MAT 345: Assignment 5

Neural Net Digit Recognition

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- b.) Programing Language Used:Guess... (its Python)
- **c.)** The smaller step would give a better result, though we initially used too small of a step that resulted in a 0 matrix for our weight gradiants. We ended up using a step of 0.01.
- d.) Below.
- **e.)** In addition to S2 = 30, iterations=1000, we tried S2 = {10, 100, 300} iterations = 500
- **f.)** Our best accuracy was as S2 = 100. We stopped 300 in the middle as after calculating times, it would have taken a week to finish. We believe larger number of nodes or more iterations would increase accuracy.

```
In [27]: import numpy as np
    import math
    import os
    import gzip
    from mnist import MNIST
    import random
    import matplotlib.pyplot as plt
    import sys
    import time
```

```
In [34]: # Step 1: Sigmoid
         # Sigmoid function for single value
          def sigmoid base(x):
             try:
                  return 1 / (1 + math.exp(-x))
              except OverflowError as error:
                  return 1
          # Sigmoid function for a matrix
          def sigmoid(X):
              result = np.matrix(X)
              row = np.size(X[0])
              for i in range(row):
                  for j in range(int(np.size(X) / row)):
                      result[j,i] = sigmoid_base(X[j,i])
                      pass
                  pass
              return result
          # Sigmoid prime function for a matrix
          def sigmoidPrime(zk):
              ak = sigmoid(zk)
              return np.multiply(ak, 1 - ak)
```

```
In [3]: # Create the Y label, ex, label=2 = [0, 1, 0, ..., 0], (1x10)
# index 0 represents 1, index 9 represents 0

def CreateLabelMatrix(label):
    index = label - 1
    if(index == -1):
        index = 9
        pass
    result = np.zeros((10,))
    result[index] = 1
    return result
```

```
In [38]: class NeuralNetwork:
             # input D: DataSet(All images)
             # input L: LabelSet(All labels)
             # input S2: number of nodes in hidden layer
             def init (self, D, L, S2, iterations = 10000, debugMode = False):
                 self.D = D
                 self.L = L
                 self.S2 = S2
                 # Random epsilon
                 epsilon = 0.1
                 # Step 2. Initialize W1 and W2 with proper dimensions
                 self.W1 = np.random.random((S2, 784 + 1)) * 2 * epsilon - epsilon
                 self.W2 = np.random.random((10, S2 + 1)) * 2 * epsilon - epsilon
                 tollerance = 0.0000001
                 self.tolleranceArray1 = np.full(self.W1.shape, tollerance)
                 self.tolleranceArray2 = np.full(self.W2.shape, tollerance)
                 self.debugMode = debugMode
                 self.iterations = iterations
                 pass
             # Step 5:
             def GradiantDescent(self):
                 # b.) Choose step
                 step = 0.01
                 # c.) Update rule: for k=1,2
                    Wk_t+1 = Wk_t - step * gradWk_t
                 print ("StartTime : ",end="")
                 startTime = time.time()
                 print (startTime)
                 for i in range(self.iterations):
                      print("iter:", i, end='\r')
                      self.gradW1 = np.zeros((self.S2, 784 + 1))
                      self.gradW2 = np.zeros((10, self.S2 + 1))
                      # a.) Weights initialized
                      self.feedforward backprop() # FOREVER
                      # use Logistic regression
                      W1_n = self.W1 - np.multiply(step, self.gradW1)
                      W2 n = self.W2 - np.multiply(step, self.gradW2)
                      if ( (abs(self.W1 - W1 n) < self.tolleranceArray1).all() \</pre>
                          and (abs(self.W2 - W2 n) < self.tolleranceArray2).all()):</pre>
                          if(self.debugMode):
                              print("Tollerance won. Iteration count:", i)
                          self.W1 = W1_n
                          self.W2 = W2 n
                          break
```

```
# check for iteration
        if i == (self.iterations - 1):
            if(self.debugMode):
                print("Iteration won")
            self.W1 = W1 n
            self.W2 = W2 n
            break
        self.W1 = W1 n
        self.W2 = W2 n
        pass
   endTime = time.time()
    print("Total Elapsed Time: ", endTime - startTime)
    print("DONE!")
   pass
# Step 3: For each Datapoint in D:
def feedforward backprop(self):
   # For each datapoint, feed forward and back propagate
   for i in range(len(self.D)):
        # initialize x and y for use
        self.x = self.D[i]
        # TODO: RESET THIS
        self.y = CreateLabelMatrix(self.L[i]).reshape(-1,1)
        #self.y = self.L[i]
        self.feedforward()
        self.backprop()
        pass
   # Average the gradiants
    self.gradW1 = self.gradW1 / len(self.D)
    self.gradW2 = self.gradW2 / len(self.D)
   pass
def feedforward(self):
   # a.) Let a1 = [1, X] (with bais term)
   self.a1 = np.column stack((1,np.matrix(self.x))).reshape(-1,1)
   # b.) Let z2 = W1*a1 (dim S2x1)
    self.z2 = (self.W1*self.a1)
   \# c.) Let a2 = sigmoid(z2), and add bias term
   self.a2 = np.row stack((1,sigmoid(self.z2)))
   # d.) Let z3 = W2*a2 (dim 10x1)
   self.z3 = self.W2*self.a2
   \# e.) Let a3 = sigmoid(z3)
   self.a3 = sigmoid(self.z3)
    if self.debugMode:
        print("----")
```

```
print("a2:\n", self.a2)
        print("a1:\n", self.a1)
        print("z2:\n", self.z2)
        print("z3:\n", self.z3)
        print("a3:\n", self.a3)
        pass
    pass
def backprop(self):
    # a.) Let d3 = a3 - y (dim\ 10x1)
    d3 = self.a3 - self.y
    # b.1) Let W~2 be W2 with bias term removed, (dim 10xS2)
    W_t2 = np.delete(self.W2, 0, axis=1)
    \# b.2) Let d2 = \lceil W \sim 2 \rceil . T * d3 (x) sigmoid prime(z2), (dim S2x1)
    d2 = np.multiply(W_t2.T * d3, sigmoidPrime(self.z2))
    # c.) Compute set of partial derivatives wrt. the weights, k=1,2
          gW1(x,y) = d2[a1].T --> size S2x785
          qW2(x,y) = d3[a2].T --> size 10x(S2+1)
    gW1 = d2 * self.a1.T
    gW2 = d3 * self.a2.T
    self.gradW1 = self.gradW1 + gW1
    self.gradW2 = self.gradW2 + gW2
    if self.debugMode:
        print("----")
        print("d3\n", d3)
        print("W_t2\n", W_t2)
        print("d2\n", d2)
        print("gw1\n", gW1)
        print("gw2\n", gW2)
        pass
    pass
def predictSingle(self, x):
    a1 = np.matrix(x)
    a1 = np.column_stack((1,a1)).reshape(-1,1)
    z2 = (self.W1*a1)
    a2 = np.row stack((1,sigmoid(z2)))
    z3 = self.W2*a2
    a3 = sigmoid(z3)
    result = np.argmax(a3) + 1
    if(result == 10):
        result = 0
        pass
    return result
```

```
def predictData(self, D2, L2):
                 numberArray = [0, 0, 0, 0, 0, 0, 0, 0, 0]
                 numberArrayPred = [0, 0, 0, 0, 0, 0, 0, 0, 0]
                 correct = 0
                for i in range(len(D2)):
                    predicted = self.predictSingle(D2[i])
                    numberArray[L2[i]] += 1
                    if predicted == L2[i]:
                        correct += 1
                        numberArrayPred[predicted] += 1
                    pass
                 print("Correct:", correct, " Total:", len(L2))
                 print("Accuracy:", correct / len(L2) * 100, "%")
                 print("Number, PredictedRight, Total")
                 for i in range(10):
                    pass
In [4]: # Load in the data using MNIST
         mndata = MNIST('Data')
         train images, train labels = mndata.load training()
         test images, test labels = mndata.load testing()
In [41]: | nn = NeuralNetwork(train images, train labels, 30, 1000)
         print("NN Done!")
         nn.GradiantDescent()
         NN Done!
         StartTime: 1575619117.343763
         Total Elapsed Time: 24742.66812801361
         DONE!
In [42]: | nn.predictData(test_images, test_labels)
         Correct: 7415 Total: 10000
         Accuracy: 74.15 %
         Number, PredictedRight, Total
                948 980
         1
                1115 1135
         2
                576 1032
         3
                838 1010
         4
                779 982
         5
                259 892
                869 958
         6
         7
                876 1028
         8
                490 974
         9
                665 1009
```

REPORT. D.)

```
In [45]: for i in range(len(nn.W1)):
    print(nn.W1[i])
```

```
[ 0.08471124 -0.03778911 0.03962886 -0.07785324
                                                    0.05595806 -0.07601101
  -0.01837129 -0.02050651 -0.03293702 -0.01157805
                                                    0.07105064 -0.04003524
  0.06422594
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                                                               0.07921738
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-0.08097775
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 0.0386441
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                                      0.10369783 -0.06234688 -0.06149768
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             0.04384443 -0.03990591
                                      0.08627702
                                                   0.01908275
                                                               0.07322284
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             0.03164977 -0.08914369
                                      0.06102822 -0.091742
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            -0.07627654 -0.00650115
                                      0.00157451 -0.02257662
-0.04723252
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             0.0089655
                          0.0634284
                                      0.06126364 -0.02158464
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                         0.04934924 -0.09572301 -0.06488537
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             0.02799092
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 0.04393207 -0.07248848
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 0.06592179 -0.09060646 -0.01611938 -0.08355086
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-0.09945422 -0.01060771 -0.08400602 -0.05945729
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-0.03016854 -0.08523725
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                  -0.22042258, 0.0088458, -0.09343174, -0.24543456, -0.17222994,
                   0.0048834 , 0.09095688, -0.01735602, -0.21329898, -0.22672736,
                  -0.19304233, -0.07221874, -0.260204 , -0.0865731 , -0.1007783 ,
                  -0.12144778, -0.12547693, -0.06034663, -0.121016 , -0.16665356,
                  -0.03878249, -0.13833518, -0.18581578, -0.09426512, 0.1987074,
                   0.12533177],
                 [-0.06035415, -0.17407469, 0.2124726 , -0.22558083, -0.19534725,
```

```
-0.22920867, 0.0583178, -0.03226403, -0.01224566, -0.15493123, 0.03606359, 0.15253479, -0.51358241, -0.11062362, -0.09207535, 0.1762357, -0.11175706, 0.01629482, -0.12247979, -0.28043775, -0.21682566, -0.22938611, 0.13470786, -0.09581652, -0.08779041, -0.13153771, 0.13925351, -0.2106788, 0.02219518, -0.26200729, -0.35741534], [-0.07125864, -0.03625668, -0.39051543, -0.16791268, -0.03492691, -0.14993826, 0.23238909, -0.02503361, 0.03776065, -0.20116329, -0.59550097, -0.28348235, 0.19027726, 0.13913793, -0.08853494, -0.22800418, -0.14425919, 0.04530884, 0.51132407, -0.01688459, -0.16087896, -0.17344584, 0.01440548, -0.1572013, -0.08273713, -0.60090766, -0.26926894, -0.10055839, -0.07718926, -0.27119729, 0.13453832]])
```

S2 = 100, iterations = 500

```
In [46]: nn2 = NeuralNetwork(train_images, train_labels, 100, 500)
    print("NN Done!")
    nn2.GradiantDescent()
```

NN Done!

StartTime: 1575651473.4134407

Total Elapsed Time: 22776.92486190796

DONE!

```
In [47]: nn2.predictData(test images, test labels)
```

Correct: 8104 Total: 10000

Accuracy: 81.04 %

Number, PredictedRight, Total

0 934 980 1 1097 1135 2 793 1032 3 863 1010 4 814 982 5 470 892 6 855 958

7 906 1028 8 646 974

9 726 1009

```
In [6]:
        nn = NeuralNetwork(train images, train labels, 300, 500)
        print("NN Done!")
        nn.GradiantDescent()
        NN Done!
        StartTime: 1575652042.3771405
        iter: 32
        KeyboardInterrupt
                                                   Traceback (most recent call last)
        <ipython-input-6-ad24212b30bc> in <module>
              1 nn = NeuralNetwork(train images, train labels, 300, 500)
              2 print("NN Done!")
        ----> 3 nn.GradiantDescent()
        <ipython-input-4-ce8f0a19b0d2> in GradiantDescent(self)
             43
                            # a.) Weights initialized
        ---> 44
                            self.feedforward backprop() # FOREVER
             45
             46
                            # use logistic regression
        <ipython-input-4-ce8f0a19b0d2> in feedforward backprop(self)
                            #self.y = self.L[i]
             85
             86
        ---> 87
                            self.feedforward()
             88
                            self.backprop()
             89
                            pass
        <ipython-input-4-ce8f0a19b0d2> in feedforward(self)
             99
            100
                        # b.) Let z2 = W1*a1 (dim S2x1)
        --> 101
                        self.z2 = (self.W1*self.a1)
            102
            103
                        # c.) Let a2 = sigmoid(z2), and add bias term
        ~\AppData\Roaming\Python\Python37\site-packages\numpy\matrixlib\defmatrix.py
         in __mul__(self, other)
            218
                        if isinstance(other, (N.ndarray, list, tuple)) :
            219
                            # This promotes 1-D vectors to row vectors
        --> 220
                             return N.dot(self, asmatrix(other))
            221
                        if isscalar(other) or not hasattr(other, ' rmul '):
            222
                             return N.dot(self, other)
        < array function internals> in dot(*args, **kwargs)
        KeyboardInterrupt:
```

```
In [7]: nn.predictData(test_images, test_labels)
             Correct: 4015 Total: 10000
             Accuracy: 40.15000000000000 %
             Number, PredictedRight, Total
                     569 980
             1
                     917 1135
             2
                     270 1032
             3
                     501 1010
             4
                     100 982
             5
                     260 892
             6
                     169 958
             7
                     401 1028
             8
                     347 974
             9
                     481 1009
S2 = 10, iterations = 500
    In [8]: | nn2 = NeuralNetwork(train_images, train_labels, 10, 500)
             print("NN Done!")
             nn2.GradiantDescent()
             NN Done!
             StartTime : 1575657818.9525685
             Total Elapsed Time: 8435.950342178345
             DONE!
    In [9]: nn2.predictData(test images, test labels)
             Correct: 2147 Total: 10000
             Accuracy: 21.47 %
             Number, PredictedRight, Total
                     220 980
             1
                     1111 1135
             2
                     0 1032
             3
                     799 1010
             4
                     0 982
             5
                     0 892
             6
                     0 958
             7
                     17 1028
             8
                     0 974
             9
                     0 1009
```