# TensorFlow
## - MNIST example -

Aug. 2019

Ando Ki, Ph.D.
adki@future-ds.com

## Table of contents

# Get TensorFlow packages

- This package is required to utilize MNIST dataset.
- Go to the project directory

```
$ cd $(PROJECT)/codes
```

- Get a copy of TensorFlow package

```
$ git clone https://github.com/tensorflow/tensorflow.git
```

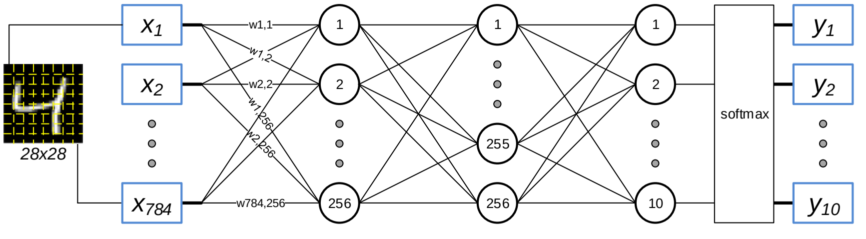
  - or visit following site and get a copy of it
    - check directory hierarchy and its name; modify if necessary

https://github.com/tensorflow/tensorflow



# MNIST using MLP

- MLP (Multi-Layer Perceptron) applies to MNIST
  - 784 (28x28) inputs of black and white → converted to floating number 0.0 ~ 1.0
  - 10 outputs representing digit 0 to 9
  - Two hidden layer
  - 256 features for each hidden layer



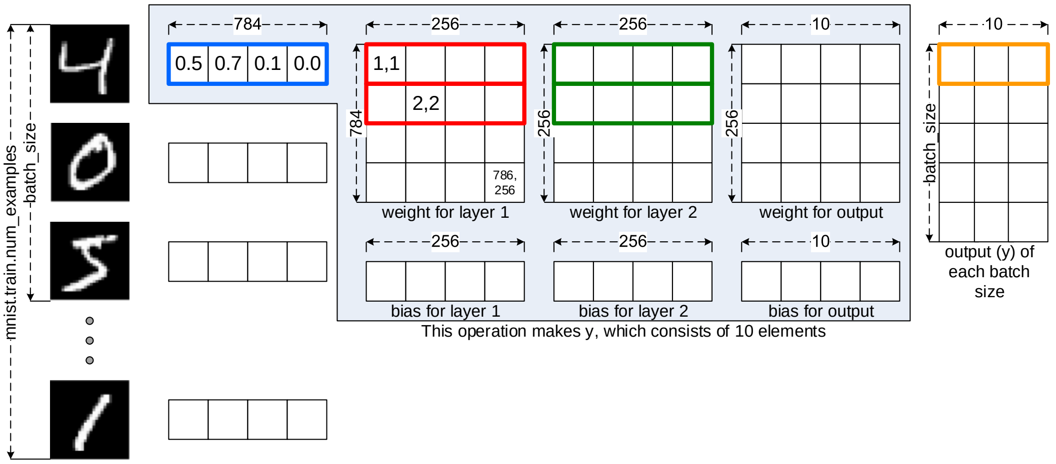

$(PROJECT)/codes/tensorflow-projects/mnist-projects/mlp

# MNIST using MLP

- Total testing patterns
  - 60K images (train patterns: 55K images)
- Batch number
  - 100 ➔ group 600 batches (train batches: 550)
- Epoch number
  - The number of whole trainings (forward calculation and back propagation)



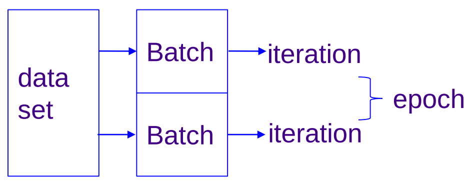
# MNIST using MLP



# Terminology

- Iteration
  - Forward and backward for a number of inputs (i.e., batch or minibatch)
- Batch or minibatch
  - A number of inputs (e.g., testing images) to complete an iteration
  - Batch size: the number of training examples in one forward/backward pass
    - The bigger the batch size, the more memory space needed
  - Minibatch
    - Take a small number of examples at a time, ranging from 1 to a few hundred, during one iteration
- Epoch
  - one epoch: one forward pass and one backward pass of all the training examples
  - it contains a number of iterations

- 1 epoch = (number of iterations)
- = (total training examples) /
- (batch size or minibatch size)






# TensorFlow oprators

- tf.placeholder()
- tf.Variable()
- tf.global_variables_initilizer()
- tf.add()
- tf.matmul()
- tf.reduce_mean()
- tf.nn.relu()
- tf.train.AdamOptimizer()
- tf.train.GradientDescentOptimizer()
- tf.argmax()

# MNIST using MLP

$(PROJECT)/codes/tensorflow-projects/mnist-projects/mlp/mnist_mlp.py

```
#----------------------------------------------------------------------
import os
import sys
os.environ['TF_CPP_MIN_LOG_LEVEL']='2'
sys.path.append(os.path.dirname("../../../tensorflow/tensorflow"))
#----------------------------------------------------------------------
import tensorflow as tf
import tensorflow as tf
import numpy as np
from random import randint
import matplotlib.pyplot as plt
#----------------------------------------------------------------------
# Import MNIST data
from tensorflow.examples.tutorials.mnist import input_data
mnist = input_data.read_data_sets("../dataset", one_hot=True)
#----------------------------------------------------------------------
# Parameters
learning_rate = 0.01
training_epochs = 1000
batch_size = 100
display_step = 10
```

Depress warnings

Path where to find module

TensorFlow module

MNIST dataset handling module

Read MNIST dataset

Parameters

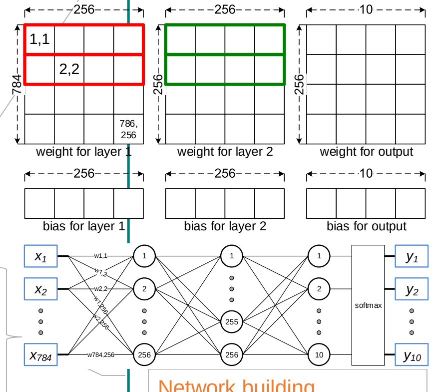


# MNIST using MLP

```
#----------------------------------------------------------------------
# tf Graph Input
x = tf.placeholder("float", [None, 784], name="x-input")
y = tf.placeholder("float", [None, 10], name="y-output")

#----------------------------------------------------------------------
# Model weights
W1 = tf.Variable(tf.random_normal([784,256]), name="weight1")
b1 = tf.Variable(tf.random_normal([256]), name="bias1")
W2 = tf.Variable(tf.random_normal([256,256]), name="weight2")
b2 = tf.Variable(tf.random_normal([256]), name="bias2")
W3 = tf.Variable(tf.random_normal([256,10]), name="weight-out")
b3 = tf.Variable(tf.random_normal([10]), name="bias-out")

#----------------------------------------------------------------------
# inference -> hypothesis
layer_1 = tf.add(tf.matmul(x, W1), b1)
layer_1 = tf.nn.sigmoid(layer_1, name="layer1-sigmoid")
layer_2 = tf.add(tf.matmul(layer_1, W2), b2)
layer_2 = tf.nn.sigmoid(layer_2, name="layer2-sigmoid")
out_layer = tf.add(tf.matmul(layer_2, W3), b3)
infer = tf.nn.softmax(out_layer, name="infer")
```

Input and output

Network parameters




Network building

Note softmax

# MNIST using MLP

```
#------------------------------------------------------------------------
# Minimize error using cross entropy
cost = tf.reduce_mean(-tf.reduce_sum(y * tf.log(infer), reduction_indices=1))
optimizer = tf.train.GradientDescentOptimizer(learning_rate).minimize(cost)

#------------------------------------------------------------------------
# Evaluate -- 0~1 accuracy
correct  = tf.equal(tf.argmax(infer, 1), tf.argmax(y,1))
accuracy = tf.reduce_mean(tf.cast(correct, "float"))

#------------------------------------------------------------------------
# Initializing the variables
init = tf.global_variables_initializer()

#------------------------------------------------------------------------
# Add ops to save and restore all the variables
saver = tf.train.Saver()
```

cost and optimizer

y => (100, 10)
cost will be scalar

Accuracy

Initialize

Prepare for save/restore



# MNIST using MLP

```
with tf.Session() as sess:
    sess.run(init)
    # tensorboard --logdir=./logs
    # http://localhost:6006
    write = tf.summary.FileWriter('./logs', sess.graph)
    # Training cycle
    for epoch in range(training_epochs):
       avg_cost = 0.
       total_batch = int( mnist.train.num_examples / batch_size )
       # Loop over all batches
       for i in range(total_batch):
          batch_xs, batch_ys = mnist.train.next_batch(batch_size)
          # Fit training using batch data
          sess.run(optimizer, feed_dict={x: batch_xs, y: batch_ys})
          # Compute average loss
          avg_cost += sess.run(cost, feed_dict={x: batch_xs, y: batch_ys})
         avg_accu += sess.run(accuracy, feed_dict={x: batch_xs, y: batch_ys})

       avg_cost /= total_batch
       avg_accu /=total_batch
       # Distplay logs per epoch step
       if epoch % display_step == 0:
         print "Epoch:", "%04d" % (epoch + 1), "cost=", "{:.9f}".format(avg_cost),\
                                                  "accuracy=", "{:.6f}".format(avg_accu)
       if avg_accu>0.95:
         break
```

training epochs = 100

total_batch = 550

batch_xs = (100, 784)
batch_ys = (100, 10)

Stop when sufficient accuracy has been reached

# MNIST using MLP

```
with tf.Session() as sess:
    sess.run(init)
    # tensorboard --logdir=./logs
    # http://localhost:6006
    write = tf.summary.FileWriter('./logs', sess.graph)
    # Training cycle
    for epoch in range(training_epochs):
        avg_cost = 0.
        total_batch = int( mnist.train.num_examples / batch_size )
        # Loop over all batches
        for i in range(total_batch):
            batch_xs, batch_ys = mnist.train.next_batch(batch_size)
            # Fit training using batch data
            sess.run(optimizer, feed_dict={x: batch_xs, y: batch_ys})
            # Compute average loss
            avg_cost += sess.run(cost, feed_dict={x: batch_xs, y: batch_ys})
           avg_accu += sess.run(accuracy, feed_dict={x: batch_xs, y: batch_ys})

        avg_cost /= total_batch
        avg_accu /=total_batch
        # Display logs per epoch step
        if epoch % display_step == 0:
           print "Epoch:", "%04d" % (epoch + 1), "cost=", "{:.9f}".format(avg_cost),\
                                                         "accuracy=", "{:.6f}".format(avg_accu)
        if avg_accu>0.95:
           break
```

epoch times over all data set

for each batch



# MNIST using MLP

```
    # Save weights
    saver.save(sess, "./model/model.ckpt")

    #------------------------------------------------------------------------
    # Test model
    print "Accuracy:", accuracy.eval({x: mnist.test.images, y: mnist.test.labels})

    #------------------------------------------------------------------------
    # predict & show
    r = randint(0, mnist.test.num_examples - 1)
    print "Label: " , sess.run(tf.argmax(mnist.test.labels[r:r+1], 1))
    print "Prediction: " , sess.run(tf.argmax(infer, 1), {x: mnist.test.images[r:r+1]})
    # show the img
    plt.imshow(mnist.test.images[r:r+1].reshape(28, 28),
                    cmap="Greys", interpolation="nearest")
    plt.show()
#------------------------------------------------------------------------
```

Save network parameters

Check accuracy for validation set

Pick a number between 0 ~ num_examples

Print which label

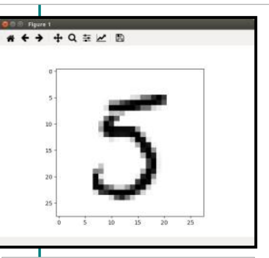
Inference

Show image

# MNIST using MLP

```
(tensorflow)$ python mnist_mlp.py
Extracting ../dataset/train-images-idx3-ubyte.gz
Extracting ../dataset/train-labels-idx1-ubyte.gz
Extracting ../dataset/t10k-images-idx3-ubyte.gz
Extracting ../dataset/t10k-labels-idx1-ubyte.gz
Epoch: 0001 cost= 5.25198 accuracy= 0.30315
Epoch: 0011 cost= 0.89775 accuracy= 0.77602
Epoch: 0021 cost= 0.64263 accuracy= 0.82938
Epoch: 0031 cost= 0.52474 accuracy= 0.85504
Epoch: 0041 cost= 0.45274 accuracy= 0.87211
Epoch: 0051 cost= 0.40308 accuracy= 0.88496
Epoch: 0061 cost= 0.36560 accuracy= 0.89400
……
Epoch: 0161 cost= 0.20485 accuracy= 0.93944
Epoch: 0171 cost= 0.19650 accuracy= 0.94225
Epoch: 0181 cost= 0.18897 accuracy= 0.94424
Epoch: 0191 cost= 0.18194 accuracy= 0.94656
Epoch: 0201 cost= 0.17524 accuracy= 0.94880
Optimization finished
Accuracy: 0.9113
Label:  [5]
Prediction:  [5]
^C
(tensorflow)$ tensorboard –logdir=logs
```

When 'matplotlib' is missing:
$ sudo apt-get install libpng-dev
$ sudo apt-get install libfreetype6-dev
$ pip install matplotlib



Training accuracy

Validation accuracy

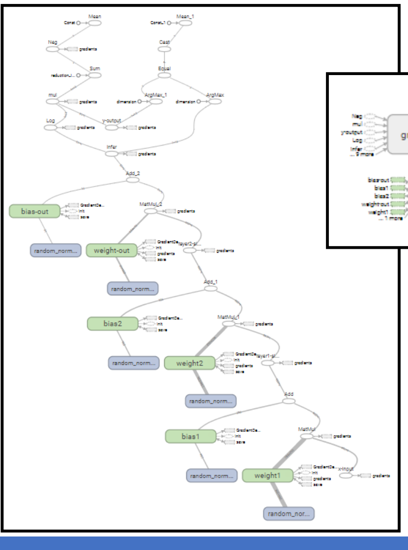
Predict correct label

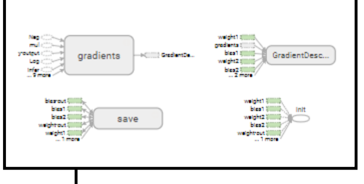
Invoke tensor board

15

# MNIST using MLP

invoke web browser: http://localhost:6006
Then select 'GRAPH' menu






16

# MNIST using MLP inference

$(PROJECT)/codes/tensorflow-projects/mnist-projects/mlp/mnist_inference.py

```
#-----------------------------------------------------------------------
import os
import sys
os.environ['TF_CPP_MIN_LOG_LEVEL']='2'
sys.path.append(os.path.dirname("../../../tensorflow/tensorflow"))

#-----------------------------------------------------------------------
import tensorflow as tf
from random import randint
import matplotlib.pyplot as plt

#-----------------------------------------------------------------------
sess = tf.Session()

#-----------------------------------------------------------------------
# Create the network
saver = tf.train.import_meta_graph("./model/model.ckpt.meta")

#-----------------------------------------------------------------------
# Restore parameters
saver.restore(sess, "./model/model.ckpt")
```

Build network from save data file

Restore network parameters from saved data file



# MNIST using MLP inference

```
#-----------------------------------------------------------------------
# get references of graph and tensors
graph = tf.get_default_graph()
x = graph.get_tensor_by_name("x-input:0");
y = graph.get_tensor_by_name("y-output:0");
infer = graph.get_tensor_by_name("infer:0")

#-----------------------------------------------------------------------
# testing data-set
#-----------------------------------------------------------------------
# Import MNIST data
from tensorflow.examples.tutorials.mnist import input_data
mnist = input_data.read_data_sets("../dataset", one_hot=True)
```

Get graph

Get input and output

Get inference operator node

MNIST dataset handling module

Read MNIST dataset

# MNIST using MLP inference

```
#------------------------------------------------------------------------
# predict & show
for i in range (10):
    r = randint(0, mnist.test.num_examples - 1)
    print "Label: " , sess.run(tf.argmax(mnist.test.labels[r:r+1], 1))
    print "Prediction: " , sess.run(tf.argmax(infer, 1),\
                            {x: mnist.test.images[r:r+1]})

    #-------------------------------------------------------------------
    # show the img
    plt.imshow(mnist.test.images[r:r+1].reshape(28, 28),\
            cmap="Greys", interpolation="nearest")
    plt.show()

#------------------------------------------------------------------------
```

Test 10 patterns

Pick a number between 0 ~ num_examples

Print which label

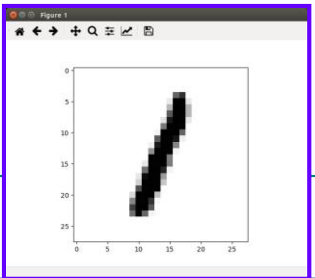
Inference

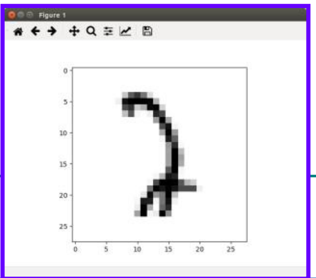
Show image

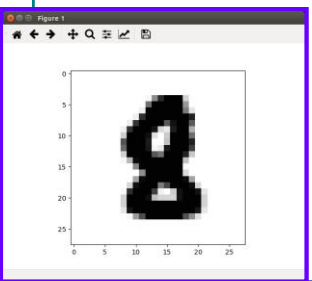


# MNIST using MLP inference

```
(tensorflow)$ python mnist_inference.py
Extracting ../dataset/train-images-idx3-ubyte.gz
Extracting ../dataset/train-labels-idx1-ubyte.gz
Extracting ../dataset/t10k-images-idx3-ubyte.gz
Extracting ../dataset/t10k-labels-idx1-ubyte.gz
Label:  [1]
Prediction:  [1]
Label:  [2]
Prediction:  [2]
Label:  [8]
Prediction:  [8]
```







# MNIST using MLP

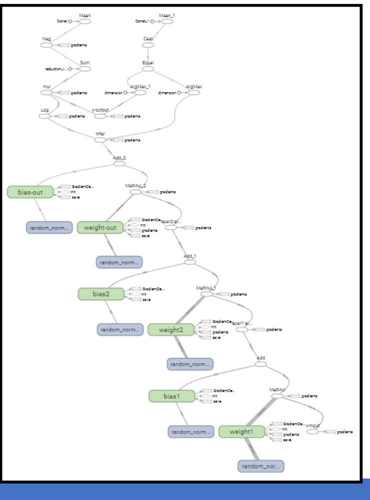
- This example shows how to use MLP to test MNIST
  - Step 1: go to your project directory
    - [user@host] cd $(PROJECT)/codes/tensorflow-project/mnist-project/mlp
  - Step 2: see the codes
  - Step 3: run Python under virtual environment
    - (do not forget to run ‘$ source ~/tensorflow/bin/activate’)
    - [user@host]  python mnist_mlp.py
    - [user@host] python mnist_inference.py

```
[user@host] cd $(PROJECT)/codes/tensorflow-project/mnist-project/mlp
[user@host] python mnist_mlp.py
[user@host] python mnist_inference.py
```



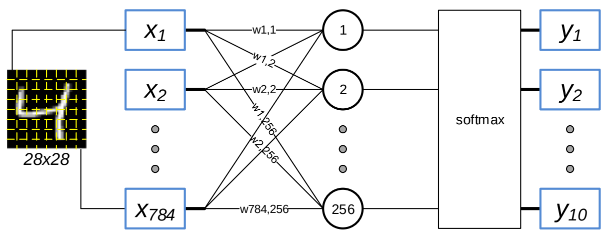
# MNIST using MLP

- Make more structured style using “with tf.name.scope(“LAYER1”):”



# MNIST using single hidden layer network

- Logistic regression for MNIST
  - 784 (28x28) inputs of black and white ➔ converted to floating number 0.0 ~ 1.0
  - 10 outputs representing digit 0 to 9
  - one hidden layer
  - 256 features for each hidden layer



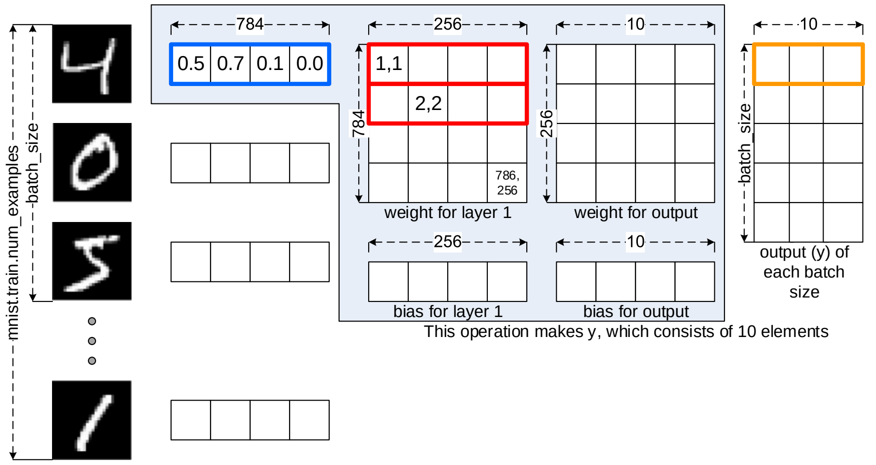

$(PROJECT)/codes/tensorflow-projects/mnist-projects/single



# MNIST using single hidden layer network

- Total testing patterns
  - 60K images
- Batch number
  - 100 ➔ group 600 batches
- Epoch number
  - The number of whole trainings (forward calculation and back propagation)

# MNIST using single hidden layer network






# MNIST using single hidden layer network

***.... common parts are not shown ....***

```
# tf Graph Input
x = tf.placeholder("float", [None, 784], name="x-input") # mnist data image of
shape 28*28
y = tf.placeholder("float", [None, 10], name="y-output") # 0-9 digits recognition =>
10 classes

#----------------------------------------------------------------------
# Model weights
W = tf.Variable(tf.zeros([784, 10]), name="weight")
b = tf.Variable(tf.zeros([10]), name="bias")

#----------------------------------------------------------------------
# inference -> hypothesis
infer = tf.nn.softmax(tf.matmul(x, W) + b, name="infer")

# Minimize error using cross entropy
cost = tf.reduce_mean(-tf.reduce_sum(y * tf.log(infer), reduction_indices=1))
optimizer = tf.train.GradientDescentOptimizer(learning_rate).minimize(cost)
# Evaluate -- 0~1 accuracy
correct  = tf.equal(tf.argmax(infer, 1), tf.argmax(y,1))
accuracy = tf.reduce_mean(tf.cast(correct, "float"))

# Initializing the variables
init = tf.global_variables_initializer()
```

# MNIST using single hidden layer network

```
#----------------------------------------------------------------------
with tf.Session() as sess:
    sess.run(init)
    # Training cycle
    for epoch in range(training_epochs):
        avg_cost = 0.; avg_accu = 0.
        total_batch = int( mnist.train.num_examples / batch_size )
        # Loop over all batches
        for i in range(total_batch):
            batch_xs, batch_ys = mnist.train.next_batch(batch_size)
            # Fit training using batch data
            sess.run(optimizer, feed_dict={x: batch_xs, y: batch_ys})
            # Compute average loss
            avg_cost += sess.run(cost, feed_dict={x: batch_xs, y: batch_ys})
            avg_accu += sess.run(accuracy, feed_dict={x: batch_xs, y: batch_ys})
        avg_cost /= total_batch;  avg_accu /= total_batch
        # Distplay logs per epoch step
        if epoch % display_step == 0:
          print "Epoch:", "%04d" % (epoch + 1),\
                "cost=", "{:.5f}".format(avg_cost),\
                "accuracy=", "{:.5f}".format(avg_accu)
        if avg_accu>0.95:
          break
    print "Optimization finished“
```

***…. common parts are not shown ….***

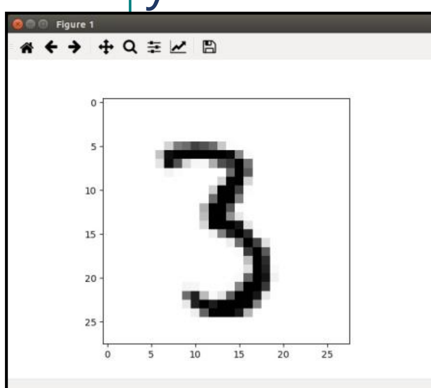
epoch times over all data set

for each batch

27

# MNIST using single hidden layer network

```
(tensorflow)$ python mnist_single.py
Extracting ../dataset/train-images-idx3-ubyte.gz
Extracting ../dataset/train-labels-idx1-ubyte.gz
Extracting ../dataset/t10k-images-idx3-ubyte.gz
Extracting ../dataset/t10k-labels-idx1-ubyte.gz
Epoch: 0001 cost= 10.12062 accuracy= 0.12273
Epoch: 0011 cost= 1.31484 accuracy= 0.74938
Epoch: 0021 cost= 0.97869 accuracy= 0.80429
Epoch: 0031 cost= 0.83487 accuracy= 0.82842
… …
Epoch: 0071 cost= 0.61011 accuracy= 0.86305
Epoch: 0081 cost= 0.58191 accuracy= 0.86751
Epoch: 0091 cost= 0.55826 accuracy= 0.87131
… …
Epoch: 0191 cost= 0.43436 accuracy= 0.89205
Epoch: 0201 cost= 0.42729 accuracy= 0.89313
Epoch: 0211 cost= 0.42070 accuracy= 0.89489
… …
Epoch: 0471 cost= 0.33196 accuracy= 0.91184
Epoch: 0481 cost= 0.33010 accuracy= 0.91236
Epoch: 0491 cost= 0.32824 accuracy= 0.91265
Optimization finished
Accuracy: 0.9106
Label:  [3]
Prediction:  [3]
```




Training accuracy

Validation accuracy

Predict correct label

28

# MNIST using single hidden layer network

- This example shows how to use single hidden layer to test MNIST
  - Step 1: go to your project directory
    - [user@host] cd $(PROJECT)/codes/tensorflow-project/mnist-project/single
  - Step 2: see the codes
  - Step 3: run Python under virtual environment
    - (do not forget to run '$ source ~/tensorflow/bin/activate')
    - [user@host]  python mnist_single.py
    - [user@host] python mnist_inference.py

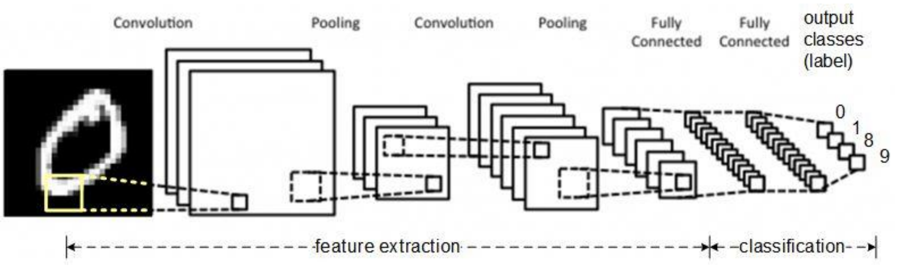
Prepare your own code in
$(PROJECT)/codes/tensorflow-projects/mnist-projects/single

```
[user@host] cd $(PROJECT)/codes/tensorflow-project/mnist-project/single
[user@host] python mnist_single.py
[user@host] python mnist_inference.py
```



# MNIST using CNN

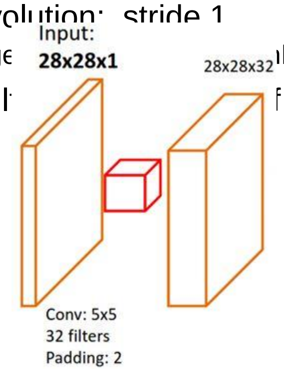
- Logistic regression for MNIST
  - 784 (28x28) inputs of black and white ➔ converted to floating number 0.0 ~ 1.0
  - 10 outputs representing digit 0 to 9
  - one hidden layer
  - 256 features for each hidden layer




$(PROJECT)/codes/tensorflow-projects/mnist-projects/cnn

# MNIST using CNN: 1st convolutional layer

- Input: 28x28 pixels
- Convolution filter: 32 kernels with 5x5
- Convolution: stride 1
  - It ge ber of elements
- Resul f 28x28

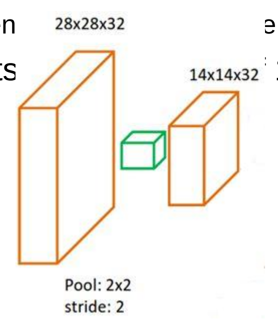



```
… …
with tf.name_scope("WEIGHT-BIAS"):
    weights = {
          # 5x5 conv, 1 input, 32 outputs
          'wc1': tf.Variable(tf.random_normal([5, 5, 1, 32]),\
                 name="wc1"),
… …

with tf.name_scope("CONV-POOL-1"):
       # Convolution Layer
       conv1 = conv2d(x, weights['wc1'], biases['bc1'])

… …

def conv2d(x, W, b, strides=1):
   with tf.name_scope("CONV"):
       # Conv2D wrapper, with bias and relu activation
       x = tf.nn.conv2d(x, W, strides=[1, strides, strides, 1],\
            padding='SAME')
       x = tf.nn.bias_add(x, b)
       return tf.nn.relu(x)
```



# MNIST using CNN: 1st pooling

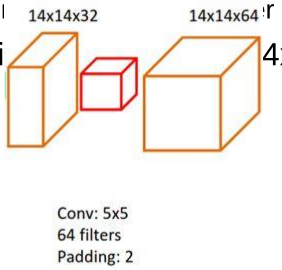
- Input: 32 features with 28x28
- Max pooling filter: 5x5
- Convolution: stride 2
  - It gen elements
- Results 14x14




```
with tf.name_scope("CONV-POOL-1"):
       # Convolution Layer
       conv1 = conv2d(x, weights['wc1'], biases['bc1'])
       # Max Pooling (down-sampling)
       conv1 = maxpool2d(conv1, k=2)
```

# MNIST using CNN: 2nd convolutional layer

- Input: 32 features with 14x14 pixels
- Convolution filter: 64 kernels with 5x5
- Convolution:  stride 1
  - It gene r of elements
- Results i 4x14

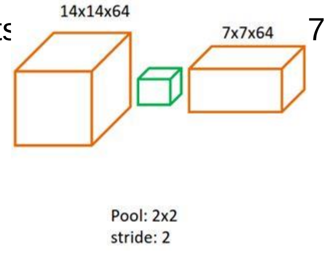



```
… …
with tf.name_scope("WEIGHT-BIAS"):
    weights = {
          # 5x5 conv, 1 input, 32 outputs
          'wc1': tf.Variable(tf.random_normal([5, 5, 1, 32]),
name="wc1"),
          # 5x5 conv, 32 inputs, 64 outputs
          'wc2': tf.Variable(tf.random_normal([5, 5, 32, 64]),
name="wc2"),
… …
 with tf.name_scope("CONV-POOL-2"):
       # Convolution Layer
       conv2 = conv2d(conv1, weights['wc2'], biases['bc2'])
       # Max Pooling (down-sampling)
       conv2 = maxpool2d(conv2, k=2)
… …
def conv2d(x, W, b, strides=1):
   with tf.name_scope("CONV"):
       # Conv2D wrapper, with bias and relu activation
       x = tf.nn.conv2d(x, W, strides=[1, strides, strides, 1],\
            padding='SAME')
       x = tf.nn.bias_add(x, b)
       return tf.nn.relu(x)
```



# MNIST using CNN: 2nd pooling

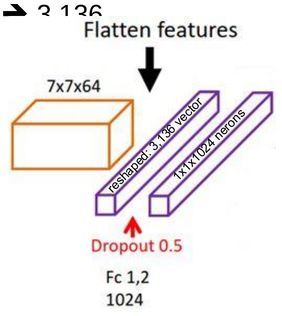
- Input: 64 features with 14x14
- Max pooling filter: 2x2
- Convolution:  stride 2
  - It generates ½  number of elements
- Results 7




```
with tf.name_scope("CONV-POOL-2"):
       # Convolution Layer
       conv2 = conv2d(conv1, weights['wc2'], biases['bc2'])
       # Max Pooling (down-sampling)
       conv2 = maxpool2d(conv2, k=2)
```

# MNIST using CNN: fully connected layer

- Input: 64 features with 7x7
- Reshaping: 3-D array to 1-D vector
  - 64x7x7 → 3,136
- Neurons:

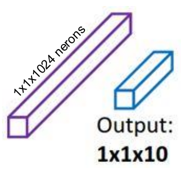



```
with tf.name_scope("FC"):
        # Fully connected layer
        # Reshape conv2 output to fit fully connected layer input
        fc1 = tf.reshape(conv2, [-1, weights['wd1'].get_shape().as_list()[0]])
        fc1 = tf.add(tf.matmul(fc1, weights['wd1']), biases['bd1'])
        fc1 = tf.nn.relu(fc1)
        # Apply Dropout
        fc1 = tf.nn.dropout(fc1, dropout)
```

35

# MNIST using CNN: read-out layer

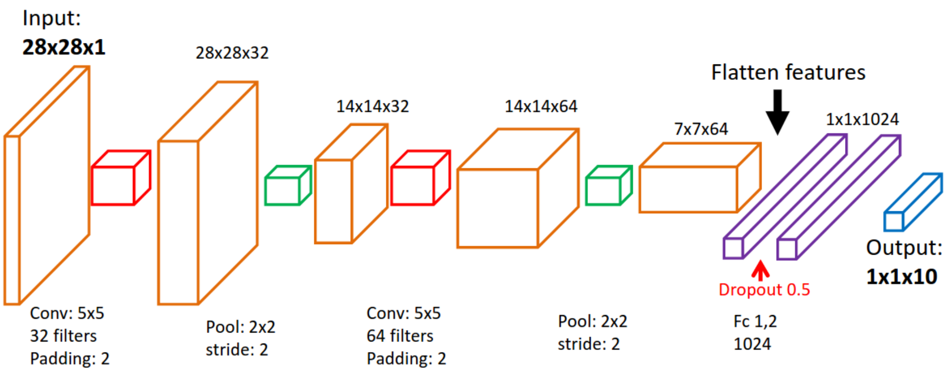
- Input: 1024 neurons
- Output: 10 classes




```
with tf.name_scope("OUT"):
        # Output, class prediction
        out = tf.add(tf.matmul(fc1, weights['out']), biases['out'], name="add-output")
```

36

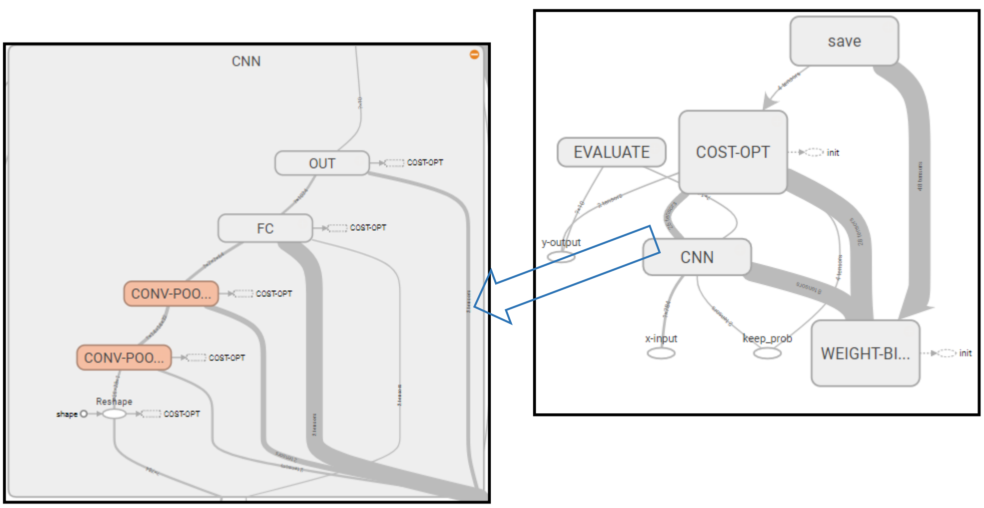
# MNIST using CNN




http://www.cnblogs.com/BigBallon/p/6701846.html

37

# MNIST using CNN




38

# MNIST using CNN

- This example shows how to use CNN to test MNIST
  - Step 1: go to your project directory
    - [user@host] cd $(PROJECT)/codes/tensorflow-project/mnist-project/cnn
  - Step 2: see the codes
  - Step 3: run Python under virtual environment
    - (do not forget to run '$ source ~/tensorflow/bin/activate')
    - [user@host]  python mnist_cnn.py
    - [user@host] python mnist_inference.py

```
[user@host] cd $(PROJECT)/codes/tensorflow-project/mnist-project/cnn
[user@host] python mnist_cnn.py
[user@host] python mnist_inference.py
```

39

㈜퓨쳐디자인시스템
34051 대전광역시 유성구 문지로 193, KAIST 문지캠퍼스, F723호
(042) 864-0211~0212 / contact@future-ds.com / www.future-ds.com

Future Design Systems, Inc.
Faculty Wing F723, KAIST Munji Campus, 193 Munji-ro, Yuseong-gu, Daejeon 34051, Korea
+82-042-864-0211~0212 / contact@future-ds.com / www.future-ds.com


FUTURE
Design Systems