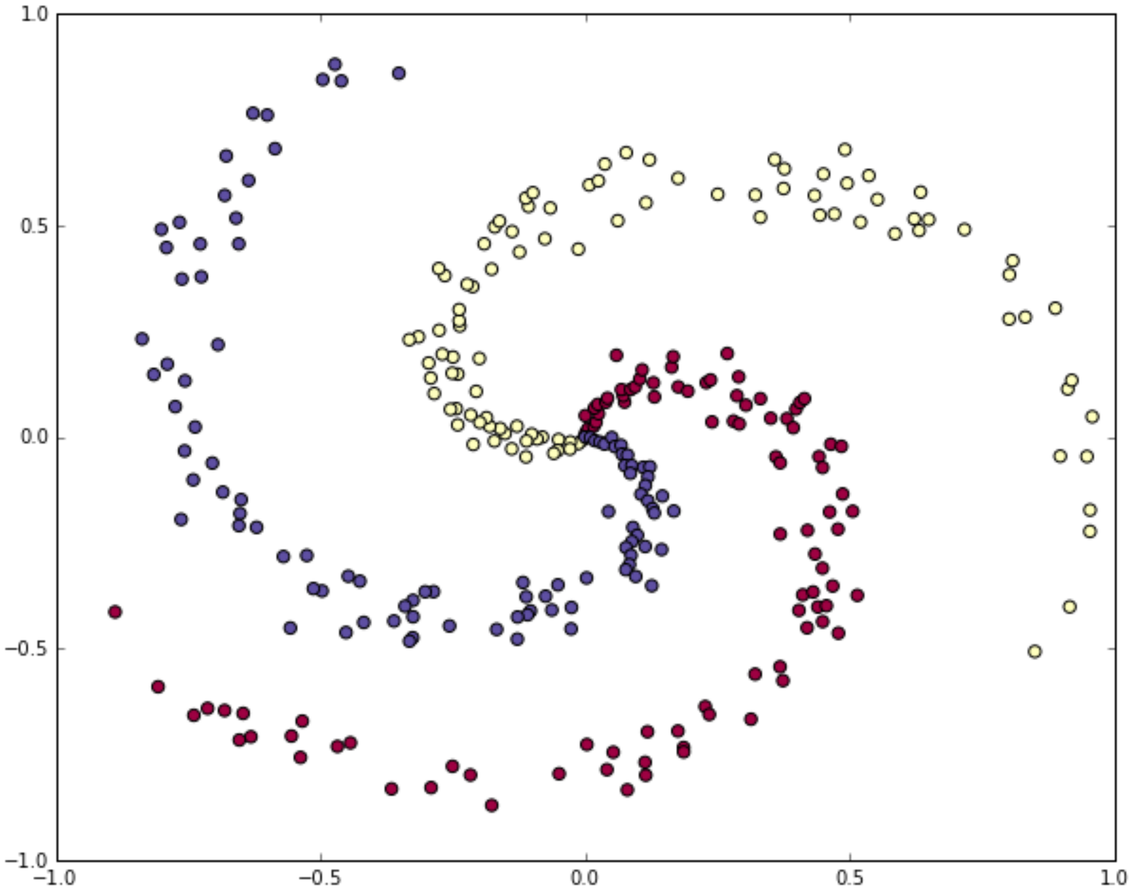
In [1]:
```
# A bit of setup
import numpy as np
import matplotlib.pyplot as plt

%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'

# for auto-reloading extenrnal modules
# see http://stackoverflow.com/questions/1907993/autoreload-of-modules-in
-ipython
%load_ext autoreload
%autoreload 2
```

In [323]:
```
np.random.seed(0)
N = 100 # number of points per class
D = 2 # dimensionality
K = 3 # number of classes
X = np.zeros((N*K,D))
y = np.zeros(N*K, dtype='uint8')
for j in xrange(K):
  ix = range(N*j,N*(j+1))
  r = np.linspace(0.0,1,N) # radius
  t = np.linspace(j*4,(j+1)*4,N) + np.random.randn(N)*0.2 # theta
  X[ix] = np.c_[r*np.sin(t), r*np.cos(t)]
  y[ix] = j
fig = plt.figure()
plt.scatter(X[:, 0], X[:, 1], c=y, s=40, cmap=plt.cm.Spectral)
plt.xlim([-1,1])
plt.ylim([-1,1])
#fig.savefig('spiral_raw.png')
```



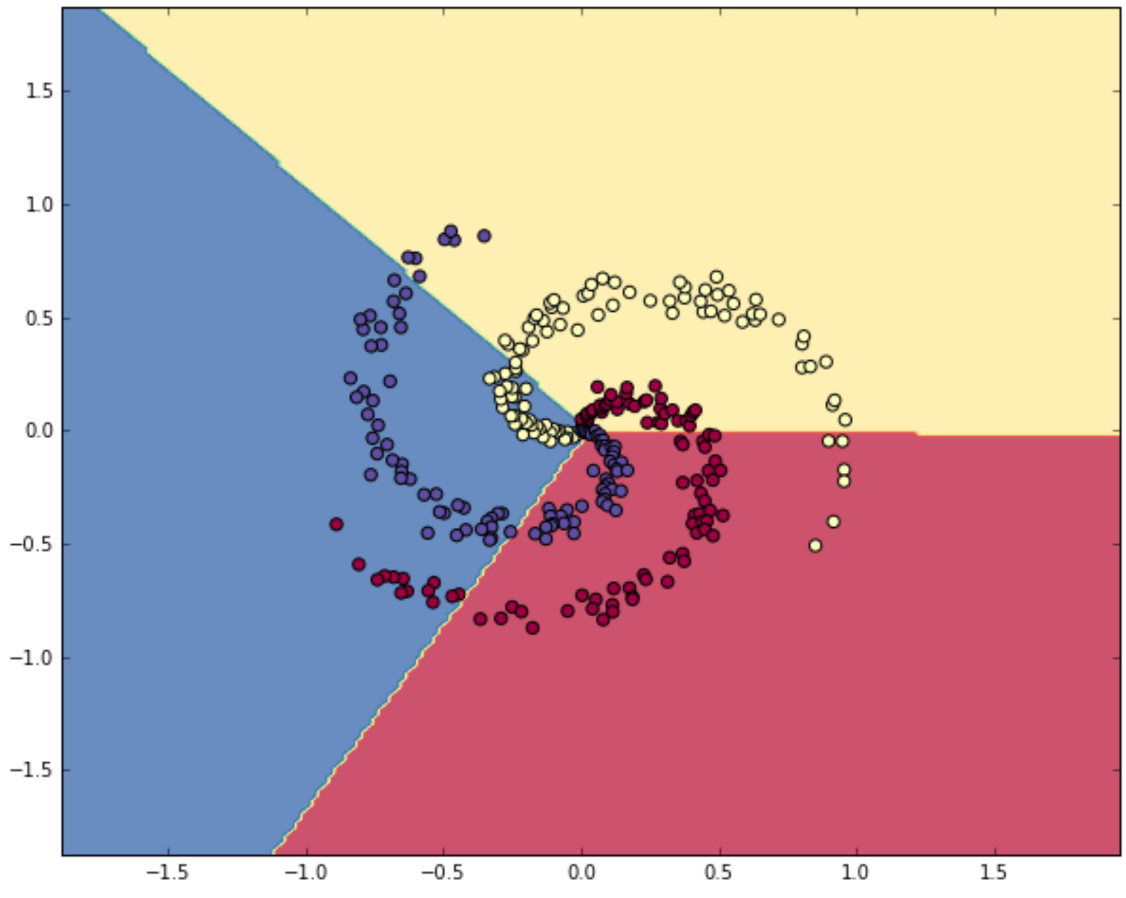
In [329]:
```
#Train a Linear Classifier

# initialize parameters randomly
W = 0.01 * np.random.randn(D,K)
b = np.zeros((1,K))

# some hyperparameters
step_size = 1e-0
reg = 1e-3 # regularization strength

# gradient descent loop
num_examples = X.shape[0]
for i in xrange(200):

  # evaluate class scores, [N x K]
  scores = np.dot(X, W) + b

  # compute the class probabilities
  exp_scores = np.exp(scores)
  probs = exp_scores / np.sum(exp_scores, axis=1, keepdims=True) # [N x
K]

  # compute the loss: average cross-entropy loss and regularization
  corect_logprobs = -np.log(probs[range(num_examples),y])
  data_loss = np.sum(corect_logprobs)/num_examples
  reg_loss = 0.5*reg*np.sum(W*W)
  loss = data_loss + reg_loss
  if i % 10 == 0:
    print "iteration %d: loss %f" % (i, loss)

  # compute the gradient on scores
  dscores = probs
  dscores[range(num_examples),y] -= 1
  dscores /= num_examples

  # backpropate the gradient to the parameters (W,b)
  dW = np.dot(X.T, dscores)
  db = np.sum(dscores, axis=0, keepdims=True)

  dW += reg*W # regularization gradient

  # perform a parameter update
  W += -step_size * dW
  b += -step_size * db
```

```
iteration 0: loss 1.096956
iteration 10: loss 0.917265
iteration 20: loss 0.851503
iteration 30: loss 0.822336
iteration 40: loss 0.807586
iteration 50: loss 0.799448
iteration 60: loss 0.794681
iteration 70: loss 0.791764
iteration 80: loss 0.789920
iteration 90: loss 0.788726
iteration 100: loss 0.787938
iteration 110: loss 0.787409
iteration 120: loss 0.787049
iteration 130: loss 0.786803
iteration 140: loss 0.786633
iteration 150: loss 0.786514
iteration 160: loss 0.786431
iteration 170: loss 0.786373
iteration 180: loss 0.786331
iteration 190: loss 0.786302
```

In [330]:
```
# evaluate training set accuracy
scores = np.dot(X, W) + b
predicted_class = np.argmax(scores, axis=1)
print 'training accuracy: %.2f' % (np.mean(predicted_class == y))
```

```
training accuracy: 0.49
```

In [331]:
```
# plot the resulting classifier
h = 0.02
x_min, x_max = X[:, 0].min() - 1, X[:, 0].max() + 1
y_min, y_max = X[:, 1].min() - 1, X[:, 1].max() + 1
xx, yy = np.meshgrid(np.arange(x_min, x_max, h),
                     np.arange(y_min, y_max, h))
Z = np.dot(np.c_[xx.ravel(), yy.ravel()], W) + b
Z = np.argmax(Z, axis=1)
Z = Z.reshape(xx.shape)
fig = plt.figure()
plt.contourf(xx, yy, Z, cmap=plt.cm.Spectral, alpha=0.8)
plt.scatter(X[:, 0], X[:, 1], c=y, s=40, cmap=plt.cm.Spectral)
plt.xlim(xx.min(), xx.max())
plt.ylim(yy.min(), yy.max())
#fig.savefig('spiral_linear.png')
```



In [332]:
```
# initialize parameters randomly
h = 100 # size of hidden layer
W = 0.01 * np.random.randn(D,h)
b = np.zeros((1,h))
W2 = 0.01 * np.random.randn(h,K)
b2 = np.zeros((1,K))

# some hyperparameters
step_size = 1e-0
reg = 1e-3 # regularization strength

# gradient descent loop
num_examples = X.shape[0]
for i in xrange(10000):

  # evaluate class scores, [N x K]
  hidden_layer = np.maximum(0, np.dot(X, W) + b) # note, ReLU activation
  scores = np.dot(hidden_layer, W2) + b2

  # compute the class probabilities
  exp_scores = np.exp(scores)
  probs = exp_scores / np.sum(exp_scores, axis=1, keepdims=True) # [N x
K]

  # compute the loss: average cross-entropy loss and regularization
  corect_logprobs = -np.log(probs[range(num_examples),y])
  data_loss = np.sum(corect_logprobs)/num_examples
  reg_loss = 0.5*reg*np.sum(W*W) + 0.5*reg*np.sum(W2*W2)
  loss = data_loss + reg_loss
  if i % 1000 == 0:
    print "iteration %d: loss %f" % (i, loss)

  # compute the gradient on scores
  dscores = probs
  dscores[range(num_examples),y] -= 1
  dscores /= num_examples

  # backpropate the gradient to the parameters
  # first backprop into parameters W2 and b2
  dW2 = np.dot(hidden_layer.T, dscores)
  db2 = np.sum(dscores, axis=0, keepdims=True)
  # next backprop into hidden layer
  dhidden = np.dot(dscores, W2.T)
  # backprop the ReLU non-linearity
  dhidden[hidden_layer <= 0] = 0
  # finally into W,b
  dW = np.dot(X.T, dhidden)
  db = np.sum(dhidden, axis=0, keepdims=True)

  # add regularization gradient contribution
  dW2 += reg * W2
  dW += reg * W

  # perform a parameter update
  W += -step_size * dW
  b += -step_size * db
  W2 += -step_size * dW2
  b2 += -step_size * db2
```

```
iteration 0: loss 1.098744
iteration 1000: loss 0.294946
iteration 2000: loss 0.259301
iteration 3000: loss 0.248310
iteration 4000: loss 0.246170
iteration 5000: loss 0.245649
iteration 6000: loss 0.245491
iteration 7000: loss 0.245400
iteration 8000: loss 0.245335
iteration 9000: loss 0.245292
```

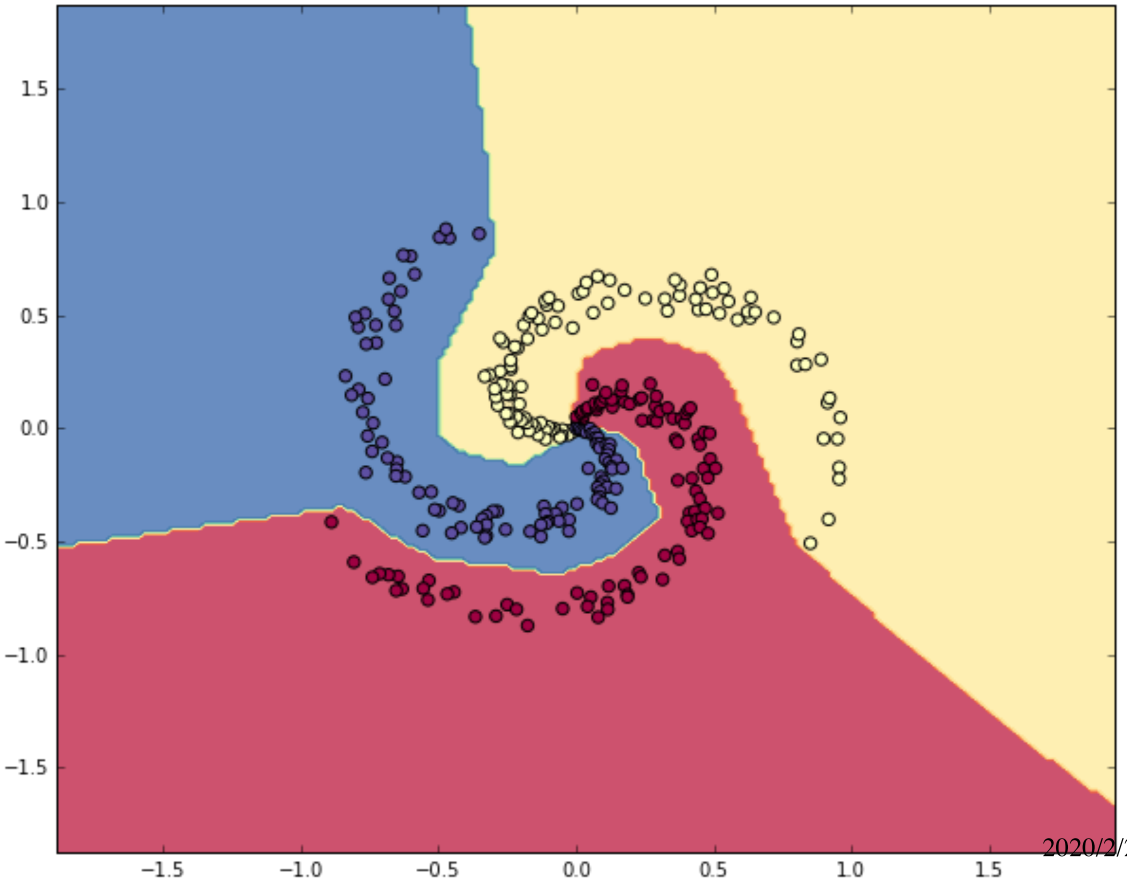
In [333]:

```
# evaluate training set accuracy
hidden_layer = np.maximum(0, np.dot(X, W) + b)
scores = np.dot(hidden_layer, W2) + b2
predicted_class = np.argmax(scores, axis=1)
print 'training accuracy: %.2f' % (np.mean(predicted_class == y))
```

```
training accuracy: 0.98
```

In [336]:

```
# plot the resulting classifier
h = 0.02
x_min, x_max = X[:, 0].min() - 1, X[:, 0].max() + 1
y_min, y_max = X[:, 1].min() - 1, X[:, 1].max() + 1
xx, yy = np.meshgrid(np.arange(x_min, x_max, h),
                     np.arange(y_min, y_max, h))
Z = np.dot(np.maximum(0, np.dot(np.c_[xx.ravel(), yy.ravel()], W) + b), W
2) + b2
Z = np.argmax(Z, axis=1)
Z = Z.reshape(xx.shape)
fig = plt.figure()
plt.contourf(xx, yy, Z, cmap=plt.cm.Spectral, alpha=0.8)
plt.scatter(X[:, 0], X[:, 1], c=y, s=40, cmap=plt.cm.Spectral)
plt.xlim(xx.min(), xx.max())
plt.ylim(yy.min(), yy.max())
#fig.savefig('spiral_net.png')
```



```
In [ ]:
```