x.max() + 0.5
```

```
    y_min, y_max = y.min() - 0.5, y.max() + 0.5
    xx, yy = np.meshgrid(np.arange(x_min, x_max, h),
                         np.arange(y_min, y_max, h))
    return xx, yy

def plot_contours(ax, predict, xx, yy, **params):
    Z = predict(np.c_[xx.ravel(), yy.ravel()])
    Z = Z.reshape(xx.shape)
    out = ax.contourf(xx, yy, Z, **params)
    return out

def plot_boundary():
    xx, yy = make_meshgrid(X_train[:,0], X_train[:,1])
    predict_functions = [ffn.predict_h1, ffn.predict_h2, ffn.predict_h3]

    for i in range(3):

      fig, ax = plt.subplots(figsize=(10,5))

      plot_contours(ax, predict_functions[i], xx, yy,
                    cmap=my_cmap, alpha=0.2)
      ax.scatter(X_train[:,0], X_train[:,1], c=Y_train, cmap=my_cmap, alpha=0.8
      ax.set_xlim(xx.min(), xx.max())
      ax.set_ylim(yy.min(), yy.max())
      ax.set_xlabel('X1')
      ax.set_ylabel('X2')
      ax.set_title("h"+str(i+1))

    return True

plot_boundary()
```

Out[ ]: True



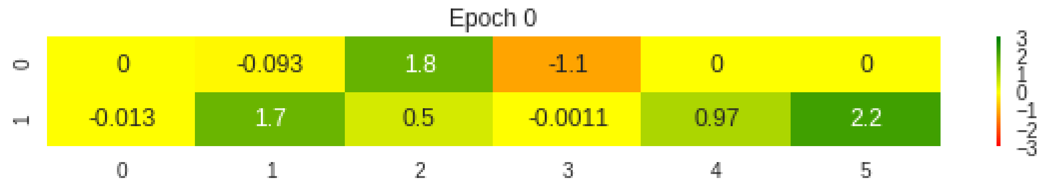


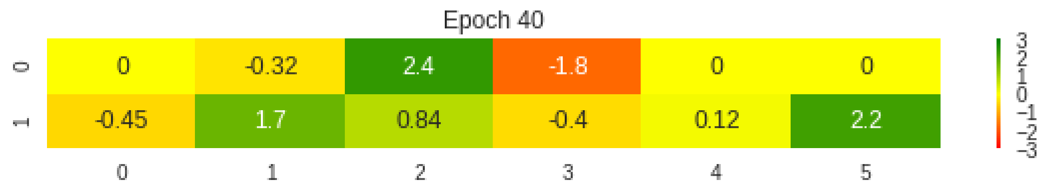


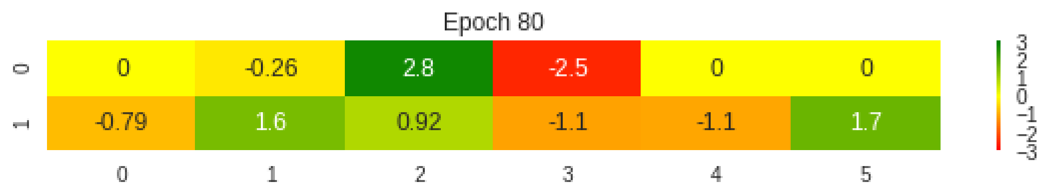
In [ ]:
```
def plot_heat_map(epoch):
    fig = plt.figure(figsize=(10, 1))
    sns.heatmap(weight_matrices[epoch], annot=True, cmap=my_cmap, vmin=-3, vma
    plt.title("Epoch "+str(epoch))

    fig.canvas.draw()
    image = np.frombuffer(fig.canvas.tostring_rgb(), dtype='uint8')
    image = image.reshape(fig.canvas.get_width_height()[::-1] + (3,))

    return image
```

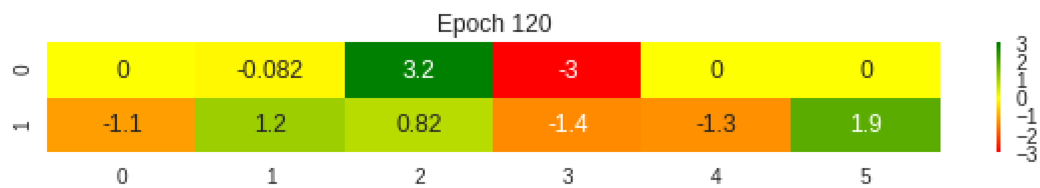
In [ ]:
```
imageio.mimsave('./weights_viz.gif', [plot_heat_map(i) for i in range(0,len(we
```

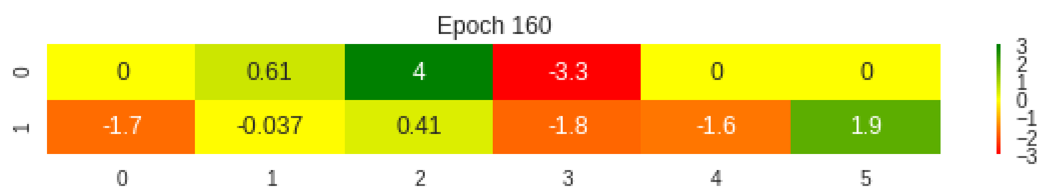
```
/usr/local/lib/python3.6/dist-packages/matplotlib/pyplot.py:514: RuntimeWarnin
g: More than 20 figures have been opened. Figures created through the pyplot i
nterface (`matplotlib.pyplot.figure`) are retained until explicitly closed and
may consume too much memory. (To control this warning, see the rcParam `figur
e.max_open_warning`).
  max_open_warning, RuntimeWarning)
```

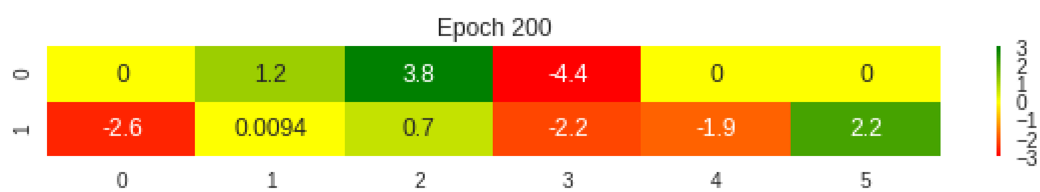


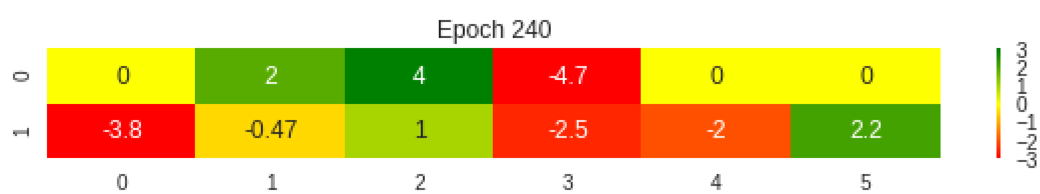


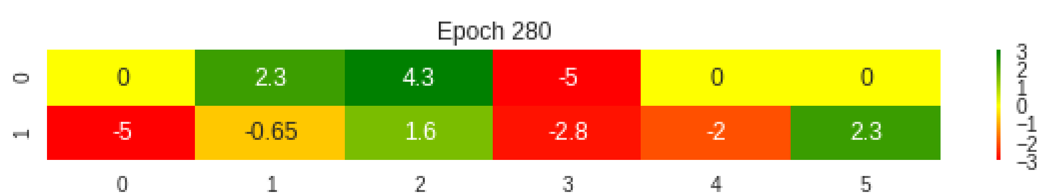


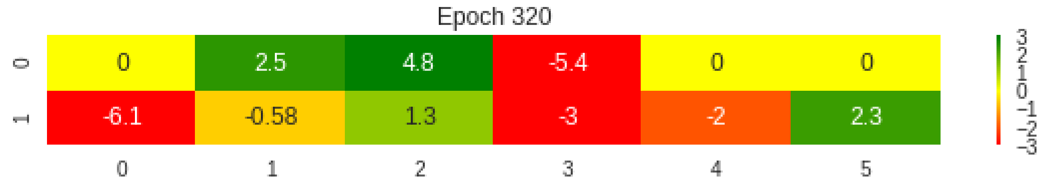


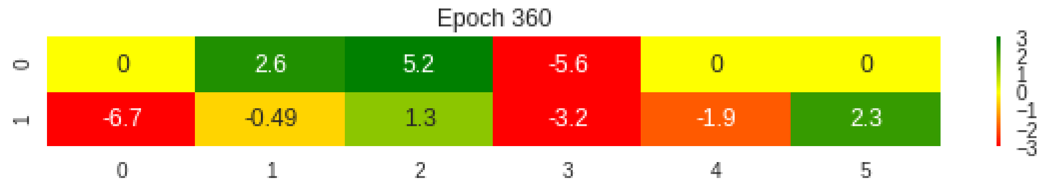


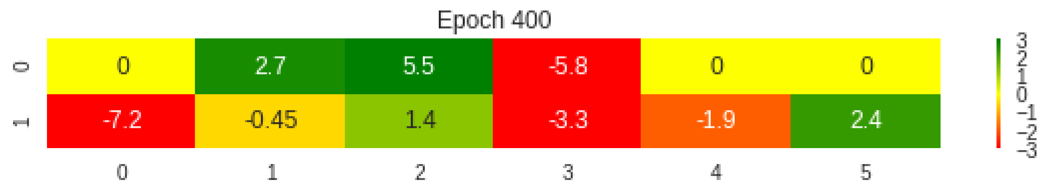


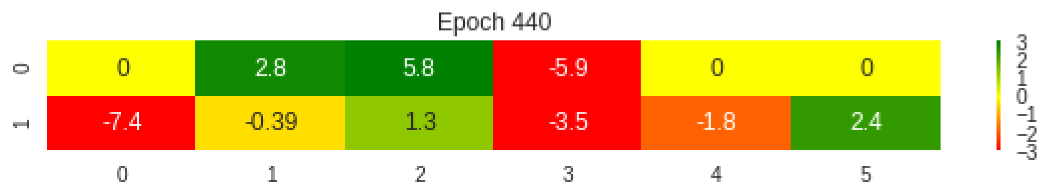


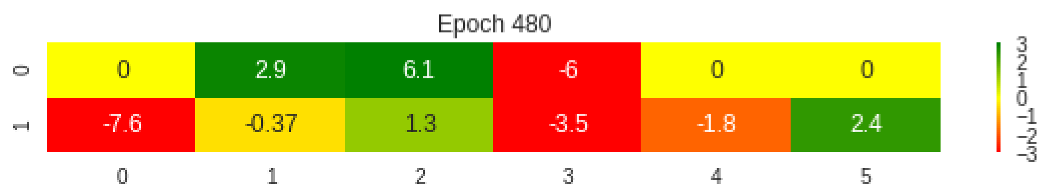


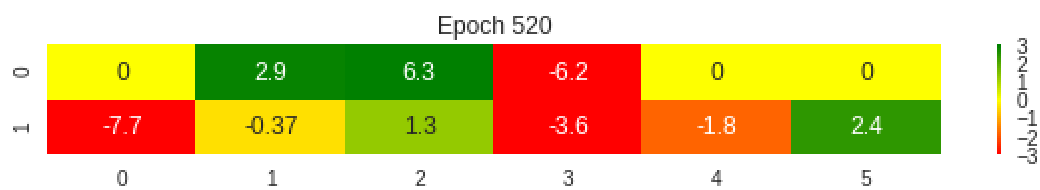

Epoch 320
0 2.5 4.8 -5.4 0 0
-6.1 -0.58 1.3 -3 -2 2.3

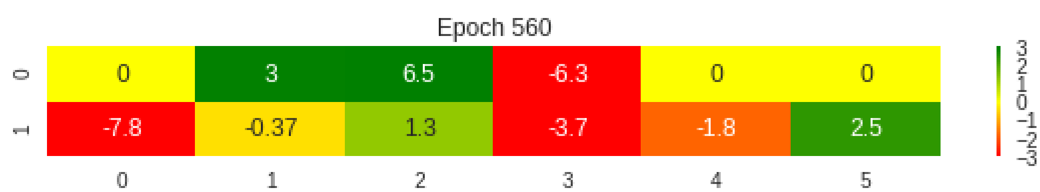

Epoch 360
0 2.6 5.2 -5.6 0 0
-6.7 -0.49 1.3 -3.2 -1.9 2.3

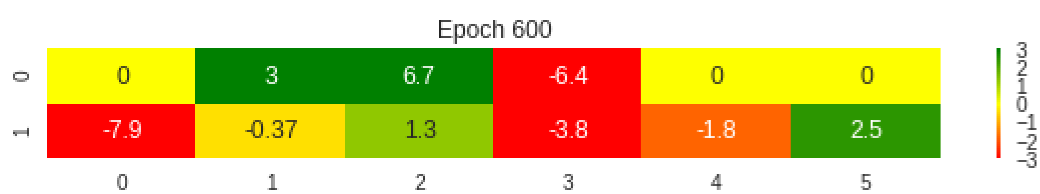

Epoch 400
0 2.7 5.5 -5.8 0 0
-7.2 -0.45 1.4 -3.3 -1.9 2.4

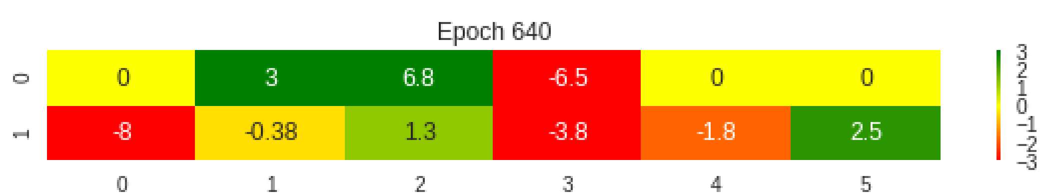

Epoch 440
0 2.8 5.8 -5.9 0 0
-7.4 -0.39 1.3 -3.5 -1.8 2.4

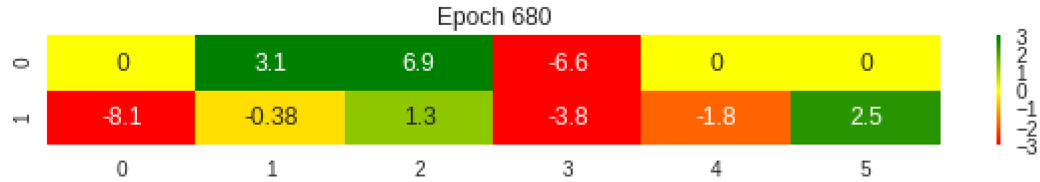

Epoch 480
0 2.9 6.1 -6 0 0
-7.6 -0.37 1.3 -3.5 -1.8 2.4

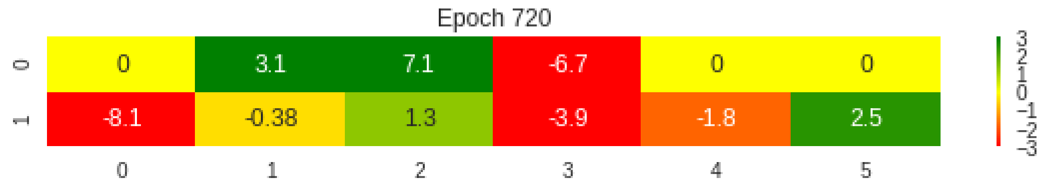

Epoch 520
0 2.9 6.3 -6.2 0 0
-7.7 -0.37 1.3 -3.6 -1.8 2.4

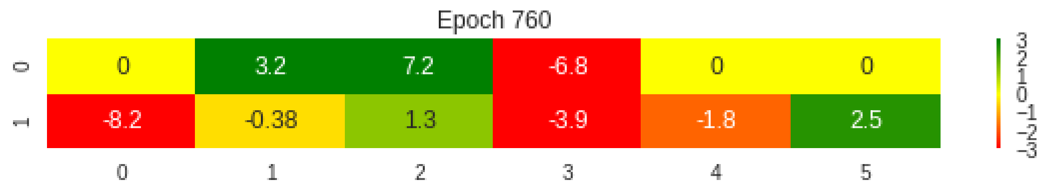

Epoch 560
0 3 6.5 -6.3 0 0
-7.8 -0.37 1.3 -3.7 -1.8 2.5

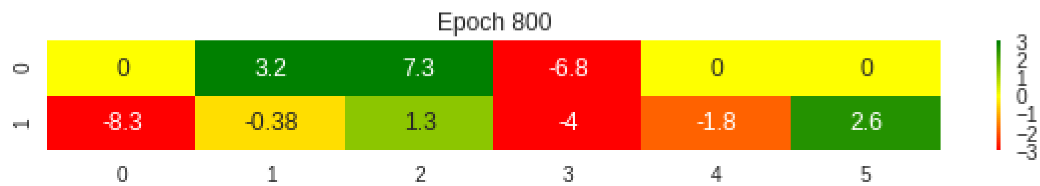

Epoch 600
0 3 6.7 -6.4 0 0
-7.9 -0.37 1.3 -3.8 -1.8 2.5

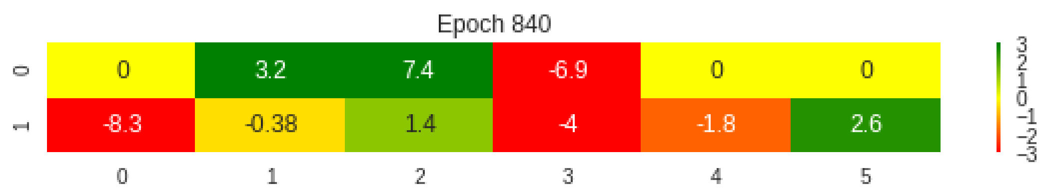

Epoch 640
0 3 6.8 -6.5 0 0
-8 -0.38 1.3 -3.8 -1.8 2.5

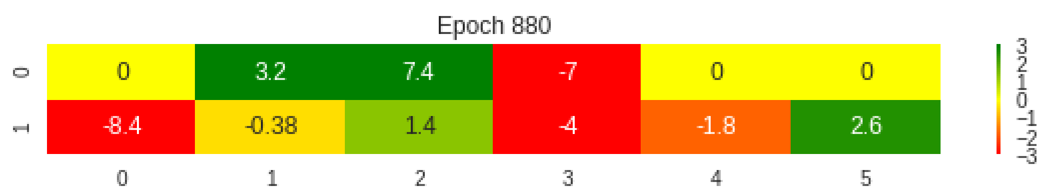

Epoch 680
0 3.1 6.9 -6.6 0 0
-8.1 -0.38 1.3 -3.8 -1.8 2.5
0 1 2 3 4 5
0 1
3 2 1 0 −1 −2 −3

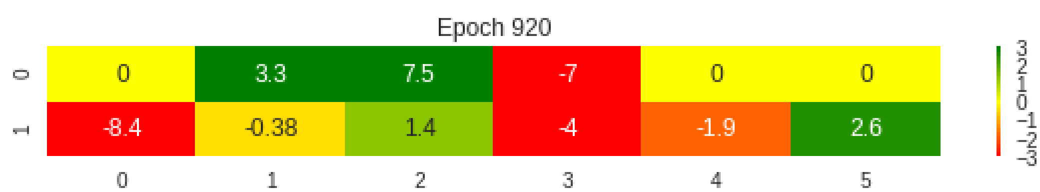

Epoch 720
0 3.1 7.1 -6.7 0 0
-8.1 -0.38 1.3 -3.9 -1.8 2.5
0 1 2 3 4 5
0 1
3 2 1 0 −1 −2 −3

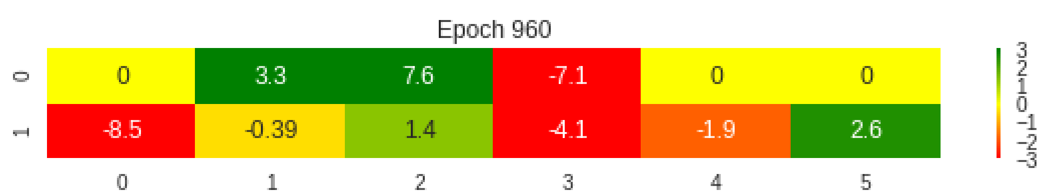

Epoch 760
0 3.2 7.2 -6.8 0 0
-8.2 -0.38 1.3 -3.9 -1.8 2.5
0 1 2 3 4 5
0 1
3 2 1 0 −1 −2 −3

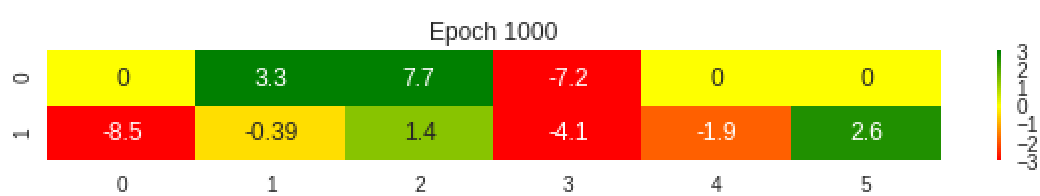

Epoch 800
0 3.2 7.3 -6.8 0 0
-8.3 -0.38 1.3 -4 -1.8 2.6
0 1 2 3 4 5
0 1
3 2 1 0 −1 −2 −3

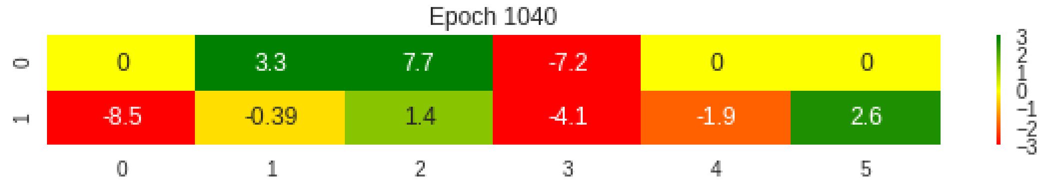

Epoch 840
0 3.2 7.4 -6.9 0 0
-8.3 -0.38 1.4 -4 -1.8 2.6
0 1 2 3 4 5
0 1
3 2 1 0 −1 −2 −3

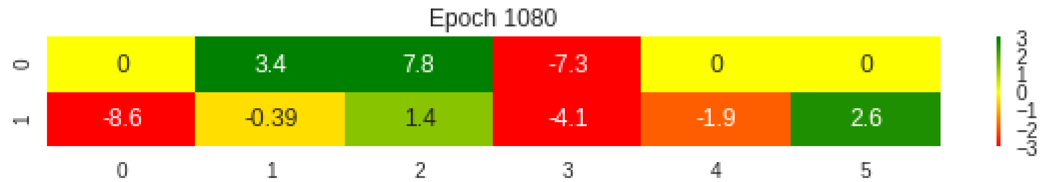

Epoch 880
0 3.2 7.4 -7 0 0
-8.4 -0.38 1.4 -4 -1.8 2.6
0 1 2 3 4 5
0 1
3 2 1 0 −1 −2 −3

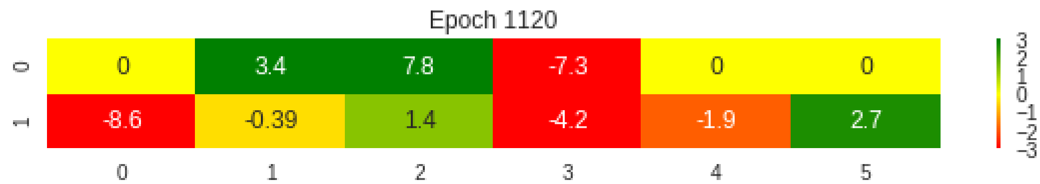

Epoch 920
0 3.3 7.5 -7 0 0
-8.4 -0.38 1.4 -4 -1.9 2.6
0 1 2 3 4 5
0 1
3 2 1 0 −1 −2 −3

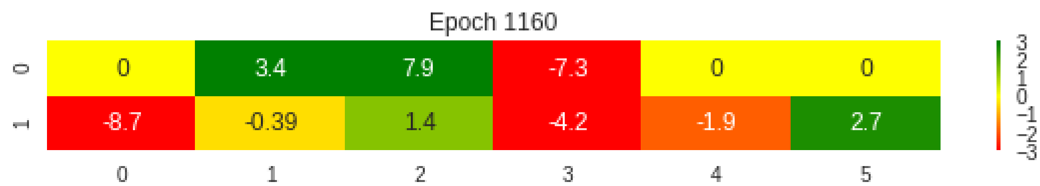

Epoch 960
0 3.3 7.6 -7.1 0 0
-8.5 -0.39 1.4 -4.1 -1.9 2.6
0 1 2 3 4 5
0 1
3 2 1 0 −1 −2 −3

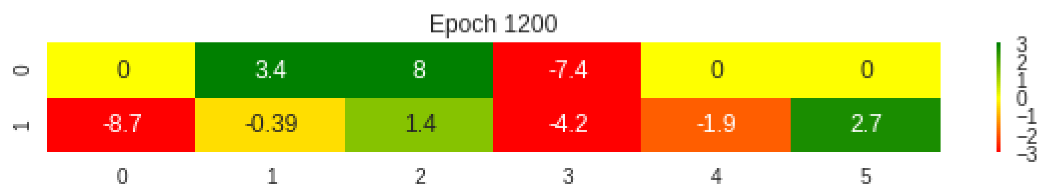

Epoch 1000
0 3.3 7.7 -7.2 0 0
-8.5 -0.39 1.4 -4.1 -1.9 2.6
0 1 2 3 4 5
0 1
3 2 1 0 −1 −2 −3

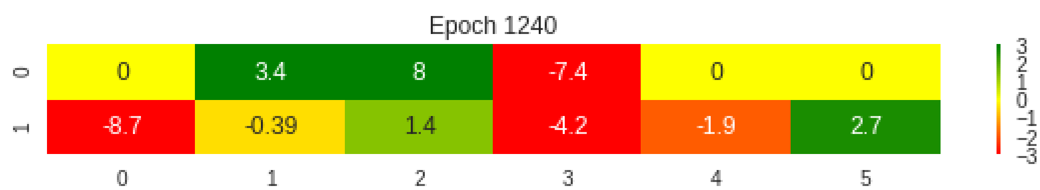

Epoch 1040
0 3.3 7.7 -7.2 0 0
-8.5 -0.39 1.4 -4.1 -1.9 2.6
0 1 2 3 4 5
3 2 1 0 −1 −2 −3

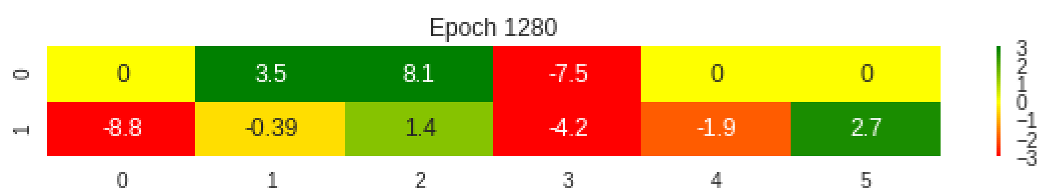

Epoch 1080
0 3.4 7.8 -7.3 0 0
-8.6 -0.39 1.4 -4.1 -1.9 2.6
0 1 2 3 4 5
3 2 1 0 −1 −2 −3

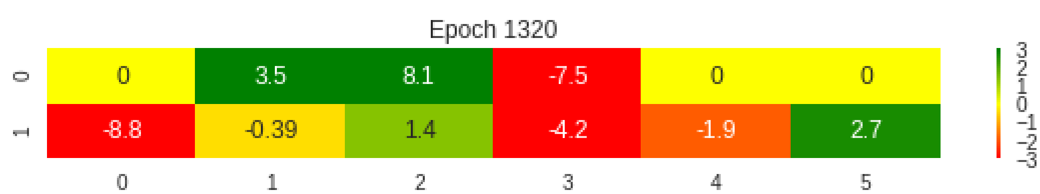

Epoch 1120
0 3.4 7.8 -7.3 0 0
-8.6 -0.39 1.4 -4.2 -1.9 2.7
0 1 2 3 4 5
3 2 1 0 −1 −2 −3

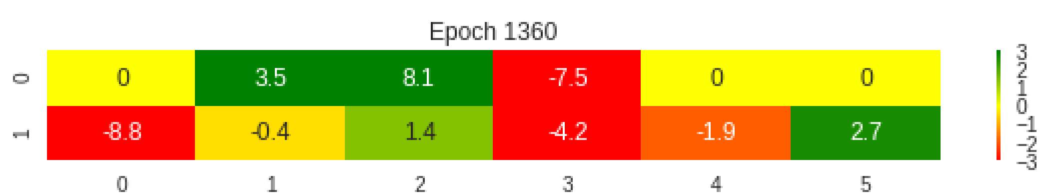

Epoch 1160
0 3.4 7.9 -7.3 0 0
-8.7 -0.39 1.4 -4.2 -1.9 2.7
0 1 2 3 4 5
3 2 1 0 −1 −2 −3

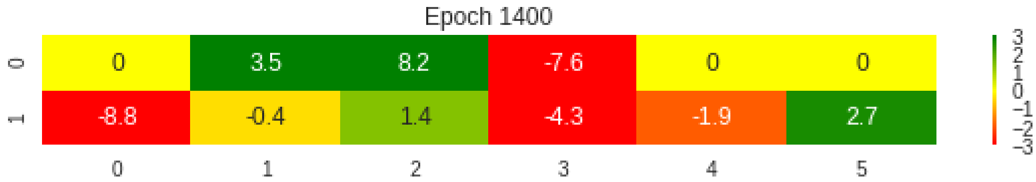

Epoch 1200
0 3.4 8 -7.4 0 0
-8.7 -0.39 1.4 -4.2 -1.9 2.7
0 1 2 3 4 5
3 2 1 0 −1 −2 −3

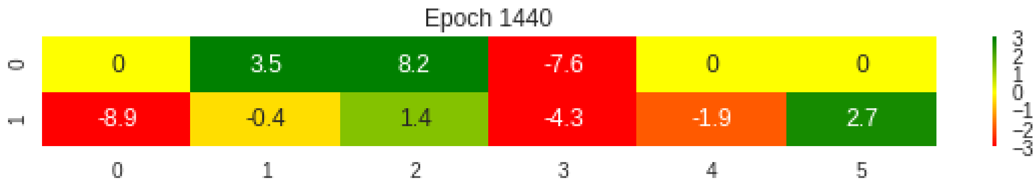

Epoch 1240
0 3.4 8 -7.4 0 0
-8.7 -0.39 1.4 -4.2 -1.9 2.7
0 1 2 3 4 5
3 2 1 0 −1 −2 −3

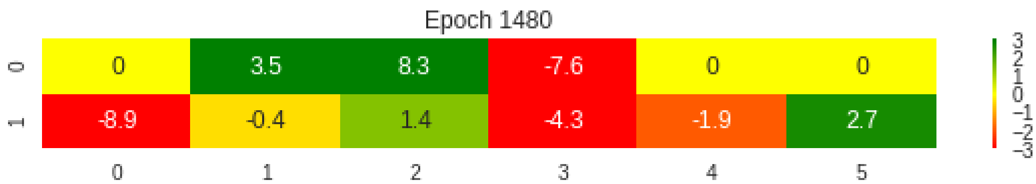

Epoch 1280
0 3.5 8.1 -7.5 0 0
-8.8 -0.39 1.4 -4.2 -1.9 2.7
0 1 2 3 4 5
3 2 1 0 −1 −2 −3

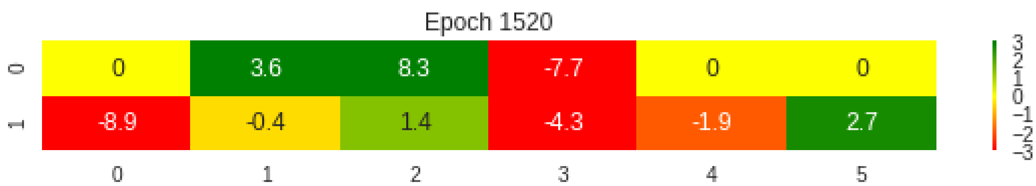

Epoch 1320
0 3.5 8.1 -7.5 0 0
-8.8 -0.39 1.4 -4.2 -1.9 2.7
0 1 2 3 4 5
3 2 1 0 −1 −2 −3

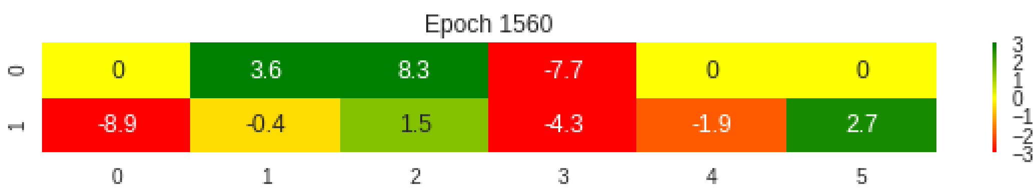

Epoch 1360
0 3.5 8.1 -7.5 0 0
-8.8 -0.4 1.4 -4.2 -1.9 2.7
0 1 2 3 4 5
3 2 1 0 −1 −2 −3

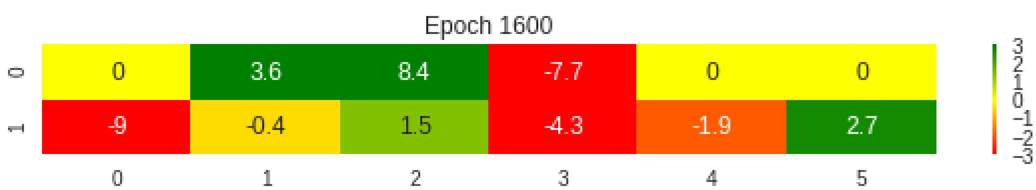

Epoch 1400
0 3.5 8.2 -7.6 0 0
-8.8 -0.4 1.4 -4.3 -1.9 2.7
0 1 2 3 4 5
0 1
3 2 1 0 −1 −2 −3

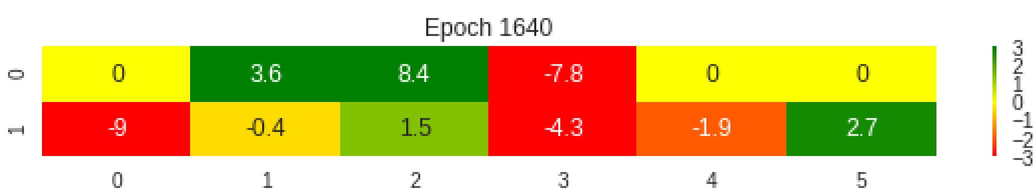

Epoch 1440
0 3.5 8.2 -7.6 0 0
-8.9 -0.4 1.4 -4.3 -1.9 2.7
0 1 2 3 4 5
0 1
3 2 1 0 −1 −2 −3

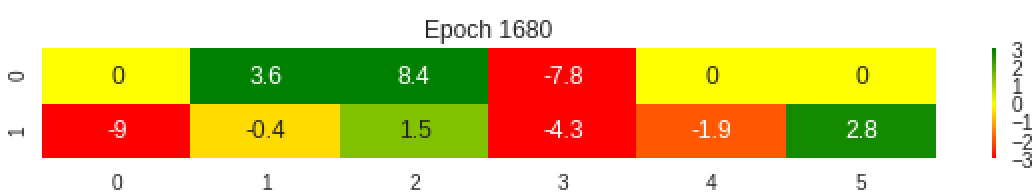

Epoch 1480
0 3.5 8.3 -7.6 0 0
-8.9 -0.4 1.4 -4.3 -1.9 2.7
0 1 2 3 4 5
0 1
3 2 1 0 −1 −2 −3

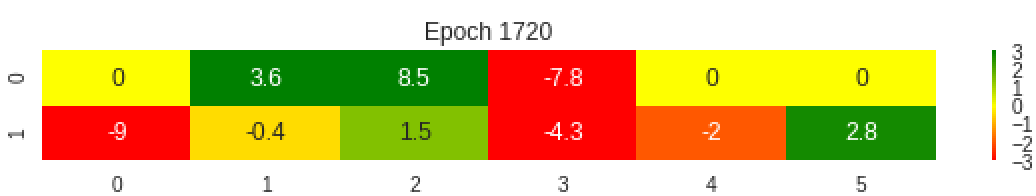

Epoch 1520
0 3.6 8.3 -7.7 0 0
-8.9 -0.4 1.4 -4.3 -1.9 2.7
0 1 2 3 4 5
0 1
3 2 1 0 −1 −2 −3

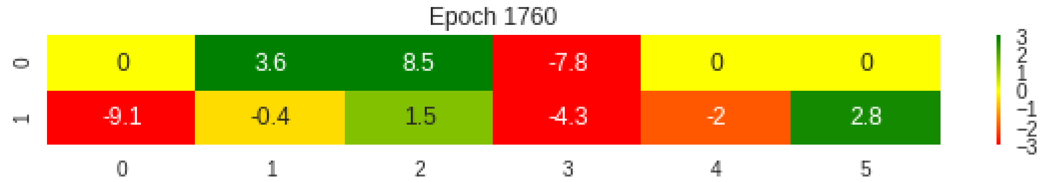

Epoch 1560
0 3.6 8.3 -7.7 0 0
-8.9 -0.4 1.5 -4.3 -1.9 2.7
0 1 2 3 4 5
0 1
3 2 1 0 −1 −2 −3

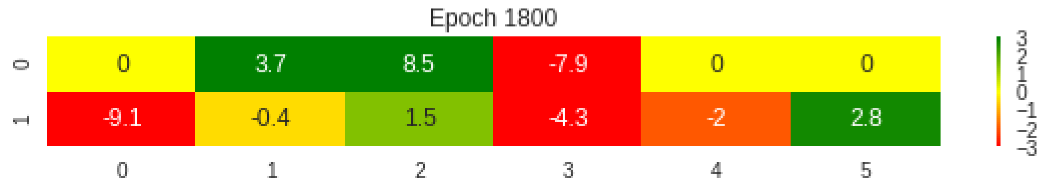

Epoch 1600
0 3.6 8.4 -7.7 0 0
-9 -0.4 1.5 -4.3 -1.9 2.7
0 1 2 3 4 5
0 1
3 2 1 0 −1 −2 −3

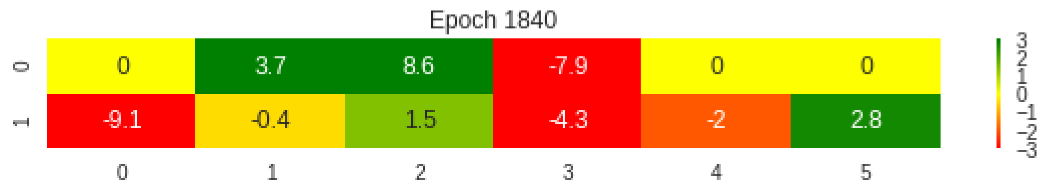

Epoch 1640
0 3.6 8.4 -7.8 0 0
-9 -0.4 1.5 -4.3 -1.9 2.7
0 1 2 3 4 5
0 1
3 2 1 0 −1 −2 −3

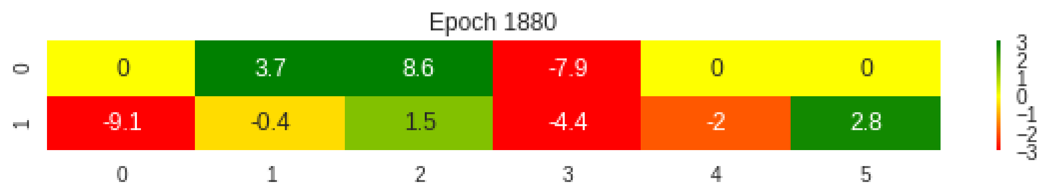

Epoch 1680
0 3.6 8.4 -7.8 0 0
-9 -0.4 1.5 -4.3 -1.9 2.8
0 1 2 3 4 5
0 1
3 2 1 0 −1 −2 −3

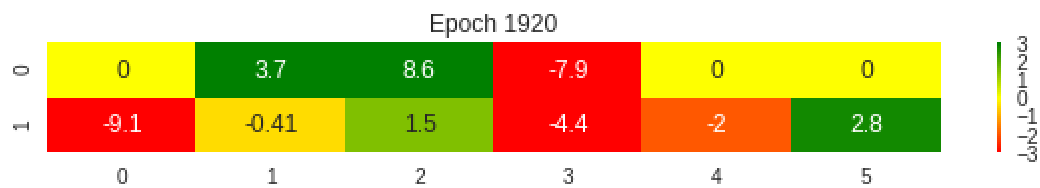

Epoch 1720
0 3.6 8.5 -7.8 0 0
-9 -0.4 1.5 -4.3 -2 2.8
0 1 2 3 4 5
0 1
3 2 1 0 −1 −2 −3

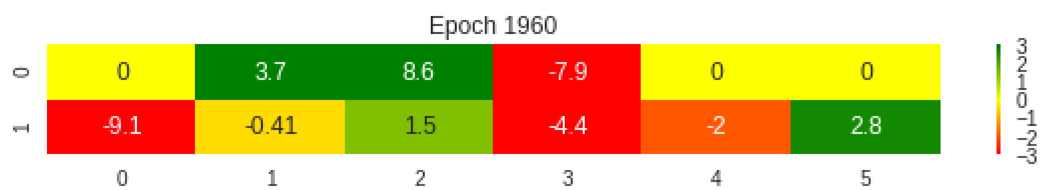












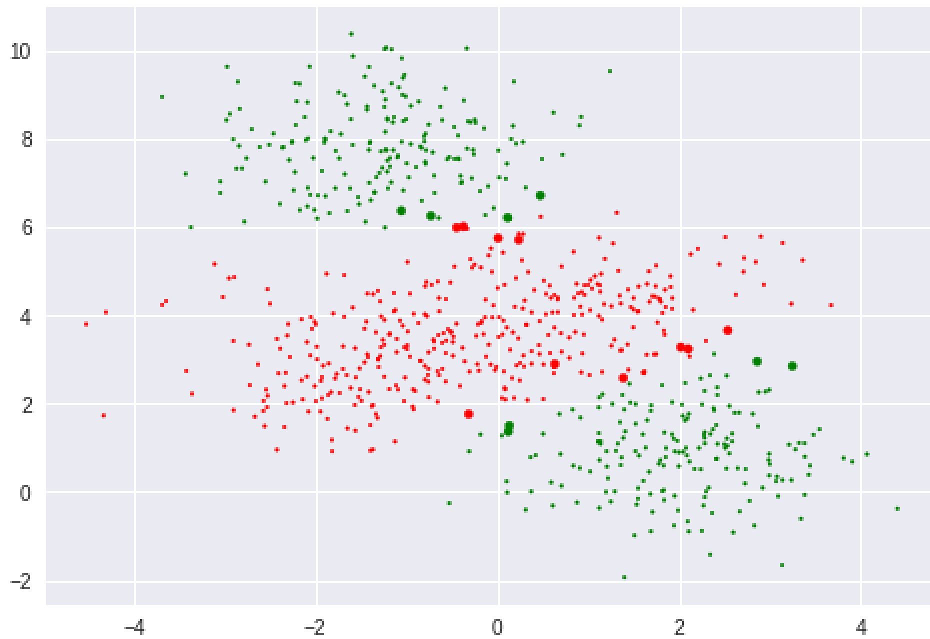
In [ ]:
```
from IPython import display
HTML('<img src="weights_viz.gif">')
```

Out[ ]:

In [ ]:
```
Y_pred_train = ffn.predict(X_train)
Y_pred_binarised_train = (Y_pred_train >= 0.5).astype("int").ravel()
Y_pred_val = ffn.predict(X_val)
Y_pred_binarised_val = (Y_pred_val >= 0.5).astype("int").ravel()
accuracy_train = accuracy_score(Y_pred_binarised_train, Y_train)
accuracy_val = accuracy_score(Y_pred_binarised_val, Y_val)

print("Training accuracy", round(accuracy_train, 2))
print("Validation accuracy", round(accuracy_val, 2))
```

```
Training accuracy 0.98
Validation accuracy 0.94
```

In [ ]:
```
plt.scatter(X_train[:,0], X_train[:,1], c=Y_pred_binarised_train, cmap=my_cmap
plt.show()
```



Multi class classification

In [ ]:
```
X_train, X_val, Y_train, Y_val = train_test_split(data, labels_orig, stratify=
print(X_train.shape, X_val.shape, labels_orig.shape)
```

```
(750, 2) (250, 2) (1000,)
```

In [ ]:
```
enc = OneHotEncoder()
# 0 -> (1, 0, 0, 0), 1 -> (0, 1, 0, 0), 2 -> (0, 0, 1, 0), 3 -> (0, 0, 0, 1)
y_OH_train = enc.fit_transform(np.expand_dims(Y_train,1)).toarray()
y_OH_val = enc.fit_transform(np.expand_dims(Y_val,1)).toarray()
print(y_OH_train.shape, y_OH_val.shape)
```

```
(750, 4) (250, 4)
```

```
/usr/local/lib/python3.6/dist-packages/sklearn/preprocessing/_encoders.py:371:
FutureWarning: The handling of integer data will change in version 0.22. Curre
ntly, the categories are determined based on the range [0, max(values)], while
in the future they will be determined based on the unique values.
If you want the future behaviour and silence this warning, you can specify "ca
tegories='auto'".
In case you used a LabelEncoder before this OneHotEncoder to convert the categ
ories to integers, then you can now use the OneHotEncoder directly.
  warnings.warn(msg, FutureWarning)
/usr/local/lib/python3.6/dist-packages/sklearn/preprocessing/_encoders.py:371:
FutureWarning: The handling of integer data will change in version 0.22. Curre
ntly, the categories are determined based on the range [0, max(values)], while
in the future they will be determined based on the unique values.
If you want the future behaviour and silence this warning, you can specify "ca
tegories='auto'".
In case you used a LabelEncoder before this OneHotEncoder to convert the categ
ories to integers, then you can now use the OneHotEncoder directly.
  warnings.warn(msg, FutureWarning)
```

In [ ]:
```
class FFSN_MultiClass_Specific:

  def __init__(self):
    np.random.seed(0)
```

```
    self.w1 = np.random.randn()
    self.w2 = np.random.randn()
    self.w3 = np.random.randn()
    self.w4 = np.random.randn()
    self.w5 = np.random.randn()
    self.w6 = np.random.randn()
    self.w7 = np.random.randn()
    self.w8 = np.random.randn()
    self.w9 = np.random.randn()
    self.w10 = np.random.randn()
    self.w11 = np.random.randn()
    self.w12 = np.random.randn()
    self.b1 = 0
    self.b2 = 0
    self.b3 = 0
    self.b4 = 0
    self.b5 = 0
    self.b6 = 0

  def sigmoid(self, x):
    return 1.0/(1.0 + np.exp(-x))

  def forward_pass(self, x):
    # input layer
    self.x1, self.x2 = x

    # hidden layer
    self.a1 = self.w1*self.x1 + self.w2*self.x2 + self.b1
    self.h1 = self.sigmoid(self.a1)
    self.a2 = self.w3*self.x1 + self.w4*self.x2 + self.b2
    self.h2 = self.sigmoid(self.a2)

    # output layer
    self.a3 = self.w5*self.h1 + self.w6*self.h2 + self.b3
    self.a4 = self.w7*self.h1 + self.w8*self.h2 + self.b4
    self.a5 = self.w9*self.h1 + self.w10*self.h2 + self.b5
    self.a6 = self.w11*self.h1 + self.w12*self.h2 + self.b5
    sum_exps = np.sum([np.exp(self.a3), np.exp(self.a4), np.exp(self.a5), np.e
    self.h3 = np.exp(self.a3)/sum_exps
    self.h4 = np.exp(self.a4)/sum_exps
    self.h5 = np.exp(self.a5)/sum_exps
    self.h6 = np.exp(self.a6)/sum_exps

    return np.array([self.h3, self.h4, self.h5, self.h6])

  def grad(self, x, y):
    self.forward_pass(x)
    self.y1, self.y2, self.y3, self.y4 = y

    self.dw5 = (self.h3-self.y1) * self.h1
    self.dw6 = (self.h3-self.y1) * self.h2
    self.db3 = (self.h3-self.y1)

    self.dw7 = (self.h4-self.y2) * self.h1
    self.dw8 = (self.h4-self.y2) * self.h2
    self.db4 = (self.h4-self.y2)

    self.dw9 = (self.h5-self.y3) * self.h1
    self.dw10 = (self.h5-self.y3) * self.h2
    self.db5 = (self.h5-self.y3)
```

```
    self.dw11 = (self.h6-self.y4) * self.h1
    self.dw12 = (self.h6-self.y4) * self.h2
    self.db6 = (self.h6-self.y4)

    self.dh1 = (self.h3-self.y1)*self.w5 + (self.h4-self.y2)*self.w7 + (self.h!
    self.dw1 = self.dh1 * self.h1*(1-self.h1) * self.x1
    self.dw2 = self.dh1 * self.h1*(1-self.h1) * self.x2
    self.db1 = self.dh1 * self.h1*(1-self.h1)

    self.dh2 = (self.h3-self.y1)*self.w6 + (self.h4-self.y2)*self.w8 + (self.h!
    self.dw3 = self.dh2 * self.h2*(1-self.h2) * self.x1
    self.dw4 = self.dh2 * self.h2*(1-self.h2) * self.x2
    self.db2 = self.dh2 * self.h2*(1-self.h2)

  def grad_short(self, x, y):
    self.forward_pass(x)
    self.y1, self.y2, self.y3, self.y4 = y

    self.da3 = (self.h3-self.y1)
    self.da4 = (self.h4-self.y2)
    self.da5 = (self.h5-self.y3)
    self.da6 = (self.h6-self.y4)

    self.dw5 = self.da3*self.h1
    self.dw6 = self.da3*self.h2
    self.db3 = self.da3

    self.dw7 = self.da4*self.h1
    self.dw8 = self.da4*self.h2
    self.db3 = self.da4

    self.dw9 = self.da5*self.h1
    self.dw10 = self.da5*self.h2
    self.db3 = self.da5

    self.dw11 = self.da6*self.h1
    self.dw12 = self.da6*self.h2
    self.db3 = self.da6

    self.dh1 = self.da3*self.w5 + self.da4*self.w7 + self.da5*self.w9 + self.da
    self.dh2 = self.da3*self.w6 + self.da4*self.w8 + self.da5*self.w10 + self.c

    self.da1 = self.dh1 * self.h1*(1-self.h1)
    self.da2 = self.dh2 * self.h2*(1-self.h2)

    self.dw1 = self.da1*self.x1
    self.dw2 = self.da1*self.x2
    self.db1 = self.da1

    self.dw3 = self.da2*self.x1
    self.dw4 = self.da2*self.x2
    self.db2 = self.da2


  def fit(self, X, Y, epochs=1, learning_rate=1, display_loss=False, display_we

    if display_loss:
      loss = {}
```

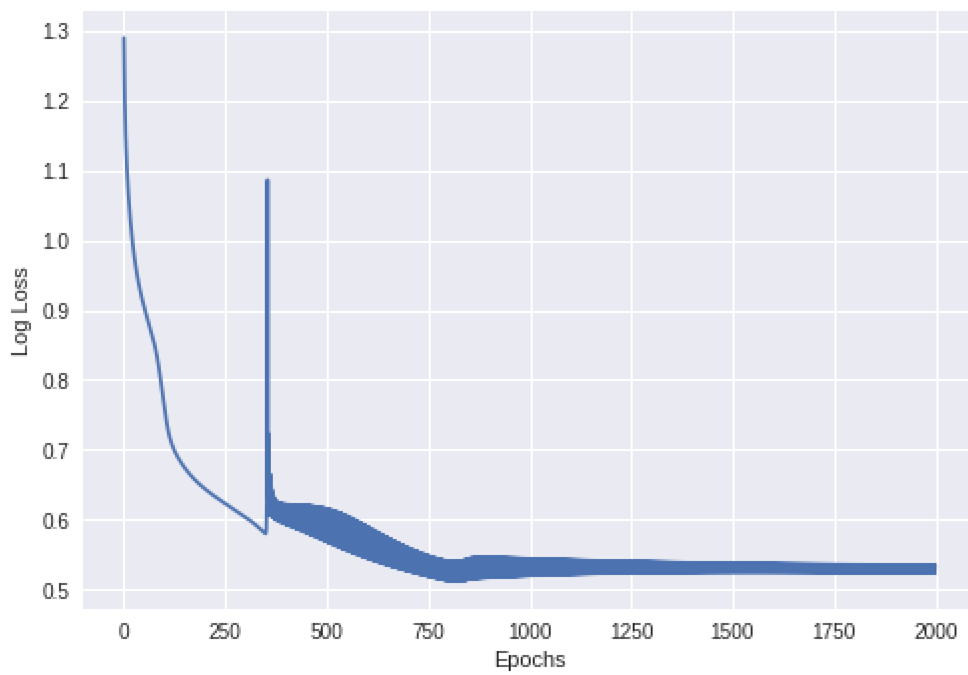
```
    for i in tqdm_notebook(range(epochs), total=epochs, unit="epoch"):
      dw1, dw2, dw3, dw4, dw5, dw6, dw7, dw8, dw9, dw10, dw11, dw12, db1, db2,
      for x, y in zip(X, Y):
        self.grad(x, y)
        dw1 += self.dw1
        dw2 += self.dw2
        dw3 += self.dw3
        dw4 += self.dw4
        dw5 += self.dw5
        dw6 += self.dw6
        dw7 += self.dw7
        dw8 += self.dw8
        dw9 += self.dw9
        dw10 += self.dw10
        dw11 += self.dw11
        dw12 += self.dw12
        db1 += self.db1
        db2 += self.db2
        db3 += self.db3
        db1 += self.db4
        db2 += self.db5
        db3 += self.db6

      m = X.shape[0]
      self.w1 -= learning_rate * dw1 / m
      self.w2 -= learning_rate * dw2 / m
      self.w3 -= learning_rate * dw3 / m
      self.w4 -= learning_rate * dw4 / m
      self.w5 -= learning_rate * dw5 / m
      self.w6 -= learning_rate * dw6 / m
      self.w7 -= learning_rate * dw7 / m
      self.w8 -= learning_rate * dw8 / m
      self.w9 -= learning_rate * dw9 / m
      self.w10 -= learning_rate * dw10 / m
      self.w11 -= learning_rate * dw11 / m
      self.w12 -= learning_rate * dw12 / m
      self.b1 -= learning_rate * db1 / m
      self.b2 -= learning_rate * db2 / m
      self.b3 -= learning_rate * db3 / m
      self.b4 -= learning_rate * db4 / m
      self.b5 -= learning_rate * db5 / m
      self.b6 -= learning_rate * db6 / m

      if display_loss:
        Y_pred = self.predict(X)
        loss[i] = log_loss(np.argmax(Y, axis=1), Y_pred)

      if display_weight:
        weight_matrix = np.array([[self.b3, self.w5, self.w6,
                                   self.b4, self.w7, self.w8,
                                   self.b5, self.w9, self.w10,
                                   self.b6, self.w11, self.w12],
                                  [0, 0, 0,
                                   self.b1, self.w1, self.w2,
                                   self.b2, self.w3, self.w4,
                                   0, 0, 0]])
        weight_matrices.append(weight_matrix)

    if display_loss:
      plt.plot(loss.values())
```

```
      plt.xlabel('Epochs')
      plt.ylabel('Log Loss')
      plt.show()

  def predict(self, X):
    Y_pred = []
    for x in X:
      y_pred = self.forward_pass(x)
      Y_pred.append(y_pred)
    return np.array(Y_pred)
```

In [ ]:

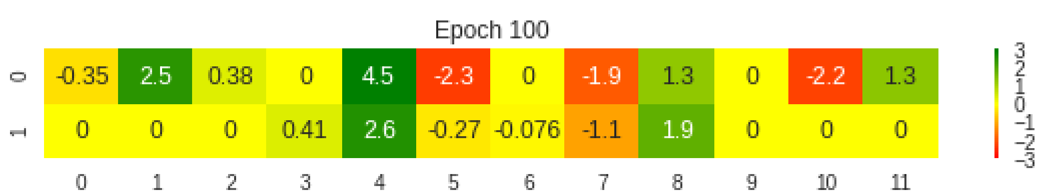
```
weight_matrices = []
ffsn_multi_specific = FFSN_MultiClass_Specific()
ffsn_multi_specific.fit(X_train,y_OH_train,epochs=2000,learning_rate=1,display_
```

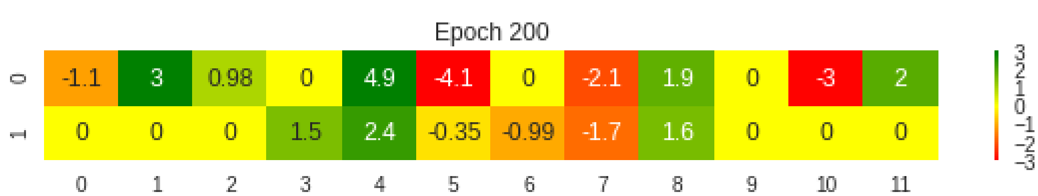
```
HBox(children=(IntProgress(value=0, max=2000), HTML(value='')))
```



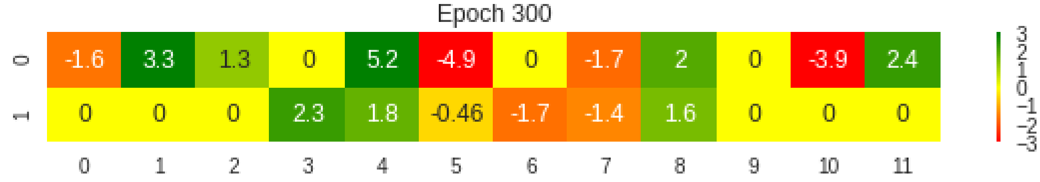
In [ ]:

```
imageio.mimsave('./weights_viz_multi_class.gif', [plot_heat_map(i) for i in ra
```

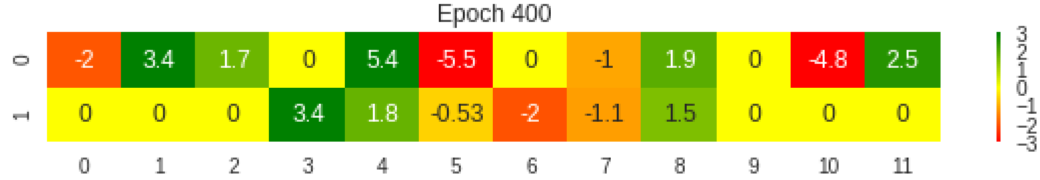




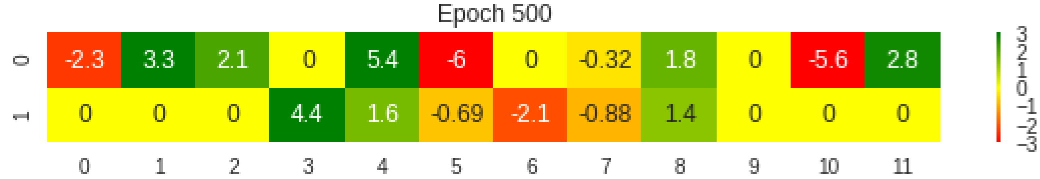
Epoch 300



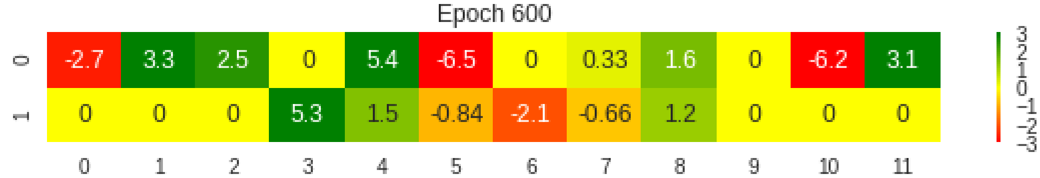
Epoch 400



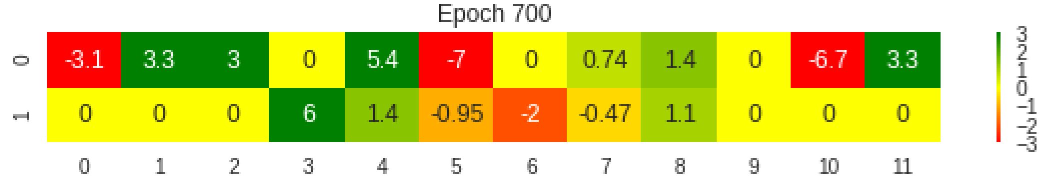
Epoch 500



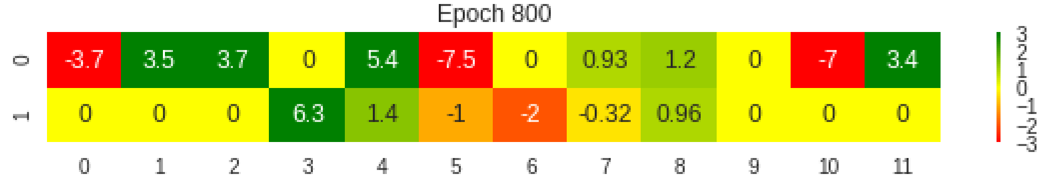
Epoch 600



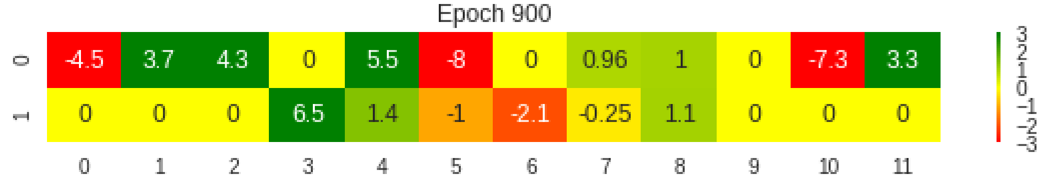
Epoch 700



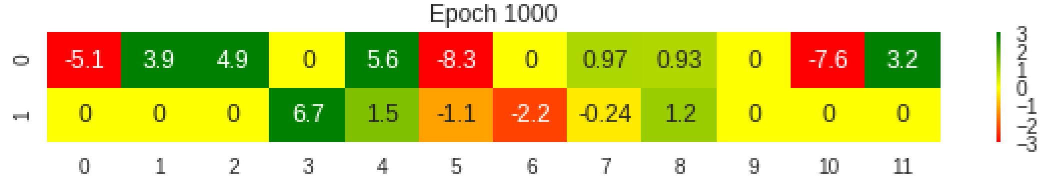
Epoch 800



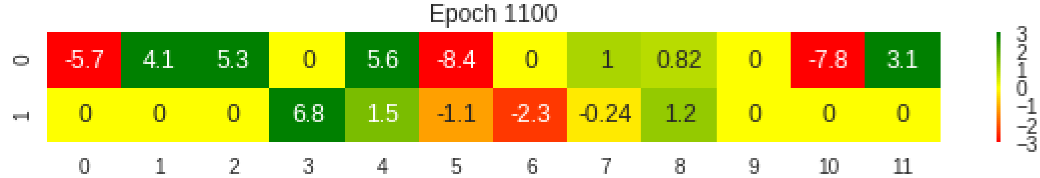
Epoch 900

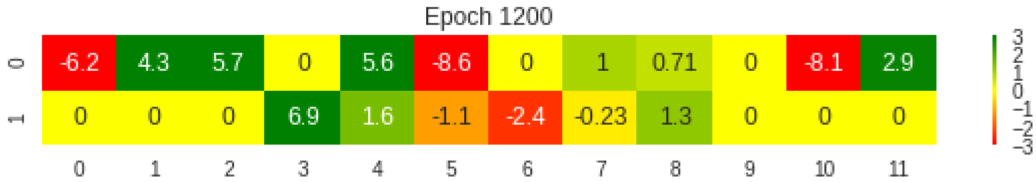


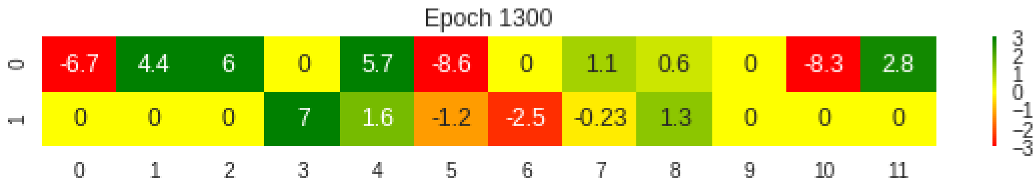
Epoch 1000

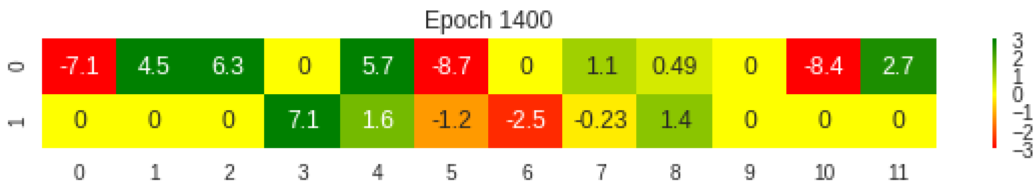


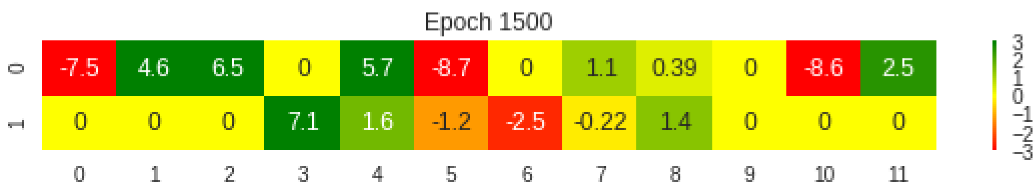
Epoch 1100

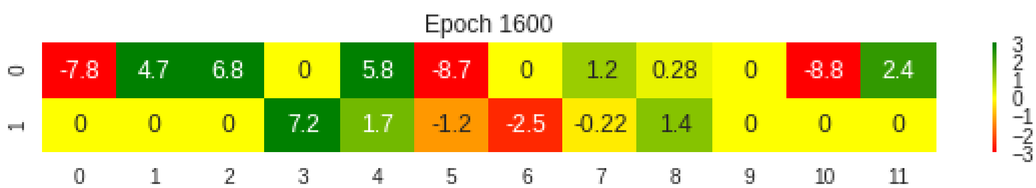


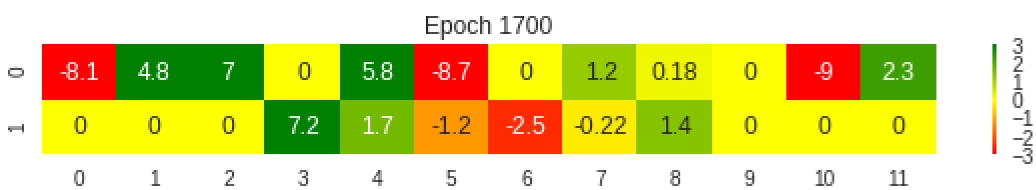


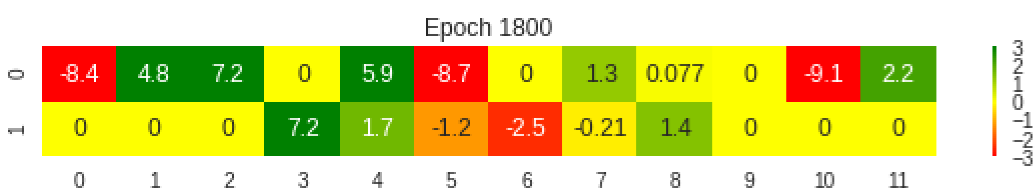


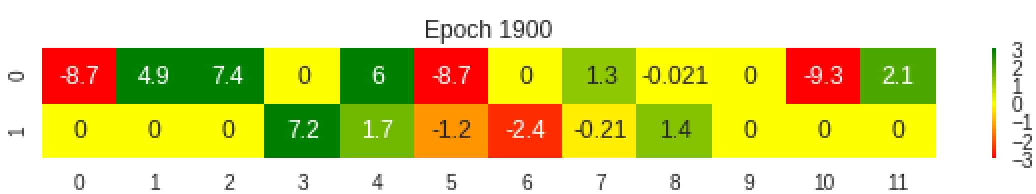












In [ ]:
```
HTML('<img src="weights_viz_multi_class.gif">')
```

Out[ ]:

In [ ]:
```
Y_pred_train = ffsn_multi_specific.predict(X_train)
Y_pred_train = np.argmax(Y_pred_train,1)
```

```
Y_pred_val = ffsn_multi_specific.predict(X_val)
Y_pred_val = np.argmax(Y_pred_val,1)

accuracy_train = accuracy_score(Y_pred_train, Y_train)
accuracy_val = accuracy_score(Y_pred_val, Y_val)

print("Training accuracy", round(accuracy_train, 2))
print("Validation accuracy", round(accuracy_val, 2))
```

```
Training accuracy 0.79
Validation accuracy 0.8
```

In [ ]:

```
plt.scatter(X_train[:,0], X_train[:,1], c=Y_pred_train, cmap=my_cmap, s=15*(np
plt.show()
```