

# A Multi-Layer Fully Connected Neural Network for lesion classification

## 1. Motivation for FCNs

Weaknesses of k-NN classifier

- Classifier must remember all the training data
- Classification is computationally expensive since it requires a lot of comparisons

Solution; Parameterized mapping from images to label scores

- Simple case is a linear classifier such as

$$s = Wx$$

$W$  in our case is a [2x190000] matrix

$x$  is a [190000x1] column vector

$s$  becomes a [2x1] matrix of class scores

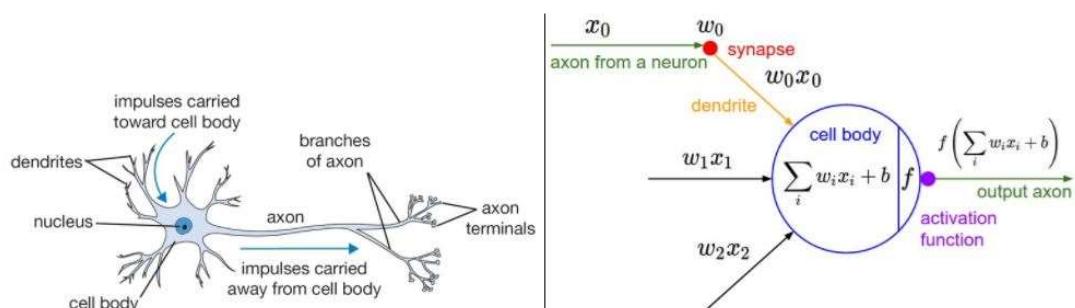
- A neural network instead computes

$$s = W_2 \max(0, W_1 x)$$

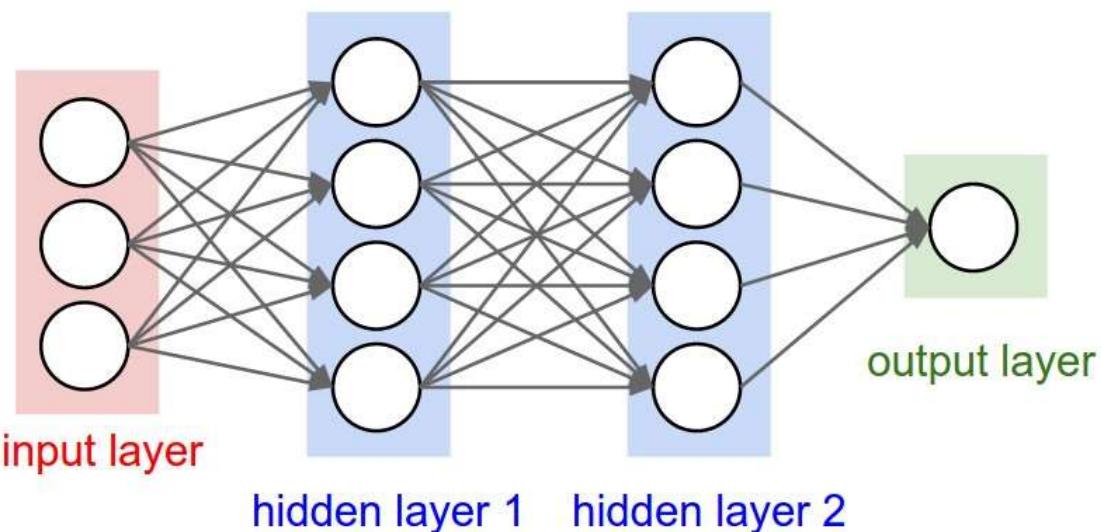
The key distinction from a linear classifier is the function  $\max(0, \cdot)$  which is a non-linearity applied elementwise

- A three-layer neural network would therefore be  $s = W_3 \max(0, W_2 \max(0, W_1 x))$

Biological motivation



Stacked together to form a fully connected nn



## 2. Data preparation

In [1]:

```
# some setup code for this notebook
import numpy as np
import matplotlib.pyplot as plt
from functions import data, Timer
timer = Timer()

# This makes matplotlib figures appear inline in the notebook
# rather than in a new window.
%matplotlib inline
plt.rcParams['figure.figsize'] = (10.0, 8.0) # set default size of plots
plt.rcParams['image.interpolation'] = 'nearest'
plt.rcParams['image.cmap'] = 'gray'

# Make the notebook reload external python modules;
# see http://stackoverflow.com/questions/1907993/autoreload-of-modules-in-ipython
%load_ext autoreload
%autoreload 2
```

### The ultra sound scan data

- 163 scans total, clinically confirmed as having either benign or malignant (cancerous) lesions
- 100 scans for training, 63 for testing
- Training data was passed through 7 transformations to give us 800 training images total
- Testing images not transformed
- Both training and testing images were resized to 224X224
- Raw pngs then converted to numpy arrays and saved

In [2]:

```
# Load the data
x_train, y_train, x_test, y_test = data.getData()

print('Training data shape: ', x_train.shape)
print('Training labels shape: ', y_train.shape)
print('Test data shape: ', x_test.shape)
print('Test labels shape: ', y_test.shape)

(800, 224, 224, 3)
(800, 1)
(63, 224, 224, 3)
(63, 1)
Training data shape: (800, 224, 224, 3)
Training labels shape: (800, 1)
Test data shape: (63, 224, 224, 3)
Test labels shape: (63, 1)
```

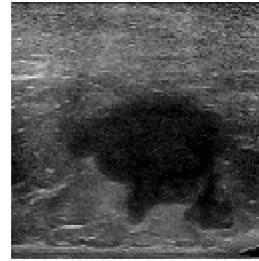
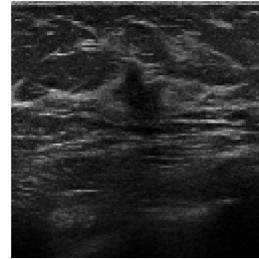
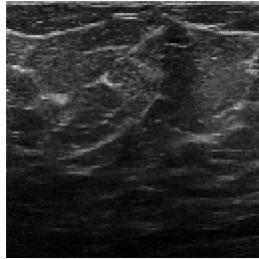
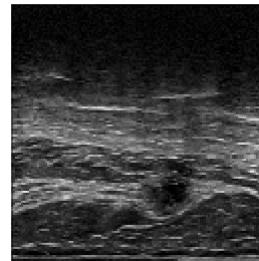
In [3]:

```
# Visualize some examples from the dataset.
# We show a few examples of training images from each class.
classes = [1, 0]
num_classes = len(classes)
samples_per_class = 3
for y, cls in enumerate(classes):
    idxs = np.flatnonzero(y_train == y)
    idxs = np.random.choice(idxs, samples_per_class, replace=False)
    for i, idx in enumerate(idxs):
        plt_idx = i * num_classes + y + 1
        plt.subplot(samples_per_class, num_classes, plt_idx)
        plt.imshow(x_train[idx].astype('uint8'))
        plt.axis('off')
        if i == 0:
            if cls == 1: title = 'Malignant'
            else: title = 'Benign'
            plt.title(title)
plt.show()
```

Malignant



Benign



In [4]:

```
# Reshape the image data into rows
x_train = np.reshape(x_train, (x_train.shape[0], -1))
x_test = np.reshape(x_test, (x_test.shape[0], -1))
```

In [5]:

```
# Subsample the training data for faster code execution in this demo
# if nmu_training = 800 then no subsampling is taking place
num_training = 800
mask = list(range(num_training))
x_train = x_train[mask]
y_train = y_train[mask]
num_test = 63
```

In [6]:

```
# confirm shapes
print('Training data shape: ', x_train.shape)
print('Training labels shape: ', y_train.shape)
print('Test data shape: ', x_test.shape)
print('Test labels shape: ', y_test.shape)
```

Training data shape: (800, 150528)  
 Training labels shape: (800, 1)  
 Test data shape: (63, 150528)  
 Test labels shape: (63, 1)

In [7]:

```
def getModelMemoryUsage(batch_size, model):
    shapes_mem_count = 0
    for l in model.layers:
        single_layer_mem = 1
        for s in l.output_shape:
            if s is None:
                continue
            single_layer_mem *= s
        shapes_mem_count += single_layer_mem

    trainable_count = np.sum([K.count_params(p) for p in set(model.trainable_weights)])
    non_trainable_count = np.sum([K.count_params(p) for p in set(model.non_trainable_weights)])

    total_memory = 4.0*batch_size*(shapes_mem_count + trainable_count + non_trainable_count)
    gbytes = np.round(total_memory / (1024.0 ** 3), 3)
    return str(gbytes) + "GB " , str(gbytes*2) + "GB "
```

### 3. Building the fcn with TensorFlow and Keras

In [8]:

```
# import keras
from keras.models import Sequential
from keras.layers import Dense, Dropout
from keras import backend as K
```

Using TensorFlow backend.

In [9]:

```
# finally we build the model
dimensions = x_train.shape[1]
print(dimensions, 'Dimensions')

hidden_1 = 256
hidden_2 = 256
drop_out_rate = 0.5
batch_size = 16

model = Sequential()
model.add(Dense(hidden_1, input_dim=dimensions, activation='relu'))
model.add(Dropout(drop_out_rate))
model.add(Dense(hidden_2, activation='relu'))
model.add(Dropout(drop_out_rate))
model.add(Dense(1, activation='sigmoid'))

model.compile(loss='binary_crossentropy', optimizer='rmsprop', metrics=['accuracy'])
```

150528 Dimensions

Lets see the model

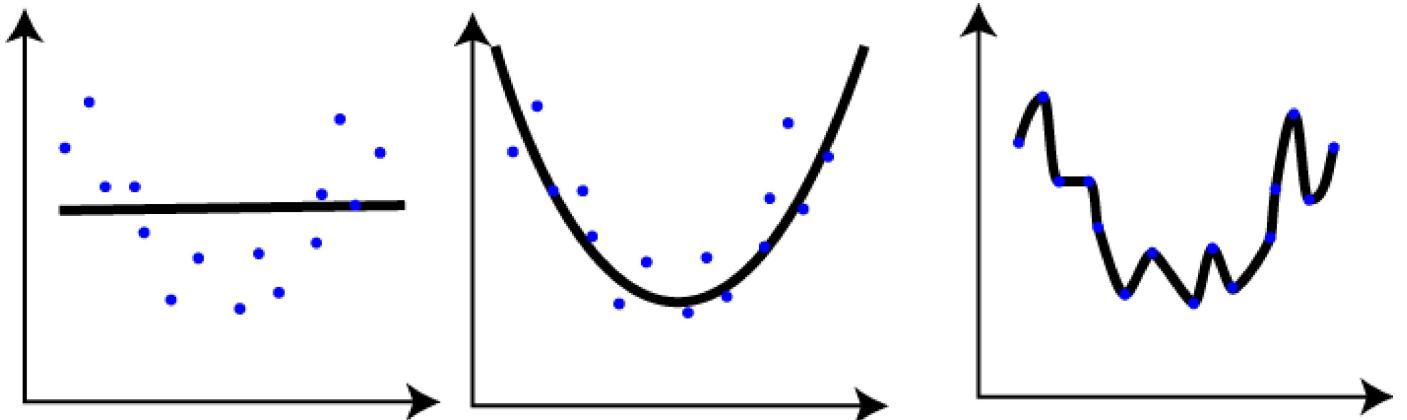
In [10]:

```
# visualize model
model.summary()
gpu, ram = getModelMemoryUsage(batch_size, model)
print("GPU Memory:" + gpu + "RAM:" + ram)
```

Layer (type)	Output Shape	Param #
<hr/>		
dense_1 (Dense)	(None, 256)	38535424
<hr/>		
dropout_1 (Dropout)	(None, 256)	0
<hr/>		
dense_2 (Dense)	(None, 256)	65792
<hr/>		
dropout_2 (Dropout)	(None, 256)	0
<hr/>		
dense_3 (Dense)	(None, 1)	257
<hr/>		
Total params: 38,601,473		
Trainable params: 38,601,473		
Non-trainable params: 0		
<hr/>		
GPU Memory:2.301GB RAM:4.602GB		

### 3

Overfitting



Avoided using many techniques; including cross validation

In [11]:

```
from sklearn.model_selection import train_test_split
from keras.callbacks import EarlyStopping, ModelCheckpoint
```

In [12]:

```
best_model_file = 'best_fcn_model.h5'
best_model = ModelCheckpoint(best_model_file, verbose=True, save_best_only=True)
network_histories = []
def fold(test_size=0.15, random_state=89, epochs=10):
    x_trf, x_val, y_trf, y_val = train_test_split(
        x_train,
        y_train,
        test_size=test_size,
        random_state=random_state)
    t = Timer()

    # early_stop = EarlyStopping(monitor='val_Loss', patience=5, verbose=1)
    t.start()
    network_history = model.fit(x_trf, y_trf,
                                validation_data = (x_val, y_val),
                                epochs=epochs,
                                batch_size=batch_size, verbose=True,
                                callbacks=[best_model])
    network_histories.append(network_history)
    t.stop('Training FCN with test %s and random state %s' % (str(test_size), str(random_st
```

In [13]:

fold()

```
Train on 680 samples, validate on 120 samples
Epoch 1/10
680/680 [=====] - 10s 15ms/step - loss: 8.4222 - acc: 0.4735 - val_loss: 4.5668 - val_acc: 0.7167

Epoch 00001: val_loss improved from inf to 4.56679, saving model to best_fcn_model.h5
Epoch 2/10
680/680 [=====] - 8s 12ms/step - loss: 7.7634 - acc: 0.5147 - val_loss: 4.5668 - val_acc: 0.7167

Epoch 00002: val_loss did not improve
Epoch 3/10
680/680 [=====] - 8s 12ms/step - loss: 7.9558 - acc: 0.5029 - val_loss: 4.5668 - val_acc: 0.7167

Epoch 00003: val_loss did not improve
Epoch 4/10
680/680 [=====] - 8s 12ms/step - loss: 8.2320 - acc: 0.4853 - val_loss: 4.5668 - val_acc: 0.7167

Epoch 00004: val_loss did not improve
Epoch 5/10
680/680 [=====] - 8s 11ms/step - loss: 8.2562 - acc: 0.4838 - val_loss: 4.5668 - val_acc: 0.7167

Epoch 00005: val_loss did not improve
Epoch 6/10
680/680 [=====] - 8s 11ms/step - loss: 8.0249 - acc: 0.4985 - val_loss: 4.5668 - val_acc: 0.7167

Epoch 00006: val_loss did not improve
Epoch 7/10
680/680 [=====] - 8s 12ms/step - loss: 8.2843 - acc: 0.4824 - val_loss: 4.5668 - val_acc: 0.7167

Epoch 00007: val_loss did not improve
Epoch 8/10
680/680 [=====] - 8s 12ms/step - loss: 7.3398 - acc: 0.5412 - val_loss: 4.5668 - val_acc: 0.7167

Epoch 00008: val_loss did not improve
Epoch 9/10
680/680 [=====] - 8s 11ms/step - loss: 7.1360 - acc: 0.5544 - val_loss: 4.5668 - val_acc: 0.7167

Epoch 00009: val_loss did not improve
Epoch 10/10
680/680 [=====] - 8s 11ms/step - loss: 5.5921 - acc: 0.6529 - val_loss: 4.5668 - val_acc: 0.7167

Epoch 00010: val_loss did not improve
Timing:: took 89 second(s) Training FCN with test 0.15 and random state 89
```

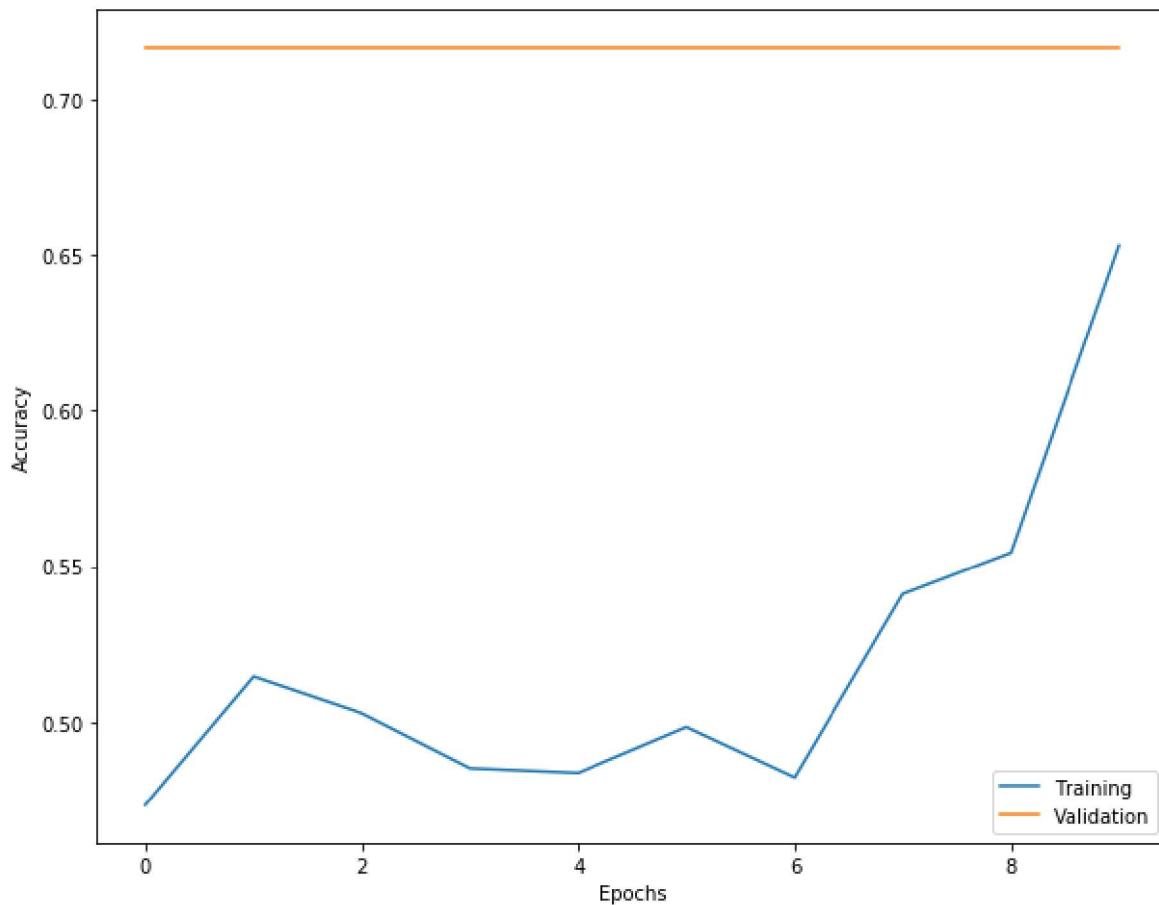
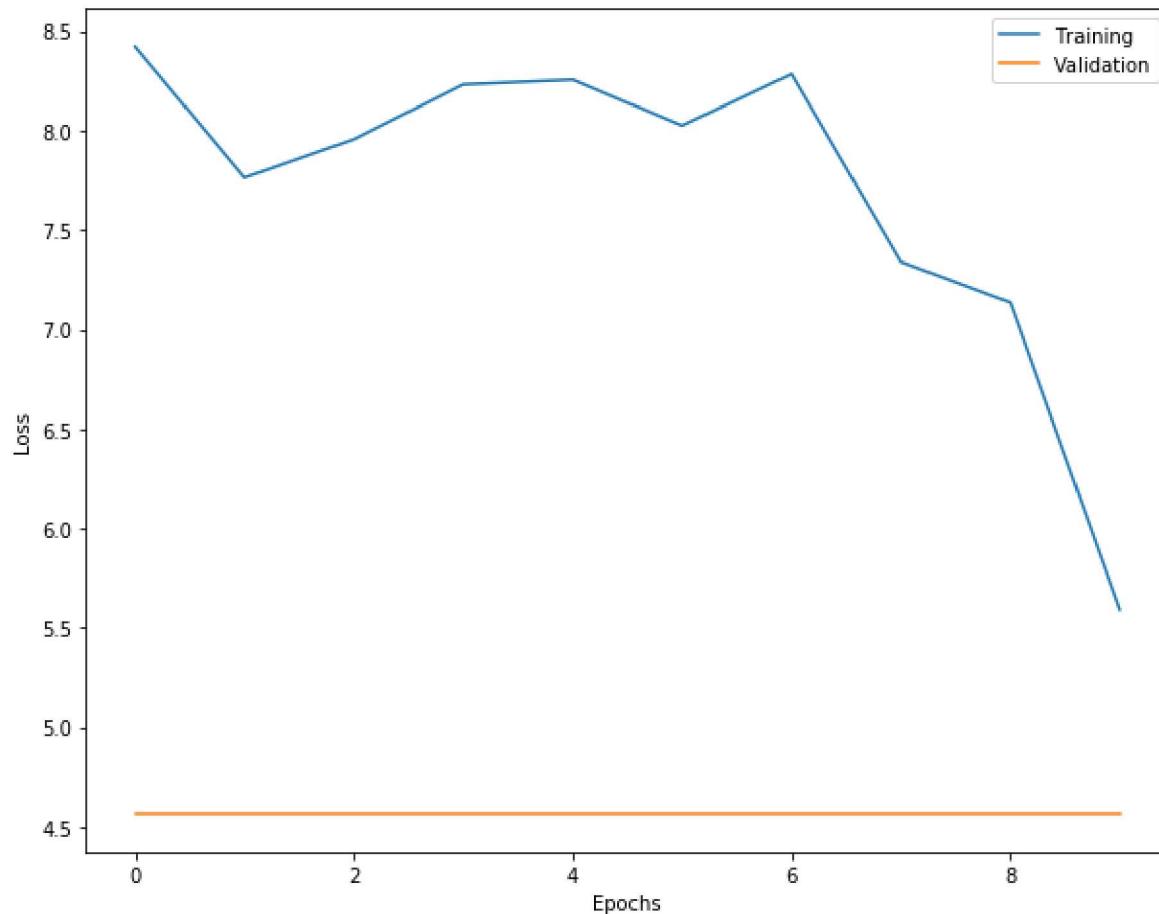
In [14]:

```
def plot_history(network_history):
    plt.figure()
    plt.xlabel('Epochs')
    plt.ylabel('Loss')
    plt.plot(network_history.history['loss'])
    plt.plot(network_history.history['val_loss'])
    plt.legend(['Training', 'Validation'])

    plt.figure()
    plt.xlabel('Epochs')
    plt.ylabel('Accuracy')
    plt.plot(network_history.history['acc'])
    plt.plot(network_history.history['val_acc'])
    plt.legend(['Training', 'Validation'], loc='lower right')
    plt.show()
```

In [15]:

```
plot_history(network_histories[0])
```



In [16]:

```
# multi fold cross validation
test_sizes = [0.1, 0.2, 0.3, 0.5, 0.6]
random_states = [1, 5, 15, 50, 100]
epochs = 10
timer.start()
for test_size in test_sizes:
    for random_state in random_states:
        fold(test_size, random_state, epochs)
timer.stop('Training %d models' % len(test_sizes)*len(random_states))
```

Train on 720 samples, validate on 80 samples  
Epoch 1/10  
720/720 [=====] - 8s 11ms/step - loss: 5.3695 - ac  
c: 0.6667 - val\_loss: 5.8428 - val\_acc: 0.6375

Epoch 00001: val\_loss did not improve  
Epoch 2/10  
720/720 [=====] - 8s 11ms/step - loss: 5.3926 - ac  
c: 0.6653 - val\_loss: 5.8428 - val\_acc: 0.6375

Epoch 00002: val\_loss did not improve  
Epoch 3/10  
720/720 [=====] - 8s 11ms/step - loss: 5.4372 - ac  
c: 0.6625 - val\_loss: 5.8428 - val\_acc: 0.6375

Epoch 00003: val\_loss did not improve  
Epoch 4/10  
720/720 [=====] - 8s 11ms/step - loss: 5.2369 - ac  
c: 0.6750 - val\_loss: 5.8428 - val\_acc: 0.6375

Epoch 00004: val\_loss did not improve  
Epoch 5/10  
720/720 [=====] - 8s 11ms/step - loss: 5.3700 - ac  
c: 0.6667 - val\_loss: 5.8428 - val\_acc: 0.6375

Epoch 00005: val\_loss did not improve  
Epoch 6/10  
720/720 [=====] - 8s 11ms/step - loss: 5.3038 - ac  
c: 0.6708 - val\_loss: 5.8428 - val\_acc: 0.6375

Epoch 00006: val\_loss did not improve  
Epoch 7/10  
720/720 [=====] - 8s 11ms/step - loss: 5.3929 - ac  
c: 0.6653 - val\_loss: 5.8428 - val\_acc: 0.6375

Epoch 00007: val\_loss did not improve  
Epoch 8/10  
720/720 [=====] - 8s 11ms/step - loss: 5.3924 - ac  
c: 0.6653 - val\_loss: 5.8428 - val\_acc: 0.6375

Epoch 00008: val\_loss did not improve  
Epoch 9/10  
720/720 [=====] - 8s 11ms/step - loss: 5.2369 - ac  
c: 0.6750 - val\_loss: 5.8428 - val\_acc: 0.6375

Epoch 00009: val\_loss did not improve  
Epoch 10/10  
720/720 [=====] - 8s 11ms/step - loss: 5.3698 - ac

```
c: 0.6667 - val_loss: 5.8428 - val_acc: 0.6375

Epoch 00010: val_loss did not improve
Timing:: took 80 second(s) Training FCN with test 0.1 and random state 1
-----
Train on 720 samples, validate on 80 samples
Epoch 1/10
720/720 [=====] - 8s 11ms/step - loss: 5.4155 - ac
c: 0.6639 - val_loss: 5.2384 - val_acc: 0.6750

Epoch 00001: val_loss did not improve
Epoch 2/10
720/720 [=====] - 8s 11ms/step - loss: 5.4596 - ac
c: 0.6611 - val_loss: 5.2384 - val_acc: 0.6750

Epoch 00002: val_loss did not improve
Epoch 3/10
720/720 [=====] - 8s 11ms/step - loss: 5.4600 - ac
c: 0.6611 - val_loss: 5.2384 - val_acc: 0.6750

Epoch 00003: val_loss did not improve
Epoch 4/10
720/720 [=====] - 8s 11ms/step - loss: 5.3707 - ac
c: 0.6667 - val_loss: 5.2384 - val_acc: 0.6750

Epoch 00004: val_loss did not improve
Epoch 5/10
720/720 [=====] - 8s 11ms/step - loss: 5.2822 - ac
c: 0.6722 - val_loss: 5.2384 - val_acc: 0.6750

Epoch 00005: val_loss did not improve
Epoch 6/10
720/720 [=====] - 8s 11ms/step - loss: 5.4812 - ac
c: 0.6597 - val_loss: 5.2384 - val_acc: 0.6750

Epoch 00006: val_loss did not improve
Epoch 7/10
720/720 [=====] - 8s 11ms/step - loss: 5.4381 - ac
c: 0.6625 - val_loss: 5.2384 - val_acc: 0.6750

Epoch 00007: val_loss did not improve
Epoch 8/10
720/720 [=====] - 8s 11ms/step - loss: 5.5489 - ac
c: 0.6556 - val_loss: 5.2384 - val_acc: 0.6750

Epoch 00008: val_loss did not improve
Epoch 9/10
720/720 [=====] - 8s 11ms/step - loss: 5.5484 - ac
c: 0.6556 - val_loss: 5.2384 - val_acc: 0.6750

Epoch 00009: val_loss did not improve
Epoch 10/10
720/720 [=====] - 8s 11ms/step - loss: 5.4374 - ac
c: 0.6625 - val_loss: 5.2384 - val_acc: 0.6750

Epoch 00010: val_loss did not improve
Timing:: took 80 second(s) Training FCN with test 0.1 and random state 5
-----
Train on 720 samples, validate on 80 samples
Epoch 1/10
720/720 [=====] - 8s 11ms/step - loss: 5.4374 - ac
```

```
c: 0.6625 - val_loss: 5.8428 - val_acc: 0.6375

Epoch 00001: val_loss did not improve
Epoch 2/10
720/720 [=====] - 8s 11ms/step - loss: 5.7625 - ac
c: 0.6417 - val_loss: 5.8428 - val_acc: 0.6375

Epoch 00002: val_loss did not improve
Epoch 3/10
720/720 [=====] - 8s 11ms/step - loss: 6.7980 - ac
c: 0.5764 - val_loss: 5.8428 - val_acc: 0.6375

Epoch 00003: val_loss did not improve
Epoch 4/10
720/720 [=====] - 8s 11ms/step - loss: 6.3308 - ac
c: 0.6056 - val_loss: 5.8428 - val_acc: 0.6375

Epoch 00004: val_loss did not improve
Epoch 5/10
720/720 [=====] - 8s 11ms/step - loss: 6.7749 - ac
c: 0.5778 - val_loss: 5.8428 - val_acc: 0.6375

Epoch 00005: val_loss did not improve
Epoch 6/10
720/720 [=====] - 8s 11ms/step - loss: 5.5762 - ac
c: 0.6528 - val_loss: 5.8428 - val_acc: 0.6375

Epoch 00006: val_loss did not improve
Epoch 7/10
720/720 [=====] - 8s 11ms/step - loss: 5.4800 - ac
c: 0.6597 - val_loss: 5.8428 - val_acc: 0.6375

Epoch 00007: val_loss did not improve
Epoch 8/10
720/720 [=====] - 8s 11ms/step - loss: 5.6798 - ac
c: 0.6472 - val_loss: 5.8428 - val_acc: 0.6375

Epoch 00008: val_loss did not improve
Epoch 9/10
720/720 [=====] - 8s 11ms/step - loss: 5.3708 - ac
c: 0.6653 - val_loss: 5.8428 - val_acc: 0.6375

Epoch 00009: val_loss did not improve
Epoch 10/10
720/720 [=====] - 8s 11ms/step - loss: 5.4369 - ac
c: 0.6625 - val_loss: 5.8428 - val_acc: 0.6375

Epoch 00010: val_loss did not improve
Timing:: took 80 second(s) Training FCN with test 0.1 and random state 15
-----
Train on 720 samples, validate on 80 samples
Epoch 1/10
720/720 [=====] - 8s 11ms/step - loss: 5.4143 - ac
c: 0.6639 - val_loss: 6.0443 - val_acc: 0.6250

Epoch 00001: val_loss did not improve
Epoch 2/10
720/720 [=====] - 8s 11ms/step - loss: 5.4145 - ac
c: 0.6639 - val_loss: 6.0443 - val_acc: 0.6250

Epoch 00002: val_loss did not improve
```

Epoch 3/10  
720/720 [=====] - 8s 11ms/step - loss: 5.3036 - ac  
c: 0.6708 - val\_loss: 6.0443 - val\_acc: 0.6250: 5.3905 -

Epoch 00003: val\_loss did not improve

Epoch 4/10  
720/720 [=====] - 8s 11ms/step - loss: 5.3919 - ac  
c: 0.6653 - val\_loss: 6.0443 - val\_acc: 0.6250

Epoch 00004: val\_loss did not improve

Epoch 5/10  
720/720 [=====] - 8s 11ms/step - loss: 5.3265 - ac  
c: 0.6694 - val\_loss: 6.0443 - val\_acc: 0.6250

Epoch 00005: val\_loss did not improve

Epoch 6/10  
720/720 [=====] - 8s 11ms/step - loss: 5.2581 - ac  
c: 0.6736 - val\_loss: 6.0443 - val\_acc: 0.6250

Epoch 00006: val\_loss did not improve

Epoch 7/10  
720/720 [=====] - 8s 11ms/step - loss: 5.3705 - ac  
c: 0.6667 - val\_loss: 6.0443 - val\_acc: 0.6250

Epoch 00007: val\_loss did not improve

Epoch 8/10  
720/720 [=====] - 8s 11ms/step - loss: 5.4593 - ac  
c: 0.6611 - val\_loss: 6.0443 - val\_acc: 0.6250

Epoch 00008: val\_loss did not improve

Epoch 9/10  
720/720 [=====] - 8s 11ms/step - loss: 5.3924 - ac  
c: 0.6653 - val\_loss: 6.0443 - val\_acc: 0.6250

Epoch 00009: val\_loss did not improve

Epoch 10/10  
720/720 [=====] - 8s 11ms/step - loss: 5.4143 - ac  
c: 0.6639 - val\_loss: 6.0443 - val\_acc: 0.6250

Epoch 00010: val\_loss did not improve

Timing:: took 79 second(s) Training FCN with test 0.1 and random state 50

-----  
Train on 720 samples, validate on 80 samples

Epoch 1/10  
720/720 [=====] - 8s 11ms/step - loss: 5.3922 - ac  
c: 0.6653 - val\_loss: 5.4399 - val\_acc: 0.6625

Epoch 00001: val\_loss did not improve

Epoch 2/10  
720/720 [=====] - 8s 11ms/step - loss: 5.4143 - ac  
c: 0.6639 - val\_loss: 5.4399 - val\_acc: 0.6625

Epoch 00002: val\_loss did not improve

Epoch 3/10  
720/720 [=====] - 8s 11ms/step - loss: 5.3919 - ac  
c: 0.6653 - val\_loss: 5.4399 - val\_acc: 0.6625

Epoch 00003: val\_loss did not improve

Epoch 4/10  
720/720 [=====] - 8s 11ms/step - loss: 5.3695 - ac  
c: 0.6667 - val\_loss: 5.4399 - val\_acc: 0.6625

```
Epoch 00004: val_loss did not improve
Epoch 5/10
720/720 [=====] - 8s 11ms/step - loss: 5.4145 - acc: 0.6639 - val_loss: 5.4399 - val_acc: 0.6625

Epoch 00005: val_loss did not improve
Epoch 6/10
720/720 [=====] - 8s 11ms/step - loss: 5.4822 - acc: 0.6597 - val_loss: 5.4399 - val_acc: 0.6625

Epoch 00006: val_loss did not improve
Epoch 7/10
720/720 [=====] - 8s 11ms/step - loss: 5.4822 - acc: 0.6597 - val_loss: 5.4399 - val_acc: 0.6625

Epoch 00007: val_loss did not improve
Epoch 8/10
720/720 [=====] - 8s 11ms/step - loss: 5.4593 - acc: 0.6611 - val_loss: 5.4399 - val_acc: 0.6625

Epoch 00008: val_loss did not improve
Epoch 9/10
720/720 [=====] - 8s 11ms/step - loss: 5.4591 - acc: 0.6611 - val_loss: 5.4399 - val_acc: 0.6625

Epoch 00009: val_loss did not improve
Epoch 10/10
720/720 [=====] - 8s 11ms/step - loss: 5.6369 - acc: 0.6500 - val_loss: 5.4399 - val_acc: 0.6625

Epoch 00010: val_loss did not improve
Timing:: took 80 second(s) Training FCN with test 0.1 and random state 100
-----
Train on 640 samples, validate on 160 samples
Epoch 1/10
640/640 [=====] - 7s 11ms/step - loss: 5.2376 - acc: 0.6750 - val_loss: 5.8428 - val_acc: 0.6375

Epoch 00001: val_loss did not improve
Epoch 2/10
640/640 [=====] - 7s 11ms/step - loss: 5.3610 - acc: 0.6672 - val_loss: 5.8428 - val_acc: 0.6375

Epoch 00002: val_loss did not improve
Epoch 3/10
640/640 [=====] - 7s 11ms/step - loss: 5.3366 - acc: 0.6687 - val_loss: 5.8428 - val_acc: 0.6375

Epoch 00003: val_loss did not improve
Epoch 4/10
640/640 [=====] - 7s 11ms/step - loss: 5.2603 - acc: 0.6734 - val_loss: 5.8428 - val_acc: 0.6375

Epoch 00004: val_loss did not improve
Epoch 5/10
640/640 [=====] - 7s 11ms/step - loss: 5.2614 - acc: 0.6734 - val_loss: 5.8428 - val_acc: 0.6375

Epoch 00005: val_loss did not improve
Epoch 6/10
```

```
640/640 [=====] - 7s 11ms/step - loss: 5.5118 - ac  
c: 0.6578 - val_loss: 5.8428 - val_acc: 0.6375
```

Epoch 00006: val\_loss did not improve

Epoch 7/10

```
640/640 [=====] - 7s 11ms/step - loss: 5.4371 - ac  
c: 0.6625 - val_loss: 5.8428 - val_acc: 0.6375
```

Epoch 00007: val\_loss did not improve

Epoch 8/10

```
640/640 [=====] - 7s 12ms/step - loss: 5.1861 - ac  
c: 0.6781 - val_loss: 5.8428 - val_acc: 0.6375
```

Epoch 00008: val\_loss did not improve

Epoch 9/10

```
640/640 [=====] - 7s 12ms/step - loss: 5.3607 - ac  
c: 0.6672 - val_loss: 5.8428 - val_acc: 0.6375
```

Epoch 00009: val\_loss did not improve

Epoch 10/10

```
640/640 [=====] - 8s 12ms/step - loss: 5.3859 - ac  
c: 0.6656 - val_loss: 5.8428 - val_acc: 0.6375
```

Epoch 00010: val\_loss did not improve

Timing:: took 73 second(s) Training FCN with test 0.2 and random state 1

-----  
Train on 640 samples, validate on 160 samples

Epoch 1/10

```
640/640 [=====] - 8s 12ms/step - loss: 5.4626 - ac  
c: 0.6609 - val_loss: 5.3391 - val_acc: 0.6687
```

Epoch 00001: val\_loss did not improve

Epoch 2/10

```
640/640 [=====] - 7s 12ms/step - loss: 5.4122 - ac  
c: 0.6641 - val_loss: 5.3391 - val_acc: 0.6687
```

Epoch 00002: val\_loss did not improve

Epoch 3/10

```
640/640 [=====] - 7s 12ms/step - loss: 5.4125 - ac  
c: 0.6641 - val_loss: 5.3391 - val_acc: 0.6687
```

Epoch 00003: val\_loss did not improve

Epoch 4/10

```
640/640 [=====] - 7s 11ms/step - loss: 5.4117 - ac  
c: 0.6641 - val_loss: 5.3391 - val_acc: 0.6687
```

Epoch 00004: val\_loss did not improve

Epoch 5/10

```
640/640 [=====] - 7s 12ms/step - loss: 5.4114 - ac  
c: 0.6641 - val_loss: 5.3391 - val_acc: 0.6687
```

Epoch 00005: val\_loss did not improve

Epoch 6/10

```
640/640 [=====] - 7s 12ms/step - loss: 5.5863 - ac  
c: 0.6531 - val_loss: 5.3391 - val_acc: 0.6687
```

Epoch 00006: val\_loss did not improve

Epoch 7/10

```
640/640 [=====] - 7s 11ms/step - loss: 5.3380 - ac  
c: 0.6687 - val_loss: 5.3391 - val_acc: 0.6687
```

```
Epoch 00007: val_loss did not improve
Epoch 8/10
640/640 [=====] - 7s 11ms/step - loss: 5.2636 - ac
c: 0.6734 - val_loss: 5.3391 - val_acc: 0.6687

Epoch 00008: val_loss did not improve
Epoch 9/10
640/640 [=====] - 7s 11ms/step - loss: 5.3388 - ac
c: 0.6687 - val_loss: 5.3391 - val_acc: 0.6687

Epoch 00009: val_loss did not improve
Epoch 10/10
640/640 [=====] - 7s 11ms/step - loss: 5.3388 - ac
c: 0.6687 - val_loss: 5.3391 - val_acc: 0.6687

Epoch 00010: val_loss did not improve
Timing:: took 73 second(s) Training FCN with test 0.2 and random state 5
-----
Train on 640 samples, validate on 160 samples
Epoch 1/10
640/640 [=====] - 7s 11ms/step - loss: 5.1371 - ac
c: 0.6812 - val_loss: 6.2458 - val_acc: 0.6125

Epoch 00001: val_loss did not improve
Epoch 2/10
640/640 [=====] - 7s 11ms/step - loss: 5.1122 - ac
c: 0.6828 - val_loss: 6.2458 - val_acc: 0.6125

Epoch 00002: val_loss did not improve
Epoch 3/10
640/640 [=====] - 7s 11ms/step - loss: 5.1021 - ac
c: 0.6828 - val_loss: 6.2458 - val_acc: 0.6125

Epoch 00003: val_loss did not improve
Epoch 4/10
640/640 [=====] - 7s 11ms/step - loss: 5.0873 - ac
c: 0.6844 - val_loss: 6.2458 - val_acc: 0.6125

Epoch 00004: val_loss did not improve
Epoch 5/10
640/640 [=====] - 7s 12ms/step - loss: 5.0873 - ac
c: 0.6844 - val_loss: 6.2458 - val_acc: 0.6125

Epoch 00005: val_loss did not improve
Epoch 6/10
640/640 [=====] - 7s 12ms/step - loss: 5.0873 - ac
c: 0.6844 - val_loss: 6.2458 - val_acc: 0.6125

Epoch 00006: val_loss did not improve
Epoch 7/10
640/640 [=====] - 7s 12ms/step - loss: 5.0873 - ac
c: 0.6844 - val_loss: 6.2458 - val_acc: 0.6125

Epoch 00007: val_loss did not improve
Epoch 8/10
640/640 [=====] - 7s 12ms/step - loss: 5.0873 - ac
c: 0.6844 - val_loss: 6.2458 - val_acc: 0.6125

Epoch 00008: val_loss did not improve
Epoch 9/10
640/640 [=====] - 7s 12ms/step - loss: 5.0873 - ac
```

c: 0.6844 - val\_loss: 6.2458 - val\_acc: 0.6125 - loss: - ETA: 0s - loss: 4.9  
280 - acc: 0.6

Epoch 00009: val\_loss did not improve

Epoch 10/10

640/640 [=====] - 7s 12ms/step - loss: 5.0873 - ac

c: 0.6844 - val\_loss: 6.2458 - val\_acc: 0.6125

Epoch 00010: val\_loss did not improve

Timing:: took 73 second(s) Training FCN with test 0.2 and random state 15

-----  
Train on 640 samples, validate on 160 samples

Epoch 1/10

640/640 [=====] - 7s 11ms/step - loss: 5.3391 - ac

c: 0.6687 - val\_loss: 5.2384 - val\_acc: 0.6750s - los

Epoch 00001: val\_loss did not improve

Epoch 2/10

640/640 [=====] - 7s 11ms/step - loss: 5.3391 - ac

c: 0.6687 - val\_loss: 5.2384 - val\_acc: 0.6750

Epoch 00002: val\_loss did not improve

Epoch 3/10

640/640 [=====] - 7s 11ms/step - loss: 5.3391 - ac

c: 0.6687 - val\_loss: 5.2384 - val\_acc: 0.6750

Epoch 00003: val\_loss did not improve

Epoch 4/10

640/640 [=====] - 7s 12ms/step - loss: 5.3391 - ac

c: 0.6687 - val\_loss: 5.2384 - val\_acc: 0.6750

Epoch 00004: val\_loss did not improve

Epoch 5/10

640/640 [=====] - 7s 12ms/step - loss: 5.3391 - ac

c: 0.6687 - val\_loss: 5.2384 - val\_acc: 0.6750

Epoch 00005: val\_loss did not improve

Epoch 6/10

640/640 [=====] - 7s 12ms/step - loss: 5.3640 - ac

c: 0.6672 - val\_loss: 5.2384 - val\_acc: 0.6750

Epoch 00006: val\_loss did not improve

Epoch 7/10

640/640 [=====] - 7s 11ms/step - loss: 5.3391 - ac

c: 0.6687 - val\_loss: 5.2384 - val\_acc: 0.6750

Epoch 00007: val\_loss did not improve

Epoch 8/10

640/640 [=====] - 7s 12ms/step - loss: 5.3391 - ac

c: 0.6687 - val\_loss: 5.2384 - val\_acc: 0.6750

Epoch 00008: val\_loss did not improve

Epoch 9/10

640/640 [=====] - 7s 12ms/step - loss: 5.3391 - ac

c: 0.6687 - val\_loss: 5.2384 - val\_acc: 0.6750

Epoch 00009: val\_loss did not improve

Epoch 10/10

640/640 [=====] - 7s 12ms/step - loss: 5.3391 - ac

c: 0.6687 - val\_loss: 5.2384 - val\_acc: 0.6750

```
Epoch 00010: val_loss did not improve
Timing:: took 73 second(s) Training FCN with test 0.2 and random state 50
-----
Train on 640 samples, validate on 160 samples
Epoch 1/10
640/640 [=====] - 7s 11ms/step - loss: 5.4147 - acc: 0.6641 - val_loss: 4.9362 - val_acc: 0.6937

Epoch 00001: val_loss did not improve
Epoch 2/10
640/640 [=====] - 7s 12ms/step - loss: 5.4147 - acc: 0.6641 - val_loss: 4.9362 - val_acc: 0.6937

Epoch 00002: val_loss did not improve
Epoch 3/10
640/640 [=====] - 7s 12ms/step - loss: 5.4147 - acc: 0.6641 - val_loss: 4.9362 - val_acc: 0.6937

Epoch 00003: val_loss did not improve
Epoch 4/10
640/640 [=====] - 7s 11ms/step - loss: 5.4147 - acc: 0.6641 - val_loss: 4.9362 - val_acc: 0.6937

Epoch 00004: val_loss did not improve
Epoch 5/10
640/640 [=====] - 7s 12ms/step - loss: 5.4147 - acc: 0.6641 - val_loss: 4.9362 - val_acc: 0.6937

Epoch 00005: val_loss did not improve
Epoch 6/10
640/640 [=====] - 7s 12ms/step - loss: 5.4147 - acc: 0.6641 - val_loss: 4.9362 - val_acc: 0.6937

Epoch 00006: val_loss did not improve
Epoch 7/10
640/640 [=====] - 7s 11ms/step - loss: 5.4147 - acc: 0.6641 - val_loss: 4.9362 - val_acc: 0.6937

Epoch 00007: val_loss did not improve
Epoch 8/10
640/640 [=====] - 7s 11ms/step - loss: 5.4147 - acc: 0.6641 - val_loss: 4.9362 - val_acc: 0.6937

Epoch 00008: val_loss did not improve
Epoch 9/10
640/640 [=====] - 7s 12ms/step - loss: 5.4147 - acc: 0.6641 - val_loss: 4.9362 - val_acc: 0.6937

Epoch 00009: val_loss did not improve
Epoch 10/10
640/640 [=====] - 7s 11ms/step - loss: 5.4396 - acc: 0.6625 - val_loss: 4.9362 - val_acc: 0.6937

Epoch 00010: val_loss did not improve
Timing:: took 73 second(s) Training FCN with test 0.2 and random state 100
-----
Train on 560 samples, validate on 240 samples
Epoch 1/10
560/560 [=====] - 7s 12ms/step - loss: 5.1233 - acc: 0.6821 - val_loss: 5.7757 - val_acc: 0.6417
```

```
Epoch 00001: val_loss did not improve
Epoch 2/10
560/560 [=====] - 7s 12ms/step - loss: 5.1233 - ac
c: 0.6821 - val_loss: 5.7757 - val_acc: 0.6417

Epoch 00002: val_loss did not improve
Epoch 3/10
560/560 [=====] - 7s 12ms/step - loss: 5.1233 - ac
c: 0.6821 - val_loss: 5.7757 - val_acc: 0.6417

Epoch 00003: val_loss did not improve
Epoch 4/10
560/560 [=====] - 7s 12ms/step - loss: 5.1233 - ac
c: 0.6821 - val_loss: 5.7757 - val_acc: 0.6417

Epoch 00004: val_loss did not improve
Epoch 5/10
560/560 [=====] - 7s 12ms/step - loss: 5.1233 - ac
c: 0.6821 - val_loss: 5.7757 - val_acc: 0.6417

Epoch 00005: val_loss did not improve
Epoch 6/10
560/560 [=====] - 7s 12ms/step - loss: 5.1233 - ac
c: 0.6821 - val_loss: 5.7757 - val_acc: 0.6417

Epoch 00006: val_loss did not improve
Epoch 7/10
560/560 [=====] - 7s 12ms/step - loss: 5.1233 - ac
c: 0.6821 - val_loss: 5.7757 - val_acc: 0.6417

Epoch 00007: val_loss did not improve
Epoch 8/10
560/560 [=====] - 7s 12ms/step - loss: 5.1517 - ac
c: 0.6804 - val_loss: 5.7757 - val_acc: 0.6417

Epoch 00008: val_loss did not improve
Epoch 9/10
560/560 [=====] - 7s 12ms/step - loss: 5.1233 - ac
c: 0.6821 - val_loss: 5.7757 - val_acc: 0.6417

Epoch 00009: val_loss did not improve
Epoch 10/10
560/560 [=====] - 7s 12ms/step - loss: 5.1233 - ac
c: 0.6821 - val_loss: 5.7757 - val_acc: 0.6417

Epoch 00010: val_loss did not improve
Timing:: took 66 second(s) Training FCN with test 0.3 and random state 1
-----
Train on 560 samples, validate on 240 samples
Epoch 1/10
560/560 [=====] - 7s 12ms/step - loss: 5.2959 - ac
c: 0.6714 - val_loss: 5.3727 - val_acc: 0.6667

Epoch 00001: val_loss did not improve
Epoch 2/10
560/560 [=====] - 7s 12ms/step - loss: 5.2959 - ac
c: 0.6714 - val_loss: 5.3727 - val_acc: 0.6667

Epoch 00002: val_loss did not improve
Epoch 3/10
560/560 [=====] - 7s 12ms/step - loss: 5.2959 - ac
```

```
c: 0.6714 - val_loss: 5.3727 - val_acc: 0.6667

Epoch 00003: val_loss did not improve
Epoch 4/10
560/560 [=====] - 7s 12ms/step - loss: 5.2959 - ac
c: 0.6714 - val_loss: 5.3727 - val_acc: 0.6667

Epoch 00004: val_loss did not improve
Epoch 5/10
560/560 [=====] - 7s 12ms/step - loss: 5.2959 - ac
c: 0.6714 - val_loss: 5.3727 - val_acc: 0.6667

Epoch 00005: val_loss did not improve
Epoch 6/10
560/560 [=====] - 7s 12ms/step - loss: 5.2959 - ac
c: 0.6714 - val_loss: 5.3727 - val_acc: 0.6667

Epoch 00006: val_loss did not improve
Epoch 7/10
560/560 [=====] - 7s 12ms/step - loss: 5.2959 - ac
c: 0.6714 - val_loss: 5.3727 - val_acc: 0.6667

Epoch 00007: val_loss did not improve
Epoch 8/10
560/560 [=====] - 7s 12ms/step - loss: 5.2959 - ac
c: 0.6714 - val_loss: 5.3727 - val_acc: 0.6667

Epoch 00008: val_loss did not improve
Epoch 9/10
560/560 [=====] - 7s 12ms/step - loss: 5.3244 - ac
c: 0.6696 - val_loss: 5.3727 - val_acc: 0.6667

Epoch 00009: val_loss did not improve
Epoch 10/10
560/560 [=====] - 7s 12ms/step - loss: 5.2959 - ac
c: 0.6714 - val_loss: 5.3727 - val_acc: 0.6667

Epoch 00010: val_loss did not improve
Timing:: took 65 second(s) Training FCN with test 0.3 and random state 5
-----
Train on 560 samples, validate on 240 samples
Epoch 1/10
560/560 [=====] - 6s 12ms/step - loss: 4.9793 - ac
c: 0.6911 - val_loss: 6.1114 - val_acc: 0.6208

Epoch 00001: val_loss did not improve
Epoch 2/10
560/560 [=====] - 7s 12ms/step - loss: 4.9793 - ac
c: 0.6911 - val_loss: 6.1114 - val_acc: 0.6208

Epoch 00002: val_loss did not improve
Epoch 3/10
560/560 [=====] - 7s 12ms/step - loss: 4.9793 - ac
c: 0.6911 - val_loss: 6.1114 - val_acc: 0.6208

Epoch 00003: val_loss did not improve
Epoch 4/10
560/560 [=====] - 7s 12ms/step - loss: 4.9793 - ac
c: 0.6911 - val_loss: 6.1114 - val_acc: 0.6208

Epoch 00004: val_loss did not improve
```

```
Epoch 5/10
560/560 [=====] - 7s 12ms/step - loss: 4.9793 - acc: 0.6911 - val_loss: 6.1114 - val_acc: 0.6208
```

```
Epoch 00005: val_loss did not improve
```

```
Epoch 6/10
```

```
560/560 [=====] - 7s 12ms/step - loss: 4.9793 - acc: 0.6911 - val_loss: 6.1114 - val_acc: 0.6208
```

```
Epoch 00006: val_loss did not improve
```

```
Epoch 7/10
```

```
560/560 [=====] - 7s 12ms/step - loss: 4.9793 - acc: 0.6911 - val_loss: 6.1114 - val_acc: 0.6208
```

```
Epoch 00007: val_loss did not improve
```

```
Epoch 8/10
```

```
560/560 [=====] - 7s 12ms/step - loss: 4.9793 - acc: 0.6911 - val_loss: 6.1114 - val_acc: 0.6208
```

```
Epoch 00008: val_loss did not improve
```

```
Epoch 9/10
```

```
560/560 [=====] - 7s 12ms/step - loss: 4.9793 - acc: 0.6911 - val_loss: 6.1114 - val_acc: 0.6208
```

```
Epoch 00009: val_loss did not improve
```

```
Epoch 10/10
```

```
560/560 [=====] - 7s 12ms/step - loss: 4.9793 - acc: 0.6911 - val_loss: 6.1114 - val_acc: 0.6208
```

```
Epoch 00010: val_loss did not improve
```

```
Timing:: took 66 second(s) Training FCN with test 0.3 and random state 15
```

```
-----
```

```
Train on 560 samples, validate on 240 samples
```

```
Epoch 1/10
```

```
560/560 [=====] - 7s 12ms/step - loss: 5.3247 - acc: 0.6696 - val_loss: 5.3055 - val_acc: 0.6708
```

```
Epoch 00001: val_loss did not improve
```

```
Epoch 2/10
```

```
560/560 [=====] - 7s 12ms/step - loss: 5.3247 - acc: 0.6696 - val_loss: 5.3055 - val_acc: 0.6708
```

```
Epoch 00002: val_loss did not improve
```

```
Epoch 3/10
```

```
560/560 [=====] - 7s 12ms/step - loss: 5.3247 - acc: 0.6696 - val_loss: 5.3055 - val_acc: 0.6708
```

```
Epoch 00003: val_loss did not improve
```

```
Epoch 4/10
```

```
560/560 [=====] - 7s 12ms/step - loss: 5.3247 - acc: 0.6696 - val_loss: 5.3055 - val_acc: 0.6708
```

```
Epoch 00004: val_loss did not improve
```

```
Epoch 5/10
```

```
560/560 [=====] - 7s 12ms/step - loss: 5.3247 - acc: 0.6696 - val_loss: 5.3055 - val_acc: 0.6708
```

```
Epoch 00005: val_loss did not improve
```

```
Epoch 6/10
```

```
560/560 [=====] - 7s 12ms/step - loss: 5.3247 - acc:
```

```
cc: 0.6696 - val_loss: 5.3055 - val_acc: 0.6708

Epoch 00006: val_loss did not improve
Epoch 7/10
560/560 [=====] - 7s 12ms/step - loss: 5.2959 - a
cc: 0.6714 - val_loss: 5.3055 - val_acc: 0.6708

Epoch 00007: val_loss did not improve
Epoch 8/10
560/560 [=====] - 7s 12ms/step - loss: 5.3247 - a
cc: 0.6696 - val_loss: 5.3055 - val_acc: 0.6708

Epoch 00008: val_loss did not improve
Epoch 9/10
560/560 [=====] - 7s 12ms/step - loss: 5.3247 - a
cc: 0.6696 - val_loss: 5.3055 - val_acc: 0.6708

Epoch 00009: val_loss did not improve
Epoch 10/10
560/560 [=====] - 7s 12ms/step - loss: 5.3247 - a
cc: 0.6696 - val_loss: 5.3055 - val_acc: 0.6708

Epoch 00010: val_loss did not improve
Timing:: took 65 second(s) Training FCN with test 0.3 and random state 50
-----
Train on 560 samples, validate on 240 samples
Epoch 1/10
560/560 [=====] - 7s 12ms/step - loss: 5.3535 - a
cc: 0.6679 - val_loss: 5.2384 - val_acc: 0.6750A: 1s - loss: 5.4686 - acc:

Epoch 00001: val_loss did not improve
Epoch 2/10
560/560 [=====] - 7s 12ms/step - loss: 5.3820 - a
cc: 0.6661 - val_loss: 5.2384 - val_acc: 0.6750

Epoch 00002: val_loss did not improve
Epoch 3/10
560/560 [=====] - 7s 12ms/step - loss: 5.3535 - a
cc: 0.6679 - val_loss: 5.2384 - val_acc: 0.6750

Epoch 00003: val_loss did not improve
Epoch 4/10
560/560 [=====] - 7s 12ms/step - loss: 5.3535 - a
cc: 0.6679 - val_loss: 5.2384 - val_acc: 0.6750

Epoch 00004: val_loss did not improve
Epoch 5/10
560/560 [=====] - 7s 12ms/step - loss: 5.3535 - a
cc: 0.6679 - val_loss: 5.2384 - val_acc: 0.6750 4s - los

Epoch 00005: val_loss did not improve
Epoch 6/10
560/560 [=====] - 7s 12ms/step - loss: 5.3535 - a
cc: 0.6679 - val_loss: 5.2384 - val_acc: 0.6750

Epoch 00006: val_loss did not improve
Epoch 7/10
560/560 [=====] - 7s 12ms/step - loss: 5.3535 - a
cc: 0.6679 - val_loss: 5.2384 - val_acc: 0.6750

Epoch 00007: val_loss did not improve
```

```
Epoch 8/10
560/560 [=====] - 7s 12ms/step - loss: 5.3535 - acc: 0.6679 - val_loss: 5.2384 - val_acc: 0.6750

Epoch 00008: val_loss did not improve
Epoch 9/10
560/560 [=====] - 7s 12ms/step - loss: 5.3535 - acc: 0.6679 - val_loss: 5.2384 - val_acc: 0.6750

Epoch 00009: val_loss did not improve
Epoch 10/10
560/560 [=====] - 7s 12ms/step - loss: 5.3820 - acc: 0.6661 - val_loss: 5.2384 - val_acc: 0.6750

Epoch 00010: val_loss did not improve
Timing:: took 65 second(s) Training FCN with test 0.3 and random state 100
-----
Train on 400 samples, validate on 400 samples
Epoch 1/10
400/400 [=====] - 5s 13ms/step - loss: 5.1578 - acc: 0.6800 - val_loss: 5.4802 - val_acc: 0.6600

Epoch 00001: val_loss did not improve
Epoch 2/10
400/400 [=====] - 5s 13ms/step - loss: 5.1578 - acc: 0.6800 - val_loss: 5.4802 - val_acc: 0.6600

Epoch 00002: val_loss did not improve
Epoch 3/10
400/400 [=====] - 5s 13ms/step - loss: 5.1578 - acc: 0.6800 - val_loss: 5.4802 - val_acc: 0.6600

Epoch 00003: val_loss did not improve
Epoch 4/10
400/400 [=====] - 5s 13ms/step - loss: 5.1578 - acc: 0.6800 - val_loss: 5.4802 - val_acc: 0.6600

Epoch 00004: val_loss did not improve
Epoch 5/10
400/400 [=====] - 5s 13ms/step - loss: 5.1578 - acc: 0.6800 - val_loss: 5.4802 - val_acc: 0.6600

Epoch 00005: val_loss did not improve
Epoch 6/10
400/400 [=====] - 5s 13ms/step - loss: 5.1578 - acc: 0.6800 - val_loss: 5.4802 - val_acc: 0.6600

Epoch 00006: val_loss did not improve
Epoch 7/10
400/400 [=====] - 5s 13ms/step - loss: 5.1578 - acc: 0.6800 - val_loss: 5.4802 - val_acc: 0.6600

Epoch 00007: val_loss did not improve
Epoch 8/10
400/400 [=====] - 5s 13ms/step - loss: 5.1578 - acc: 0.6800 - val_loss: 5.4802 - val_acc: 0.6600

Epoch 00008: val_loss did not improve
Epoch 9/10
400/400 [=====] - 5s 13ms/step - loss: 5.1976 - acc: 0.6775 - val_loss: 5.4802 - val_acc: 0.6600
```

```
Epoch 00009: val_loss did not improve
Epoch 10/10
400/400 [=====] - 5s 13ms/step - loss: 5.1578 - acc: 0.6800 - val_loss: 5.4802 - val_acc: 0.6600

Epoch 00010: val_loss did not improve
Timing:: took 51 second(s) Training FCN with test 0.5 and random state 1
-----
Train on 400 samples, validate on 400 samples
Epoch 1/10
400/400 [=====] - 5s 13ms/step - loss: 5.3593 - acc: 0.6675 - val_loss: 5.2787 - val_acc: 0.6725

Epoch 00001: val_loss did not improve
Epoch 2/10
400/400 [=====] - 5s 13ms/step - loss: 5.3593 - acc: 0.6675 - val_loss: 5.2787 - val_acc: 0.6725

Epoch 00002: val_loss did not improve
Epoch 3/10
400/400 [=====] - 5s 13ms/step - loss: 5.3593 - acc: 0.6675 - val_loss: 5.2787 - val_acc: 0.6725

Epoch 00003: val_loss did not improve
Epoch 4/10
400/400 [=====] - 5s 13ms/step - loss: 5.3593 - acc: 0.6675 - val_loss: 5.2787 - val_acc: 0.6725

Epoch 00004: val_loss did not improve
Epoch 5/10
400/400 [=====] - 5s 13ms/step - loss: 5.3593 - acc: 0.6675 - val_loss: 5.2787 - val_acc: 0.6725

Epoch 00005: val_loss did not improve
Epoch 6/10
400/400 [=====] - 5s 13ms/step - loss: 5.3593 - acc: 0.6675 - val_loss: 5.2787 - val_acc: 0.6725

Epoch 00006: val_loss did not improve
Epoch 7/10
400/400 [=====] - 5s 13ms/step - loss: 5.3593 - acc: 0.6675 - val_loss: 5.2787 - val_acc: 0.6725

Epoch 00007: val_loss did not improve
Epoch 8/10
400/400 [=====] - 5s 13ms/step - loss: 5.3593 - acc: 0.6675 - val_loss: 5.2787 - val_acc: 0.6725

Epoch 00008: val_loss did not improve
Epoch 9/10
400/400 [=====] - 5s 13ms/step - loss: 5.3593 - acc: 0.6675 - val_loss: 5.2787 - val_acc: 0.6725

Epoch 00009: val_loss did not improve
Epoch 10/10
400/400 [=====] - 5s 13ms/step - loss: 5.3593 - acc: 0.6675 - val_loss: 5.2787 - val_acc: 0.6725

Epoch 00010: val_loss did not improve
Timing:: took 51 second(s) Training FCN with test 0.5 and random state 5
```

```
-----  
Train on 400 samples, validate on 400 samples  
Epoch 1/10  
400/400 [=====] - 5s 13ms/step - loss: 4.9966 - acc: 0.6900 - val_loss: 5.6413 - val_acc: 0.6500  
  
Epoch 00001: val_loss did not improve  
Epoch 2/10  
400/400 [=====] - 5s 13ms/step - loss: 4.9966 - acc: 0.6900 - val_loss: 5.6413 - val_acc: 0.6500  
  
Epoch 00002: val_loss did not improve  
Epoch 3/10  
400/400 [=====] - 5s 13ms/step - loss: 4.9966 - acc: 0.6900 - val_loss: 5.6413 - val_acc: 0.6500  
  
Epoch 00003: val_loss did not improve  
Epoch 4/10  
400/400 [=====] - 5s 13ms/step - loss: 4.9966 - acc: 0.6900 - val_loss: 5.6413 - val_acc: 0.6500  
  
Epoch 00004: val_loss did not improve  
Epoch 5/10  
400/400 [=====] - 5s 13ms/step - loss: 4.9966 - acc: 0.6900 - val_loss: 5.6413 - val_acc: 0.6500  
  
Epoch 00005: val_loss did not improve  
Epoch 6/10  
400/400 [=====] - 5s 13ms/step - loss: 4.9966 - acc: 0.6900 - val_loss: 5.6413 - val_acc: 0.6500  
  
Epoch 00006: val_loss did not improve  
Epoch 7/10  
400/400 [=====] - 5s 13ms/step - loss: 4.9966 - acc: 0.6900 - val_loss: 5.6413 - val_acc: 0.6500  
  
Epoch 00007: val_loss did not improve  
Epoch 8/10  
400/400 [=====] - 5s 13ms/step - loss: 4.9966 - acc: 0.6900 - val_loss: 5.6413 - val_acc: 0.6500  
  
Epoch 00008: val_loss did not improve  
Epoch 9/10  
400/400 [=====] - 5s 13ms/step - loss: 4.9563 - acc: 0.6925 - val_loss: 5.6413 - val_acc: 0.6500  
  
Epoch 00009: val_loss did not improve  
Epoch 10/10  
400/400 [=====] - 5s 13ms/step - loss: 4.9966 - acc: 0.6900 - val_loss: 5.6413 - val_acc: 0.6500  
  
Epoch 00010: val_loss did not improve  
Timing:: took 51 second(s) Training FCN with test 0.5 and random state 15  
-----  
Train on 400 samples, validate on 400 samples  
Epoch 1/10  
400/400 [=====] - 5s 13ms/step - loss: 5.2384 - acc: 0.6750 - val_loss: 5.3996 - val_acc: 0.6650  
  
Epoch 00001: val_loss did not improve
```

Epoch 2/10  
400/400 [=====] - 5s 13ms/step - loss: 5.2384 - ac  
c: 0.6750 - val\_loss: 5.3996 - val\_acc: 0.6650

Epoch 00002: val\_loss did not improve

Epoch 3/10  
400/400 [=====] - 5s 13ms/step - loss: 5.2384 - ac  
c: 0.6750 - val\_loss: 5.3996 - val\_acc: 0.6650

Epoch 00003: val\_loss did not improve

Epoch 4/10  
400/400 [=====] - 5s 13ms/step - loss: 5.2384 - ac  
c: 0.6750 - val\_loss: 5.3996 - val\_acc: 0.6650

Epoch 00004: val\_loss did not improve

Epoch 5/10  
400/400 [=====] - 5s 13ms/step - loss: 5.2384 - ac  
c: 0.6750 - val\_loss: 5.3996 - val\_acc: 0.6650

Epoch 00005: val\_loss did not improve

Epoch 6/10  
400/400 [=====] - 5s 13ms/step - loss: 5.2384 - ac  
c: 0.6750 - val\_loss: 5.3996 - val\_acc: 0.6650

Epoch 00006: val\_loss did not improve

Epoch 7/10  
400/400 [=====] - 5s 13ms/step - loss: 5.2782 - ac  
c: 0.6725 - val\_loss: 5.3996 - val\_acc: 0.6650

Epoch 00007: val\_loss did not improve

Epoch 8/10  
400/400 [=====] - 5s 13ms/step - loss: 5.2384 - ac  
c: 0.6750 - val\_loss: 5.3996 - val\_acc: 0.6650

Epoch 00008: val\_loss did not improve

Epoch 9/10  
400/400 [=====] - 5s 13ms/step - loss: 5.2782 - ac  
c: 0.6725 - val\_loss: 5.3996 - val\_acc: 0.6650

Epoch 00009: val\_loss did not improve

Epoch 10/10  
400/400 [=====] - 5s 13ms/step - loss: 5.2384 - ac  
c: 0.6750 - val\_loss: 5.3996 - val\_acc: 0.6650

Epoch 00010: val\_loss did not improve

Timing:: took 51 second(s) Training FCN with test 0.5 and random state 50

-----  
Train on 400 samples, validate on 400 samples

Epoch 1/10  
400/400 [=====] - 5s 13ms/step - loss: 5.2787 - ac  
c: 0.6725 - val\_loss: 5.3593 - val\_acc: 0.6675

Epoch 00001: val\_loss did not improve

Epoch 2/10  
400/400 [=====] - 5s 13ms/step - loss: 5.2787 - ac  
c: 0.6725 - val\_loss: 5.3593 - val\_acc: 0.6675

Epoch 00002: val\_loss did not improve

Epoch 3/10  
400/400 [=====] - 5s 13ms/step - loss: 5.2787 - ac  
c: 0.6725 - val\_loss: 5.3593 - val\_acc: 0.6675

```
Epoch 0003: val_loss did not improve
Epoch 4/10
400/400 [=====] - 5s 13ms/step - loss: 5.2787 - acc: 0.6725 - val_loss: 5.3593 - val_acc: 0.6675

Epoch 0004: val_loss did not improve
Epoch 5/10
400/400 [=====] - 5s 13ms/step - loss: 5.2787 - acc: 0.6725 - val_loss: 5.3593 - val_acc: 0.6675

Epoch 0005: val_loss did not improve
Epoch 6/10
400/400 [=====] - 5s 13ms/step - loss: 5.2787 - acc: 0.6725 - val_loss: 5.3593 - val_acc: 0.6675

Epoch 0006: val_loss did not improve
Epoch 7/10
400/400 [=====] - 5s 13ms/step - loss: 5.2787 - acc: 0.6725 - val_loss: 5.3593 - val_acc: 0.6675

Epoch 0007: val_loss did not improve
Epoch 8/10
400/400 [=====] - 5s 13ms/step - loss: 5.2787 - acc: 0.6725 - val_loss: 5.3593 - val_acc: 0.6675

Epoch 0008: val_loss did not improve
Epoch 9/10
400/400 [=====] - 5s 13ms/step - loss: 5.2787 - acc: 0.6725 - val_loss: 5.3593 - val_acc: 0.6675

Epoch 0009: val_loss did not improve
Epoch 10/10
400/400 [=====] - 5s 13ms/step - loss: 5.2787 - acc: 0.6725 - val_loss: 5.3593 - val_acc: 0.6675

Epoch 0010: val_loss did not improve
Timing:: took 51 second(s) Training FCN with test 0.5 and random state 100
-----
Train on 320 samples, validate on 480 samples
Epoch 1/10
320/320 [=====] - 4s 14ms/step - loss: 5.4399 - acc: 0.6625 - val_loss: 5.2384 - val_acc: 0.6750

Epoch 0001: val_loss did not improve
Epoch 2/10
320/320 [=====] - 4s 14ms/step - loss: 5.4399 - acc: 0.6625 - val_loss: 5.2384 - val_acc: 0.6750

Epoch 0002: val_loss did not improve
Epoch 3/10
320/320 [=====] - 4s 14ms/step - loss: 5.4399 - acc: 0.6625 - val_loss: 5.2384 - val_acc: 0.6750

Epoch 0003: val_loss did not improve
Epoch 4/10
320/320 [=====] - 4s 14ms/step - loss: 5.4399 - acc: 0.6625 - val_loss: 5.2384 - val_acc: 0.6750

Epoch 0004: val_loss did not improve
Epoch 5/10
```

```
320/320 [=====] - 4s 14ms/step - loss: 5.4399 - ac  
c: 0.6625 - val_loss: 5.2384 - val_acc: 0.6750
```

Epoch 00005: val\_loss did not improve

Epoch 6/10

```
320/320 [=====] - 4s 14ms/step - loss: 5.4897 - ac  
c: 0.6594 - val_loss: 5.2384 - val_acc: 0.6750
```

Epoch 00006: val\_loss did not improve

Epoch 7/10

```
320/320 [=====] - 4s 14ms/step - loss: 5.4399 - ac  
c: 0.6625 - val_loss: 5.2384 - val_acc: 0.6750
```

Epoch 00007: val\_loss did not improve

Epoch 8/10

```
320/320 [=====] - 4s 14ms/step - loss: 5.4399 - ac  
c: 0.6625 - val_loss: 5.2384 - val_acc: 0.6750
```

Epoch 00008: val\_loss did not improve

Epoch 9/10

```
320/320 [=====] - 4s 14ms/step - loss: 5.4399 - ac  
c: 0.6625 - val_loss: 5.2384 - val_acc: 0.6750
```

Epoch 00009: val\_loss did not improve

Epoch 10/10

```
320/320 [=====] - 4s 14ms/step - loss: 5.4399 - ac  
c: 0.6625 - val_loss: 5.2384 - val_acc: 0.6750
```

Epoch 00010: val\_loss did not improve

Timing:: took 44 second(s) Training FCN with test 0.6 and random state 1

-----  
Train on 320 samples, validate on 480 samples

Epoch 1/10

```
320/320 [=====] - 4s 14ms/step - loss: 5.0369 - ac  
c: 0.6875 - val_loss: 5.5070 - val_acc: 0.6583A: 2s - loss: 5.79
```

Epoch 00001: val\_loss did not improve

Epoch 2/10

```
320/320 [=====] - 5s 14ms/step - loss: 5.0369 - ac  
c: 0.6875 - val_loss: 5.5070 - val_acc: 0.6583
```

Epoch 00002: val\_loss did not improve

Epoch 3/10

```
320/320 [=====] - 5s 14ms/step - loss: 5.0369 - ac  
c: 0.6875 - val_loss: 5.5070 - val_acc: 0.6583
```

Epoch 00003: val\_loss did not improve

Epoch 4/10

```
320/320 [=====] - 5s 14ms/step - loss: 5.0867 - ac  
c: 0.6844 - val_loss: 5.5070 - val_acc: 0.6583
```

Epoch 00004: val\_loss did not improve

Epoch 5/10

```
320/320 [=====] - 4s 14ms/step - loss: 5.0369 - ac  
c: 0.6875 - val_loss: 5.5070 - val_acc: 0.6583
```

Epoch 00005: val\_loss did not improve

Epoch 6/10

```
320/320 [=====] - 5s 14ms/step - loss: 5.0369 - ac  
c: 0.6875 - val_loss: 5.5070 - val_acc: 0.6583
```

```
Epoch 00006: val_loss did not improve
Epoch 7/10
320/320 [=====] - 5s 14ms/step - loss: 5.0369 - ac
c: 0.6875 - val_loss: 5.5070 - val_acc: 0.6583

Epoch 00007: val_loss did not improve
Epoch 8/10
320/320 [=====] - 5s 14ms/step - loss: 5.0369 - ac
c: 0.6875 - val_loss: 5.5070 - val_acc: 0.6583

Epoch 00008: val_loss did not improve
Epoch 9/10
320/320 [=====] - 4s 14ms/step - loss: 5.0369 - ac
c: 0.6875 - val_loss: 5.5070 - val_acc: 0.6583

Epoch 00009: val_loss did not improve
Epoch 10/10
320/320 [=====] - 5s 14ms/step - loss: 5.0369 - ac
c: 0.6875 - val_loss: 5.5070 - val_acc: 0.6583

Epoch 00010: val_loss did not improve
Timing:: took 45 second(s) Training FCN with test 0.6 and random state 5
-----
Train on 320 samples, validate on 480 samples
Epoch 1/10
320/320 [=====] - 5s 14ms/step - loss: 5.1880 - ac
c: 0.6781 - val_loss: 5.4063 - val_acc: 0.6646

Epoch 00001: val_loss did not improve
Epoch 2/10
320/320 [=====] - 5s 14ms/step - loss: 5.1880 - ac
c: 0.6781 - val_loss: 5.4063 - val_acc: 0.6646

Epoch 00002: val_loss did not improve
Epoch 3/10
320/320 [=====] - 5s 14ms/step - loss: 5.1880 - ac
c: 0.6781 - val_loss: 5.4063 - val_acc: 0.6646

Epoch 00003: val_loss did not improve
Epoch 4/10
320/320 [=====] - 4s 14ms/step - loss: 5.2378 - ac
c: 0.6750 - val_loss: 5.4063 - val_acc: 0.6646

Epoch 00004: val_loss did not improve
Epoch 5/10
320/320 [=====] - 4s 14ms/step - loss: 5.1880 - ac
c: 0.6781 - val_loss: 5.4063 - val_acc: 0.6646

Epoch 00005: val_loss did not improve
Epoch 6/10
320/320 [=====] - 4s 14ms/step - loss: 5.1880 - ac
c: 0.6781 - val_loss: 5.4063 - val_acc: 0.6646

Epoch 00006: val_loss did not improve
Epoch 7/10
320/320 [=====] - 5s 14ms/step - loss: 5.1880 - ac
c: 0.6781 - val_loss: 5.4063 - val_acc: 0.6646

Epoch 00007: val_loss did not improve
Epoch 8/10
320/320 [=====] - 4s 14ms/step - loss: 5.1880 - ac
```

```
c: 0.6781 - val_loss: 5.4063 - val_acc: 0.6646

Epoch 00008: val_loss did not improve
Epoch 9/10
320/320 [=====] - 5s 14ms/step - loss: 5.1880 - ac
c: 0.6781 - val_loss: 5.4063 - val_acc: 0.6646

Epoch 00009: val_loss did not improve
Epoch 10/10
320/320 [=====] - 4s 14ms/step - loss: 5.1880 - ac
c: 0.6781 - val_loss: 5.4063 - val_acc: 0.6646

Epoch 00010: val_loss did not improve
Timing:: took 44 second(s) Training FCN with test 0.6 and random state 15
-----
Train on 320 samples, validate on 480 samples
Epoch 1/10
320/320 [=====] - 4s 14ms/step - loss: 4.7851 - ac
c: 0.7031 - val_loss: 5.6413 - val_acc: 0.6500

Epoch 00001: val_loss did not improve
Epoch 2/10
320/320 [=====] - 4s 14ms/step - loss: 4.8354 - ac
c: 0.7000 - val_loss: 5.6413 - val_acc: 0.6500

Epoch 00002: val_loss did not improve
Epoch 3/10
320/320 [=====] - 4s 14ms/step - loss: 4.8354 - ac
c: 0.7000 - val_loss: 5.6413 - val_acc: 0.6500

Epoch 00003: val_loss did not improve
Epoch 4/10
320/320 [=====] - 5s 14ms/step - loss: 4.8354 - ac
c: 0.7000 - val_loss: 5.6413 - val_acc: 0.6500

Epoch 00004: val_loss did not improve
Epoch 5/10
320/320 [=====] - 4s 14ms/step - loss: 4.8354 - ac
c: 0.7000 - val_loss: 5.6413 - val_acc: 0.6500

Epoch 00005: val_loss did not improve
Epoch 6/10
320/320 [=====] - 4s 14ms/step - loss: 4.8354 - ac
c: 0.7000 - val_loss: 5.6413 - val_acc: 0.6500

Epoch 00006: val_loss did not improve
Epoch 7/10
320/320 [=====] - 4s 14ms/step - loss: 4.8354 - ac
c: 0.7000 - val_loss: 5.6413 - val_acc: 0.6500

Epoch 00007: val_loss did not improve
Epoch 8/10
320/320 [=====] - 4s 14ms/step - loss: 4.8354 - ac
c: 0.7000 - val_loss: 5.6413 - val_acc: 0.6500

Epoch 00008: val_loss did not improve
Epoch 9/10
320/320 [=====] - 4s 14ms/step - loss: 4.8354 - ac
c: 0.7000 - val_loss: 5.6413 - val_acc: 0.6500

Epoch 00009: val_loss did not improve
```

```
Epoch 10/10
320/320 [=====] - 4s 14ms/step - loss: 4.8354 - ac
c: 0.7000 - val_loss: 5.6413 - val_acc: 0.6500
```

```
Epoch 00010: val_loss did not improve
Timing:: took 44 second(s) Training FCN with test 0.6 and random state 50
-----
```

```
Train on 320 samples, validate on 480 samples
Epoch 1/10
320/320 [=====] - 5s 14ms/step - loss: 5.3884 - ac
c: 0.6656 - val_loss: 5.3391 - val_acc: 0.6687
```

```
Epoch 00001: val_loss did not improve
Epoch 2/10
320/320 [=====] - 5s 14ms/step - loss: 5.2888 - ac
c: 0.6719 - val_loss: 5.3391 - val_acc: 0.6687
```

```
Epoch 00002: val_loss did not improve
Epoch 3/10
320/320 [=====] - 4s 14ms/step - loss: 5.2888 - ac
c: 0.6719 - val_loss: 5.3391 - val_acc: 0.6687
```

```
Epoch 00003: val_loss did not improve
Epoch 4/10
320/320 [=====] - 5s 14ms/step - loss: 5.2888 - ac
c: 0.6719 - val_loss: 5.3391 - val_acc: 0.6687
```

```
Epoch 00004: val_loss did not improve
Epoch 5/10
320/320 [=====] - 4s 14ms/step - loss: 5.2888 - ac
c: 0.6719 - val_loss: 5.3391 - val_acc: 0.6687
```

```
Epoch 00005: val_loss did not improve
Epoch 6/10
320/320 [=====] - 4s 14ms/step - loss: 5.2888 - ac
c: 0.6719 - val_loss: 5.3391 - val_acc: 0.6687
```

```
Epoch 00006: val_loss did not improve
Epoch 7/10
320/320 [=====] - 5s 14ms/step - loss: 5.2888 - ac
c: 0.6719 - val_loss: 5.3391 - val_acc: 0.6687
```

```
Epoch 00007: val_loss did not improve
Epoch 8/10
320/320 [=====] - 4s 14ms/step - loss: 5.2888 - ac
c: 0.6719 - val_loss: 5.3391 - val_acc: 0.6687
```

```
Epoch 00008: val_loss did not improve
Epoch 9/10
320/320 [=====] - 4s 14ms/step - loss: 5.2888 - ac
c: 0.6719 - val_loss: 5.3391 - val_acc: 0.6687
```

```
Epoch 00009: val_loss did not improve
Epoch 10/10
320/320 [=====] - 5s 14ms/step - loss: 5.2888 - ac
c: 0.6719 - val_loss: 5.3391 - val_acc: 0.6687
```

```
Epoch 00010: val_loss did not improve
Timing:: took 45 second(s) Training FCN with test 0.6 and random state 100
-----
```

```
Timing:: took 26 minutes Training 5 modelsTraining 5 modelsTraining 5 models
```

Training 5 modelsTraining 5 models  
-----

In [17]:

```
# Load and evaluate best model
from keras.models import load_model
best_model = load_model('best_fcn_model.h5')
```

In [18]:

```
# Load test data only
x_test, y_test = data.getData()
x_test = np.reshape(x_test, (x_test.shape[0], -1))
print('Test data shape: ', x_test.shape)
print('Test labels shape: ', y_test.shape)
```

Test data shape: (63, 150528)  
Test labels shape: (63, 1)

In [19]:

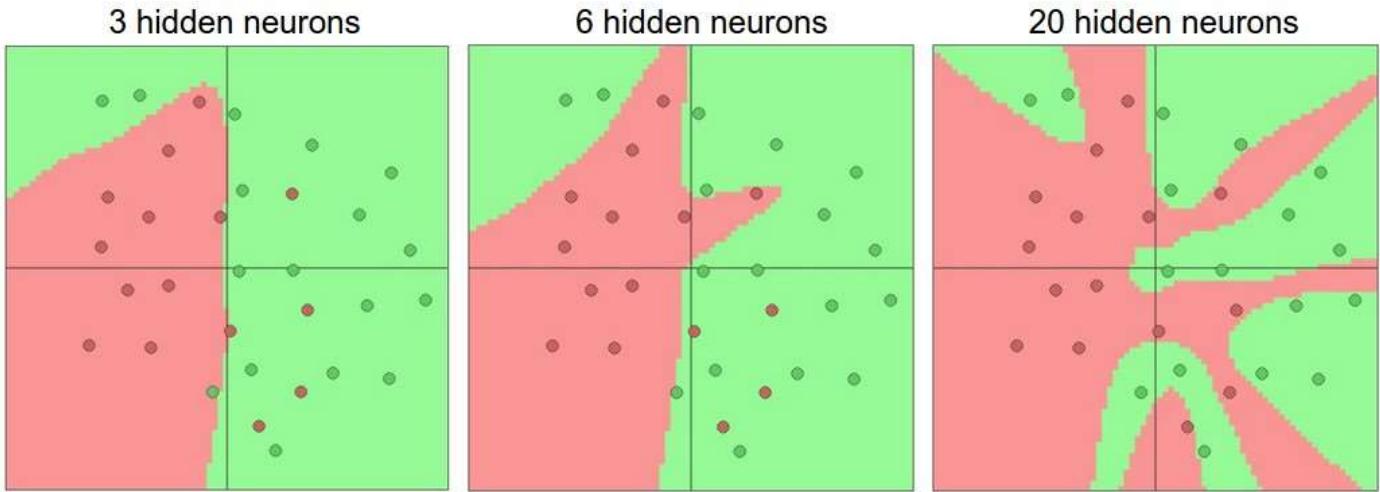
```
# Evaluate a set of images image
limit = 5
for index in range(x_test.shape[0]):
    if index > limit:
        break
    test_image = np.zeros((1, x_test.shape[1]))
    test_image[0] = x_test[index]
    true_label = y_test[index]
    prediction = best_model.predict(test_image)
    print("True label", true_label)
    print("prediction", prediction)
```

True label [0]  
prediction [[ 0.]]  
True label [0]  
prediction [[ 0.]]

## 4. Hyperparameter tuning

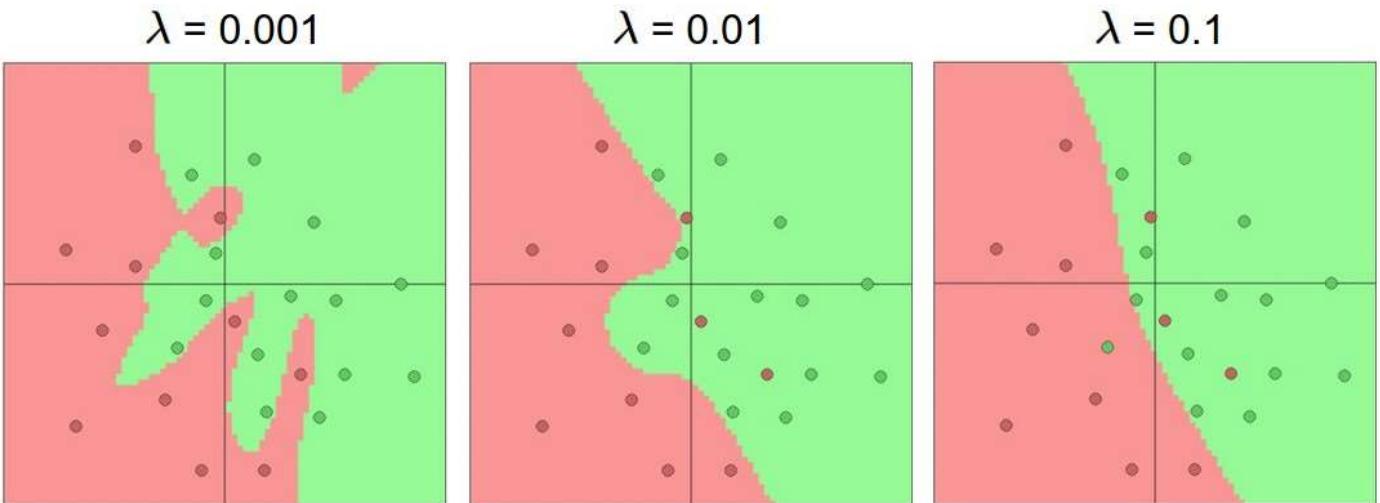
Setting number of layers and their sizes

Consider a binary classification problem



Neural Networks with more neurons can express more complicated functions. However, this is both a blessing (since we can learn to classify more complicated data) and a curse (since it is easier to overfit the training data)

Better to rely on regularization strength to control overfitting



More importantly though, in practice it is often the case that 3-layer neural networks will outperform 2-layer nets, but going even deeper (4,5,6-layer) rarely helps much more. This is in stark contrast to Convolutional Networks, where depth has been found to be an extremely important component for a good recognition system

So we move on to CNNs

In [ ]: