Recognizing Hand-Written Characters using Tensorflow

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Setting Google Account / Google Drive

When we run below code, it takes so long. Thus, we decide to use Google CoLab to save much time because Google CoLab offers decent GPU.

```
!apt-get install -y -qq software-properties-common python-software-properties modul
!add-apt-repository -y ppa:alessandro-strada/ppa 2>&1 > /dev/null
!apt-get update -qq 2>&1 > /dev/null
!apt-get -y install -qq google-drive-ocamlfuse fuse
from google.colab import auth
auth.authenticate_user()
from oauth2client.client import GoogleCredentials
creds = GoogleCredentials.get_application_default()
import getpass
!google-drive-ocamlfuse -headless -id={creds.client_id} -secret={creds.client_secre
vcode = getpass.getpass()
!echo {vcode} | google-drive-ocamlfuse -headless -id={creds.client_id} -secret={cre
```

```
E: Package 'python-software-properties' has no installation candidate
Selecting previously unselected package google-drive-ocamlfuse.
(Reading database ... 131304 files and directories currently installed.)
Preparing to unpack .../google-drive-ocamlfuse_0.7.3-0ubuntu3~ubuntu18.04.1_a
Unpacking google-drive-ocamlfuse (0.7.3-0ubuntu3~ubuntu18.04.1) ...
Setting up google-drive-ocamlfuse (0.7.3-0ubuntu3~ubuntu18.04.1) ...
Processing triggers for man-db (2.8.3-2ubuntu0.1) ...
Please, open the following URL in a web browser: https://accounts.google.com/
··········
Please, open the following URL in a web browser: https://accounts.google.com/
Please enter the verification code: Access token retrieved correctly.
```

```
!mkdir -p drive
!google-drive-ocamlfuse drive
```

Connecting Google Drive

```
!ls -ltr
```

```
total 12
drwxr-xr-x 1 root root 4096 Apr  4 20:20 sample_data
-rw-r--r-- 1 root root 2494 Apr 26 00:52 adc.json
drwxr-xr-x 2 root root 4096 Apr 26 00:52 drive
```

```
cd drive
```

```
/content/drive
```

```
cd emnist
```

```
/content/drive/emnist
```

```
!ls -ltr
```

```
total 778000
-rw-r--r-- 1 root root  36454802 Apr 25 00:06 emnist-balanced-test.csv
-rw-r--r-- 1 root root 218619475 Apr 25 00:08 emnist-balanced-train.csv
-rw-r--r-- 1 root root  77362729 Apr 25 00:09 emnist-digits-test.csv
-rw-r--r-- 1 root root 464090839 Apr 25 00:15 emnist-digits-train.csv
drwxr-xr-x 2 root root      4096 Apr 25 01:38 MNIST_data
-rw-r--r-- 1 root root     19697 Apr 25 03:23 ensemble.ipynb
-rw-r--r-- 1 root root    118367 Apr 26 00:53 MachineLearning.ipynb
```

Data

- https://www.kaggle.com/crawford/emnist

Softmax

Load data

```
import numpy as np
import pandas as pd
import matplotlib.pyplot as plt
import random
import tensorflow as tf


train = pd.read_csv('emnist-balanced-train.csv', header=None)

test = pd.read_csv('emnist-balanced-test.csv', header=None)
```

- Import libraries
- Importing training data set and test data set using Pandas

```
# Number of Train
numTrain = len(train)
print('numTrain: ', numTrain)
# Number of Test
numTest = len(test)
print('numTest: ', numTest)
# Number of Classes
numClasses = len(train[0].unique())
print('numClasses: ', numClasses)
```

```
numTrain:  112800
numTest:  18800
numClasses:  47
```

We check how many training data set and test data set there are. Also, we are able to figure out how many different output there are. If we use emnist data set, there are 47 outputs including 10 digits, 26 letters, and 11 capital letters. If we use eMNIST digit data set, the number of classes is 10 because of only 10 digits.

```
train_data = train.iloc[:, 1:]
train_labels = train.iloc[:, 0]
test_data = test.iloc[:, 1:]
test_labels = test.iloc[:, 0]
```

- train_data: Training data set without labels
- train_labels: Results of training data set
- test_data: Test data set without labels
- test_labels: Results of test data set

```
# one-hot encoding
train_labels = pd.get_dummies(train_labels)
test_labels = pd.get_dummies(test_labels)
```

Use one-hot encoding

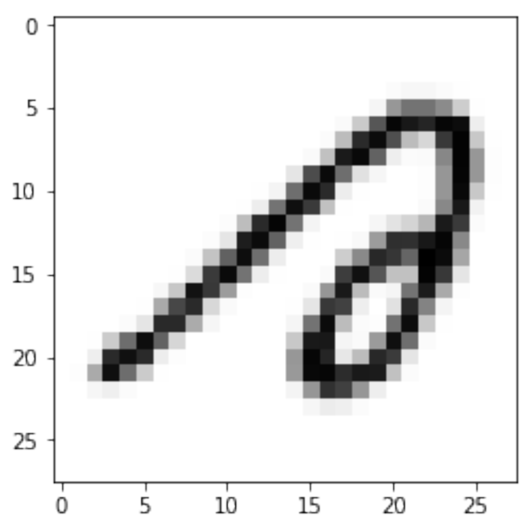
- Reference
    - http://queirozf.com/entries/one-hot-encoding-a-feature-on-a-pandas-dataframe-an-example
    - https://pandas.pydata.org/pandas-docs/stable/reference/api/pandas.get_dummies.html

```
train_data = train_data.values
train_labels = train_labels.values
test_data = test_data.values
test_labels = test_labels.values
```

Training data and test data, which categorical variables are converted by one-hot encoding, are overwritten

```
rand = random.randint(0, numTrain - 1)
```

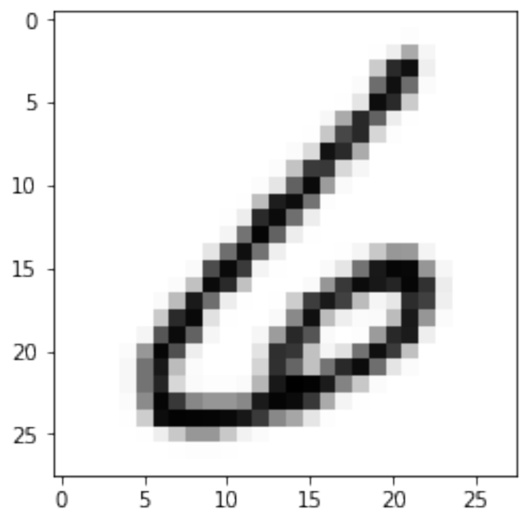
```
plt.imshow(
  train_data[rand].reshape([28, 28]),
  cmap='Greys'
  )
plt.show()
```



A training data randomly chosen are displayed.

```
def rotate(image):
    image = image.reshape([28, 28])
    image = np.fliplr(image)
    image = np.rot90(image)
    return image.reshape([28 * 28])
train_data = np.apply_along_axis(rotate, 1, train_data)/255
test_data = np.apply_along_axis(rotate, 1, test_data)/255
```

```
plt.imshow(
  train_data[rand].reshape([28, 28]),
  cmap='Greys'
  )
plt.show()
```

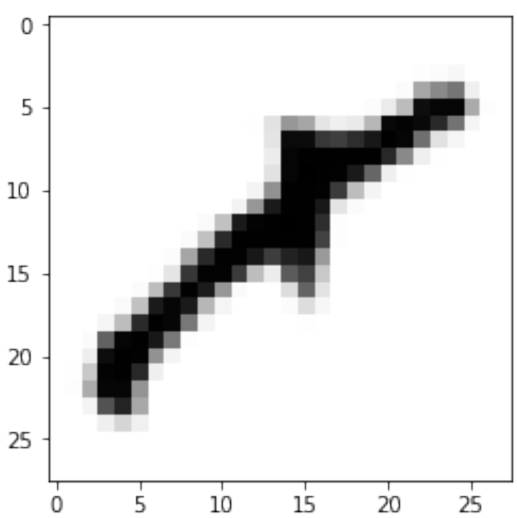


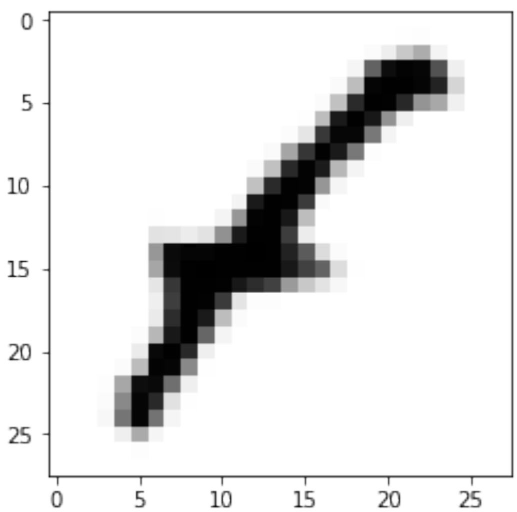
A training data which are randomly selected should be roated

```
import numpy as np
import pandas as pd
import matplotlib.pyplot as plt
import random
import tensorflow as tf
```

```
train = pd.read_csv('emnist-balanced-train.csv', header=None)

test = pd.read_csv('emnist-balanced-test.csv', header=None)

#train.head()

# Number of Train
numTrain = len(train)
# Number of Test
numTest = len(test)
# Number of Classes
numClasses = len(train[0].unique())

train_data = train.iloc[:, 1:]
train_labels = train.iloc[:, 0]
test_data = test.iloc[:, 1:]
test_labels = test.iloc[:, 0]
```

```python
# one-hot encoding
train_labels = pd.get_dummies(train_labels)
test_labels = pd.get_dummies(test_labels)
#train_labels.head()

train_data = train_data.values
train_labels = train_labels.values
test_data = test_data.values
test_labels = test_labels.values
#del train, test


rand = random.randint(0, numTrain - 1)


plt.imshow(
  train_data[rand].reshape([28, 28]),
  cmap='Greys'
  )
plt.show()


def rotate(image):
    image = image.reshape([28, 28])
    image = np.fliplr(image)
    image = np.rot90(image)
    return image.reshape([28 * 28])
train_data = np.apply_along_axis(rotate, 1, train_data)/255
test_data = np.apply_along_axis(rotate, 1, test_data)/255


plt.imshow(
  train_data[rand].reshape([28, 28]),
  cmap='Greys'
  )
plt.show()
```



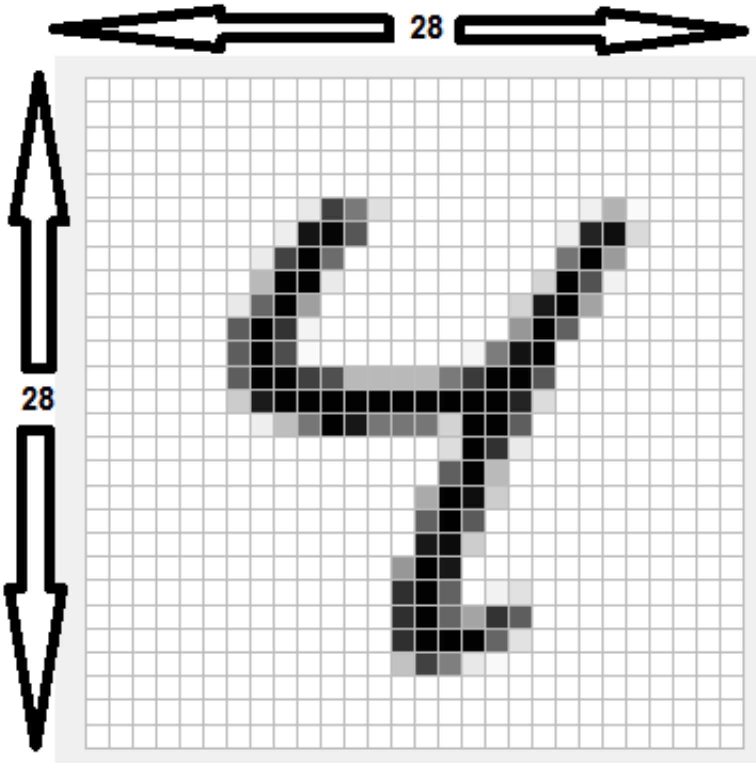


Algorithm

```
tf.set_random_seed(777)  # for reproducibility


tf.reset_default_graph()

# EMNIST data image of shape 28 * 28 = 784
X = tf.placeholder(tf.float32, [None, 784])
# 47 classes: 10 digits, 26 letters, and 11 capital letters
Y = tf.placeholder(tf.float32, [None, numClasses])
```

A given data have 28*28 image. So we need 784. Also, the data we are currently using has 47 classes, which includes 10 digits (0~9), 26 letters, and 11 capital letters.

tf.placeholder(tf.float32, [None, 784]): In the code, none means we can give the data we want




```
W = tf.Variable(tf.random_normal([784, numClasses]))
b = tf.Variable(tf.random_normal([numClasses]))

# Hypothesis (using softmax)
hypothesis = tf.nn.softmax(tf.matmul(X, W) + b)
```

```
WARNING:tensorflow:From /usr/local/lib/python3.6/dist-packages/tensorflow/pyt
Instructions for updating:
Colocations handled automatically by placer.
```

- W = tf.Variable(tf.random_normal([784, numClasses])): Input: 784, Output: numClasses, which indicates 47
- b = tf.Variable(tf.random_normal([numClasses])): Y size

Multinomial Classfication

$$W = \begin{bmatrix} w_{11} & w_{12} & \dots & w_{1n} \\ w_{21} & w_{22} & \dots & w_{2n} \\ \vdots & \vdots & \ddots & \vdots \\ w_{n1} & w_{n2} & \dots & w_{nn} \end{bmatrix}$$

$$X = \begin{bmatrix} x_1 \\ x_2 \\ \vdots \\ x_n \end{bmatrix}$$

Softmax

$$S(y_i) = \frac{e_i^y}{\sum_j e_i^y}$$

In sum, let's suppose y = XW

$$XW = y => \frac{e_i^y}{\sum_j e_i^y} => Probabilities$$

This is Softmax on Tensorflow. softmax(tf.matmul(X, W) + b). So, tf.nn.softmax computes softmax activations. We can say that

$$softmax = \frac{exp(logits)}{reduceSum(exp(logits), dim)}$$

$$cost(W) = -\frac{1}{m} \sum ylog(H(x)) + (1-y)log(1-H(x))$$

```
cost = tf.reduce_mean(-tf.reduce_sum(Y * tf.log(hypothesis), axis=1))
```

$$W = W - \alpha \frac{\partial}{\partial W} cost(W)$$

```
train = tf.train.GradientDescentOptimizer(learning_rate=0.1).minimize(cost)
```

```
WARNING:tensorflow:From /usr/local/lib/python3.6/dist-packages/tensorflow/pyt
Instructions for updating:
Use tf.cast instead.
```

```
# Test model
is_correct = tf.equal(tf.argmax(hypothesis, 1), tf.argmax(Y, 1))

# Calculate accuracy
accuracy = tf.reduce_mean(tf.cast(is_correct, tf.float32))
```

- is_correct = tf.equal(tf.argmax(hypothesis, 1), tf.argmax(Y, 1)): Hypothesis value and Y value are compared
- accuracy = tf.reduce_mean(tf.cast(is_correct, tf.float32)): Calculate average value of is_correct. This is accuracy

```
# parameters
num_epochs = 20
batch_size = 100
num_iterations = int( numTrain / batch_size)
```

- epoch = one forward pass and one backward pass of all the training examples
- batch size = Number of training examples in one forward/backward pass. The higher the batch size is, the more memory space you'll need is
- Number of iterations = number of passes, each pass using batch size number of examples. To be clear, one pass = one forward pass + one backward pass (we do not count the forward pass and backward pass as two different passes). [5]

```
batch_xs, batch_ys = train_data[i * 100: (i + 1) * 100], train_labels[i * 100: (i +
```

Training data can read 100 data at once.

```
_, cost_val = sess.run([train, cost], feed_dict={X: batch_xs, Y: batch_ys})
```

Calculate cost value using Optimization algorithm

```
# Test the model using test sets
    print(
        "Accuracy: ",
        accuracy.eval(
            session=sess, feed_dict={X: test_data, Y: test_labels}
        ),
    )
```

We use test data set which we haven't used before. So we evaluate test data set. Finally, we can calculate accuracy.

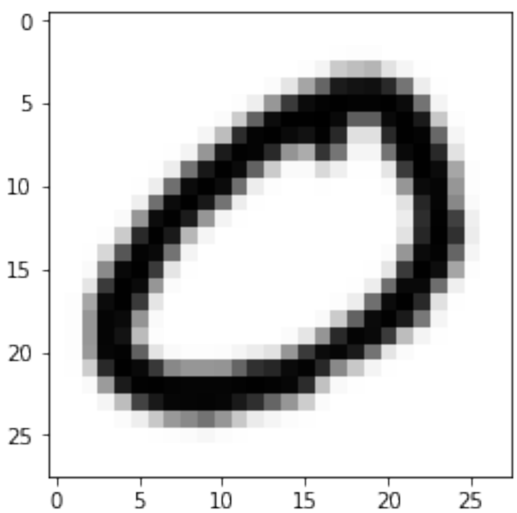
```
# Get Label and predict
    r = random.randint(0, numTest - 1)
    print("Label: ", sess.run(tf.argmax(test_labels[r : r + 1], 1)))
    print(
        "Prediction: ",
        sess.run(tf.argmax(hypothesis, 1), feed_dict={X: test_data[r : r + 1]}),
    )
```

1. Get Random value
2. Read one of test labels using argmax because we used one-hot encoding
3. For prediction, we will run hypothesis. And then, we will get the image which are the same as hypothesis.

```
with tf.Session() as sess:
    # Initialize TensorFlow variables
    sess.run(tf.global_variables_initializer())
    # Training
    for epoch in range(num_epochs):
        avg_cost = 0

        for i in range(num_iterations):
            batch_xs, batch_ys = train_data[i * 100: (i + 1) * 100], train_labels[i
            _, cost_val = sess.run([train, cost], feed_dict={X: batch_xs, Y: batch_
            avg_cost += cost_val / num_iterations

        print("Epoch: {:04d}, Cost: {:.9f}".format(epoch + 1, avg_cost))

    print("Learning finished")

    # Test the model using test sets
    print(
        "Accuracy: ",
        accuracy.eval(
            session=sess, feed_dict={X: test_data, Y: test_labels}
        ),
    )

    # Get Label and predict
    r = random.randint(0, numTest - 1)
    print("Label: ", sess.run(tf.argmax(test_labels[r : r + 1], 1)))
    print(
        "Prediction: ",
        sess.run(tf.argmax(hypothesis, 1), feed_dict={X: test_data[r : r + 1]}),
    )
```

```
plt.imshow(
    test_data[r : r + 1].reshape(28, 28),
    cmap="Greys",
    interpolation="nearest",
)
plt.show()
```

```
Epoch: 0001, Cost: 7.831361669
Epoch: 0002, Cost: 3.635979679
Epoch: 0003, Cost: 2.910056583
Epoch: 0004, Cost: 2.549824970
Epoch: 0005, Cost: 2.325167478
Epoch: 0006, Cost: 2.168853015
Epoch: 0007, Cost: 2.052359234
Epoch: 0008, Cost: 1.961268801
Epoch: 0009, Cost: 1.887505654
Epoch: 0010, Cost: 1.826184638
Epoch: 0011, Cost: 1.774160550
Epoch: 0012, Cost: 1.729304836
Epoch: 0013, Cost: 1.690116639
Epoch: 0014, Cost: 1.655501113
Epoch: 0015, Cost: 1.624637229
Epoch: 0016, Cost: 1.596895715
Epoch: 0017, Cost: 1.571785485
Epoch: 0018, Cost: 1.548917508
Epoch: 0019, Cost: 1.527979174
Epoch: 0020, Cost: 1.508715988
Learning finished
Accuracy:  0.6129255
Label:  [24]
Prediction:  [0]
```



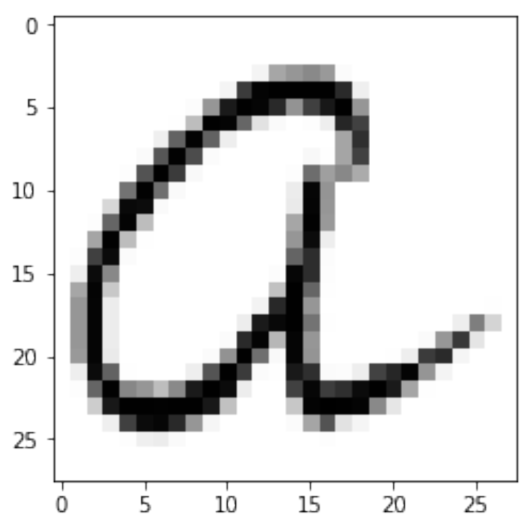
Code

Alphabet / Digits

```python
import numpy as np
import pandas as pd
import matplotlib.pyplot as plt
import random
import tensorflow as tf


train = pd.read_csv('emnist-balanced-train.csv', header=None)
#train = pd.read_csv('emnist-digits-train.csv', header=None)

test = pd.read_csv('emnist-balanced-test.csv', header=None)
#test = pd.read_csv('emnist-digits-test.csv', header=None)

#train.head()

# Number of Train
numTrain = len(train)
# Number of Test
numTest = len(test)
# Number of Classes
numClasses = len(train[0].unique())

train_data = train.iloc[:, 1:]
train_labels = train.iloc[:, 0]
test_data = test.iloc[:, 1:]
test_labels = test.iloc[:, 0]

# one-hot encoding
train_labels = pd.get_dummies(train_labels)
test_labels = pd.get_dummies(test_labels)
#train_labels.head()

train_data = train_data.values
train_labels = train_labels.values
test_data = test_data.values
test_labels = test_labels.values


rand = random.randint(0, numTrain - 1)

'''
plt.imshow(
  train_data[rand].reshape([28, 28]),
  cmap='Greys'
  )
plt.show()
'''


def rotate(image):
    image = image.reshape([28, 28])
    image = np.fliplr(image)
    image = np.rot90(image)
    return image.reshape([28 * 28])
train_data = np.apply_along_axis(rotate, 1, train_data)/255
test_data = np.apply_along_axis(rotate, 1, test_data)/255

'''
plt.imshow(
  train_data[rand].reshape([28, 28]),
  cmap='Greys'
  )
plt.show()
'''

tf.set_random_seed(777)  # for reproducibility
```

```python
tf.reset_default_graph()

# EMNIST data image of shape 28 * 28 = 784
X = tf.placeholder(tf.float32, [None, 784])
# 47 classes: 10 digits, 26 letters, and 11 capital letters
Y = tf.placeholder(tf.float32, [None, numClasses])

W = tf.Variable(tf.random_normal([784, numClasses]))
b = tf.Variable(tf.random_normal([numClasses]))

# Hypothesis (using softmax)
hypothesis = tf.nn.softmax(tf.matmul(X, W) + b)

cost = tf.reduce_mean(-tf.reduce_sum(Y * tf.log(hypothesis), axis=1))
train = tf.train.GradientDescentOptimizer(learning_rate=0.1).minimize(cost)

# Test model
is_correct = tf.equal(tf.argmax(hypothesis, 1), tf.argmax(Y, 1))

# Calculate accuracy
accuracy = tf.reduce_mean(tf.cast(is_correct, tf.float32))

# parameters
num_epochs = 20
batch_size = 100
num_iterations = int( numTrain / batch_size)

with tf.Session() as sess:
    # Initialize TensorFlow variables
    sess.run(tf.global_variables_initializer())
    # Training
    for epoch in range(num_epochs):
        avg_cost = 0

        for i in range(num_iterations):
            batch_xs, batch_ys = train_data[i * 100: (i + 1) * 100], train_labels[i
            _, cost_val = sess.run([train, cost], feed_dict={X: batch_xs, Y: batch_
            avg_cost += cost_val / num_iterations

        print("Epoch: {:04d}, Cost: {:.9f}".format(epoch + 1, avg_cost))

    print("Learning finished")

    # Test the model using test sets
    print(
        "Accuracy: ",
        accuracy.eval(
            session=sess, feed_dict={X: test_data, Y: test_labels}
        ),
    )

    # Get Label and predict
    r = random.randint(0, numTest - 1)
    print("Label: ", sess.run(tf.argmax(test_labels[r : r + 1], 1)))
    print(
        "Prediction: ",
        sess.run(tf.argmax(hypothesis, 1), feed_dict={X: test_data[r : r + 1]}),
    )

    plt.imshow(
        test_data[r : r + 1].reshape(28, 28),
        cmap="Greys",
        interpolation="nearest",
    )
    plt.show()
```

```
Epoch: 0001, Cost: 7.811212356
Epoch: 0002, Cost: 3.577890929
Epoch: 0003, Cost: 2.874251862
Epoch: 0004, Cost: 2.526106676
Epoch: 0005, Cost: 2.309650495
Epoch: 0006, Cost: 2.159337446
Epoch: 0007, Cost: 2.047290485
Epoch: 0008, Cost: 1.959520055
Epoch: 0009, Cost: 1.888236626
Epoch: 0010, Cost: 1.828750604
Epoch: 0011, Cost: 1.778055745
Epoch: 0012, Cost: 1.734127743
Epoch: 0013, Cost: 1.695548977
Epoch: 0014, Cost: 1.661293361
Epoch: 0015, Cost: 1.630596669
Epoch: 0016, Cost: 1.602875596
Epoch: 0017, Cost: 1.577675840
Epoch: 0018, Cost: 1.554637091
Epoch: 0019, Cost: 1.533469000
Epoch: 0020, Cost: 1.513934543
Learning finished
Accuracy:  0.6085106
Label:  [36]
Prediction:  [35]
```



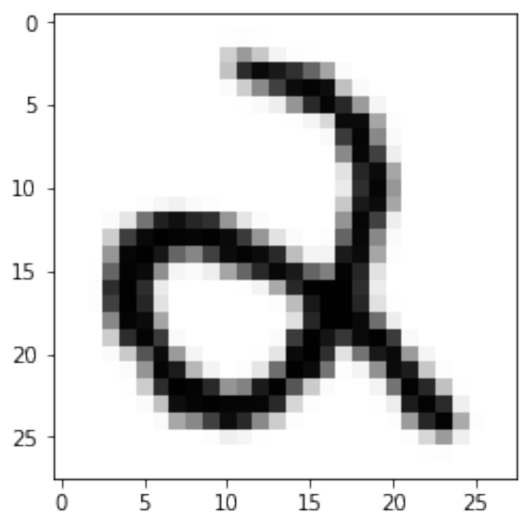
Digits

```
import numpy as np
import pandas as pd
import matplotlib.pyplot as plt
import random
import tensorflow as tf


#train = pd.read_csv('emnist-balanced-train.csv', header=None)
train = pd.read_csv('emnist-digits-train.csv', header=None)
```

```
#test = pd.read_csv('emnist-balanced-test.csv', header=None)
test = pd.read_csv('emnist-digits-test.csv', header=None)

#train.head()

# Number of Train
numTrain = len(train)
# Number of Test
numTest = len(test)
# Number of Classes
numClasses = len(train[0].unique())

train_data = train.iloc[:, 1:]
train_labels = train.iloc[:, 0]
test_data = test.iloc[:, 1:]
test_labels = test.iloc[:, 0]

# one-hot encoding
train_labels = pd.get_dummies(train_labels)
test_labels = pd.get_dummies(test_labels)
#train_labels.head()

train_data = train_data.values
train_labels = train_labels.values
test_data = test_data.values
test_labels = test_labels.values


rand = random.randint(0, numTrain - 1)

'''
plt.imshow(
  train_data[rand].reshape([28, 28]),
  cmap='Greys'
  )
plt.show()
'''

def rotate(image):
    image = image.reshape([28, 28])
    image = np.fliplr(image)
    image = np.rot90(image)
    return image.reshape([28 * 28])
train_data = np.apply_along_axis(rotate, 1, train_data)/255
test_data = np.apply_along_axis(rotate, 1, test_data)/255

'''
plt.imshow(
  train_data[rand].reshape([28, 28]),
  cmap='Greys'
  )
plt.show()
'''

tf.set_random_seed(777)  # for reproducibility
tf.reset_default_graph()

# EMNIST data image of shape 28 * 28 = 784
X = tf.placeholder(tf.float32, [None, 784])
# 47 classes: 10 digits, 26 letters, and 11 capital letters
Y = tf.placeholder(tf.float32, [None, numClasses])

W = tf.Variable(tf.random_normal([784, numClasses]))
b = tf.Variable(tf.random_normal([numClasses]))
```

```python
# Hypothesis (using softmax)
hypothesis = tf.nn.softmax(tf.matmul(X, W) + b)

cost = tf.reduce_mean(-tf.reduce_sum(Y * tf.log(hypothesis), axis=1))
train = tf.train.GradientDescentOptimizer(learning_rate=0.001).minimize(cost)

# Test model
is_correct = tf.equal(tf.argmax(hypothesis, 1), tf.argmax(Y, 1))

# Calculate accuracy
accuracy = tf.reduce_mean(tf.cast(is_correct, tf.float32))

# parameters
num_epochs = 20
batch_size = 100
num_iterations = int( numTrain / batch_size)

with tf.Session() as sess:
    # Initialize TensorFlow variables
    sess.run(tf.global_variables_initializer())
    # Training
    for epoch in range(num_epochs):
        avg_cost = 0

        for i in range(num_iterations):
            batch_xs, batch_ys = train_data[i * 100: (i + 1) * 100], train_labels[i
            _, cost_val = sess.run([train, cost], feed_dict={X: batch_xs, Y: batch_
            avg_cost += cost_val / num_iterations

        print("Epoch: {:04d}, Cost: {:.9f}".format(epoch + 1, avg_cost))

    print("Learning finished")

    # Test the model using test sets
    print(
        "Accuracy: ",
        accuracy.eval(
            session=sess, feed_dict={X: test_data, Y: test_labels}
        ),
    )

    # Get Label and predict
    r = random.randint(0, numTest - 1)
    print("Label: ", sess.run(tf.argmax(test_labels[r : r + 1], 1)))
    print(
        "Prediction: ",
        sess.run(tf.argmax(hypothesis, 1), feed_dict={X: test_data[r : r + 1]}),
    )

    plt.imshow(
        test_data[r : r + 1].reshape(28, 28),
        cmap="Greys",
        interpolation="nearest",
    )
    plt.show()
```

```
Epoch: 0001, Cost: 12.294879703
Epoch: 0002, Cost: 7.675846588
Epoch: 0003, Cost: 5.530997338
Epoch: 0004, Cost: 4.266942058
Epoch: 0005, Cost: 3.466805372
Epoch: 0006, Cost: 2.930163783
Epoch: 0007, Cost: 2.553369329
Epoch: 0008, Cost: 2.277840718
Epoch: 0009, Cost: 2.068908990
Epoch: 0010, Cost: 1.905354305
Epoch: 0011, Cost: 1.773776403
Epoch: 0012, Cost: 1.665476663
Epoch: 0013, Cost: 1.574621240
Epoch: 0014, Cost: 1.497164249
Epoch: 0015, Cost: 1.430218704
Epoch: 0016, Cost: 1.371676122
Epoch: 0017, Cost: 1.319963597
Epoch: 0018, Cost: 1.273884969
Epoch: 0019, Cost: 1.232514620
Epoch: 0020, Cost: 1.195125107
Learning finished
Accuracy:  0.7697
Label:  [2]
Prediction:  [6]
```



Neural Network

Load data

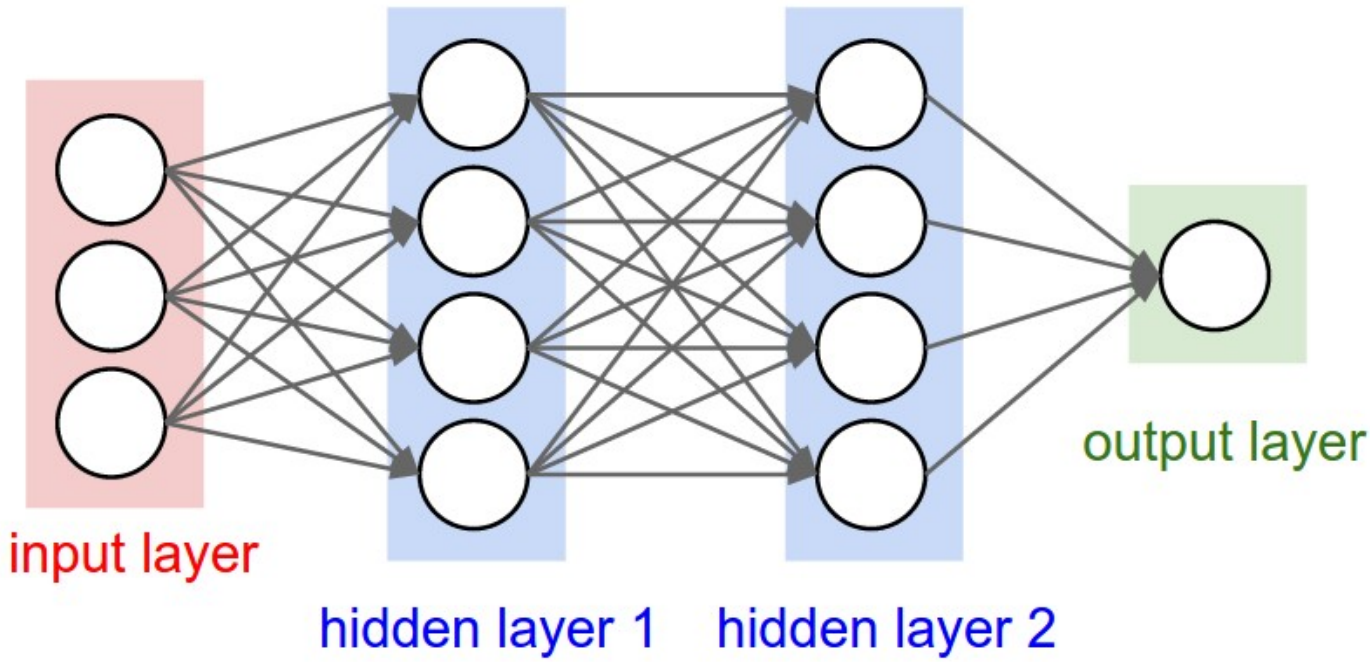
```python
import numpy as np
import pandas as pd
import matplotlib.pyplot as plt
import random
import tensorflow as tf
```

```
train = pd.read_csv('emnist-balanced-train.csv', header=None)
#train = pd.read_csv('emnist/emnist-digits-train.csv', header=None)

test = pd.read_csv('emnist-balanced-test.csv', header=None)
#test = pd.read_csv('emnist/emnist-digits-test.csv', header=None)

#train.head()

# Number of Train
numTrain = len(train)
# Number of Test
numTest = len(test)
# Number of Classes
numClasses = len(train[0].unique())
learning_rate = 0.001

train_data = train.iloc[:, 1:]
train_labels = train.iloc[:, 0]
test_data = test.iloc[:, 1:]
test_labels = test.iloc[:, 0]

# one-hot encoding
train_labels = pd.get_dummies(train_labels)
test_labels = pd.get_dummies(test_labels)
#train_labels.head()

train_data = train_data.values
train_labels = train_labels.values
test_data = test_data.values
test_labels = test_labels.values


rand = random.randint(0, numTrain - 1)

'''
plt.imshow(
  train_data[rand].reshape([28, 28]),
  cmap='Greys'
  )
plt.show()
'''

def rotate(image):
    image = image.reshape([28, 28])
    image = np.fliplr(image)
    image = np.rot90(image)
    return image.reshape([28 * 28])
train_data = np.apply_along_axis(rotate, 1, train_data)/255
test_data = np.apply_along_axis(rotate, 1, test_data)/255

'''
plt.imshow(
  train_data[rand].reshape([28, 28]),
  cmap='Greys'
  )
plt.show()
'''
```

The process of importing training data set and test data set is the same as softmax algorithm above

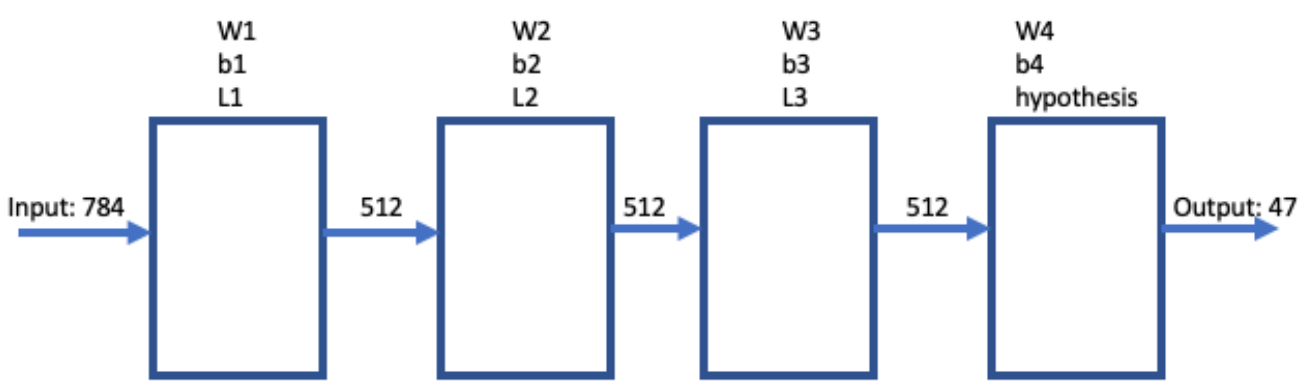
Algorithm

```
# EMNIST data image of shape 28 * 28 = 784
X = tf.placeholder(tf.float32, [None, 784])
# 47 classes: 10 digits, 26 letters, and 11 capital letters
Y = tf.placeholder(tf.float32, [None, numClasses])

W1 = tf.Variable(tf.random_normal([784, 512]))
b1 = tf.Variable(tf.random_normal([512]))
L1 = tf.nn.relu(tf.matmul(X, W1) + b1)

W2 = tf.Variable(tf.random_normal([512, 512]))
b2 = tf.Variable(tf.random_normal([512]))
L2 = tf.nn.relu(tf.matmul(L1, W2) + b2)

W3 = tf.Variable(tf.random_normal([512, 512]))
b3 = tf.Variable(tf.random_normal([512]))
L3 = tf.nn.relu(tf.matmul(L2, W3) + b3)

W4 = tf.Variable(tf.random_normal([512, numClasses]))
b4 = tf.Variable(tf.random_normal([numClasses]))
hypothesis = tf.matmul(L3, W4) + b4
```

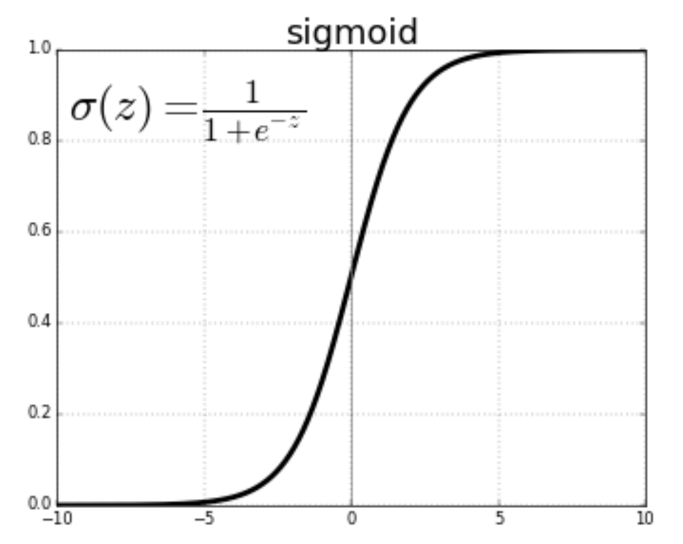


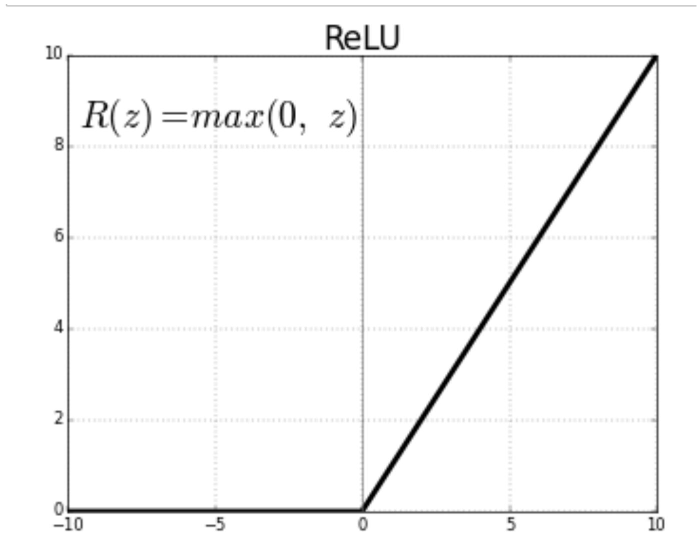
The figure[2] shows a regular 3-layer Neural Network. For the project, we are using 4-layer neural network. In other words, input layer in the code above is placeholders of X and Y. Input layer, which is a placeholder of X, is 784 because image size is 28*28. Output is 47, Y placeholder.

We have 3 hidden layers. First, hidden layer 1 (W1) has 784 inputs and 512 outputs. Hidden layers 2 and 3 have 512 inputs and 512 outpus. Since the output of hidden layer 1 is 512, we should have 512 inputs in hidden layer 2. Finally, we will get 47 outputs including 10 digits, 26 letters, and 11 capital letters. We use ReLU to calculate each layer.



ReLU: Rectified Linear Unit [4]






```
cost = tf.reduce_mean(tf.nn.softmax_cross_entropy_with_logits(logits=hypothesis, la
```

Computes softmax cross entropy between hypothesis(logits) and outputs(Y)

```
train = tf.train.AdamOptimizer(learning_rate=learning_rate).minimize(cost)
```

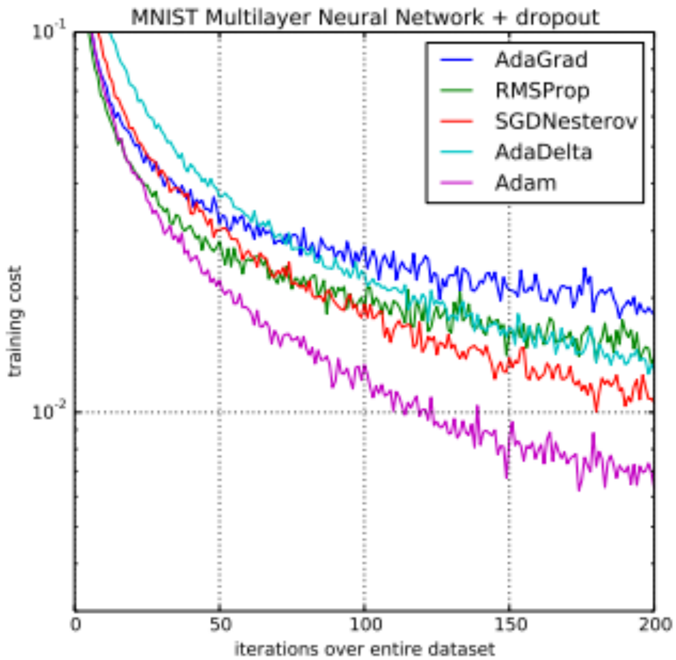
In softmax algoritm, we use GradientDescentOptimizer in order for train. However, in neural network, we use AdamOptimizer.

Here's interesting comparison in terms of optimization. The below site compares below optimazation algorithms

- SGD
- Momentum
- NAG
- Adagrad
- Adadelta
- RMSprop

http://www.denizyuret.com/2015/03/alec-radfords-animations-for.html

A reason why we use AdamOptimizer is that Adam shows the best optimization performance[3].



Tensorflow offers Adam optimization library. So we can use easily the adam optimization algorithm.
https://www.tensorflow.org/api_docs/python/tf/train/AdamOptimizer

Lastly, we will train and evaluate our training using accuracy. The code is the same as Softmax algorithm

Code

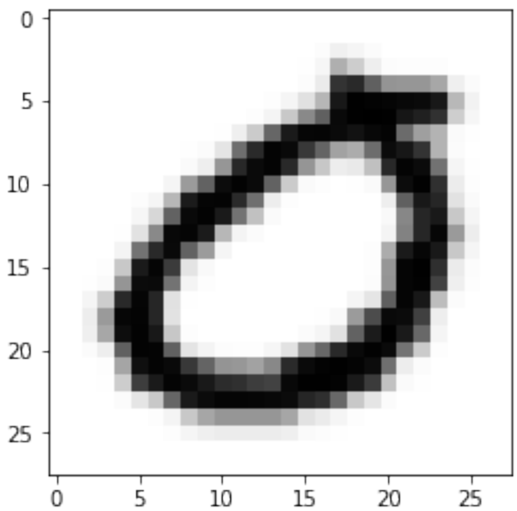
Alphabet / Digits

```
import numpy as np
import pandas as pd
import matplotlib.pyplot as plt
import random
import tensorflow as tf


train = pd.read_csv('emnist-balanced-train.csv', header=None)
#train = pd.read_csv('emnist/emnist-digits-train.csv', header=None)

test = pd.read_csv('emnist-balanced-test.csv', header=None)
#test = pd.read_csv('emnist/emnist-digits-test.csv', header=None)

#train.head()

# Number of Train
numTrain = len(train)
# Number of Test
numTest = len(test)
# Number of Classes
```

```python
numClasses = len(train[0].unique())
learning_rate = 0.001

train_data = train.iloc[:, 1:]
train_labels = train.iloc[:, 0]
test_data = test.iloc[:, 1:]
test_labels = test.iloc[:, 0]

# one-hot encoding
train_labels = pd.get_dummies(train_labels)
test_labels = pd.get_dummies(test_labels)
#train_labels.head()

train_data = train_data.values
train_labels = train_labels.values
test_data = test_data.values
test_labels = test_labels.values


rand = random.randint(0, numTrain - 1)

'''
plt.imshow(
  train_data[rand].reshape([28, 28]),
  cmap='Greys'
  )
plt.show()
'''

def rotate(image):
    image = image.reshape([28, 28])
    image = np.fliplr(image)
    image = np.rot90(image)
    return image.reshape([28 * 28])
train_data = np.apply_along_axis(rotate, 1, train_data)/255
test_data = np.apply_along_axis(rotate, 1, test_data)/255

'''
plt.imshow(
  train_data[rand].reshape([28, 28]),
  cmap='Greys'
  )
plt.show()
'''

tf.set_random_seed(777)  # for reproducibility
tf.reset_default_graph()

# EMNIST data image of shape 28 * 28 = 784
X = tf.placeholder(tf.float32, [None, 784])
# 47 classes: 10 digits, 26 letters, and 11 capital letters
Y = tf.placeholder(tf.float32, [None, numClasses])


W1 = tf.Variable(tf.random_normal([784, 512]))
b1 = tf.Variable(tf.random_normal([512]))
L1 = tf.nn.relu(tf.matmul(X, W1) + b1)

W2 = tf.Variable(tf.random_normal([512, 512]))
b2 = tf.Variable(tf.random_normal([512]))
L2 = tf.nn.relu(tf.matmul(L1, W2) + b2)

W3 = tf.Variable(tf.random_normal([512, 512]))
b3 = tf.Variable(tf.random_normal([512]))
L3 = tf.nn.relu(tf.matmul(L2, W3) + b3)
```

```
W4 = tf.Variable(tf.random_normal([512, numClasses]))
b4 = tf.Variable(tf.random_normal([numClasses]))
hypothesis = tf.matmul(L3, W4) + b4

# cost & train
cost = tf.reduce_mean(tf.nn.softmax_cross_entropy_with_logits(logits=hypothesis, la
train = tf.train.AdamOptimizer(learning_rate=learning_rate).minimize(cost)


# parameters
num_epochs = 15
batch_size = 100
print('numTrain: ', numTrain)
num_iterations = int( numTrain / batch_size)

with tf.Session() as sess:
    # Initialize TensorFlow variables
    sess.run(tf.global_variables_initializer())
    # Training
    for epoch in range(num_epochs):
        avg_cost = 0

        for i in range(num_iterations):
            batch_xs, batch_ys = train_data[i * 100: (i + 1) * 100], train_labels[i
            _, cost_val = sess.run([train, cost], feed_dict={X: batch_xs, Y: batch_
            avg_cost += cost_val / num_iterations

        print("Epoch: {:04d}, Cost: {:.9f}".format(epoch + 1, avg_cost))

    print("Learning finished")

    # Test model
    is_correct = tf.equal(tf.argmax(hypothesis, 1), tf.argmax(Y, 1))

    # Calculate accuracy
    accuracy = tf.reduce_mean(tf.cast(is_correct, tf.float32))

    # Test the model using test sets
    print("Accuracy: ", sess.run(accuracy, feed_dict={X: test_data, Y: test_labels}

    # Get Label and predict
    r = random.randint(0, numTest - 1)
    print("Label: ", sess.run(tf.argmax(test_labels[r : r + 1], 1)))
    print(
        "Prediction: ",
        sess.run(tf.argmax(hypothesis, 1), feed_dict={X: test_data[r : r + 1]}),
    )

    plt.imshow(
        test_data[r : r + 1].reshape(28, 28),
        cmap="Greys",
        interpolation="nearest",
    )
    plt.show()
```

```
numTrain:  112800
Epoch: 0001, Cost: 8642.529711351
Epoch: 0002, Cost: 2481.713991206
Epoch: 0003, Cost: 1461.960102920
Epoch: 0004, Cost: 983.205817202
Epoch: 0005, Cost: 699.275430531
Epoch: 0006, Cost: 514.055722013
Epoch: 0007, Cost: 382.135182009
Epoch: 0008, Cost: 290.110750185
Epoch: 0009, Cost: 223.293022807
Epoch: 0010, Cost: 173.172536803
Epoch: 0011, Cost: 138.131260886
Epoch: 0012, Cost: 109.862700687
Epoch: 0013, Cost: 90.336773301
Epoch: 0014, Cost: 74.091697410
Epoch: 0015, Cost: 63.775216297
Learning finished
Accuracy:  0.6993085
Label:  [0]
Prediction:  [24]
```



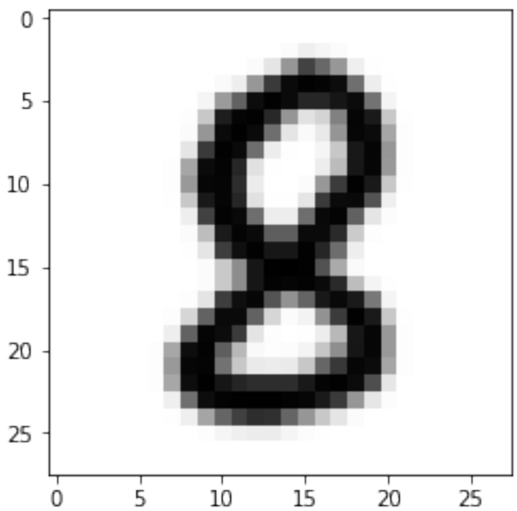
Digits

```python
import numpy as np
import pandas as pd
import matplotlib.pyplot as plt
import random
import tensorflow as tf


#train = pd.read_csv('emnist-balanced-train.csv', header=None)
train = pd.read_csv('emnist-digits-train.csv', header=None)

#test = pd.read_csv('emnist-balanced-test.csv', header=None)
test = pd.read_csv('emnist-digits-test.csv', header=None)

#train.head()

# Number of Train
```

```
numTrain = len(train)
# Number of Test
numTest = len(test)
# Number of Classes
numClasses = len(train[0].unique())
learning_rate = 0.001

train_data = train.iloc[:, 1:]
train_labels = train.iloc[:, 0]
test_data = test.iloc[:, 1:]
test_labels = test.iloc[:, 0]

# one-hot encoding
train_labels = pd.get_dummies(train_labels)
test_labels = pd.get_dummies(test_labels)
#train_labels.head()

train_data = train_data.values
train_labels = train_labels.values
test_data = test_data.values
test_labels = test_labels.values


rand = random.randint(0, numTrain - 1)

'''
plt.imshow(
  train_data[rand].reshape([28, 28]),
  cmap='Greys'
  )
plt.show()
'''


def rotate(image):
    image = image.reshape([28, 28])
    image = np.fliplr(image)
    image = np.rot90(image)
    return image.reshape([28 * 28])
train_data = np.apply_along_axis(rotate, 1, train_data)/255
test_data = np.apply_along_axis(rotate, 1, test_data)/255

'''
plt.imshow(
  train_data[rand].reshape([28, 28]),
  cmap='Greys'
  )
plt.show()
'''

tf.set_random_seed(777)  # for reproducibility
tf.reset_default_graph()

# EMNIST data image of shape 28 * 28 = 784
X = tf.placeholder(tf.float32, [None, 784])
# 47 classes: 10 digits, 26 letters, and 11 capital letters
Y = tf.placeholder(tf.float32, [None, numClasses])


W1 = tf.Variable(tf.random_normal([784, 512]))
b1 = tf.Variable(tf.random_normal([512]))
L1 = tf.nn.relu(tf.matmul(X, W1) + b1)

W2 = tf.Variable(tf.random_normal([512, 512]))
b2 = tf.Variable(tf.random_normal([512]))
L2 = tf.nn.relu(tf.matmul(L1, W2) + b2)
```

```
W3 = tf.Variable(tf.random_normal([512, 512]))
b3 = tf.Variable(tf.random_normal([512]))
L3 = tf.nn.relu(tf.matmul(L2, W3) + b3)

W4 = tf.Variable(tf.random_normal([512, numClasses]))
b4 = tf.Variable(tf.random_normal([numClasses]))
hypothesis = tf.matmul(L3, W4) + b4

# cost & train
cost = tf.reduce_mean(tf.nn.softmax_cross_entropy_with_logits(logits=hypothesis, la
train = tf.train.AdamOptimizer(learning_rate=learning_rate).minimize(cost)


# parameters
num_epochs = 15
batch_size = 100
print('numTrain: ', numTrain)
num_iterations = int( numTrain / batch_size)

with tf.Session() as sess:
    # Initialize TensorFlow variables
    sess.run(tf.global_variables_initializer())
    # Training
    for epoch in range(num_epochs):
        avg_cost = 0

        for i in range(num_iterations):
            batch_xs, batch_ys = train_data[i * 100: (i + 1) * 100], train_labels[i
            _, cost_val = sess.run([train, cost], feed_dict={X: batch_xs, Y: batch_
            avg_cost += cost_val / num_iterations

        print("Epoch: {:04d}, Cost: {:.9f}".format(epoch + 1, avg_cost))

    print("Learning finished")

    # Test model
    is_correct = tf.equal(tf.argmax(hypothesis, 1), tf.argmax(Y, 1))

    # Calculate accuracy
    accuracy = tf.reduce_mean(tf.cast(is_correct, tf.float32))

    # Test the model using test sets
    print("Accuracy: ", sess.run(accuracy, feed_dict={X: test_data, Y: test_labels}

    # Get Label and predict
    r = random.randint(0, numTest - 1)
    print("Label: ", sess.run(tf.argmax(test_labels[r : r + 1], 1)))
    print(
        "Prediction: ",
        sess.run(tf.argmax(hypothesis, 1), feed_dict={X: test_data[r : r + 1]}),
    )

    plt.imshow(
        test_data[r : r + 1].reshape(28, 28),
        cmap="Greys",
        interpolation="nearest",
    )
    plt.show()
```

```
numTrain:  240000
Epoch: 0001, Cost: 1254.097743122
Epoch: 0002, Cost: 246.871940774
Epoch: 0003, Cost: 137.709690004
Epoch: 0004, Cost: 86.881786227
Epoch: 0005, Cost: 59.710167026
Epoch: 0006, Cost: 44.622771997
Epoch: 0007, Cost: 35.687775417
Epoch: 0008, Cost: 27.622199425
Epoch: 0009, Cost: 24.814995090
Epoch: 0010, Cost: 21.613631717
Epoch: 0011, Cost: 19.230210329
Epoch: 0012, Cost: 17.108183406
Epoch: 0013, Cost: 15.746177453
Epoch: 0014, Cost: 14.488535248
Epoch: 0015, Cost: 13.864103281
Learning finished
Accuracy:  0.9823
Label:  [8]
Prediction:  [8]
```



Xavier Initialization

Load data

```
import numpy as np
import pandas as pd
import matplotlib.pyplot as plt
import random
import tensorflow as tf
```

```
train = pd.read_csv('emnist-balanced-train.csv', header=None)
#train = pd.read_csv('emnist/emnist-digits-train.csv', header=None)
```

```
test = pd.read_csv('emnist-balanced-test.csv', header=None)
#test = pd.read_csv('emnist/emnist-digits-test.csv', header=None)

#train.head()

# Number of Train
numTrain = len(train)
# Number of Test
numTest = len(test)
# Number of Classes
numClasses = len(train[0].unique())
learning_rate = 0.001

train_data = train.iloc[:, 1:]
train_labels = train.iloc[:, 0]
test_data = test.iloc[:, 1:]
test_labels = test.iloc[:, 0]

# one-hot encoding
train_labels = pd.get_dummies(train_labels)
test_labels = pd.get_dummies(test_labels)
#train_labels.head()

train_data = train_data.values
train_labels = train_labels.values
test_data = test_data.values
test_labels = test_labels.values


rand = random.randint(0, numTrain - 1)

'''
plt.imshow(
  train_data[rand].reshape([28, 28]),
  cmap='Greys'
  )
plt.show()
'''

def rotate(image):
    image = image.reshape([28, 28])
    image = np.fliplr(image)
    image = np.rot90(image)
    return image.reshape([28 * 28])
train_data = np.apply_along_axis(rotate, 1, train_data)/255
test_data = np.apply_along_axis(rotate, 1, test_data)/255

'''
plt.imshow(
  train_data[rand].reshape([28, 28]),
  cmap='Greys'
  )
plt.show()
'''
```

The process of importing training data set and test data set is the same as softmax algorithm above. The initial value at first is very important to train the data set. That is, we should make sure the weights are just right, not too small, and not too big.

Algorithm

```
# EMNIST data image of shape 28 * 28 = 784
X = tf.placeholder(tf.float32, [None, 784])
# 47 classes: 10 digits, 26 letters, and 11 capital letters
Y = tf.placeholder(tf.float32, [None, numClasses])


# weights & bias for nn layers
W1 = tf.get_variable("W1", shape=[784, 512], initializer=tf.contrib.layers.xavier_i
b1 = tf.Variable(tf.random_normal([512]))
L1 = tf.nn.relu(tf.matmul(X, W1) + b1)

W2 = tf.get_variable("W2", shape=[512, 512], initializer=tf.contrib.layers.xavier_i
b2 = tf.Variable(tf.random_normal([512]))
L2 = tf.nn.relu(tf.matmul(L1, W2) + b2)

W3 = tf.get_variable("W3", shape=[512, 512], initializer=tf.contrib.layers.xavier_i
b3 = tf.Variable(tf.random_normal([512]))
L3 = tf.nn.relu(tf.matmul(L2, W3) + b3)

W4 = tf.get_variable("W4", shape=[512, numClasses], initializer=tf.contrib.layers.x
b4 = tf.Variable(tf.random_normal([numClasses]))
hypothesis = tf.matmul(L3, W4) + b4
```

Basic algorithm is the same as Neural Network above. A difference between Xavier algorithm and Neural Network is an initialization value [6]. Input and output are randomly provided like below.

```
np.random.randn(input, output)/np.sqrt(input)
```

Google implemented prettytensor for Xavier initialization[7]. However, fortunately, tensorflow offers Xavier initialization library. So we use the library in hidden layer 1, 2, and 3.

```
W1 = tf.get_variable("W1", shape=[784, 512], initializer=tf.contrib.layers.xavier_i
W2 = tf.get_variable("W2", shape=[512, 512], initializer=tf.contrib.layers.xavier_i
W3 = tf.get_variable("W3", shape=[512, 512], initializer=tf.contrib.layers.xavier_i
W4 = tf.get_variable("W4", shape=[512, numClasses], initializer=tf.contrib.layers.x
```

Lastly, we use identical cost and Adam optimization like neural networks and then train and evaluate our training using accuracy. The code is the same as above.

Cost values of Xavier are much lower than cost values of neural networks

Code

Alphabet / Digits

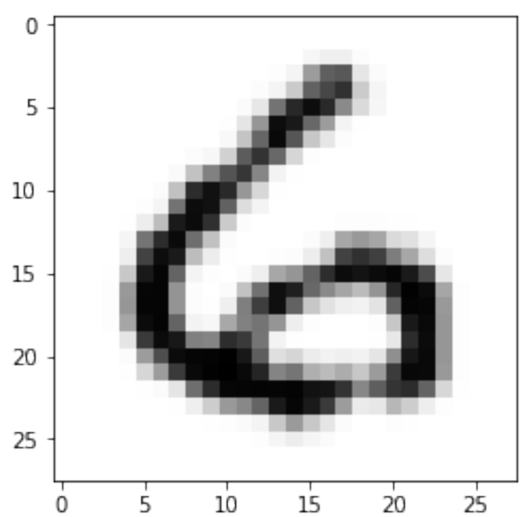
```
import numpy as np
```

```python
import pandas as pd
import matplotlib.pyplot as plt
import random
import tensorflow as tf


train = pd.read_csv('emnist-balanced-train.csv', header=None)
#train = pd.read_csv('emnist/emnist-digits-train.csv', header=None)

test = pd.read_csv('emnist-balanced-test.csv', header=None)
#test = pd.read_csv('emnist/emnist-digits-test.csv', header=None)

#train.head()

# Number of Train
numTrain = len(train)
# Number of Test
numTest = len(test)
# Number of Classes
numClasses = len(train[0].unique())
learning_rate = 0.001

train_data = train.iloc[:, 1:]
train_labels = train.iloc[:, 0]
test_data = test.iloc[:, 1:]
test_labels = test.iloc[:, 0]

# one-hot encoding
train_labels = pd.get_dummies(train_labels)
test_labels = pd.get_dummies(test_labels)
#train_labels.head()

train_data = train_data.values
train_labels = train_labels.values
test_data = test_data.values
test_labels = test_labels.values


rand = random.randint(0, numTrain - 1)

'''
plt.imshow(
  train_data[rand].reshape([28, 28]),
  cmap='Greys'
  )
plt.show()
'''

def rotate(image):
    image = image.reshape([28, 28])
    image = np.fliplr(image)
    image = np.rot90(image)
    return image.reshape([28 * 28])
train_data = np.apply_along_axis(rotate, 1, train_data)/255
test_data = np.apply_along_axis(rotate, 1, test_data)/255

'''
plt.imshow(
  train_data[rand].reshape([28, 28]),
  cmap='Greys'
  )
plt.show()
'''

tf.set_random_seed(777)  # for reproducibility
```

```python
tf.reset_default_graph()

# EMNIST data image of shape 28 * 28 = 784
X = tf.placeholder(tf.float32, [None, 784])
# 47 classes: 10 digits, 26 letters, and 11 capital letters
Y = tf.placeholder(tf.float32, [None, numClasses])


# weights & bias for nn layers
W1 = tf.get_variable("W1", shape=[784, 512], initializer=tf.contrib.layers.xavier_i
b1 = tf.Variable(tf.random_normal([512]))
L1 = tf.nn.relu(tf.matmul(X, W1) + b1)

W2 = tf.get_variable("W2", shape=[512, 512], initializer=tf.contrib.layers.xavier_i
b2 = tf.Variable(tf.random_normal([512]))
L2 = tf.nn.relu(tf.matmul(L1, W2) + b2)

W3 = tf.get_variable("W3", shape=[512, 512], initializer=tf.contrib.layers.xavier_i
b3 = tf.Variable(tf.random_normal([512]))
L3 = tf.nn.relu(tf.matmul(L2, W3) + b3)

W4 = tf.get_variable("W4", shape=[512, numClasses], initializer=tf.contrib.layers.x
b4 = tf.Variable(tf.random_normal([numClasses]))
hypothesis = tf.matmul(L3, W4) + b4

# cost & train
cost = tf.reduce_mean(tf.nn.softmax_cross_entropy_with_logits(logits=hypothesis, la
train = tf.train.AdamOptimizer(learning_rate=learning_rate).minimize(cost)


# parameters
num_epochs = 15
batch_size = 100
print('numTrain: ', numTrain)
num_iterations = int( numTrain / batch_size)

with tf.Session() as sess:
    # Initialize TensorFlow variables
    sess.run(tf.global_variables_initializer())
    # Training
    for epoch in range(num_epochs):
        avg_cost = 0

        for i in range(num_iterations):
            batch_xs, batch_ys = train_data[i * 100: (i + 1) * 100], train_labels[i
            _, cost_val = sess.run([train, cost], feed_dict={X: batch_xs, Y: batch_
            avg_cost += cost_val / num_iterations

        print("Epoch: {:04d}, Cost: {:.9f}".format(epoch + 1, avg_cost))

    print("Learning finished")

    # Test model
    is_correct = tf.equal(tf.argmax(hypothesis, 1), tf.argmax(Y, 1))

    # Calculate accuracy
    accuracy = tf.reduce_mean(tf.cast(is_correct, tf.float32))

    # Test the model using test sets
    print("Accuracy: ", sess.run(accuracy, feed_dict={X: test_data, Y: test_labels}


    # Get Label and predict
    r = random.randint(0, numTest - 1)
    print("Label: ", sess.run(tf.argmax(test_labels[r : r + 1], 1)))
```

```python
print(
    "Prediction: ",
    sess.run(tf.argmax(hypothesis, 1), feed_dict={X: test_data[r : r + 1]}),
)

plt.imshow(
    test_data[r : r + 1].reshape(28, 28),
    cmap="Greys",
    interpolation="nearest",
)
plt.show()
```

```
WARNING: The TensorFlow contrib module will not be included in TensorFlow 2.(
For more information, please see:
  * https://github.com/tensorflow/community/blob/master/rfcs/20180907-contrib
  * https://github.com/tensorflow/addons
If you depend on functionality not listed there, please file an issue.

numTrain:  112800
Epoch: 0001, Cost: 0.922173137
Epoch: 0002, Cost: 0.501473968
Epoch: 0003, Cost: 0.411888543
Epoch: 0004, Cost: 0.357318249
Epoch: 0005, Cost: 0.319102287
Epoch: 0006, Cost: 0.288661301
Epoch: 0007, Cost: 0.262170818
Epoch: 0008, Cost: 0.242621696
Epoch: 0009, Cost: 0.229773155
Epoch: 0010, Cost: 0.212708886
Epoch: 0011, Cost: 0.199395352
Epoch: 0012, Cost: 0.196674012
Epoch: 0013, Cost: 0.183474308
Epoch: 0014, Cost: 0.173996904
Epoch: 0015, Cost: 0.170004412
Learning finished
Accuracy:  0.8368085
Label:  [6]
Prediction:  [6]
```



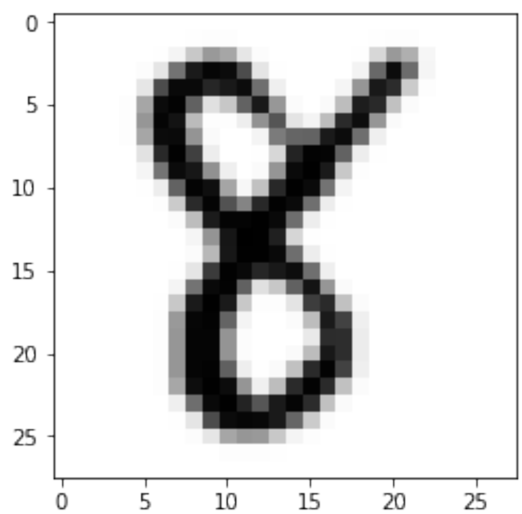
Digits

```
import numpy as np
import pandas as pd
import matplotlib.pyplot as plt
import random
import tensorflow as tf


#train = pd.read_csv('emnist-balanced-train.csv', header=None)
train = pd.read_csv('emnist-digits-train.csv', header=None)

#test = pd.read_csv('emnist-balanced-test.csv', header=None)
test = pd.read_csv('emnist-digits-test.csv', header=None)

#train.head()

# Number of Train
numTrain = len(train)
# Number of Test
numTest = len(test)
# Number of Classes
numClasses = len(train[0].unique())
learning_rate = 0.001

train_data = train.iloc[:, 1:]
train_labels = train.iloc[:, 0]
test_data = test.iloc[:, 1:]
test_labels = test.iloc[:, 0]

# one-hot encoding
train_labels = pd.get_dummies(train_labels)
test_labels = pd.get_dummies(test_labels)
#train_labels.head()

train_data = train_data.values
train_labels = train_labels.values
test_data = test_data.values
test_labels = test_labels.values


rand = random.randint(0, numTrain - 1)

'''
plt.imshow(
  train_data[rand].reshape([28, 28]),
  cmap='Greys'
  )
plt.show()
'''

def rotate(image):
    image = image.reshape([28, 28])
    image = np.fliplr(image)
    image = np.rot90(image)
    return image.reshape([28 * 28])
train_data = np.apply_along_axis(rotate, 1, train_data)/255
test_data = np.apply_along_axis(rotate, 1, test_data)/255

'''
plt.imshow(
  train_data[rand].reshape([28, 28]),
```

```
  cmap='Greys'
  )
plt.show()
'''

tf.set_random_seed(777)  # for reproducibility
tf.reset_default_graph()

# EMNIST data image of shape 28 * 28 = 784
X = tf.placeholder(tf.float32, [None, 784])
# 47 classes: 10 digits, 26 letters, and 11 capital letters
Y = tf.placeholder(tf.float32, [None, numClasses])


# weights & bias for nn layers
W1 = tf.get_variable("W1", shape=[784, 512], initializer=tf.contrib.layers.xavier_i
b1 = tf.Variable(tf.random_normal([512]))
L1 = tf.nn.relu(tf.matmul(X, W1) + b1)

W2 = tf.get_variable("W2", shape=[512, 512], initializer=tf.contrib.layers.xavier_i
b2 = tf.Variable(tf.random_normal([512]))
L2 = tf.nn.relu(tf.matmul(L1, W2) + b2)

W3 = tf.get_variable("W3", shape=[512, 512], initializer=tf.contrib.layers.xavier_i
b3 = tf.Variable(tf.random_normal([512]))
L3 = tf.nn.relu(tf.matmul(L2, W3) + b3)

W4 = tf.get_variable("W4", shape=[512, numClasses], initializer=tf.contrib.layers.x
b4 = tf.Variable(tf.random_normal([numClasses]))
hypothesis = tf.matmul(L3, W4) + b4

# cost & train
cost = tf.reduce_mean(tf.nn.softmax_cross_entropy_with_logits(logits=hypothesis, la
train = tf.train.AdamOptimizer(learning_rate=learning_rate).minimize(cost)


# parameters
num_epochs = 15
batch_size = 100
print('numTrain: ', numTrain)
num_iterations = int( numTrain / batch_size)

with tf.Session() as sess:
    # Initialize TensorFlow variables
    sess.run(tf.global_variables_initializer())
    # Training
    for epoch in range(num_epochs):
        avg_cost = 0

        for i in range(num_iterations):
            batch_xs, batch_ys = train_data[i * 100: (i + 1) * 100], train_labels[i
            _, cost_val = sess.run([train, cost], feed_dict={X: batch_xs, Y: batch_
            avg_cost += cost_val / num_iterations

        print("Epoch: {:04d}, Cost: {:.9f}".format(epoch + 1, avg_cost))

    print("Learning finished")

    # Test model
    is_correct = tf.equal(tf.argmax(hypothesis, 1), tf.argmax(Y, 1))

    # Calculate accuracy
    accuracy = tf.reduce_mean(tf.cast(is_correct, tf.float32))

    # Test the model using test sets
```

```
print("Accuracy: ", sess.run(accuracy, feed_dict={X: test_data, Y: test_labels}


# Get Label and predict
r = random.randint(0, numTest - 1)
print("Label: ", sess.run(tf.argmax(test_labels[r : r + 1], 1)))
print(
    "Prediction: ",
    sess.run(tf.argmax(hypothesis, 1), feed_dict={X: test_data[r : r + 1]}),
)

plt.imshow(
    test_data[r : r + 1].reshape(28, 28),
    cmap="Greys",
    interpolation="nearest",
)
plt.show()
```

```
numTrain:  240000
Epoch: 0001, Cost: 0.112610524
Epoch: 0002, Cost: 0.047038741
Epoch: 0003, Cost: 0.035235770
Epoch: 0004, Cost: 0.028168916
Epoch: 0005, Cost: 0.023147189
Epoch: 0006, Cost: 0.020137726
Epoch: 0007, Cost: 0.018170127
Epoch: 0008, Cost: 0.016829032
Epoch: 0009, Cost: 0.015006357
Epoch: 0010, Cost: 0.014536648
Epoch: 0011, Cost: 0.013235325
Epoch: 0012, Cost: 0.012501067
Epoch: 0013, Cost: 0.012648829
Epoch: 0014, Cost: 0.011626684
Epoch: 0015, Cost: 0.010933093
Learning finished
Accuracy:  0.988775
Label:  [8]
Prediction:  [8]
```



Dropout

Load data

```
import numpy as np
import pandas as pd
import matplotlib.pyplot as plt
import random
import tensorflow as tf


train = pd.read_csv('emnist-balanced-train.csv', header=None)
#train = pd.read_csv('emnist/emnist-digits-train.csv', header=None)

test = pd.read_csv('emnist-balanced-test.csv', header=None)
#test = pd.read_csv('emnist/emnist-digits-test.csv', header=None)

#train.head()

# Number of Train
numTrain = len(train)
# Number of Test
numTest = len(test)
# Number of Classes
numClasses = len(train[0].unique())
learning_rate = 0.001

train_data = train.iloc[:, 1:]
train_labels = train.iloc[:, 0]
test_data = test.iloc[:, 1:]
test_labels = test.iloc[:, 0]

# one-hot encoding
train_labels = pd.get_dummies(train_labels)
test_labels = pd.get_dummies(test_labels)
#train_labels.head()

train_data = train_data.values
train_labels = train_labels.values
test_data = test_data.values
test_labels = test_labels.values


rand = random.randint(0, numTrain - 1)

'''
plt.imshow(
  train_data[rand].reshape([28, 28]),
  cmap='Greys'
  )
plt.show()
'''

def rotate(image):
    image = image.reshape([28, 28])
    image = np.fliplr(image)
    image = np.rot90(image)
    return image.reshape([28 * 28])
```

```
train_data = np.apply_along_axis(rotate, 1, train_data)/255
test_data = np.apply_along_axis(rotate, 1, test_data)/255

'''
plt.imshow(
  train_data[rand].reshape([28, 28]),
  cmap='Greys'
  )
plt.show()
'''
```

The process of importing training data set and test data set is the same as above

Algorithm

```
# dropout (keep_prob) rate
keep_prob = tf.placeholder(tf.float32)

# weights & bias for nn layers
W1 = tf.get_variable("W1", shape=[784, 512], initializer=tf.contrib.layers.xavier_i
b1 = tf.Variable(tf.random_normal([512]))
L1 = tf.nn.relu(tf.matmul(X, W1) + b1)
L1 = tf.nn.dropout(L1, keep_prob=keep_prob)

W2 = tf.get_variable("W2", shape=[512, 512], initializer=tf.contrib.layers.xavier_i
b2 = tf.Variable(tf.random_normal([512]))
L2 = tf.nn.relu(tf.matmul(L1, W2) + b2)
L2 = tf.nn.dropout(L2, keep_prob=keep_prob)

W3 = tf.get_variable("W3", shape=[512, 512], initializer=tf.contrib.layers.xavier_i
b3 = tf.Variable(tf.random_normal([512]))
L3 = tf.nn.relu(tf.matmul(L2, W3) + b3)
L3 = tf.nn.dropout(L3, keep_prob=keep_prob)

W4 = tf.get_variable("W4", shape=[512, numClasses], initializer=tf.contrib.layers.x
b4 = tf.Variable(tf.random_normal([numClasses]))
hypothesis = tf.matmul(L3, W4) + b4
```

We use dropout like below[8].

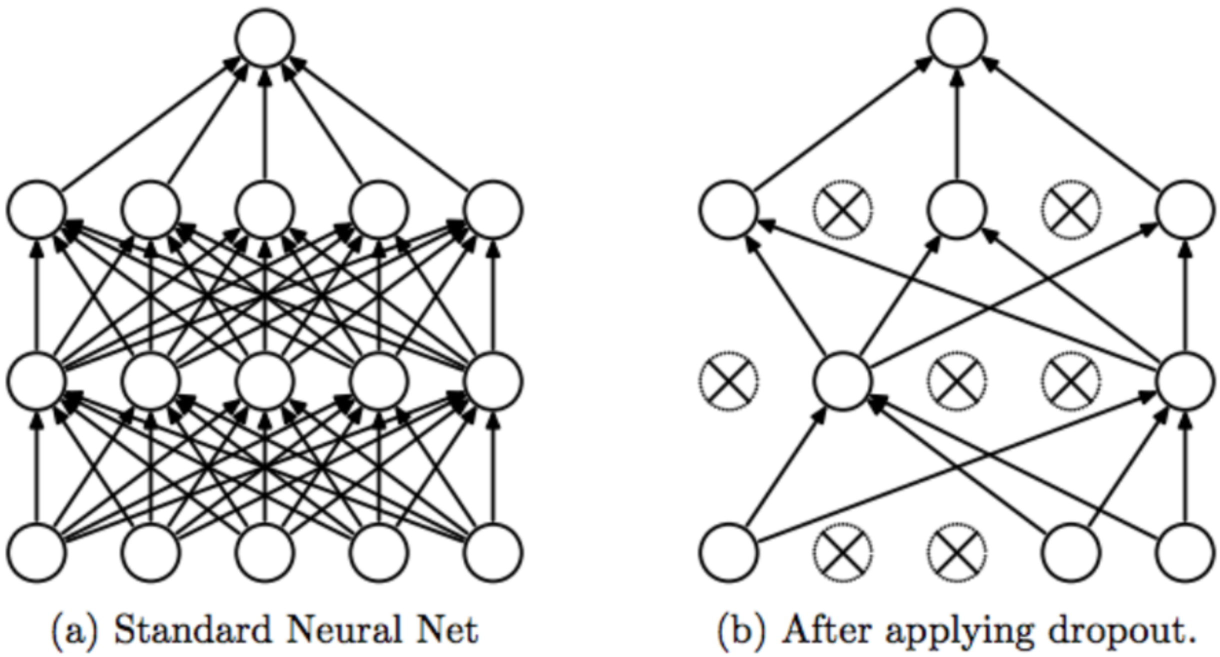


Figure (a) shows general neural networks. Figure (b) indicates dropout which means that nodes are randomly disconnected. So, we should set randomly some neurons to zero in the forword pass. This avoids overfitting because networks can memorize training data set while training. We use dropout when we train data set. However, when we test data set, we should not apply dropout to the networks. If we use dropout during the test, we can't evaluate our training dataset well.

```
L1 = tf.nn.dropout(L1, keep_prob=keep_prob)
L2 = tf.nn.dropout(L2, keep_prob=keep_prob)
L3 = tf.nn.dropout(L3, keep_prob=keep_prob)
```

In order to implement dropout, we can add only one line due to tensorflow library. In the code, input is L1/L2/L3 and output is also L1/L2/L3. keep_prob means how much networks keep. According to what we study, 50%~70% of networks are kept while training.

Training

Training code is very similar to neural networks and Xavier except for keep_prob. Since we use dropout, we should add keep_prob when we train and test data set.

```
_, cost_val = sess.run([train, cost], feed_dict={X: batch_xs, Y: batch_ys, keep_pro
```

We would like to keep 70% of networks while training. Therefore, keep_prob: 0.7 in the code above during training.

Testing

Without keep_prob, the code is almost identical with neural networks and Xavier.

```
# Test the model using test sets
print("Accuracy: ", sess.run(accuracy, feed_dict={X: test_data, Y: test_labels, kee
```

As we discussed above, we need to keep 100% of networks while testing even if we apply dropout during training. Therefore, keep_prob: 1 which means that we will not drop any networks.

Code

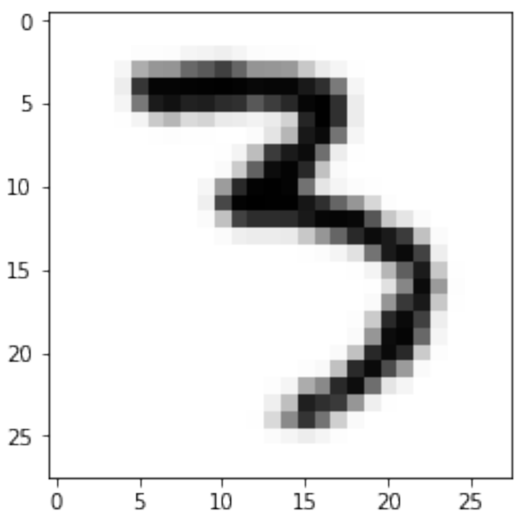
Alphabet/Digits

```
import numpy as np
import pandas as pd
import matplotlib.pyplot as plt
import random
import tensorflow as tf


train = pd.read_csv('emnist-balanced-train.csv', header=None)
#train = pd.read_csv('emnist/emnist-digits-train.csv', header=None)

test = pd.read_csv('emnist-balanced-test.csv', header=None)
#test = pd.read_csv('emnist/emnist-digits-test.csv', header=None)

#train.head()

# Number of Train
numTrain = len(train)
# Number of Test
numTest = len(test)
# Number of Classes
numClasses = len(train[0].unique())
learning_rate = 0.001

train_data = train.iloc[:, 1:]
train_labels = train.iloc[:, 0]
test_data = test.iloc[:, 1:]
test_labels = test.iloc[:, 0]

# one-hot encoding
train_labels = pd.get_dummies(train_labels)
test_labels = pd.get_dummies(test_labels)
#train_labels.head()

train_data = train_data.values
train_labels = train_labels.values
test_data = test_data.values
test_labels = test_labels.values
```

```
rand = random.randint(0, numTrain - 1)

'''
plt.imshow(
  train_data[rand].reshape([28, 28]),
  cmap='Greys'
  )
plt.show()
'''

def rotate(image):
    image = image.reshape([28, 28])
    image = np.fliplr(image)
    image = np.rot90(image)
    return image.reshape([28 * 28])
train_data = np.apply_along_axis(rotate, 1, train_data)/255
test_data = np.apply_along_axis(rotate, 1, test_data)/255

'''
plt.imshow(
  train_data[rand].reshape([28, 28]),
  cmap='Greys'
  )
plt.show()
'''

tf.set_random_seed(777)  # for reproducibility
tf.reset_default_graph()

# EMNIST data image of shape 28 * 28 = 784
X = tf.placeholder(tf.float32, [None, 784])
# 47 classes: 10 digits, 26 letters, and 11 capital letters
Y = tf.placeholder(tf.float32, [None, numClasses])

# dropout (keep_prob) rate  0.7 on training, but should be 1 for testing
keep_prob = tf.placeholder(tf.float32)

# weights & bias for nn layers
W1 = tf.get_variable("W1", shape=[784, 512], initializer=tf.contrib.layers.xavier_i
b1 = tf.Variable(tf.random_normal([512]))
L1 = tf.nn.relu(tf.matmul(X, W1) + b1)
L1 = tf.nn.dropout(L1, keep_prob=keep_prob)

W2 = tf.get_variable("W2", shape=[512, 512], initializer=tf.contrib.layers.xavier_i
b2 = tf.Variable(tf.random_normal([512]))
L2 = tf.nn.relu(tf.matmul(L1, W2) + b2)
L2 = tf.nn.dropout(L2, keep_prob=keep_prob)

W3 = tf.get_variable("W3", shape=[512, 512], initializer=tf.contrib.layers.xavier_i
b3 = tf.Variable(tf.random_normal([512]))
L3 = tf.nn.relu(tf.matmul(L2, W3) + b3)
L3 = tf.nn.dropout(L3, keep_prob=keep_prob)

W4 = tf.get_variable("W4", shape=[512, numClasses], initializer=tf.contrib.layers.x
b4 = tf.Variable(tf.random_normal([numClasses]))
hypothesis = tf.matmul(L3, W4) + b4

# cost & train
cost = tf.reduce_mean(tf.nn.softmax_cross_entropy_with_logits(logits=hypothesis, la
train = tf.train.AdamOptimizer(learning_rate=learning_rate).minimize(cost)



# parameters
num_epochs = 15
```

```python
batch_size = 100
print('numTrain: ', numTrain)
num_iterations = int( numTrain / batch_size)

with tf.Session() as sess:
    # Initialize TensorFlow variables
    sess.run(tf.global_variables_initializer())
    # Training
    for epoch in range(num_epochs):
        avg_cost = 0

        for i in range(num_iterations):
            batch_xs, batch_ys = train_data[i * 100: (i + 1) * 100], train_labels[i
            _, cost_val = sess.run([train, cost], feed_dict={X: batch_xs, Y: batch_
            avg_cost += cost_val / num_iterations

        print("Epoch: {:04d}, Cost: {:.9f}".format(epoch + 1, avg_cost))

    print("Learning finished")

    # Test model
    is_correct = tf.equal(tf.argmax(hypothesis, 1), tf.argmax(Y, 1))

    # Calculate accuracy
    accuracy = tf.reduce_mean(tf.cast(is_correct, tf.float32))

    # Test the model using test sets
    print("Accuracy: ", sess.run(accuracy, feed_dict={X: test_data, Y: test_labels,


    # Get Label and predict
    r = random.randint(0, numTest - 1)
    print("Label: ", sess.run(tf.argmax(test_labels[r : r + 1], 1)))
    print(
        "Prediction: ",
        sess.run(tf.argmax(hypothesis, 1), feed_dict={X: test_data[r : r + 1], keep
    )

    plt.imshow(
        test_data[r : r + 1].reshape(28, 28),
        cmap="Greys",
        interpolation="nearest",
    )
    plt.show()
```

```
numTrain:  112800
Epoch: 0001, Cost: 1.251659688
Epoch: 0002, Cost: 0.728741870
Epoch: 0003, Cost: 0.641459946
Epoch: 0004, Cost: 0.590681597
Epoch: 0005, Cost: 0.561483818
Epoch: 0006, Cost: 0.539457501
Epoch: 0007, Cost: 0.522869468
Epoch: 0008, Cost: 0.505910995
Epoch: 0009, Cost: 0.499571343
Epoch: 0010, Cost: 0.490593512
Epoch: 0011, Cost: 0.480654343
Epoch: 0012, Cost: 0.479461333
Epoch: 0013, Cost: 0.472976663
Epoch: 0014, Cost: 0.461963027
Epoch: 0015, Cost: 0.455598501
Learning finished
Accuracy:  0.84957445
Label:  [3]
Prediction:  [3]
```



Digits

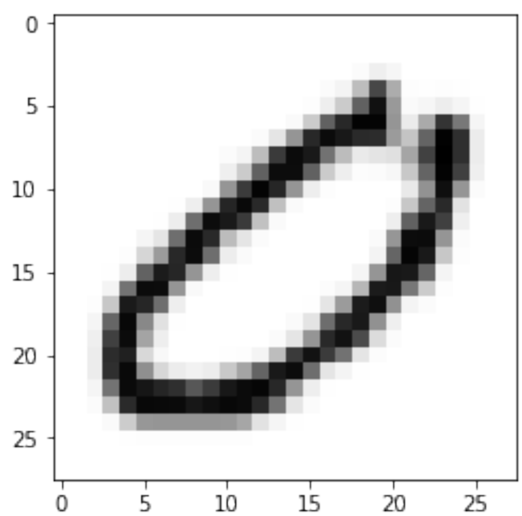
```python
import numpy as np
import pandas as pd
import matplotlib.pyplot as plt
import random
import tensorflow as tf


#train = pd.read_csv('emnist-balanced-train.csv', header=None)
train = pd.read_csv('emnist-digits-train.csv', header=None)

#test = pd.read_csv('emnist-balanced-test.csv', header=None)
test = pd.read_csv('emnist-digits-test.csv', header=None)
```

```
#train.head()

# Number of Train
numTrain = len(train)
# Number of Test
numTest = len(test)
# Number of Classes
numClasses = len(train[0].unique())
learning_rate = 0.001

train_data = train.iloc[:, 1:]
train_labels = train.iloc[:, 0]
test_data = test.iloc[:, 1:]
test_labels = test.iloc[:, 0]

# one-hot encoding
train_labels = pd.get_dummies(train_labels)
test_labels = pd.get_dummies(test_labels)
#train_labels.head()

train_data = train_data.values
train_labels = train_labels.values
test_data = test_data.values
test_labels = test_labels.values


rand = random.randint(0, numTrain - 1)

'''
plt.imshow(
  train_data[rand].reshape([28, 28]),
  cmap='Greys'
  )
plt.show()
'''

def rotate(image):
    image = image.reshape([28, 28])
    image = np.fliplr(image)
    image = np.rot90(image)
    return image.reshape([28 * 28])
train_data = np.apply_along_axis(rotate, 1, train_data)/255
test_data = np.apply_along_axis(rotate, 1, test_data)/255

'''
plt.imshow(
  train_data[rand].reshape([28, 28]),
  cmap='Greys'
  )
plt.show()
'''

tf.set_random_seed(777)  # for reproducibility
tf.reset_default_graph()

# EMNIST data image of shape 28 * 28 = 784
X = tf.placeholder(tf.float32, [None, 784])
# 47 classes: 10 digits, 26 letters, and 11 capital letters
Y = tf.placeholder(tf.float32, [None, numClasses])

# dropout (keep_prob) rate  0.7 on training, but should be 1 for testing
keep_prob = tf.placeholder(tf.float32)

# weights & bias for nn layers
W1 = tf.get_variable("W1", shape=[784, 512], initializer=tf.contrib.layers.xavier_i
```

```
b1 = tf.Variable(tf.random_normal([512]))
L1 = tf.nn.relu(tf.matmul(X, W1) + b1)
L1 = tf.nn.dropout(L1, keep_prob=keep_prob)

W2 = tf.get_variable("W2", shape=[512, 512], initializer=tf.contrib.layers.xavier_i
b2 = tf.Variable(tf.random_normal([512]))
L2 = tf.nn.relu(tf.matmul(L1, W2) + b2)
L2 = tf.nn.dropout(L2, keep_prob=keep_prob)

W3 = tf.get_variable("W3", shape=[512, 512], initializer=tf.contrib.layers.xavier_i
b3 = tf.Variable(tf.random_normal([512]))
L3 = tf.nn.relu(tf.matmul(L2, W3) + b3)
L3 = tf.nn.dropout(L3, keep_prob=keep_prob)

W4 = tf.get_variable("W4", shape=[512, numClasses], initializer=tf.contrib.layers.x
b4 = tf.Variable(tf.random_normal([numClasses]))
hypothesis = tf.matmul(L3, W4) + b4

# cost & train
cost = tf.reduce_mean(tf.nn.softmax_cross_entropy_with_logits(logits=hypothesis, la
train = tf.train.AdamOptimizer(learning_rate=learning_rate).minimize(cost)



# parameters
num_epochs = 15
batch_size = 100
print('numTrain: ', numTrain)
num_iterations = int( numTrain / batch_size)

with tf.Session() as sess:
    # Initialize TensorFlow variables
    sess.run(tf.global_variables_initializer())
    # Training
    for epoch in range(num_epochs):
        avg_cost = 0

        for i in range(num_iterations):
            batch_xs, batch_ys = train_data[i * 100: (i + 1) * 100], train_labels[i
            _, cost_val = sess.run([train, cost], feed_dict={X: batch_xs, Y: batch_
            avg_cost += cost_val / num_iterations

        print("Epoch: {:04d}, Cost: {:.9f}".format(epoch + 1, avg_cost))

    print("Learning finished")

    # Test model
    is_correct = tf.equal(tf.argmax(hypothesis, 1), tf.argmax(Y, 1))

    # Calculate accuracy
    accuracy = tf.reduce_mean(tf.cast(is_correct, tf.float32))

    # Test the model using test sets
    print("Accuracy: ", sess.run(accuracy, feed_dict={X: test_data, Y: test_labels,


    # Get Label and predict
    r = random.randint(0, numTest - 1)
    print("Label: ", sess.run(tf.argmax(test_labels[r : r + 1], 1)))
    print(
        "Prediction: ",
        sess.run(tf.argmax(hypothesis, 1), feed_dict={X: test_data[r : r + 1], keep
    )

    plt.imshow(
```

```
        test_data[r : r + 1].reshape(28, 28),
        cmap="Greys",
        interpolation="nearest",
    )
    plt.show()
```

```
numTrain:  240000
Epoch: 0001, Cost: 0.175710808
Epoch: 0002, Cost: 0.081280281
Epoch: 0003, Cost: 0.067423555
Epoch: 0004, Cost: 0.059984454
Epoch: 0005, Cost: 0.056014791
Epoch: 0006, Cost: 0.051717673
Epoch: 0007, Cost: 0.050206302
Epoch: 0008, Cost: 0.046855801
Epoch: 0009, Cost: 0.044953876
Epoch: 0010, Cost: 0.043244649
Epoch: 0011, Cost: 0.044239188
Epoch: 0012, Cost: 0.043146146
Epoch: 0013, Cost: 0.040557425
Epoch: 0014, Cost: 0.040846657
Epoch: 0015, Cost: 0.040241697
Learning finished
Accuracy:  0.990575
Label:  [0]
Prediction:  [0]
```



Convolutional Neural Networks (CNN)

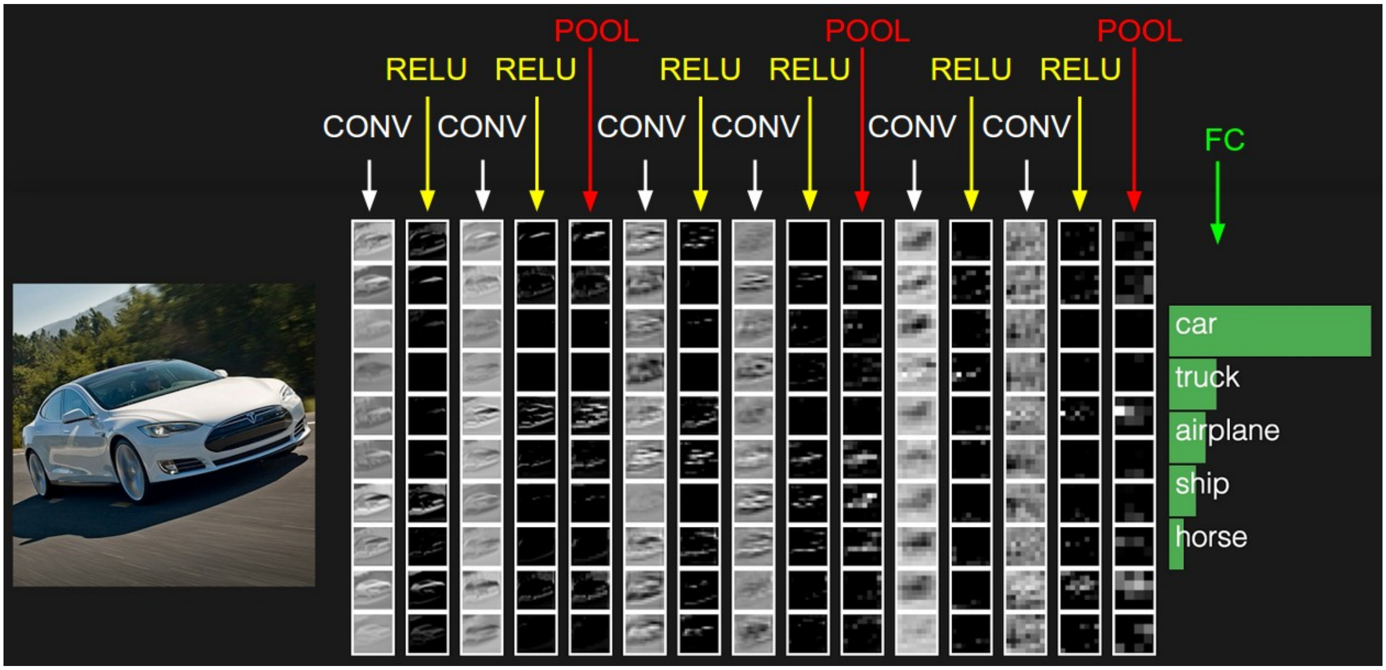
Load data

```
import numpy as np
import pandas as pd
import matplotlib.pyplot as plt
import random
```

```
import tensorflow as tf


train = pd.read_csv('emnist-balanced-train.csv', header=None)
#train = pd.read_csv('emnist/emnist-digits-train.csv', header=None)

test = pd.read_csv('emnist-balanced-test.csv', header=None)
#test = pd.read_csv('emnist/emnist-digits-test.csv', header=None)

#train.head()

# Number of Train
numTrain = len(train)
# Number of Test
numTest = len(test)
# Number of Classes
numClasses = len(train[0].unique())
learning_rate = 0.001

train_data = train.iloc[:, 1:]
train_labels = train.iloc[:, 0]
test_data = test.iloc[:, 1:]
test_labels = test.iloc[:, 0]

# one-hot encoding
train_labels = pd.get_dummies(train_labels)
test_labels = pd.get_dummies(test_labels)
#train_labels.head()

train_data = train_data.values
train_labels = train_labels.values
test_data = test_data.values
test_labels = test_labels.values


rand = random.randint(0, numTrain - 1)

'''
plt.imshow(
    train_data[rand].reshape([28, 28]),
    cmap='Greys'
    )
plt.show()
'''

def rotate(image):
    image = image.reshape([28, 28])
    image = np.fliplr(image)
    image = np.rot90(image)
    return image.reshape([28 * 28])
train_data = np.apply_along_axis(rotate, 1, train_data)/255
test_data = np.apply_along_axis(rotate, 1, test_data)/255

'''
plt.imshow(
    train_data[rand].reshape([28, 28]),
    cmap='Greys'
    )
plt.show()
'''
```

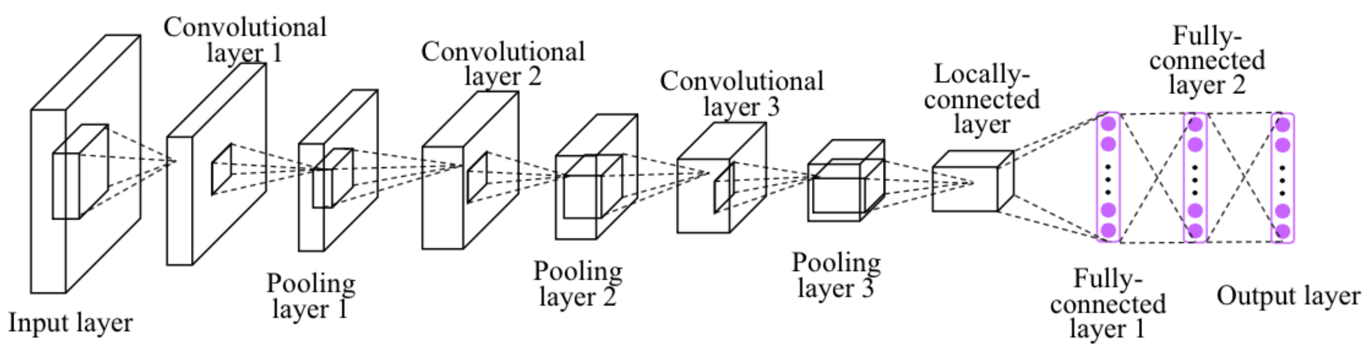
The process of importing training data set and test data set is the same as softmax algorithm above

Algorithm



- Input: Our input is 28x28 image.
- CONV layer: The layer will compute the output which are connected to local regions in the input
- RELU layer: We use ReLU in order to apply an elementwise activation function
- POOL layer: The layer will make a smaller image than original image by performing a downsampling operation
- FC layer: FC stands for Fully Connected. The layer will compute the classes [2]

We use below CNN structure [9]



Input layer

```
# EMNIST data image of shape 28 * 28 = 784
X = tf.placeholder(tf.float32, [None, 784])
# 47 classes: 10 digits, 26 letters, and 11 capital letters
Y = tf.placeholder(tf.float32, [None, numClasses])
```

```
X_img = tf.reshape(X, [-1, 28, 28, 1])
```

- -1 indicates tensorflow decides the number of images.
- Image size is 28 x 28.
- color is 1. In other words, it is black and white.

Convolutional layer1

```
W1 = tf.Variable(tf.random_normal([3, 3, 1, 32], stddev=0.01))
```

A filter size is 3x3 and color is the same as image size. And we will use 32 filters, which are different images.

```
# (28, 28, 32)
tf.nn.conv2d(X_img, W1, strides=[1, 1, 1, 1], padding='SAME')
```

1. The filter, which is 1x1, will move to 1 step. That is, strides tells how many steps can move at once.
2. padding='SAME': Input image size and output image size are identical regardless of image size.
3. After convolution 2d is done, image size is 28x28 like original image size.

```
L1 = tf.nn.relu(L1)
```

We use ReLU after convoluational layer

Pooling layer 1

```
# (14, 14, 32)
tf.nn.max_pool(L1, ksize=[1,2,2,1], strides=[1,2,2,1], padding='SAME')
```

Input is L1 which is previous data set. Kernel size is 2x2 and filter size is also 2x2. Since strides is 2x2, original images will decrease. For instance, the image is 28x28 and modified image is 14x14 due to the stride, which is the filter. So, we will have 32 different images after max-pooling.

```
L1 = tf.nn.dropout(L1, keep_prob=keep_prob)
```

Last step is to use dropout

Convolutional layer 2

```
# L2 Img Input shape=(n, 14, 14, 32)
# Conv = (n, 14, 14, 64)
W2 = tf.Variable(tf.random_normal([3, 3, 32, 64], stddev=0.01))
L2 = tf.nn.conv2d(L1, W2, strides=[1, 1, 1, 1], padding='SAME')
L2 = tf.nn.relu(L2)
```

Since we have 32 different images after pooling layer 1, we should use 32 colors as an input. Also, we increases the number of filters

Pooling layer 2

```
# Pool = (n, 7, 7, 64)
L2 = tf.nn.max_pool(L2, ksize=[1,2,2,1], strides=[1,2,2,1], padding='SAME')
L2 = tf.nn.dropout(L2, keep_prob=keep_prob)
```

It is the same as pooling layer 1

Convolutional layer 3

```
# L3 Img Input shape=(n, 7, 7, 64)
# Conv = (n, 7, 7, 128)
W3 = tf.Variable(tf.random_normal([3, 3, 64, 128], stddev=0.01))
L3 = tf.nn.conv2d(L2, W3, strides=[1, 1, 1, 1], padding='SAME')
L3 = tf.nn.relu(L3)
```

Like convolutional layer 3, after pooling layer 2, there are 64 different images. So, our input should be 64 and we increases the number of filters.

Pooling layer 3

```
# Pool = (n, 4, 4, 128)
L3 = tf.nn.max_pool(L3, ksize=[1,2,2,1], strides=[1,2,2,1], padding='SAME')
L3 = tf.nn.dropout(L3, keep_prob=keep_prob)
```

It is the same as pooling layer 2

Locally Connected layer

```
# Reshape = (n, 4 * 4 * 128)
L3_flat = tf.reshape(L3, [-1, 128 * 4 * 4])
```

Before our image gets into fully connected layer, we need to reshape our image. In convolutional layer 3, we have 4x4 and 128 different images after pooling. The reason why there are 128 different images is the number of filters in convolutional layer 3. In order to reshape array size, we should multiply 4x4x128.

Fully Connected layer 1

```
W4 = tf.get_variable("W4", shape=[128*4*4, 625], initializer=tf.contrib.layers.xavi
b4 = tf.Variable(tf.random_normal([625]))
L4 = tf.nn.relu(tf.matmul(L3_flat, W4)+b4)
L4 = tf.nn.dropout(L4, keep_prob=keep_prob)
```

This is first fully connected layer. Output of array shape will be 625. And then, we use ReLU and dropout such as convolutional layer and pooling layer.

Fully Connected layer 2

```
W5 = tf.get_variable("W5", shape=[625, numClasses], initializer=tf.contrib.layers.x
b5 = tf.Variable(tf.random_normal([numClasses]))
logits = tf.matmul(L4, W5) + b5
```

Lastly, our real output should be the number of classes, which is 47.

Train

```
_, cost_val = sess.run([train, cost], feed_dict={X: batch_xs, Y: batch_ys, keep_pro
```

Like we discusses above dropout algorithm, when we train data set, we would like to keep 70% of networks.

Test

```
sess.run(tf.argmax(logits, 1), feed_dict={X: test_data[r : r + 1], keep_prob: 1})
```

However, we need to use all the networks when we test data set.

Code

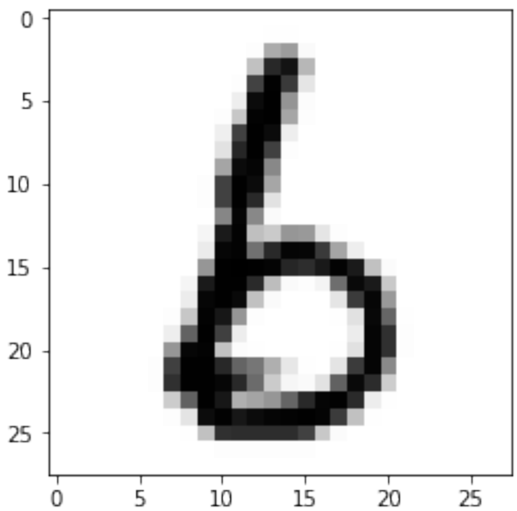
Alphabet/Digits

```
import numpy as np
import pandas as pd
import matplotlib.pyplot as plt
import random
import tensorflow as tf


train = pd.read_csv('emnist-balanced-train.csv', header=None)
#train = pd.read_csv('emnist/emnist-digits-train.csv', header=None)

test = pd.read_csv('emnist-balanced-test.csv', header=None)
#test = pd.read_csv('emnist/emnist-digits-test.csv', header=None)

#train.head()

# Number of Train
numTrain = len(train)
# Number of Test
numTest = len(test)
# Number of Classes
numClasses = len(train[0].unique())
learning_rate = 0.001

train_data = train.iloc[:, 1:]
train_labels = train.iloc[:, 0]
test_data = test.iloc[:, 1:]
test_labels = test.iloc[:, 0]

# one-hot encoding
train_labels = pd.get_dummies(train_labels)
test_labels = pd.get_dummies(test_labels)
#train_labels.head()

train_data = train_data.values
train_labels = train_labels.values
test_data = test_data.values
test_labels = test_labels.values


rand = random.randint(0, numTrain - 1)

'''
plt.imshow(
    train_data[rand].reshape([28, 28]),
    cmap='Greys'
    )
plt.show()
'''

def rotate(image):
    image = image.reshape([28, 28])
    image = np.fliplr(image)
    image = np.rot90(image)
    return image.reshape([28 * 28])
train_data = np.apply_along_axis(rotate, 1, train_data)/255
```

```
test_data = np.apply_along_axis(rotate, 1, test_data)/255

'''
plt.imshow(
    train_data[rand].reshape([28, 28]),
    cmap='Greys'
    )
plt.show()
'''

tf.set_random_seed(777)  # for reproducibility
tf.reset_default_graph()

# EMNIST data image of shape 28 * 28 = 784
X = tf.placeholder(tf.float32, [None, 784])
# 47 classes: 10 digits, 26 letters, and 11 capital letters
Y = tf.placeholder(tf.float32, [None, numClasses])
X_img = tf.reshape(X, [-1, 28, 28, 1])

# dropout (keep_prob) rate  0.7 on training, but should be 1 for testing
keep_prob = tf.placeholder(tf.float32)

# L1 Img Input shape=(n, 28, 28, 1)
# Conv = (n, 28, 28, 32)
# Pool = (n, 14, 14, 32)
W1 = tf.Variable(tf.random_normal([3, 3, 1, 32], stddev=0.01))
L1 = tf.nn.conv2d(X_img, W1, strides=[1, 1, 1, 1], padding='SAME')
L1 = tf.nn.relu(L1)
L1 = tf.nn.max_pool(L1, ksize=[1,2,2,1], strides=[1,2,2,1], padding='SAME')
L1 = tf.nn.dropout(L1, keep_prob=keep_prob)

# L2 Img Input shape=(n, 14, 14, 32)
# Conv = (n, 14, 14, 64)
# Pool = (n, 7, 7, 64)
W2 = tf.Variable(tf.random_normal([3, 3, 32, 64], stddev=0.01))
L2 = tf.nn.conv2d(L1, W2, strides=[1, 1, 1, 1], padding='SAME')
L2 = tf.nn.relu(L2)
L2 = tf.nn.max_pool(L2, ksize=[1,2,2,1], strides=[1,2,2,1], padding='SAME')
L2 = tf.nn.dropout(L2, keep_prob=keep_prob)

# L3 Img Input shape=(n, 7, 7, 64)
# Conv = (n, 7, 7, 128)
# Pool = (n, 4, 4, 128)
# Reshape = (n, 4 * 4 * 128)
W3 = tf.Variable(tf.random_normal([3, 3, 64, 128], stddev=0.01))
L3 = tf.nn.conv2d(L2, W3, strides=[1, 1, 1, 1], padding='SAME')
L3 = tf.nn.relu(L3)
L3 = tf.nn.max_pool(L3, ksize=[1,2,2,1], strides=[1,2,2,1], padding='SAME')
L3 = tf.nn.dropout(L3, keep_prob=keep_prob)
L3_flat = tf.reshape(L3, [-1, 128 * 4 * 4])

# L4 Fully Connected (FC) 4x4x128 inputs -> 625 outputs
W4 = tf.get_variable("W4", shape=[128*4*4, 625], initializer=tf.contrib.layers.xavi
b4 = tf.Variable(tf.random_normal([625]))
L4 = tf.nn.relu(tf.matmul(L3_flat, W4)+b4)
L4 = tf.nn.dropout(L4, keep_prob=keep_prob)

# L5 Final Fully Connected (FC) 625 inputs -> numClasses outputs
W5 = tf.get_variable("W5", shape=[625, numClasses], initializer=tf.contrib.layers.x
b5 = tf.Variable(tf.random_normal([numClasses]))
logits = tf.matmul(L4, W5) + b5


# cost & train
cost = tf.reduce_mean(tf.nn.softmax_cross_entropy_with_logits(logits=logits, labels
```

```python
train = tf.train.AdamOptimizer(learning_rate=learning_rate).minimize(cost)



# parameters
num_epochs = 15
batch_size = 100
print('numTrain: ', numTrain)
num_iterations = int( numTrain / batch_size)

with tf.Session() as sess:
    # Initialize TensorFlow variables
    sess.run(tf.global_variables_initializer())
    # Training
    for epoch in range(num_epochs):
        avg_cost = 0

        for i in range(num_iterations):
            batch_xs, batch_ys = train_data[i * 100: (i + 1) * 100], train_labels[i
            _, cost_val = sess.run([train, cost], feed_dict={X: batch_xs, Y: batch_
            avg_cost += cost_val / num_iterations

        print("Epoch: {:04d}, Cost: {:.9f}".format(epoch + 1, avg_cost))

    print("Learning finished")

    # Test model
    is_correct = tf.equal(tf.argmax(logits, 1), tf.argmax(Y, 1))

    # Calculate accuracy
    accuracy = tf.reduce_mean(tf.cast(is_correct, tf.float32))

    # Test the model using test sets
    print("Accuracy: ", sess.run(accuracy, feed_dict={X: test_data, Y: test_labels,


    # Get Label and predict
    r = random.randint(0, numTest - 1)
    print("Label: ", sess.run(tf.argmax(test_labels[r : r + 1], 1)))
    print(
        "Prediction: ",
        sess.run(tf.argmax(logits, 1), feed_dict={X: test_data[r : r + 1], keep_pro
    )

    plt.imshow(
        test_data[r : r + 1].reshape(28, 28),
        cmap="Greys",
        interpolation="nearest",
    )
    plt.show()
```

```
numTrain:  112800
Epoch: 0001, Cost: 1.059922579
Epoch: 0002, Cost: 0.515719846
Epoch: 0003, Cost: 0.449088449
Epoch: 0004, Cost: 0.412468898
Epoch: 0005, Cost: 0.390916076
Epoch: 0006, Cost: 0.373371925
Epoch: 0007, Cost: 0.359837109
Epoch: 0008, Cost: 0.349027968
Epoch: 0009, Cost: 0.336722072
Epoch: 0010, Cost: 0.331467421
Epoch: 0011, Cost: 0.325443666
Epoch: 0012, Cost: 0.317864727
Epoch: 0013, Cost: 0.311824368
Epoch: 0014, Cost: 0.309578560
Epoch: 0015, Cost: 0.303445078
Learning finished
Accuracy:  0.89090425
Label:  [37]
Prediction:  [37]
```



Digits

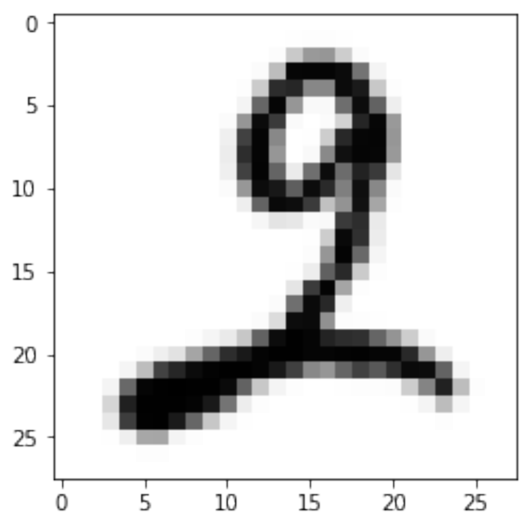
```
import numpy as np
import pandas as pd
import matplotlib.pyplot as plt
import random
import tensorflow as tf


#train = pd.read_csv('emnist-balanced-train.csv', header=None)
train = pd.read_csv('emnist-digits-train.csv', header=None)

#test = pd.read_csv('emnist-balanced-test.csv', header=None)
test = pd.read_csv('emnist-digits-test.csv', header=None)

#train.head()

# Number of Train
```

```
numTrain = len(train)
# Number of Test
numTest = len(test)
# Number of Classes
numClasses = len(train[0].unique())
learning_rate = 0.001

train_data = train.iloc[:, 1:]
train_labels = train.iloc[:, 0]
test_data = test.iloc[:, 1:]
test_labels = test.iloc[:, 0]

# one-hot encoding
train_labels = pd.get_dummies(train_labels)
test_labels = pd.get_dummies(test_labels)
#train_labels.head()

train_data = train_data.values
train_labels = train_labels.values
test_data = test_data.values
test_labels = test_labels.values


rand = random.randint(0, numTrain - 1)

'''
plt.imshow(
    train_data[rand].reshape([28, 28]),
    cmap='Greys'
    )
plt.show()
'''

def rotate(image):
    image = image.reshape([28, 28])
    image = np.fliplr(image)
    image = np.rot90(image)
    return image.reshape([28 * 28])
train_data = np.apply_along_axis(rotate, 1, train_data)/255
test_data = np.apply_along_axis(rotate, 1, test_data)/255

'''
plt.imshow(
    train_data[rand].reshape([28, 28]),
    cmap='Greys'
    )
plt.show()
'''

tf.set_random_seed(777)  # for reproducibility
tf.reset_default_graph()

# EMNIST data image of shape 28 * 28 = 784
X = tf.placeholder(tf.float32, [None, 784])
# 47 classes: 10 digits, 26 letters, and 11 capital letters
Y = tf.placeholder(tf.float32, [None, numClasses])
X_img = tf.reshape(X, [-1, 28, 28, 1])

# dropout (keep_prob) rate  0.7 on training, but should be 1 for testing
keep_prob = tf.placeholder(tf.float32)

# L1 Img Input shape=(n, 28, 28, 1)
# Conv = (n, 28, 28, 32)
# Pool = (n, 14, 14, 32)
W1 = tf.Variable(tf.random_normal([3, 3, 1, 32], stddev=0.01))
```

```
L1 = tf.nn.conv2d(X_img, W1, strides=[1, 1, 1, 1], padding='SAME')
L1 = tf.nn.relu(L1)
L1 = tf.nn.max_pool(L1, ksize=[1,2,2,1], strides=[1,2,2,1], padding='SAME')
L1 = tf.nn.dropout(L1, keep_prob=keep_prob)

# L2 Img Input shape=(n, 14, 14, 32)
# Conv = (n, 14, 14, 64)
# Pool = (n, 7, 7, 64)
W2 = tf.Variable(tf.random_normal([3, 3, 32, 64], stddev=0.01))
L2 = tf.nn.conv2d(L1, W2, strides=[1, 1, 1, 1], padding='SAME')
L2 = tf.nn.relu(L2)
L2 = tf.nn.max_pool(L2, ksize=[1,2,2,1], strides=[1,2,2,1], padding='SAME')
L2 = tf.nn.dropout(L2, keep_prob=keep_prob)

# L3 Img Input shape=(n, 7, 7, 64)
# Conv = (n, 7, 7, 128)
# Pool = (n, 4, 4, 128)
# Reshape = (n, 4 * 4 * 128)
W3 = tf.Variable(tf.random_normal([3, 3, 64, 128], stddev=0.01))
L3 = tf.nn.conv2d(L2, W3, strides=[1, 1, 1, 1], padding='SAME')
L3 = tf.nn.relu(L3)
L3 = tf.nn.max_pool(L3, ksize=[1,2,2,1], strides=[1,2,2,1], padding='SAME')
L3 = tf.nn.dropout(L3, keep_prob=keep_prob)
L3_flat = tf.reshape(L3, [-1, 128 * 4 * 4])

# L4 Fully Connected (FC) 4x4x128 inputs -> 625 outputs
W4 = tf.get_variable("W4", shape=[128*4*4, 625], initializer=tf.contrib.layers.xavi
b4 = tf.Variable(tf.random_normal([625]))
L4 = tf.nn.relu(tf.matmul(L3_flat, W4)+b4)
L4 = tf.nn.dropout(L4, keep_prob=keep_prob)

# L5 Final Fully Connected (FC) 625 inputs -> numClasses outputs
W5 = tf.get_variable("W5", shape=[625, numClasses], initializer=tf.contrib.layers.x
b5 = tf.Variable(tf.random_normal([numClasses]))
logits = tf.matmul(L4, W5) + b5


# cost & train
cost = tf.reduce_mean(tf.nn.softmax_cross_entropy_with_logits(logits=logits, labels
train = tf.train.AdamOptimizer(learning_rate=learning_rate).minimize(cost)



# parameters
num_epochs = 15
batch_size = 100
print('numTrain: ', numTrain)
num_iterations = int( numTrain / batch_size)

with tf.Session() as sess:
    # Initialize TensorFlow variables
    sess.run(tf.global_variables_initializer())
    # Training
    for epoch in range(num_epochs):
        avg_cost = 0

        for i in range(num_iterations):
            batch_xs, batch_ys = train_data[i * 100: (i + 1) * 100], train_labels[i
            _, cost_val = sess.run([train, cost], feed_dict={X: batch_xs, Y: batch_
            avg_cost += cost_val / num_iterations

        print("Epoch: {:04d}, Cost: {:.9f}".format(epoch + 1, avg_cost))

    print("Learning finished")
```

```python
# Test model
is_correct = tf.equal(tf.argmax(logits, 1), tf.argmax(Y, 1))

# Calculate accuracy
accuracy = tf.reduce_mean(tf.cast(is_correct, tf.float32))

# Test the model using test sets
print("Accuracy: ", sess.run(accuracy, feed_dict={X: test_data, Y: test_labels,


# Get Label and predict
r = random.randint(0, numTest - 1)
print("Label: ", sess.run(tf.argmax(test_labels[r : r + 1], 1)))
print(
    "Prediction: ",
    sess.run(tf.argmax(logits, 1), feed_dict={X: test_data[r : r + 1], keep_pro
)

plt.imshow(
    test_data[r : r + 1].reshape(28, 28),
    cmap="Greys",
    interpolation="nearest",
)
plt.show()
```

```
WARNING: The TensorFlow contrib module will not be included in TensorFlow 2.(
For more information, please see:
  * https://github.com/tensorflow/community/blob/master/rfcs/20180907-contril
  * https://github.com/tensorflow/addons
If you depend on functionality not listed there, please file an issue.

numTrain:  240000
Epoch: 0001, Cost: 0.132140247
Epoch: 0002, Cost: 0.040341742
Epoch: 0003, Cost: 0.032980858
Epoch: 0004, Cost: 0.029762897
Epoch: 0005, Cost: 0.027134110
Epoch: 0006, Cost: 0.024512553
Epoch: 0007, Cost: 0.023280032
Epoch: 0008, Cost: 0.021658956
Epoch: 0009, Cost: 0.021289860
Epoch: 0010, Cost: 0.020385694
Epoch: 0011, Cost: 0.019163505
Epoch: 0012, Cost: 0.020146366
Epoch: 0013, Cost: 0.017946620
Epoch: 0014, Cost: 0.018162947
Epoch: 0015, Cost: 0.017307029
Learning finished
Accuracy:  0.996125
Label:  [2]
Prediction:  [2]
```



Ensemble

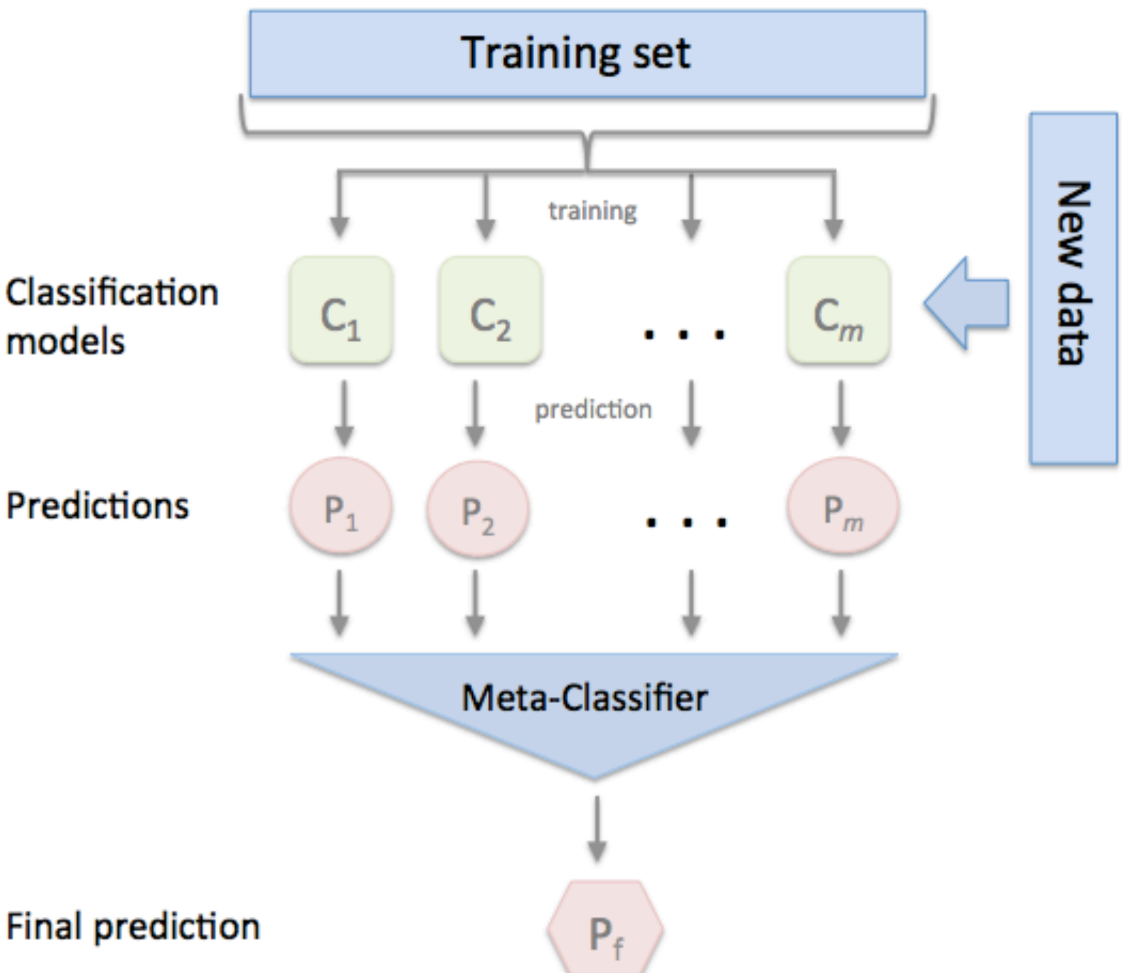
Load data

```
import numpy as np
import pandas as pd
import matplotlib.pyplot as plt
import random
import tensorflow as tf


train = pd.read_csv('emnist-balanced-train.csv', header=None)
#train = pd.read_csv('emnist/emnist-digits-train.csv', header=None)

test = pd.read_csv('emnist-balanced-test.csv', header=None)
#test = pd.read_csv('emnist/emnist-digits-test.csv', header=None)

#train.head()

# Number of Train
numTrain = len(train)
# Number of Test
numTest = len(test)
# Number of Classes
numClasses = len(train[0].unique())
learning_rate = 0.001

train_data = train.iloc[:, 1:]
train_labels = train.iloc[:, 0]
test_data = test.iloc[:, 1:]
test_labels = test.iloc[:, 0]

# one-hot encoding
train_labels = pd.get_dummies(train_labels)
test_labels = pd.get_dummies(test_labels)
#train_labels.head()

train_data = train_data.values
train_labels = train_labels.values
test_data = test_data.values
test_labels = test_labels.values


rand = random.randint(0, numTrain - 1)

'''
plt.imshow(
    train_data[rand].reshape([28, 28]),
    cmap='Greys'
    )
plt.show()
'''

def rotate(image):
    image = image.reshape([28, 28])
    image = np.fliplr(image)
    image = np.rot90(image)
    return image.reshape([28 * 28])
train_data = np.apply_along_axis(rotate, 1, train_data)/255
test_data = np.apply_along_axis(rotate, 1, test_data)/255
```

The process of importing training data set and test data set is the same as softmax algorithm above

Algorithm

In this algorith, we use tensorflow layer. So, we use tf.layers.conv2d instead of tf.nn.conv2d as an example. This is because we realize tensorflow layer is easier to use.



- Classification models: We train several data set

    When new data are added

- Predictions: Each classes make each prediction value, which is accuracy
- Finally, predicted values are combined

Convolutaional/Pooling layer 1

```
# Convolutional Layer 1 and Pooling Layer 1
conv1 = tf.layers.conv2d(inputs=X_img, filters=32, kernel_size=[3, 3], padding="SAM
```

tf.layers.conv2d

- input: An image 28x28
- filter: We use 32 filters.
- kernel_size: This is the filter size. We use 3x3 filter
- padding="SAME": Input image size and output image size are identical regardless of image size.
- activation: We use ReLU

```
pool1 = tf.layers.max_pooling2d(inputs=conv1, pool_size=[2, 2], padding="SAME", str
```

tf.layers.max_pooling2d

- input: we use previous layer, which is conv1
- pool_size: We use 2x2 filter size. Since pool size is 2x2, original images will decrease. For instance, the image is 28x28 and modified image is 14x14 due to the stride, which is the filter.
- strides: The number of steps to move forward at once

```
dropout1 = tf.layers.dropout(inputs=pool1, rate=0.3, training=self.training)
```

tf.layers.dropout

- input: We use previous pooling layer, which is pool1
- rate: We would like to keep 30% of networks to apply dropout
- training: Wether to either train or test. So, this is boolean value. If we are testing, dropout rate is automatically 1.

Convolutional/Pooling layer 2

```
# Convolutional Layer 2 and Pooling Layer 2
conv2 = tf.layers.conv2d(inputs=dropout1, filters=64, kernel_size=[3, 3], padding="
pool2 = tf.layers.max_pooling2d(inputs=conv2, pool_size=[2, 2], padding="SAME", str
dropout2 = tf.layers.dropout(inputs=pool2, rate=0.3, training=self.training)
```

It is the same as convolutional layer 1 and pooling layer 1. However, the number of filters is different

Convolutional/Pooling layer 3

```
# Convolutional Layer 3 and Pooling Layer 3
conv3 = tf.layers.conv2d(inputs=dropout2, filters=128, kernel_size=[3, 3], padding=
pool3 = tf.layers.max_pooling2d(inputs=conv3, pool_size=[2, 2], padding="SAME", str
dropout3 = tf.layers.dropout(inputs=pool3, rate=0.3, training=self.training)
```

It is the same as convolutional layer 2 and pooling layer 2. However, the number of filters is different

Fully Connected layer

```
# Dense Layer with Relu
flat = tf.reshape(dropout3, [-1, 128 * 4 * 4])
```

Before we get into the Fully Connected layer, we should reshape array size. In pooling layer3, there are 128 different images and the image size is 4*4. So, array shape should be 128x4x4.

```
dense4 = tf.layers.dense(inputs=flat, units=625, activation=tf.nn.relu)
dropout4 = tf.layers.dropout(inputs=dense4, rate=0.5, training=self.training)
```

We use tf.layers.dense in order for Fully Connected layer

- input: Reshaped array
- units: A number of outputs
- activation: We use ReLU

Dropout is the same as above

Train

```
models = []
num_models = 4
for m in range(num_models):
    models.append(Model(sess, "model" + str(m)))
```

We use 4 models. So we make 4 models.

```
# Train each model
for m_idx, m in enumerate(models):
  c, _ = m.train(batch_xs, batch_ys)
  avg_cost_list[m_idx] += c / num_iterations
```

We train each models. This is a difference between CNN above and ensemble. avg_cost_list has each accuracy value of each models.

Test

```
# Test & accuracy
predictions = np.zeros([numTest, numClasses])
for m_idx, m in enumerate(models):
    print(m_idx, 'Accuracy:', m.get_accuracy(test_data, test_labels))
    p = m.predict(test_data)
    predictions += p
```

We make 47 arrays becaue of the number of outputs. Each prediction is added, which is predictions in the code.

```
ensemble_correct_prediction = tf.equal(tf.argmax(predictions, 1), tf.argmax(test_la
ensemble_accuracy = tf.reduce_mean(tf.cast(ensemble_correct_prediction, tf.float32)
```

We compare prediction value with test label. And then, we can calculate the accuracy.

Code

Alphabet/Digits

```
import numpy as np
import pandas as pd
import matplotlib.pyplot as plt
import random
import tensorflow as tf


train = pd.read_csv('emnist-balanced-train.csv', header=None)
#train = pd.read_csv('emnist/emnist-digits-train.csv', header=None)

test = pd.read_csv('emnist-balanced-test.csv', header=None)
#test = pd.read_csv('emnist/emnist-digits-test.csv', header=None)

#train.head()

# Number of Train
numTrain = len(train)
# Number of Test
numTest = len(test)
# Number of Classes
numClasses = len(train[0].unique())
learning_rate = 0.001

train_data = train.iloc[:, 1:]
train_labels = train.iloc[:, 0]
test_data = test.iloc[:, 1:]
test_labels = test.iloc[:, 0]

# one-hot encoding
train_labels = pd.get_dummies(train_labels)
test_labels = pd.get_dummies(test_labels)
#train_labels.head()

train_data = train_data.values
```

```
train_labels = train_labels.values
test_data = test_data.values
test_labels = test_labels.values


rand = random.randint(0, numTrain - 1)

'''
plt.imshow(
    train_data[rand].reshape([28, 28]),
    cmap='Greys'
    )
plt.show()
'''

def rotate(image):
    image = image.reshape([28, 28])
    image = np.fliplr(image)
    image = np.rot90(image)
    return image.reshape([28 * 28])
train_data = np.apply_along_axis(rotate, 1, train_data)/255
test_data = np.apply_along_axis(rotate, 1, test_data)/255



class Model:

    def __init__(self, sess, name):
        self.sess = sess
        self.name = name
        self._runEnsemble()

    def _runEnsemble(self):
        with tf.variable_scope(self.name):
            self.training = tf.placeholder(tf.bool)

            # EMNIST data image of shape 28 * 28 = 784
            self.X = tf.placeholder(tf.float32, [None, 784])
            # 47 classes: 10 digits, 26 letters, and 11 capital letters
            self.Y = tf.placeholder(tf.float32, [None, numClasses])
            # Input Image
            X_img = tf.reshape(self.X, [-1, 28, 28, 1])

            # Convolutional Layer 1 and Pooling Layer 1
            conv1 = tf.layers.conv2d(inputs=X_img, filters=32, kernel_size=[3, 3],
            pool1 = tf.layers.max_pooling2d(inputs=conv1, pool_size=[2, 2], padding
            dropout1 = tf.layers.dropout(inputs=pool1, rate=0.3, training=self.trai

            # Convolutional Layer 2 and Pooling Layer 2
            conv2 = tf.layers.conv2d(inputs=dropout1, filters=64, kernel_size=[3, 3
            pool2 = tf.layers.max_pooling2d(inputs=conv2, pool_size=[2, 2], padding
            dropout2 = tf.layers.dropout(inputs=pool2, rate=0.3, training=self.trai

            # Convolutional Layer 3 and Pooling Layer 3
            conv3 = tf.layers.conv2d(inputs=dropout2, filters=128, kernel_size=[3,
            pool3 = tf.layers.max_pooling2d(inputs=conv3, pool_size=[2, 2], padding
            dropout3 = tf.layers.dropout(inputs=pool3, rate=0.3, training=self.trai

            # Dense Layer with Relu
            flat = tf.reshape(dropout3, [-1, 128 * 4 * 4])
            dense4 = tf.layers.dense(inputs=flat, units=625, activation=tf.nn.relu)
            dropout4 = tf.layers.dropout(inputs=dense4, rate=0.5, training=self.tra

            # Logits (no activation) Layer: L5 Final FC 625 inputs -> outputs
            self.logits = tf.layers.dense(inputs=dropout4, units=numClasses)
```

```
        # define cost/loss & optimizer
        self.cost = tf.reduce_mean(tf.nn.softmax_cross_entropy_with_logits(logits=s
        self.optimizer = tf.train.AdamOptimizer(learning_rate=learning_rate).minimi

        correct_prediction = tf.equal(tf.argmax(self.logits, 1), tf.argmax(self.Y,
        self.accuracy = tf.reduce_mean(tf.cast(correct_prediction, tf.float32))

    def predict(self, x_test, training=False):
        return self.sess.run(self.logits, feed_dict={self.X: x_test, self.training:

    def get_accuracy(self, x_test, y_test, training=False):
        return self.sess.run(self.accuracy, feed_dict={self.X: x_test, self.Y: y_te

    def train(self, x_data, y_data, training=True):
        return self.sess.run([self.cost, self.optimizer], feed_dict={self.X: x_data

# initialize
sess = tf.Session()

models = []
num_models = 4
for m in range(num_models):
    models.append(Model(sess, "model" + str(m)))

sess.run(tf.global_variables_initializer())

print('Learning Started!')

num_epochs = 15
batch_size = 100
print('numTrain: ', numTrain)
num_iterations = int( numTrain / batch_size)


# Train
for epoch in range(num_epochs):
    avg_cost_list = np.zeros(len(models))
    for i in range(num_iterations):
        batch_xs, batch_ys = train_data[i * 100: (i + 1) * 100], train_labels[i * 1

        # Train each model
        for m_idx, m in enumerate(models):
            c, _ = m.train(batch_xs, batch_ys)
            avg_cost_list[m_idx] += c / num_iterations

    print('Epoch:', '%04d' % (epoch + 1), 'cost =', avg_cost_list)

print('Learning Finished!')


# Test & accuracy
predictions = np.zeros([numTest, numClasses])
for m_idx, m in enumerate(models):
    print(m_idx, 'Accuracy:', m.get_accuracy(test_data, test_labels))
    p = m.predict(test_data)
    predictions += p

ensemble_correct_prediction = tf.equal(tf.argmax(predictions, 1), tf.argmax(test_la
ensemble_accuracy = tf.reduce_mean(tf.cast(ensemble_correct_prediction, tf.float32)
print('Final accuracy:', sess.run(ensemble_accuracy))
```

```
WARNING:tensorflow:From <ipython-input-7-4aeab7799e58>:79: conv2d (from tenso
Instructions for updating:
```

```
Instructions for updating:
Use keras.layers.conv2d instead.
WARNING:tensorflow:From /usr/local/lib/python3.6/dist-packages/tensorflow/py
Instructions for updating:
Colocations handled automatically by placer.
WARNING:tensorflow:From <ipython-input-7-4aeab7799e58>:80: max_pooling2d (fr
Instructions for updating:
Use keras.layers.max_pooling2d instead.
WARNING:tensorflow:From <ipython-input-7-4aeab7799e58>:81: dropout (from ten
Instructions for updating:
Use keras.layers.dropout instead.
WARNING:tensorflow:From /usr/local/lib/python3.6/dist-packages/tensorflow/py
Instructions for updating:
Please use `rate` instead of `keep_prob`. Rate should be set to `rate = 1 - 
WARNING:tensorflow:From <ipython-input-7-4aeab7799e58>:95: dense (from tenso
Instructions for updating:
Use keras.layers.dense instead.
WARNING:tensorflow:From <ipython-input-7-4aeab7799e58>:102: softmax_cross_en
Instructions for updating:

Future major versions of TensorFlow will allow gradients to flow
into the labels input on backprop by default.

See `tf.nn.softmax_cross_entropy_with_logits_v2`.

Learning Started!
numTrain:  112800
Epoch: 0001 cost = [0.93694787 0.96545307 0.96958477 0.95645672]
Epoch: 0002 cost = [0.51001651 0.52268768 0.51578384 0.51749801]
Epoch: 0003 cost = [0.44954652 0.46018538 0.45869213 0.45723559]
Epoch: 0004 cost = [0.42094525 0.42600334 0.42507715 0.42196886]
Epoch: 0005 cost = [0.39802434 0.40422068 0.4024648  0.40161107]
Epoch: 0006 cost = [0.38610352 0.3868933  0.38614775 0.38660766]
Epoch: 0007 cost = [0.37033975 0.37395777 0.3706577  0.37284704]
Epoch: 0008 cost = [0.35975115 0.36336663 0.35888761 0.36276961]
Epoch: 0009 cost = [0.35073441 0.3545419  0.35260872 0.35529837]
Epoch: 0010 cost = [0.34365498 0.34878156 0.34508266 0.34724383]
Epoch: 0011 cost = [0.33927261 0.34045809 0.33935128 0.34327952]
Epoch: 0012 cost = [0.3334537  0.3365682  0.33567896 0.33747963]
Epoch: 0013 cost = [0.32677686 0.32869293 0.32912845 0.33117159]
Epoch: 0014 cost = [0.32393402 0.32300278 0.32438993 0.32769079]
Epoch: 0015 cost = [0.32108156 0.32197558 0.31911203 0.32423962]
Learning Finished!
0 Accuracy: 0.89079785
1 Accuracy: 0.89143616
2 Accuracy: 0.8932447
3 Accuracy: 0.8907447
Final accuracy: 0.89521277
```

Digits

```
import numpy as np
import pandas as pd
import matplotlib.pyplot as plt
import random
import tensorflow as tf


#train = pd.read_csv('emnist-balanced-train.csv', header=None)
train = pd.read_csv('emnist-digits-train.csv', header=None)

#test = pd.read_csv('emnist-balanced-test.csv', header=None)
test = pd.read_csv('emnist-digits-test.csv', header=None)

#train.head()

# Number of Train
numTrain = len(train)
# Number of Test
numTest = len(test)
# Number of Classes
numClasses = len(train[0].unique())
learning_rate = 0.001

train_data = train.iloc[:, 1:]
train_labels = train.iloc[:, 0]
test_data = test.iloc[:, 1:]
test_labels = test.iloc[:, 0]

# one-hot encoding
train_labels = pd.get_dummies(train_labels)
test_labels = pd.get_dummies(test_labels)
#train_labels.head()

train_data = train_data.values
train_labels = train_labels.values
test_data = test_data.values
test_labels = test_labels.values


rand = random.randint(0, numTrain - 1)

'''
plt.imshow(
    train_data[rand].reshape([28, 28]),
    cmap='Greys'
    )
plt.show()
'''

def rotate(image):
    image = image.reshape([28, 28])
    image = np.fliplr(image)
    image = np.rot90(image)
    return image.reshape([28 * 28])
train_data = np.apply_along_axis(rotate, 1, train_data)/255
```

```python
test_data = np.apply_along_axis(rotate, 1, test_data)/255


class Model:

    def __init__(self, sess, name):
        self.sess = sess
        self.name = name
        self._runEnsemble()

    def _runEnsemble(self):
        with tf.variable_scope(self.name):
            self.training = tf.placeholder(tf.bool)

            # EMNIST data image of shape 28 * 28 = 784
            self.X = tf.placeholder(tf.float32, [None, 784])
            # 47 classes: 10 digits, 26 letters, and 11 capital letters
            self.Y = tf.placeholder(tf.float32, [None, numClasses])
            # Input Image
            X_img = tf.reshape(self.X, [-1, 28, 28, 1])

            # Convolutional Layer 1 and Pooling Layer 1
            conv1 = tf.layers.conv2d(inputs=X_img, filters=32, kernel_size=[3, 3],
            pool1 = tf.layers.max_pooling2d(inputs=conv1, pool_size=[2, 2], padding
            dropout1 = tf.layers.dropout(inputs=pool1, rate=0.3, training=self.trai

            # Convolutional Layer 2 and Pooling Layer 2
            conv2 = tf.layers.conv2d(inputs=dropout1, filters=64, kernel_size=[3, 3
            pool2 = tf.layers.max_pooling2d(inputs=conv2, pool_size=[2, 2], padding
            dropout2 = tf.layers.dropout(inputs=pool2, rate=0.3, training=self.trai

            # Convolutional Layer 3 and Pooling Layer 3
            conv3 = tf.layers.conv2d(inputs=dropout2, filters=128, kernel_size=[3,
            pool3 = tf.layers.max_pooling2d(inputs=conv3, pool_size=[2, 2], padding
            dropout3 = tf.layers.dropout(inputs=pool3, rate=0.3, training=self.trai

            # Dense Layer with Relu
            flat = tf.reshape(dropout3, [-1, 128 * 4 * 4])
            dense4 = tf.layers.dense(inputs=flat, units=625, activation=tf.nn.relu)
            dropout4 = tf.layers.dropout(inputs=dense4, rate=0.5, training=self.tra

            # Logits (no activation) Layer: L5 Final FC 625 inputs -> outputs
            self.logits = tf.layers.dense(inputs=dropout4, units=numClasses)

        # define cost/loss & optimizer
        self.cost = tf.reduce_mean(tf.nn.softmax_cross_entropy_with_logits(logits=s
        self.optimizer = tf.train.AdamOptimizer(learning_rate=learning_rate).minimi

        correct_prediction = tf.equal(tf.argmax(self.logits, 1), tf.argmax(self.Y,
        self.accuracy = tf.reduce_mean(tf.cast(correct_prediction, tf.float32))

    def predict(self, x_test, training=False):
        return self.sess.run(self.logits, feed_dict={self.X: x_test, self.training:

    def get_accuracy(self, x_test, y_test, training=False):
        return self.sess.run(self.accuracy, feed_dict={self.X: x_test, self.Y: y_te

    def train(self, x_data, y_data, training=True):
        return self.sess.run([self.cost, self.optimizer], feed_dict={self.X: x_data

# initialize
sess = tf.Session()

models = []
```

```
num_models = 4
for m in range(num_models):
    models.append(Model(sess, "model" + str(m)))

sess.run(tf.global_variables_initializer())

print('Learning Started!')

num_epochs = 15
batch_size = 100
print('numTrain: ', numTrain)
num_iterations = int( numTrain / batch_size)


# Train
for epoch in range(num_epochs):
    avg_cost_list = np.zeros(len(models))
    for i in range(num_iterations):
        batch_xs, batch_ys = train_data[i * 100: (i + 1) * 100], train_labels[i * 1

        # Train each model
        for m_idx, m in enumerate(models):
            c, _ = m.train(batch_xs, batch_ys)
            avg_cost_list[m_idx] += c / num_iterations

    print('Epoch:', '%04d' % (epoch + 1), 'cost =', avg_cost_list)

print('Learning Finished!')


# Test & accuracy
predictions = np.zeros([numTest, numClasses])
for m_idx, m in enumerate(models):
    print(m_idx, 'Accuracy:', m.get_accuracy(test_data, test_labels))
    p = m.predict(test_data)
    predictions += p

ensemble_correct_prediction = tf.equal(tf.argmax(predictions, 1), tf.argmax(test_la
ensemble_accuracy = tf.reduce_mean(tf.cast(ensemble_correct_prediction, tf.float32)
print('Final accuracy:', sess.run(ensemble_accuracy))
```

```
WARNING:tensorflow:From <ipython-input-9-0917ef1bdd41>:79: conv2d (from tenso
Instructions for updating:
Use keras.layers.conv2d instead.
WARNING:tensorflow:From /usr/local/lib/python3.6/dist-packages/tensorflow/pyt
Instructions for updating:
Colocations handled automatically by placer.
WARNING:tensorflow:From <ipython-input-9-0917ef1bdd41>:80: max_pooling2d (fro
Instructions for updating:
Use keras.layers.max_pooling2d instead.
WARNING:tensorflow:From <ipython-input-9-0917ef1bdd41>:81: dropout (from tens
Instructions for updating:
Use keras.layers.dropout instead.
WARNING:tensorflow:From /usr/local/lib/python3.6/dist-packages/tensorflow/pyt
Instructions for updating:
Please use `rate` instead of `keep_prob`. Rate should be set to `rate = 1 - k
WARNING:tensorflow:From <ipython-input-9-0917ef1bdd41>:95: dense (from tenso
Instructions for updating:
Use keras.layers.dense instead.
```

```
WARNING:tensorflow:From <ipython-input-9-0917ef1bdd41>:102: softmax_cross_ent
Instructions for updating:

Future major versions of TensorFlow will allow gradients to flow
into the labels input on backprop by default.

See `tf.nn.softmax_cross_entropy_with_logits_v2`.

Learning Started!
numTrain:  240000
Epoch: 0001 cost = [0.10468324 0.10184871 0.10251109 0.10327382]
Epoch: 0002 cost = [0.03955471 0.03966181 0.04028189 0.03961207]
Epoch: 0003 cost = [0.03291164 0.03285973 0.03267252 0.03280353]
Epoch: 0004 cost = [0.02949152 0.02939486 0.02953999 0.02957595]
Epoch: 0005 cost = [0.02754066 0.02755699 0.02666415 0.02744095]
Epoch: 0006 cost = [0.02618295 0.02627841 0.02529343 0.0257399 ]
Epoch: 0007 cost = [0.02505093 0.02504658 0.02427934 0.0251797 ]
Epoch: 0008 cost = [0.02341027 0.02411584 0.02372315 0.02406025]
Epoch: 0009 cost = [0.02358986 0.02329099 0.02328037 0.02309247]
Epoch: 0010 cost = [0.02355568 0.02233755 0.0228784  0.02300813]
Epoch: 0011 cost = [0.02229733 0.02200331 0.0218251  0.02277981]
Epoch: 0012 cost = [0.02233569 0.02140354 0.02109605 0.02199041]
Epoch: 0013 cost = [0.02120303 0.02134857 0.02285071 0.02114544]
Epoch: 0014 cost = [0.02178189 0.02170915 0.02136285 0.02185103]
Epoch: 0015 cost = [0.02130419 0.02103714 0.02110437 0.02036902]
Learning Finished!
0 Accuracy: 0.9966
1 Accuracy: 0.996625
2 Accuracy: 0.996575
3 Accuracy: 0.996425
Final accuracy: 0.997225
```

Summary

	Alphabet/Digits	Digits
Logistic Regression	0.6085106	0.7697
Neural Networks	0.6993085	0.9823
Xavier	0.8368085	0.988775
Dropout	0.84957445	0.990575
CNN	0.89090425	0.996125
Ensemble	0.89521277	0.997225

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