4. theano neural networks

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0.1 4. Neural Networks Learning in Theano

The aim of this IPython notebook is to show some features of the Python **Theano** library in the field of machine learning. It has been developped by the LISA group at the University of Montreal (see: http://deeplearning.net/software/theano/). The notebook also relies on other standard Python libraries such as numpy, pandas and matplotlib.

To exemplify the use of **Theano**, this notebook solves the assignments of the Machine Learning MOOC provided by **Coursera** (see: https://www.coursera.org/learn/machine-learning) and performed in Stanford University by **Andrew Ng** (see: http://www.andrewng.org/).

The original MOOC assignments should to be programmed with the **Octave** language (see: https://www.gnu.org/software/octave/).The idea with this notebook is to provide Python developpers with interesting examples programmed using **Theano**.

This notebook has been developped using the Anaconda Python 3.4 distribution provided by **Continuum Analytics** (see: https://www.continuum.io/). It requires the **Jupyter Notebook** (see: http://jupyter.org/).

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0.1.1 4.1 Neural Networks

4.1.1 Visualizing the data

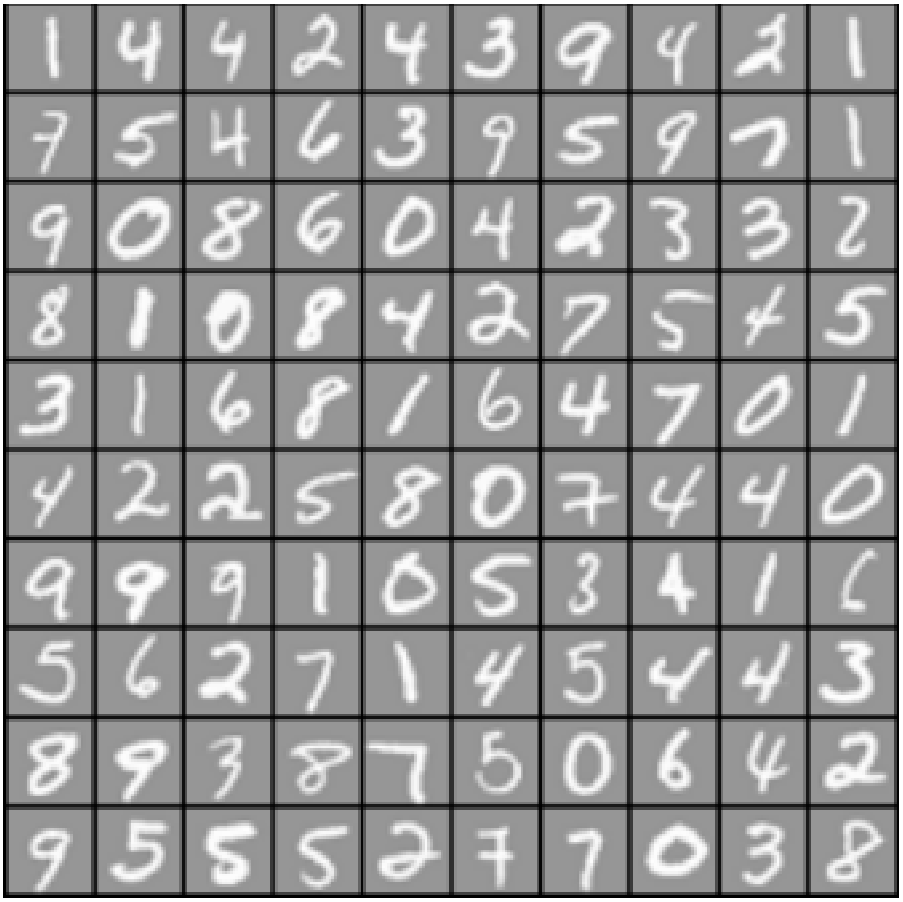
```
In [1]: import theano
        import numpy as np
        import theano.tensor as T
        from theano.tensor.nnet import sigmoid
        import scipy.io as sio
        data = sio.loadmat('data/ex4data1.mat')
        X, Y = data['X'], data['y'].T[0]
        m = X.shape[0]
```

```
In [2]: %matplotlib inline
        import pandas as pnd
        import matplotlib.pyplot as plt

        def display_data(X, Y):
            example_width = int(np.sqrt(X.shape[1]))

            # Compute rows, cols
            m, n = X.shape
            example_height = int(n / example_width)

            # Compute number of items to display
```

```python
    display_rows = int(np.floor(np.sqrt(m)))
    display_cols = int(np.ceil(m / display_rows))

    # Between images padding
    pad = 1

    # Setup blank display
    display_array = - np.ones((pad + display_rows * (example_height + pad),\
                               pad + display_cols * (example_width + pad)))

    # Copy each example into a patch on the display array
    # dataset contains 20 pixel by 20 pixel grayscale images of the digit
    curr_ex = 0
    for j in range(display_rows):
        for i in range(display_cols):
            if curr_ex >= m:
                break
            # Get the max value of the patch
            max_val = max(abs(X[curr_ex]))
            display_array[(pad + j * (example_height + pad)):(pad + j * (example_height + pad))+
                          (pad + i * (example_width + pad)):(pad + i * (example_width + pad))+e
                            np.reshape(X[curr_ex], (example_height, example_width)) / max_val
            curr_ex += 1
        if curr_ex >= m:
            break

    plt.figure(figsize=(8,6))
    plt.axis('off')
    plt.imshow(display_array.T, cmap="Greys_r")

    df = pnd.DataFrame(Y.reshape((display_rows, display_cols)).T)
    df = df.replace(10,0) # 0 is mapped to 10 in Y
    print(df)
```

In [3]:
```python
rnd = np.random.permutation(m)[0:100]
sel = X[rnd,:] # 100 random digits
res = Y[rnd]
display_data(sel, res)
```

	0	1	2	3	4	5	6	7	8	9
0	1	4	4	2	4	3	9	4	2	1
1	7	5	4	6	3	9	5	9	7	1
2	9	0	8	6	0	4	2	3	3	2
3	8	1	0	8	4	2	7	5	4	5
4	3	1	6	8	1	6	4	7	0	1
5	4	2	2	5	8	0	7	4	4	0
6	9	9	9	1	0	5	3	4	1	6
7	5	6	2	7	1	4	5	4	4	3
8	8	9	3	8	7	5	0	6	4	2
9	9	5	5	5	2	7	7	0	3	8



4.1.2 Feedforward and cost function

In [4]:
```
def T_add_ones(x, a, b):
    var = T.concatenate([T.ones(a), x.flatten().T])
    return var.reshape((b, a))

X1 = np.c_[np.ones(m), X] # Add intercept term to X
X1 = X1.T

# load precomputed network parameters
weights = sio.loadmat('data/ex4weights.mat')
t1 = weights['Theta1']
t2 = weights['Theta2']

print("X1:", X1.shape)
print("theta1:", t1.shape)
print("theta2:", t2.shape)

# layer sizes
input_layer_size = X.shape[1]
```

```
        hidden_layer_size = t1.shape[0]
        num_labels = t2.shape[0]

        print('\ninput_layer_size: %i' % input_layer_size)
        print('hidden_layer_size: %i' % hidden_layer_size)
        print('num_labels: %i' % num_labels)

        x = T.matrix('x')
        y = T.vector('y')
        theta1 = theano.shared(t1, 'theta1')
        theta2 = theano.shared(t2, 'theta2')

        # first layer
        y1 = sigmoid(T.dot(theta1, x))

        # second layer
        y2 = T_add_ones(y1, m, hidden_layer_size+1)
        y3 = sigmoid(T.dot(theta2, y2))

        J = 0
        for i in range(num_labels):
            yy = T.eq(y,i+1)
            J += -T.sum(yy * T.log(y3[i,:]) + (1 - yy) * T.log(1 - y3[i,:])) / m

        cost = theano.function([x, y], J)

        print('\ncost: %f' % cost(X1, Y))
```

```
X1: (401, 5000)
theta1: (25, 401)
theta2: (10, 26)

input_layer_size: 400
hidden_layer_size: 25
num_labels: 10

cost: 0.287629
```

4.1.3 Regularized cost function

In [5]:
```
# Weight regularization parameter (we set this to 0 here).
lambda_ = 1

x = T.matrix('x')
y = T.vector('y')
theta1 = theano.shared(t1, 'theta1')
theta2 = theano.shared(t2, 'theta2')

# first layer
y1 = sigmoid(T.dot(theta1, x))

# second layer
y2 = T_add_ones(y1, m, hidden_layer_size+1)
y3 = sigmoid(T.dot(theta2, y2))
```

```
        # regularization on theta1 and theta2
        reg = lambda_ * (T.sum(theta1[:,1:]**2) + T.sum(theta2[:,1:]**2)) / 2 / m
        J = reg
        for i in range(num_labels):
            yy = T.eq(y,i+1)
            J += -T.sum(yy * T.log(y3[i,:]) + (1 - yy) * T.log(1 - y3[i,:])) / m

        cost = theano.function([x, y], J)

        print('cost: %f' % cost(X1, Y))
```

```
cost: 0.383770
```

0.2 4.2 Backpropagation

0.2.1 4.2.1 Sigmoid gradient

```
In [6]: x = T.matrix('x')
        h = 1.0 / (1.0 + T.exp(-x))
        h_grad = h * (1-h)

        sigmoid2 = theano.function([x], h)
        sigmoid2_grad = theano.function([x], h*(1-h))
        print(sigmoid2(np.array([[-1, -0.5, 0, 0.5, 1]])))
        print(sigmoid2_grad(np.array([[-1, -0.5, 0, 0.5, 1]])))
```

```
[[ 0.26894142  0.37754067  0.5         0.62245933  0.73105858]]
[[ 0.19661193  0.23500371  0.25        0.23500371  0.19661193]]
```

0.2.2 4.2.2 Random initialization

```
In [7]: def rand_initialize_weights(l_in, l_out, epsilon_init):
            return np.random.rand(l_out, l_in+1) * 2 * epsilon_init - epsilon_init

        epsilon_init = 0.12
        t1 = rand_initialize_weights(input_layer_size, hidden_layer_size, epsilon_init)
        t2 = rand_initialize_weights(hidden_layer_size, num_labels, epsilon_init)
        t = np.concatenate([t1.flatten(), t2.flatten()])
```

0.2.3 4.2.3 Backpropagation

```
In [8]: def T_add_ones(x, a, b):
            var = T.concatenate([T.ones(a), x.flatten().T])
            return var.reshape((b, a))

        theta = theano.shared(t, 'theta')

        # Choose some alpha value
        alpha = 1

        x = T.matrix('x')
        y = T.vector('y')

        # first layer
        theta1 = theta[:t1.shape[0]*t1.shape[1]]
        theta1 = theta1.reshape((t1.shape[0],t1.shape[1]))
```

```
        y1 = sigmoid(T.dot(theta1, x))

        # second layer
        y2 = T_add_ones(y1, m, hidden_layer_size+1)
        theta2 = theta[t1.shape[0]*t1.shape[1]:]
        theta2 = theta2.reshape((t2.shape[0],t2.shape[1]))
        y3 = sigmoid(T.dot(theta2, y2))

        J = 0
        for i in range(num_labels):
            yy = T.eq(y,i+1)
            J += -T.sum(yy * T.log(y3[i,:]) + (1 - yy) * T.log(1 - y3[i,:])) / m

        grad = T.grad(J, theta)

        train = theano.function([x,y], [J, y3], updates = [(theta, theta-alpha*grad)])

        for i in range(2000):
            costM, y3 = train(X1,Y)
            if i%500 == 0:
                print('[%i] %f' % (i, costM))

        print('cost: %f' % costM)
```

```
[0] 6.944886
[500] 0.474386
[1000] 0.332647
[1500] 0.259193
cost: 0.211194
```

In [9]:
```
# number of positive predictions where best prediction == Y-1
accuracy = np.sum(np.argmax(y3, axis=0) == (Y-1))/len(Y)
print('Train Accuracy: %f' % accuracy)
```

```
Train Accuracy: 0.978000
```

0.2.4 4.2.4 Regularized Neural Networks

In [12]:
```
theta = theano.shared(t, 'theta')

# Weight regularization parameter (we set this to 0 here).
lambda_ = 3

# Choose some alpha value
alpha = 1

# Weight regularization parameter (we set this to 0 here).
lambda_ = 1

x = T.matrix('x')
y = T.vector('y')

# first layer
theta1 = theta[:t1.shape[0]*t1.shape[1]]
theta1 = theta1.reshape((t1.shape[0],t1.shape[1]))
```

```
        y1 = sigmoid(T.dot(theta1,x))

        # second layer
        y2 = T_add_ones(y1, m, hidden_layer_size+1)
        theta2 = theta[t1.shape[0]*t1.shape[1]:]
        theta2 = theta2.reshape((t2.shape[0],t2.shape[1]))
        y3 = sigmoid(T.dot(theta2, y2))

        # regularization on theta1 and theta2
        reg = lambda_ * (T.sum(theta1[:,1:]**2) + T.sum(theta2[:,1:]**2)) / 2 / m

        J = reg
        for i in range(num_labels):
            yy = T.eq(y,i+1)
            J += -T.sum(yy * T.log(y3[i,:]) + (1 - yy) * T.log(1 - y3[i,:])) / m

        grad = T.grad(J, theta)

        train = theano.function([x,y], [J, y3], updates = [(theta, theta-alpha*grad)])

        for i in range(2000):
            costM, y3 = train(X1,Y)
            if i%500 == 0:
                print('[%i] %f' % (i, costM))

        print('cost: %f' % costM)
```

```
[0] 6.949777
[500] 0.560771
[1000] 0.457988
[1500] 0.414050
cost: 0.390036
```

```
In [11]: # number of positive predictions where best prediction == Y-1
         accuracy = np.sum(np.argmax(y3, axis=0) == (Y-1))/len(Y)
         print('Train Accuracy: %f' % accuracy)
```

```
Train Accuracy: 0.973200
```

```
In [ ]:
```