In [2]:
```
%matplotlib inline
import matplotlib.pyplot as plt
import numpy as np
import torch
from torch import autograd
import torch.nn.functional as F
import time

images = np.load("D:/work/JHUschoolStuff/machinelearning/project1/cs475_project_data/images.npy")
labels = np.load("D:/work/JHUschoolStuff/machinelearning/project1/cs475_project_data/labels.npy")
test = np.load("D:/work/JHUschoolStuff/machinelearning/project1/cs475_project_data/test_images.npy")
height = images.shape[1]
width = images.shape[2]
size = height * width
images = (images - images.mean()) / images.std()
data = images.reshape(images.shape[0],size)
data = torch.from_numpy(data).float()
labels = torch.from_numpy(labels).float()
test_data = test.reshape(test.shape[0], size)
test_data = (test_data - test_data.mean()) / test_data.std()
train_seqs = data[0:45000,:]
train_labels = labels[0:45000]
val_seqs = data[45000:,:]
val_labels = labels[45000:]
```

In [3]:
```
class TwoLayerNN(torch.nn.Module):
    def __init__(self, layer_1):
        super().__init__()
        self.layer_1 = torch.nn.Linear(height * width, layer_1)
        self.layer_2 = torch.nn.Linear(layer_1, 5)
        self.drop = torch.nn.Dropout(p = 0.3)
    def forward(self, x):
        x = self.layer_1(x)
        y = F.relu(x)
        y = self.drop(y)
        z = self.layer_2(y)
        return z
```

In [14]:
```
class ThreeLayerNN(torch.nn.Module):
    def __init__(self, layer_1, layer_2):
        super().__init__()
        self.layer_1 = torch.nn.Linear(height * width, layer_1)
        self.layer_2 = torch.nn.Linear(layer_1, layer_2)
        self.layer_3 = torch.nn.Linear(layer_2, 5)
    def forward(self, x):
        x = self.layer_1(x)
        y = F.relu(x)
        z = self.layer_2(y)
        a = F.relu(z)
        b = self.layer_3(a)
```

```
        return b
```

In [15]:
```
class FourLayerNN(torch.nn.Module):
    def __init__(self, layer_1, layer_2, layer_3):
        super().__init__()
        self.layer_1 = torch.nn.Linear(height * width, layer_1)
        self.layer_2 = torch.nn.Linear(layer_1, layer_2)
        self.layer_3 = torch.nn.Linear(layer_2, layer_3)
        self.layer_4 = torch.nn.Linear(layer_3, 5)
    def forward(self, x):
        x = self.layer_1(x)
        y = F.relu(x)
        z = self.layer_2(y)
        a = F.relu(z)
        b = self.layer_3(a)
        c = F.relu(b)
        d = self.layer_4(c)
        return d
```

In [4]:
```
def train(model, optimizer, batch_size):
    # model.train() puts our model in train mode, which can require differ
ent
    # behavior than eval mode (for example in the case of dropout).
    model.train()

    # i is is a 1-D array with shape [batch_size]
    i = np.random.choice(train_seqs.shape[0], size=batch_size, replace=Fal
se)
    i = torch.from_numpy(i).long()
    x = autograd.Variable(train_seqs[i, :])
    y = autograd.Variable(train_labels[i]).long()
    optimizer.zero_grad()
    y_hat_ = model(x)
    loss = F.multi_margin_loss(y_hat_, y) #using multi_margin_loss for las
t one
    #loss = F.cross_entropy(y_hat_, y)
    loss.backward()
    optimizer.step()
    return loss.data[0]
```

In [5]:
```
def approx_train_accuracy(model):
    model.eval()
    i = np.random.choice(train_seqs.shape[0], size=1000, replace=False)
    i = torch.from_numpy(i).long()
    x = autograd.Variable(train_seqs[i, :])
    y = autograd.Variable(train_labels[i]).long()
    y_hat_ = model(x)
    y_hat = np.zeros(1000)
    for i in range(1000):
        y_hat[i] = torch.max(y_hat_[i,:].data, 0)[1][0]
    return accuracy(y_hat, y.data.numpy())
```

In [6]:
```
def val_accuracy(model):
    model.eval()
    x = autograd.Variable(val_seqs)
```

```
    y = autograd.Variable(val_labels)
    y_hat_ = model(x)
    y_hat = np.zeros(5000)
    for i in range(5000):
        y_hat[i] = torch.max(y_hat_[i,:].data, 0)[1][0]
    return accuracy(y_hat, y.data.numpy())
```

In [7]:
```
def accuracy(y, y_hat):
    return (y == y_hat).astype(np.float).mean()
```

In [8]:
```
def plot(train_accs, val_accs):
    plt.figure(200)
    plt.title('Training Accuracy')
    plt.xlabel('Iteration')
    plt.ylabel('Accuracy')
    plt.plot(train_accs, 'b')
    plt.show()
    plt.figure(300)
    plt.title('Validation Accuracy')
    plt.xlabel('Iteration')
    plt.ylabel('Accuracy')
    plt.plot(val_accs, 'b')
    plt.show()
```

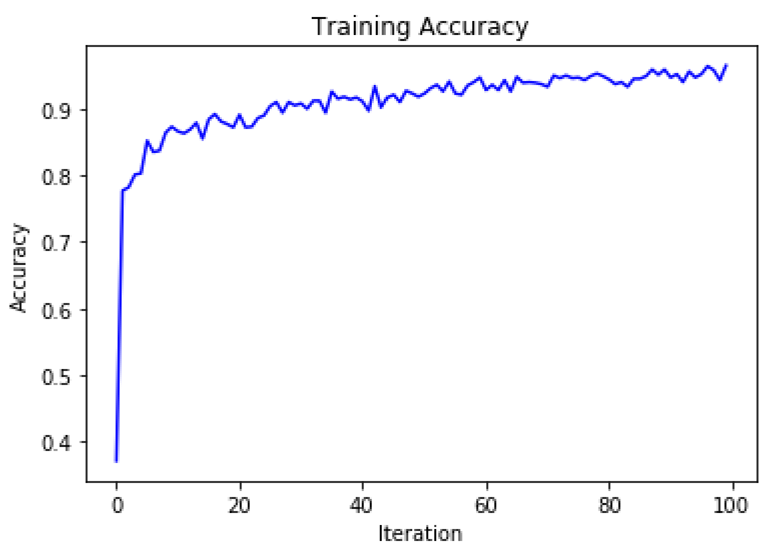
In [9]:
```
def runModel(model, batch_size, NUM_OPT_STEPS, optimizer):
    train_accs, val_accs = [], []
    for i in range(NUM_OPT_STEPS):
        train(model, optimizer, batch_size)
        if i % 100 == 0:
            train_accs.append(approx_train_accuracy(model))
            val_accs.append(val_accuracy(model))
            print("%6d %5.2f %5.2f" % (i, train_accs[-1], val_accs[-1]))
    plot(train_accs, val_accs)
```

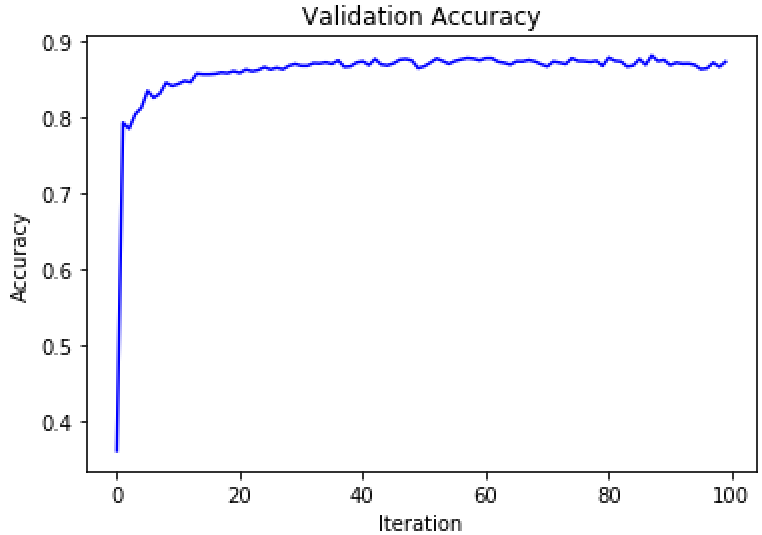
In [22]:
```
three_layer = ThreeLayerNN(200, 100)
optimizer_three_layer = torch.optim.Adam(three_layer.parameters(), lr=0.00
1)
runModel(three_layer, 32, 10000, optimizer_three_layer)
```

```
     0  0.37  0.36
   100  0.78  0.79
   200  0.78  0.79
   300  0.80  0.80
   400  0.80  0.81
   500  0.85  0.83
   600  0.83  0.83
   700  0.84  0.83
   800  0.86  0.85
   900  0.87  0.84
  1000  0.87  0.84
  1100  0.86  0.85
  1200  0.87  0.85
  1300  0.88  0.86
  1400  0.85  0.86
  1500  0.88  0.86
  1600  0.89  0.86
```

```
1700  0.88  0.86
1800  0.88  0.86
1900  0.87  0.86
2000  0.89  0.86
2100  0.87  0.86
2200  0.87  0.86
2300  0.89  0.86
2400  0.89  0.87
2500  0.90  0.86
2600  0.91  0.87
2700  0.89  0.86
2800  0.91  0.87
2900  0.91  0.87
3000  0.91  0.87
3100  0.90  0.87
3200  0.91  0.87
3300  0.91  0.87
3400  0.89  0.87
3500  0.93  0.87
3600  0.92  0.88
3700  0.92  0.87
3800  0.91  0.87
3900  0.92  0.87
4000  0.91  0.87
4100  0.90  0.87
4200  0.93  0.88
4300  0.90  0.87
4400  0.92  0.87
4500  0.92  0.87
4600  0.91  0.88
4700  0.93  0.88
4800  0.92  0.87
4900  0.92  0.86
5000  0.92  0.87
5100  0.93  0.87
5200  0.94  0.88
5300  0.93  0.87
5400  0.94  0.87
5500  0.92  0.87
5600  0.92  0.88
5700  0.94  0.88
5800  0.94  0.88
5900  0.95  0.88
6000  0.93  0.88
6100  0.94  0.88
6200  0.93  0.87
6300  0.94  0.87
6400  0.93  0.87
6500  0.95  0.87
6600  0.94  0.87
6700  0.94  0.88
6800  0.94  0.87
6900  0.94  0.87
7000  0.93  0.87
7100  0.95  0.87
7200  0.95  0.87
7300  0.95  0.87
```

```
7400  0.95  0.88
7500  0.95  0.87
7600  0.94  0.87
7700  0.95  0.87
7800  0.95  0.87
7900  0.95  0.87
8000  0.94  0.88
8100  0.94  0.87
8200  0.94  0.87
8300  0.93  0.87
8400  0.94  0.87
8500  0.94  0.88
8600  0.95  0.87
8700  0.96  0.88
8800  0.95  0.87
8900  0.96  0.88
9000  0.95  0.87
9100  0.95  0.87
9200  0.94  0.87
9300  0.96  0.87
9400  0.95  0.87
9500  0.95  0.86
9600  0.96  0.86
9700  0.96  0.87
9800  0.94  0.87
9900  0.96  0.87
```



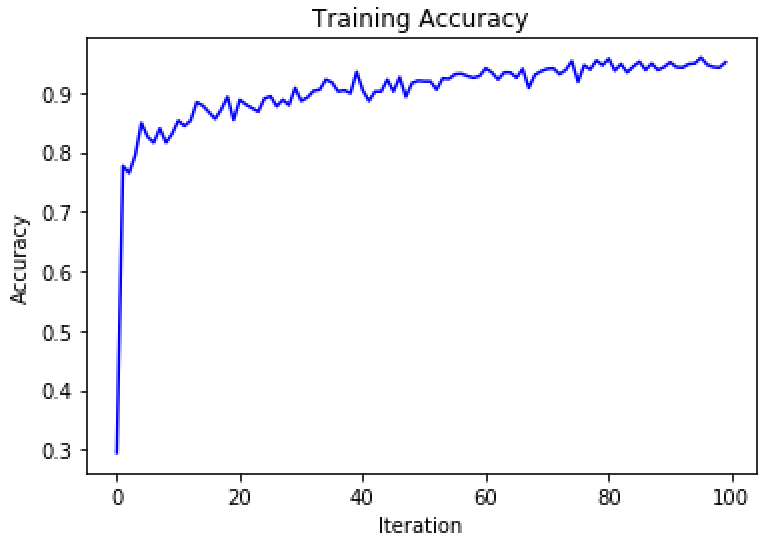


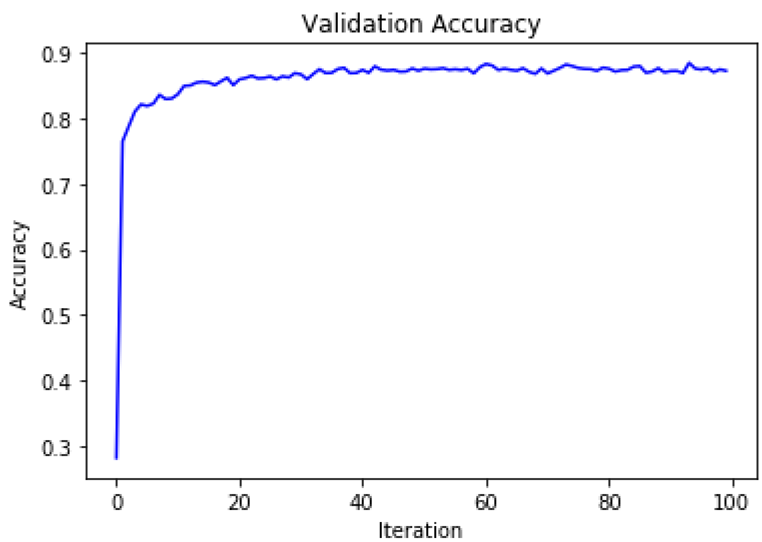
In [23]:
```
four_layer = FourLayerNN(200, 100, 50)
optimizer_four_layer = torch.optim.Adam(four_layer.parameters(), lr=0.001)
runModel(four_layer, 32, 10000, optimizer_four_layer)
```

```
   0  0.29  0.28
 100  0.78  0.76
 200  0.77  0.79
 300  0.80  0.81
 400  0.85  0.82
 500  0.83  0.82
 600  0.82  0.82
 700  0.84  0.84
 800  0.82  0.83
 900  0.83  0.83
1000  0.85  0.84
1100  0.84  0.85
1200  0.85  0.85
1300  0.88  0.85
1400  0.88  0.86
1500  0.87  0.85
1600  0.86  0.85
1700  0.87  0.86
1800  0.89  0.86
1900  0.85  0.85
2000  0.89  0.86
2100  0.88  0.86
2200  0.87  0.86
2300  0.87  0.86
2400  0.89  0.86
2500  0.89  0.86
2600  0.88  0.86
2700  0.89  0.86
2800  0.88  0.86
2900  0.91  0.87
3000  0.89  0.87
3100  0.89  0.86
3200  0.90  0.87
3300  0.91  0.87
3400  0.92  0.87
```

```
3500  0.92  0.87
3600  0.90  0.87
3700  0.90  0.88
3800  0.90  0.87
3900  0.94  0.87
4000  0.90  0.87
4100  0.89  0.87
4200  0.90  0.88
4300  0.90  0.87
4400  0.92  0.87
4500  0.90  0.87
4600  0.93  0.87
4700  0.89  0.87
4800  0.92  0.88
4900  0.92  0.87
5000  0.92  0.88
5100  0.92  0.87
5200  0.91  0.87
5300  0.92  0.88
5400  0.92  0.87
5500  0.93  0.87
5600  0.93  0.87
5700  0.93  0.88
5800  0.93  0.87
5900  0.93  0.88
6000  0.94  0.88
6100  0.93  0.88
6200  0.92  0.87
6300  0.93  0.88
6400  0.93  0.87
6500  0.93  0.87
6600  0.94  0.88
6700  0.91  0.87
6800  0.93  0.87
6900  0.94  0.88
7000  0.94  0.87
7100  0.94  0.87
7200  0.93  0.88
7300  0.94  0.88
7400  0.95  0.88
7500  0.92  0.88
7600  0.95  0.88
7700  0.94  0.87
7800  0.95  0.87
7900  0.95  0.88
8000  0.96  0.88
8100  0.94  0.87
8200  0.95  0.87
8300  0.93  0.87
8400  0.94  0.88
8500  0.95  0.88
8600  0.94  0.87
8700  0.95  0.87
8800  0.94  0.88
8900  0.94  0.87
9000  0.95  0.87
9100  0.94  0.87
```

```
9200  0.94  0.87
9300  0.95  0.88
9400  0.95  0.88
9500  0.96  0.87
9600  0.95  0.88
9700  0.94  0.87
9800  0.94  0.87
9900  0.95  0.87
```



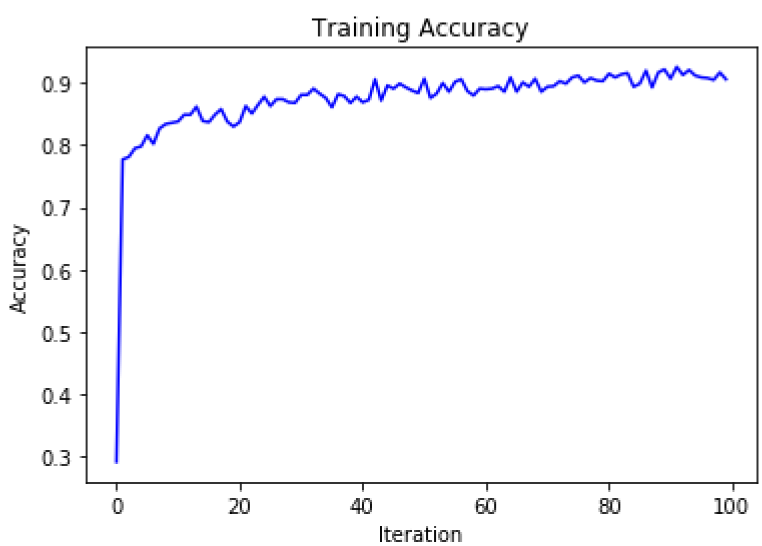


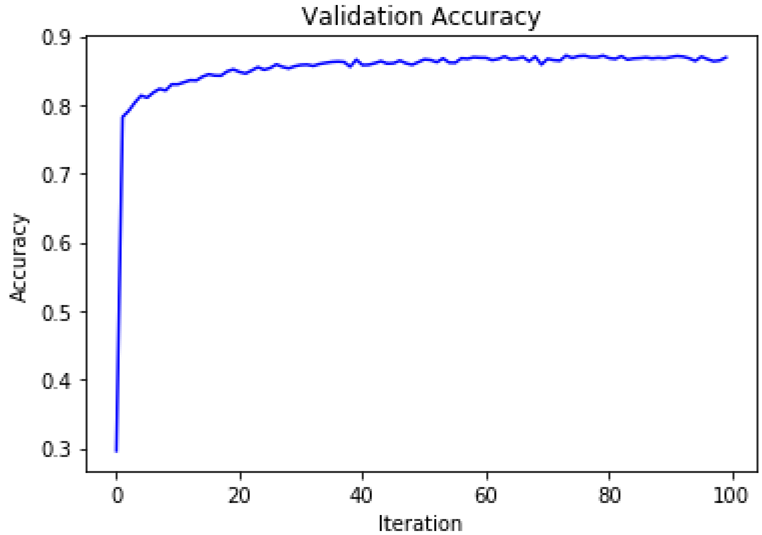
In [24]:
```
two_layer = TwoLayerNN(100) #using dropout at 0.3
optimizer_two_layer = torch.optim.Adam(two_layer.parameters(), lr=0.001)
runModel(two_layer, 32, 10000, optimizer_two_layer)
```

```
   0  0.29  0.30
 100  0.78  0.78
 200  0.78  0.79
 300  0.80  0.80
 400  0.80  0.81
 500  0.82  0.81
 600  0.80  0.82
 700  0.83  0.82
 800  0.83  0.82
 900  0.84  0.83
```

1000	0.84	0.83
1100	0.85	0.83
1200	0.85	0.84
1300	0.86	0.84
1400	0.84	0.84
1500	0.84	0.84
1600	0.85	0.84
1700	0.86	0.84
1800	0.84	0.85
1900	0.83	0.85
2000	0.84	0.85
2100	0.86	0.85
2200	0.85	0.85
2300	0.86	0.85
2400	0.88	0.85
2500	0.86	0.85
2600	0.87	0.86
2700	0.87	0.86
2800	0.87	0.85
2900	0.87	0.86
3000	0.88	0.86
3100	0.88	0.86
3200	0.89	0.86
3300	0.88	0.86
3400	0.88	0.86
3500	0.86	0.86
3600	0.88	0.86
3700	0.88	0.86
3800	0.87	0.86
3900	0.88	0.87
4000	0.87	0.86
4100	0.87	0.86
4200	0.91	0.86
4300	0.87	0.86
4400	0.90	0.86
4500	0.89	0.86
4600	0.90	0.86
4700	0.89	0.86
4800	0.89	0.86
4900	0.88	0.86
5000	0.91	0.87
5100	0.88	0.87
5200	0.88	0.86
5300	0.90	0.87
5400	0.89	0.86
5500	0.90	0.86
5600	0.91	0.87
5700	0.89	0.87
5800	0.88	0.87
5900	0.89	0.87
6000	0.89	0.87
6100	0.89	0.86
6200	0.90	0.87
6300	0.89	0.87
6400	0.91	0.87
6500	0.89	0.87
6600	0.90	0.87

```
6700  0.89  0.86
6800  0.91  0.87
6900  0.89  0.86
7000  0.89  0.87
7100  0.90  0.86
7200  0.90  0.86
7300  0.90  0.87
7400  0.91  0.87
7500  0.91  0.87
7600  0.90  0.87
7700  0.91  0.87
7800  0.90  0.87
7900  0.90  0.87
8000  0.92  0.87
8100  0.91  0.87
8200  0.91  0.87
8300  0.92  0.87
8400  0.89  0.87
8500  0.90  0.87
8600  0.92  0.87
8700  0.89  0.87
8800  0.92  0.87
8900  0.92  0.87
9000  0.91  0.87
9100  0.93  0.87
9200  0.91  0.87
9300  0.92  0.87
9400  0.91  0.86
9500  0.91  0.87
9600  0.91  0.87
9700  0.91  0.86
9800  0.92  0.86
9900  0.91  0.87
```



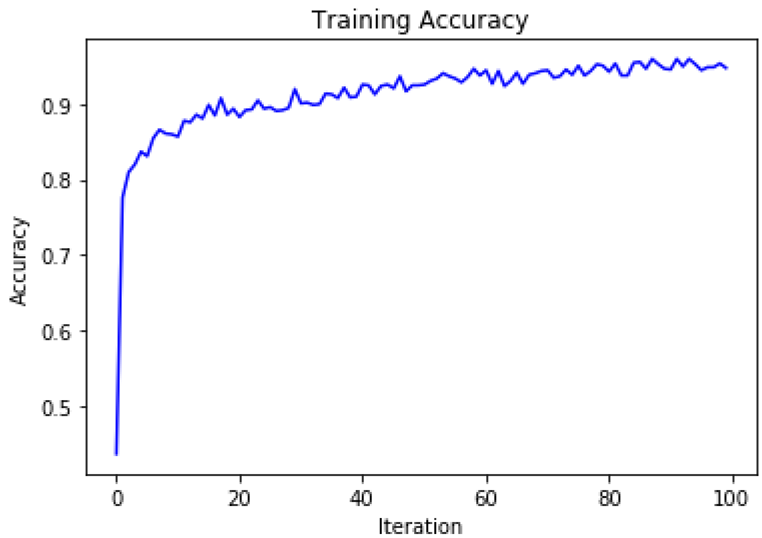


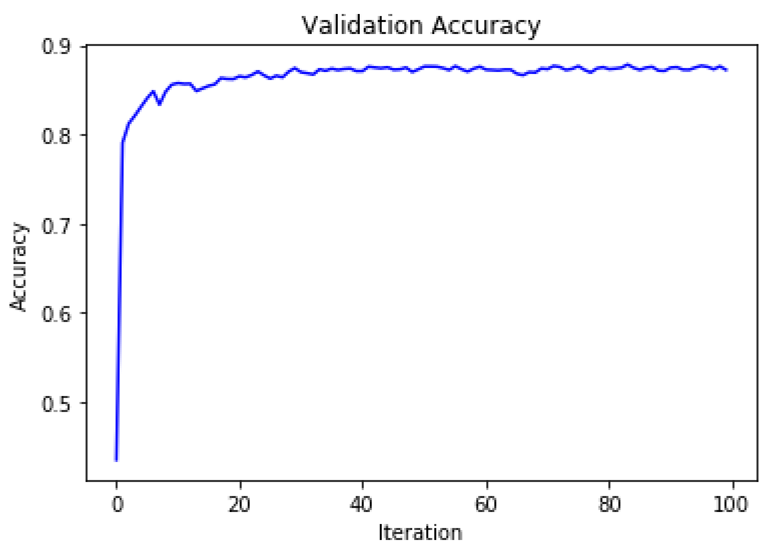
In [10]:
```
start = time.time()
two_layer = TwoLayerNN(200) #using dropout at 0.3
optimizer_two_layer = torch.optim.Adam(two_layer.parameters(), lr=0.001)
runModel(two_layer, 65, 10000, optimizer_two_layer)#using multi hinge loss
end = time.time()
print(end - start)
```

```
    0  0.44  0.43
  100  0.78  0.79
  200  0.81  0.81
  300  0.82  0.82
  400  0.84  0.83
  500  0.83  0.84
  600  0.85  0.85
  700  0.87  0.83
  800  0.86  0.85
  900  0.86  0.86
 1000  0.86  0.86
 1100  0.88  0.86
 1200  0.88  0.86
 1300  0.89  0.85
 1400  0.88  0.85
 1500  0.90  0.85
 1600  0.89  0.86
 1700  0.91  0.86
 1800  0.89  0.86
 1900  0.89  0.86
 2000  0.88  0.87
 2100  0.89  0.86
 2200  0.89  0.87
 2300  0.91  0.87
 2400  0.89  0.87
 2500  0.90  0.86
 2600  0.89  0.87
 2700  0.89  0.86
 2800  0.90  0.87
 2900  0.92  0.87
 3000  0.90  0.87
 3100  0.90  0.87
```

```
3200  0.90  0.87
3300  0.90  0.87
3400  0.91  0.87
3500  0.91  0.87
3600  0.91  0.87
3700  0.92  0.87
3800  0.91  0.87
3900  0.91  0.87
4000  0.93  0.87
4100  0.93  0.88
4200  0.91  0.88
4300  0.92  0.87
4400  0.93  0.88
4500  0.92  0.87
4600  0.94  0.87
4700  0.92  0.88
4800  0.93  0.87
4900  0.93  0.87
5000  0.93  0.88
5100  0.93  0.88
5200  0.93  0.88
5300  0.94  0.87
5400  0.94  0.87
5500  0.93  0.88
5600  0.93  0.87
5700  0.94  0.87
5800  0.95  0.87
5900  0.94  0.88
6000  0.94  0.87
6100  0.93  0.87
6200  0.94  0.87
6300  0.92  0.87
6400  0.93  0.87
6500  0.94  0.87
6600  0.93  0.87
6700  0.94  0.87
6800  0.94  0.87
6900  0.94  0.87
7000  0.94  0.87
7100  0.94  0.88
7200  0.94  0.88
7300  0.95  0.87
7400  0.94  0.87
7500  0.95  0.88
7600  0.94  0.87
7700  0.94  0.87
7800  0.95  0.87
7900  0.95  0.88
8000  0.94  0.87
8100  0.95  0.87
8200  0.94  0.87
8300  0.94  0.88
8400  0.95  0.87
8500  0.96  0.87
8600  0.95  0.87
8700  0.96  0.88
8800  0.95  0.87
```

```
8900  0.95  0.87
9000  0.95  0.87
9100  0.96  0.88
9200  0.95  0.87
9300  0.96  0.87
9400  0.95  0.88
9500  0.94  0.88
9600  0.95  0.88
9700  0.95  0.87
9800  0.95  0.88
9900  0.95  0.87
```






```
80.23156976699829
```

Best validation accuracy achieved was 88. This was using my two layer neural net with 200 units, learning rate of 0.001 using Adam optimizer, 10k optimization steps, and 65 batch size. This was also run with a dropout before the second layer with probability 0.3 and using multi hinge loss instead of cross entropy loss. The total time was about 76 seconds.