TensorFlow Tutorial

전현호

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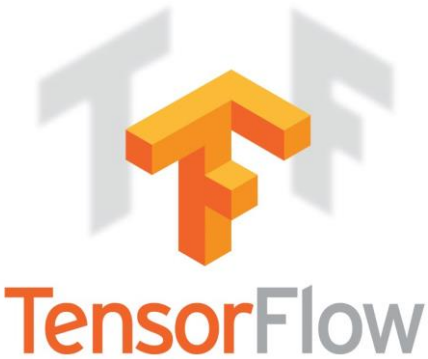
2. Install TensorFlow
3. Data type
4. Linear regression + Plot
5. MNIST
6. Multi Layer Perceptron (NN, FCN)
7. Convolutional NN

What is TensorFlow?



다차원 배열

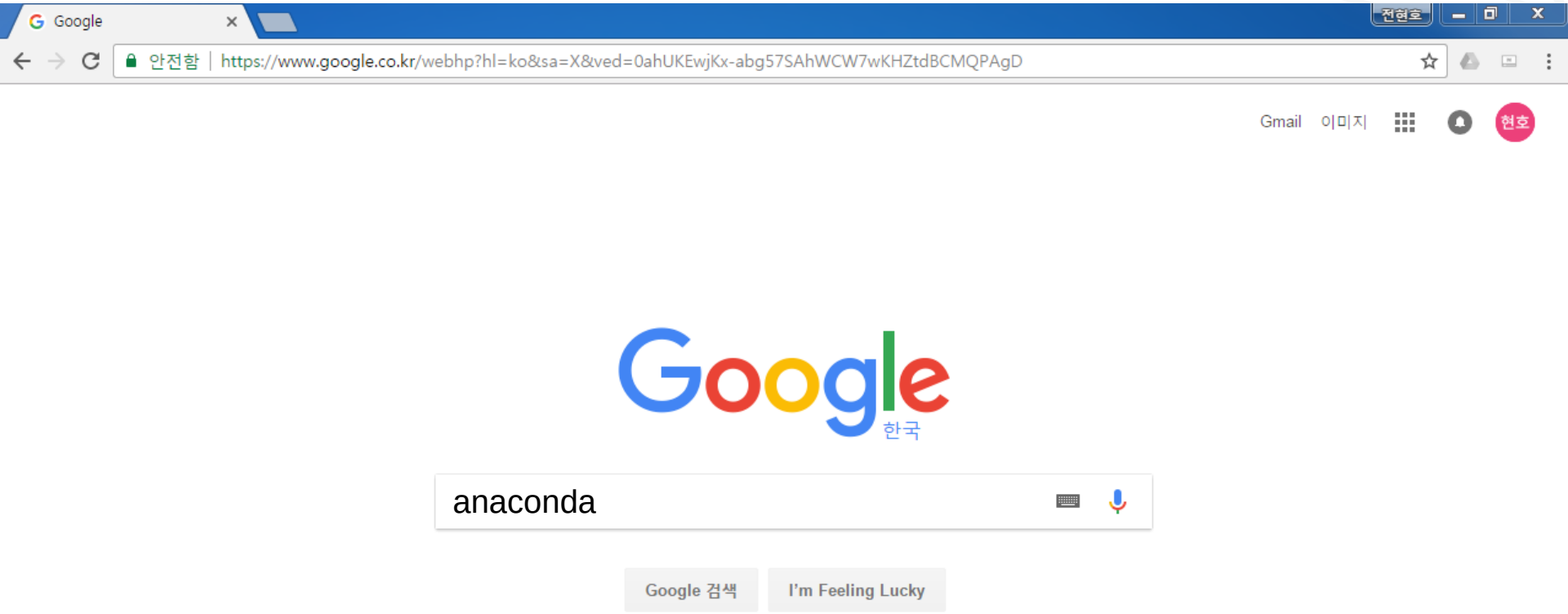
- 텐서플로우(TensorFlow) : 구글에서 개발한 기계 학습 및 딥러닝용 오픈소스 라이브러리
- 왜 텐서플로우를 사용해야 하는가?
  - 구현이 쉬움 (연산, 신경망 구조)
  - 여러 CPU 및 GPU에서 동작이 가능함
  - 데이터 및 구조를 시각적으로 확인할 수 있음 (TensorBoard)
  - 기타 등등 (뒤에서 설명)

TensorFlow Dev Summit - 17.02.16

- 텐서플로우 1.0 공식 버전 릴리즈
- 빨라짐 : 8GPUs + inception v3 모델을 사용할 경우 7.3배 속도 향상
  64GPUs + Inception v3 모델을 사용할 경우 58배 속도 향상
- 유연해짐 : 더 고급 수준의 API 추가 및 딥러닝 라이브러리중 하나인 Keras와 완벽한 호환성을 제공하는 새로운 tf.keras 모듈이 추가됨
- 기타 등등
- Python tf_upgrade.py --infile *InputFile* --outfile *OutputFile*
- pip install tensorflow로 대부분 환경에서 바로 업데이트 가능

Install TensorFlow

1. Anaconda3 4.2.0 버전 설치 (Python 3.5)



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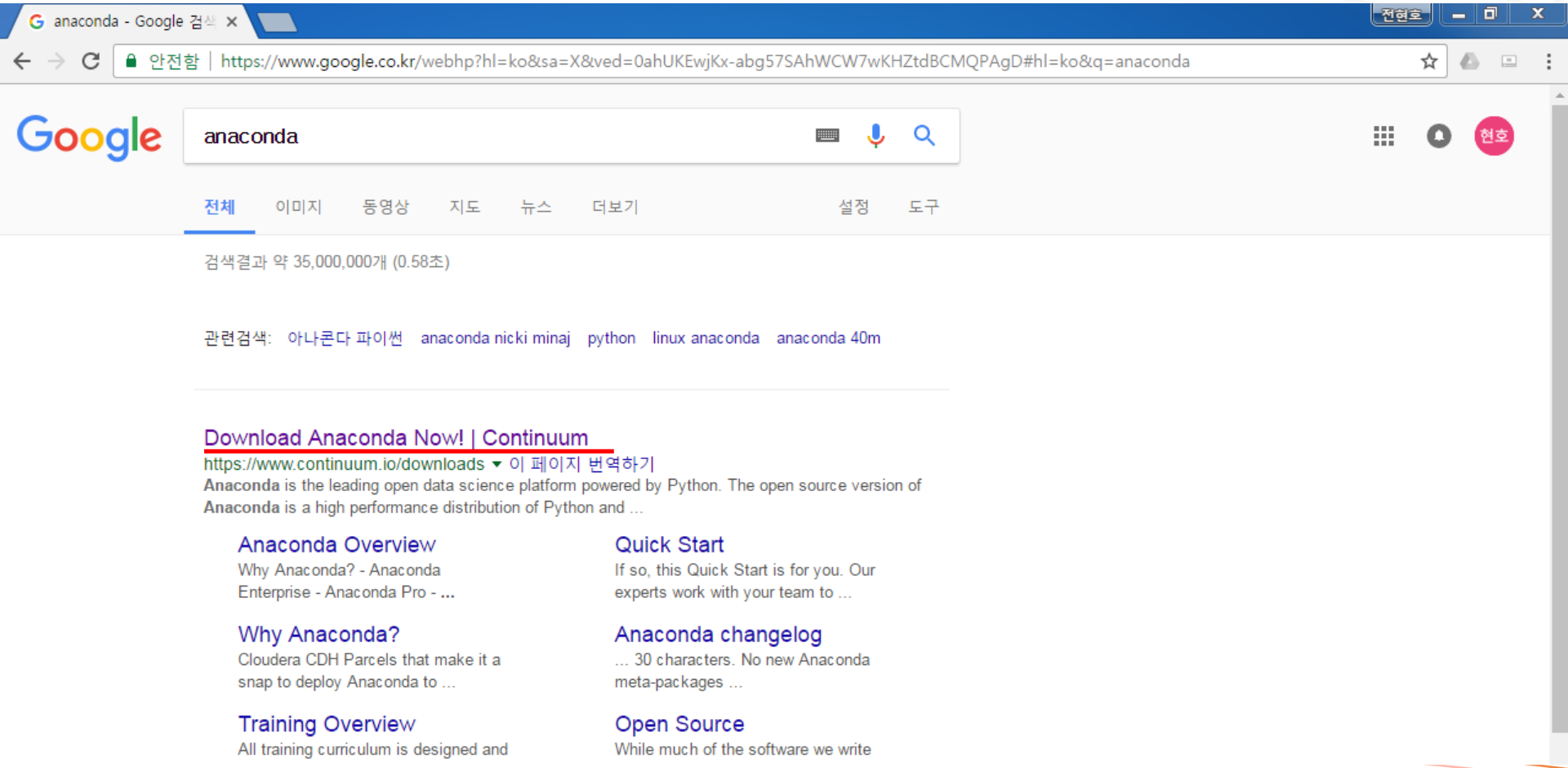

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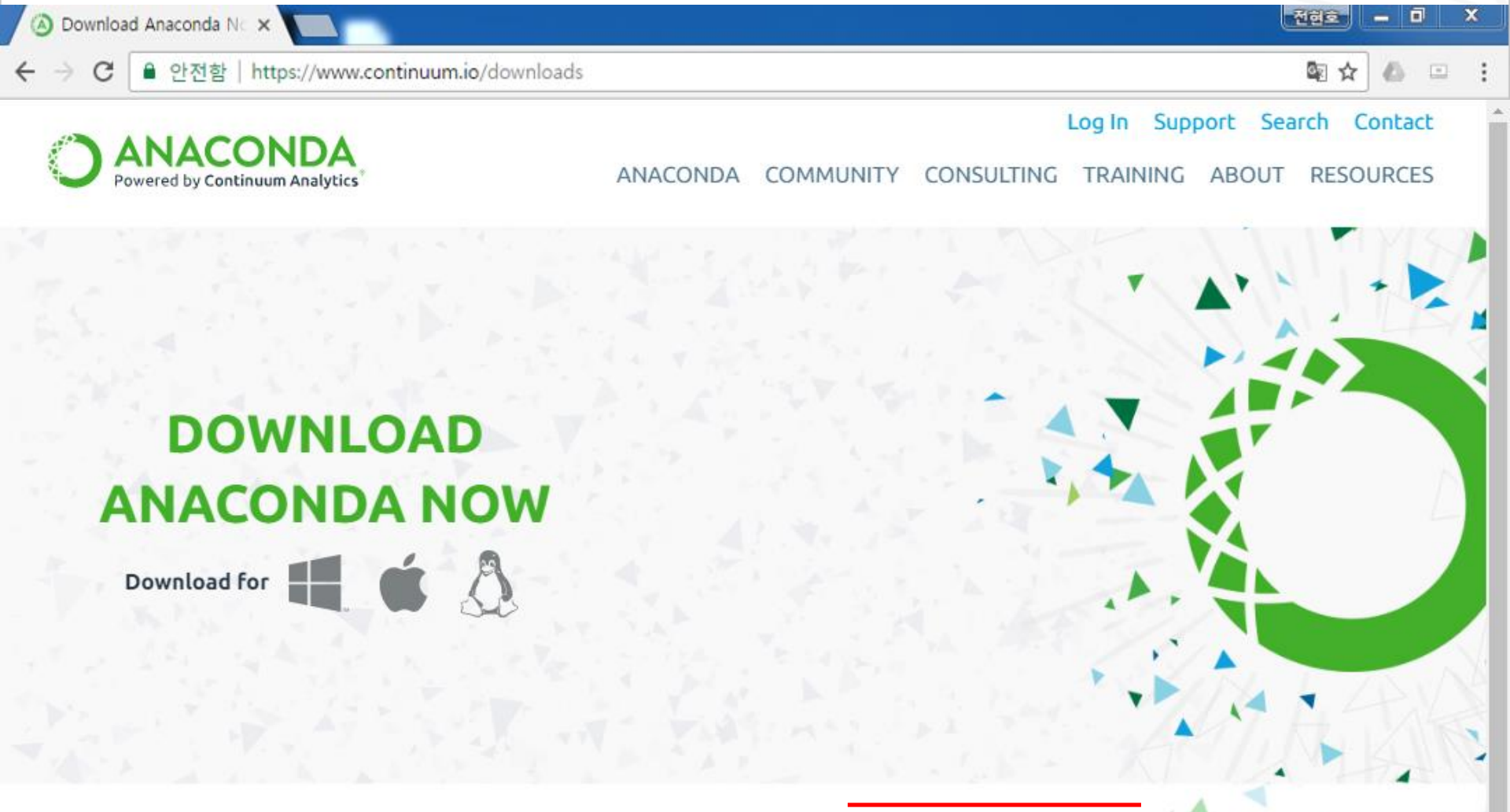

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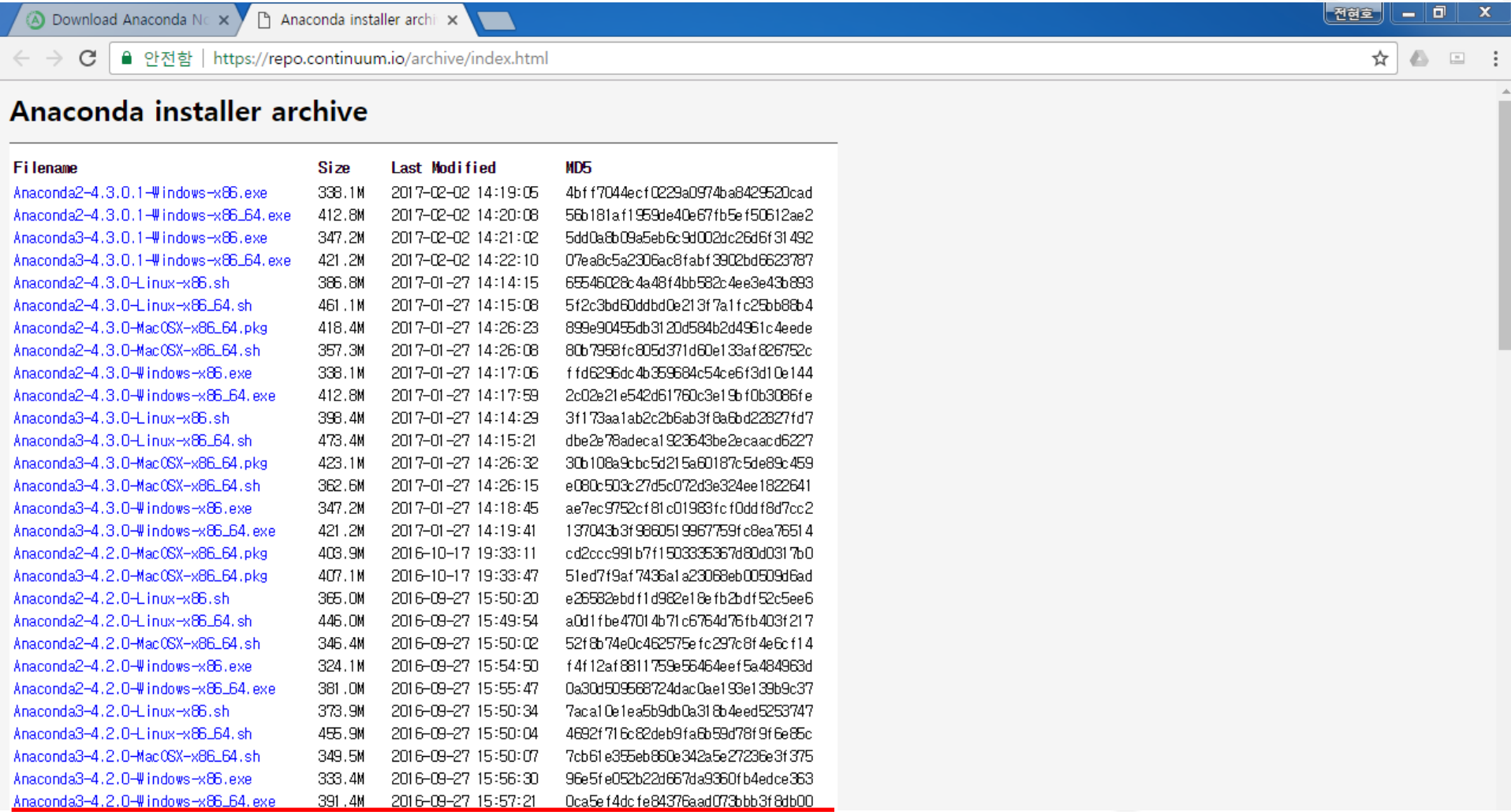

Anaconda installer archive

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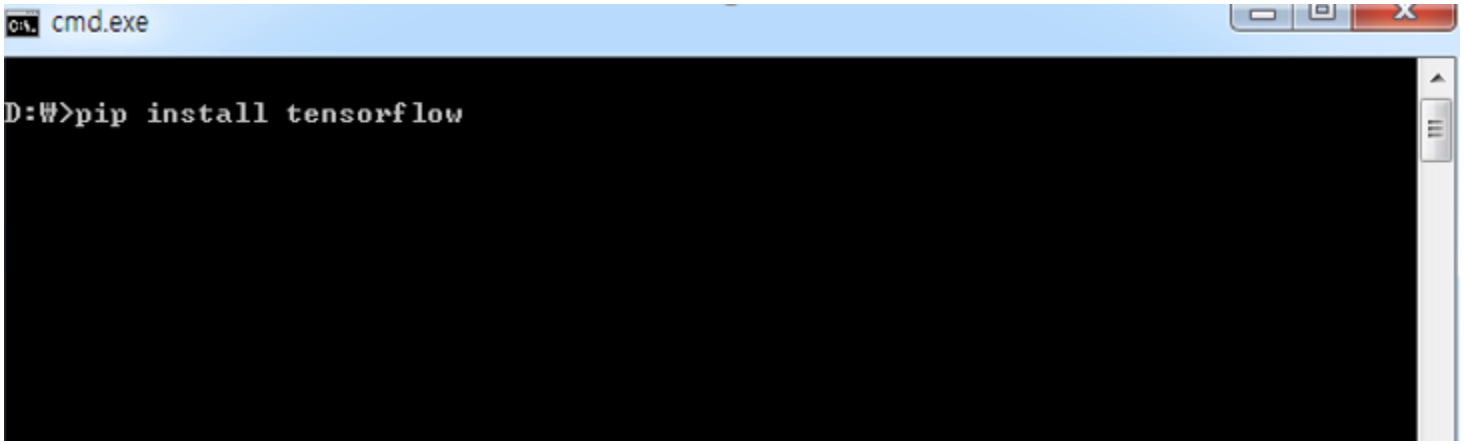
Install TensorFlow

2. TensorFlow 설치 – CPU 버전

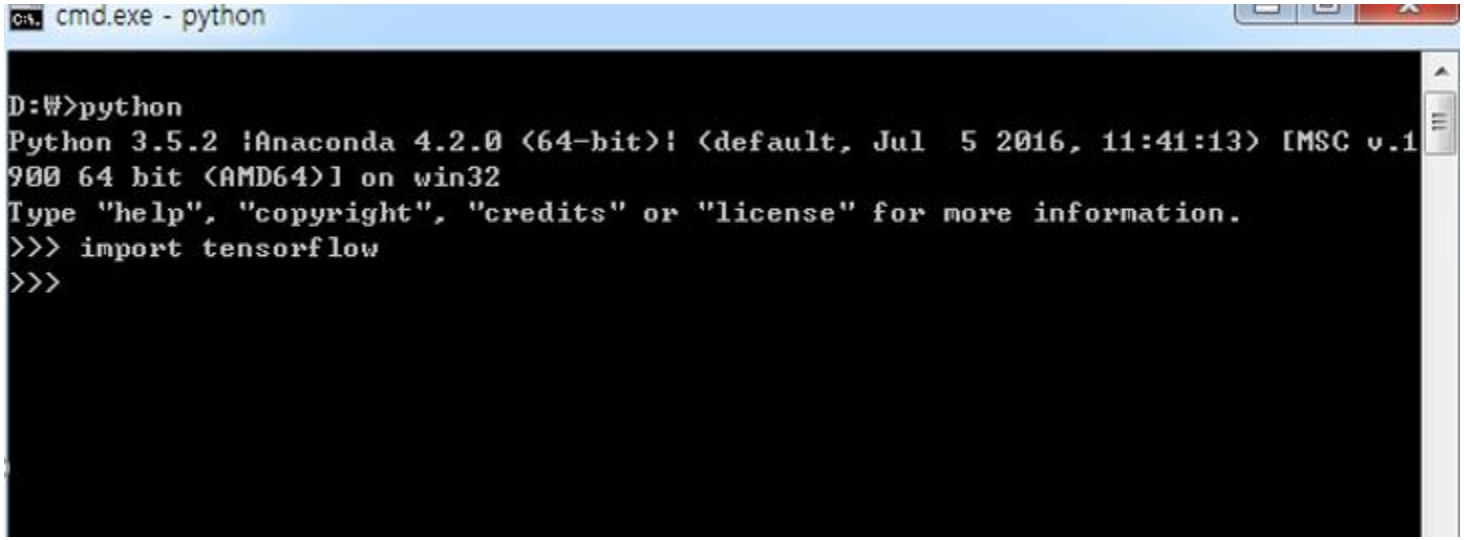
- cmd창에 pip install tensorflow 입력



Install TensorFlow

3. 설치 확인

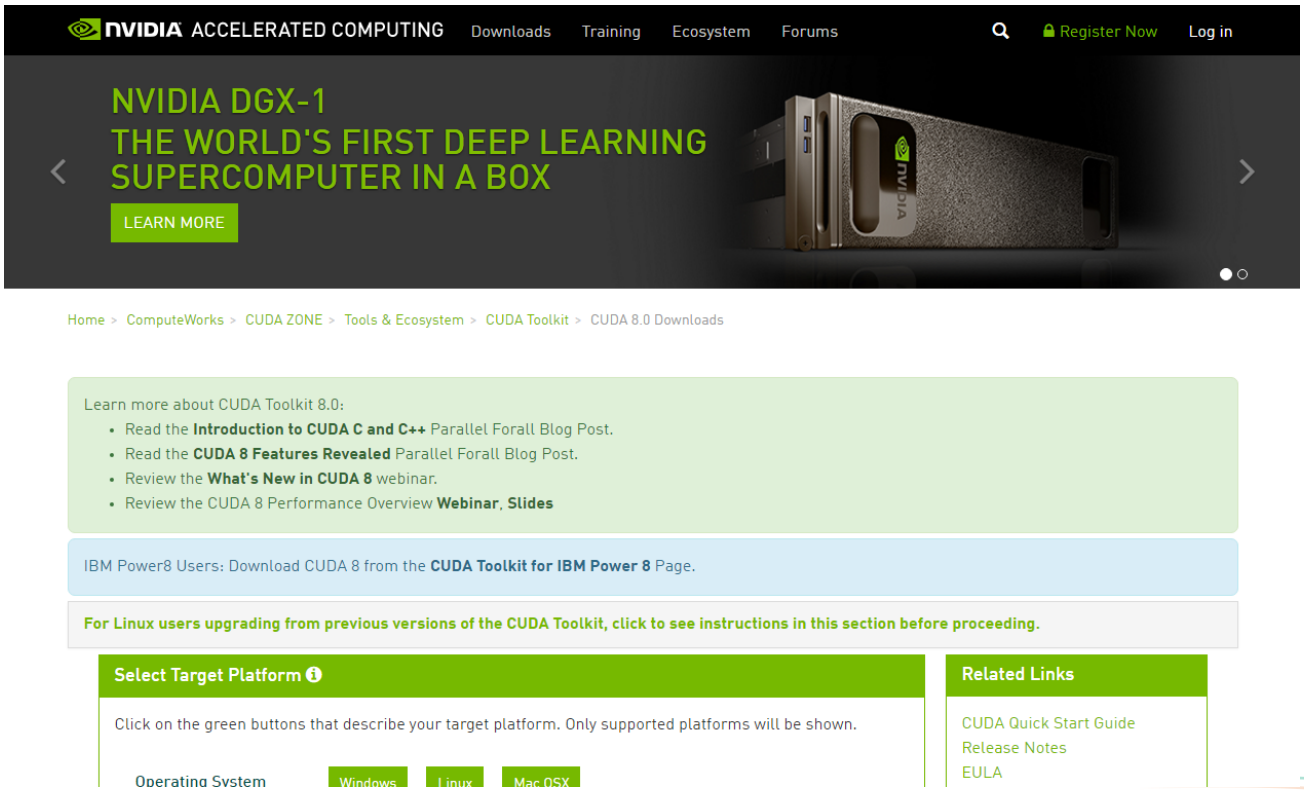
- Python을 실행시킨 후 import tensorflow를 통해 에러가 나는지 확인



Install TensorFlow

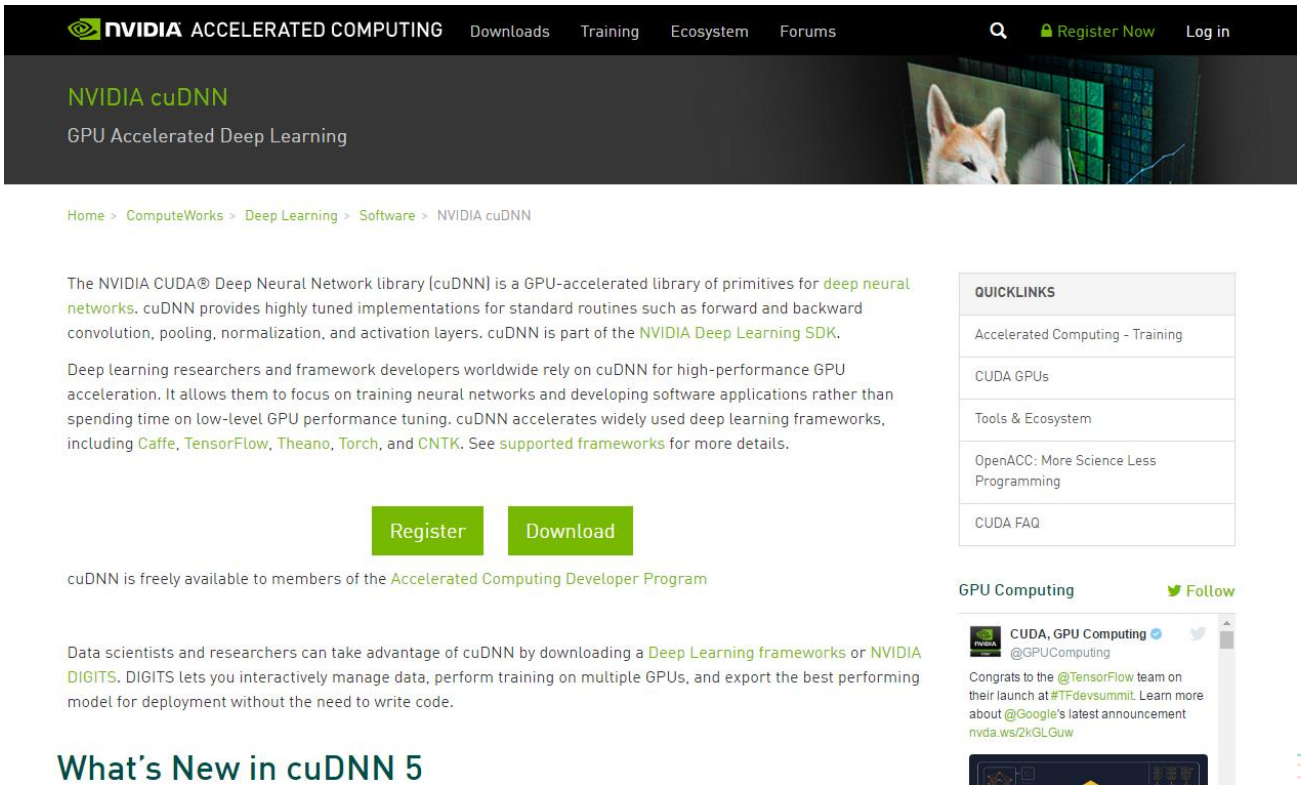
- GPU 버전 설치 과정

1. CUDA 8.0 버전 설치 (https://developer.nvidia.com/cuda-downloads)



Install TensorFlow

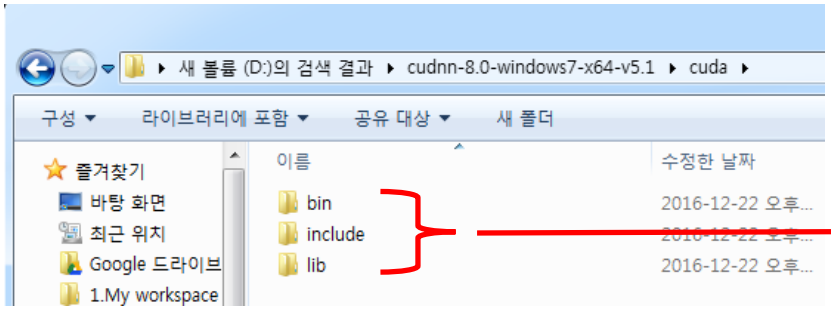
2. cuDNN 5.1 버전 설치 (https://developer.nvidia.com/cudnn)
   간단한 등록 과정을 요구함

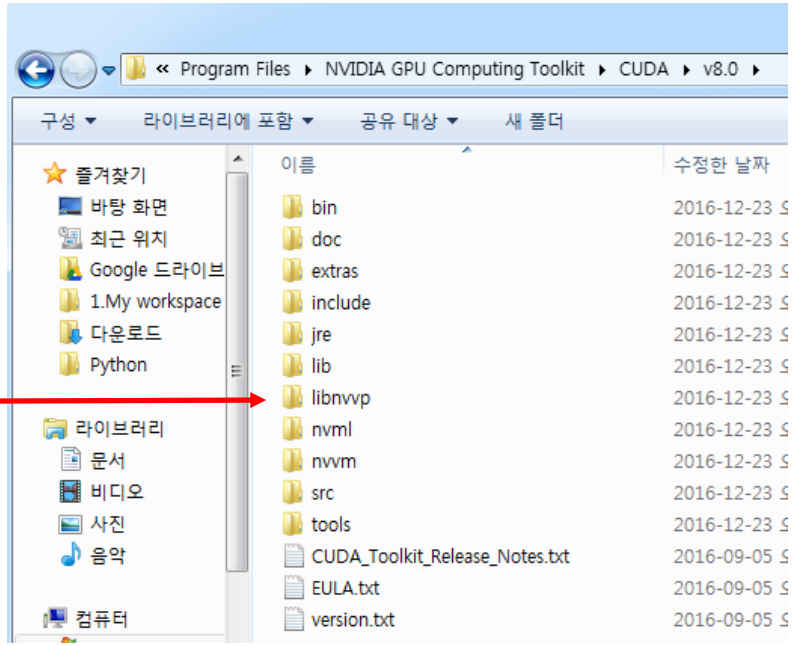


Install TensorFlow

3. cuDNN 파일의 압축풀기

4. 결과로 나오는 bin, include, lib 폴더를 CUDA가 설치된 경로로 접근하여 붙여넣기



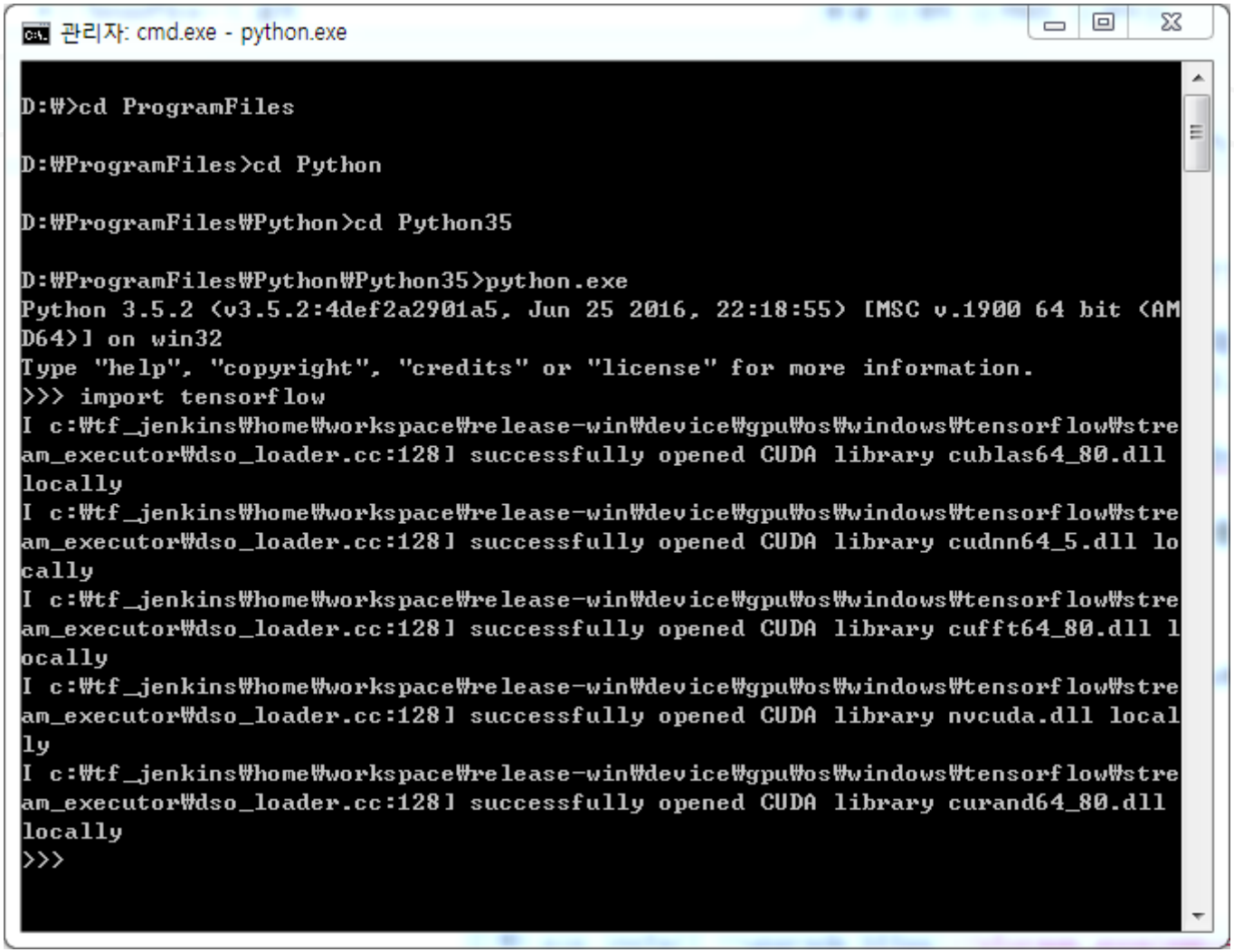


Install TensorFlow

5. Tensorflow 설치 - GPU 버전

   - cmd창에 pip install tensorflow-gpu 입력
   - CPU버전과 마찬가지로 설치가 잘 되었는지 확인

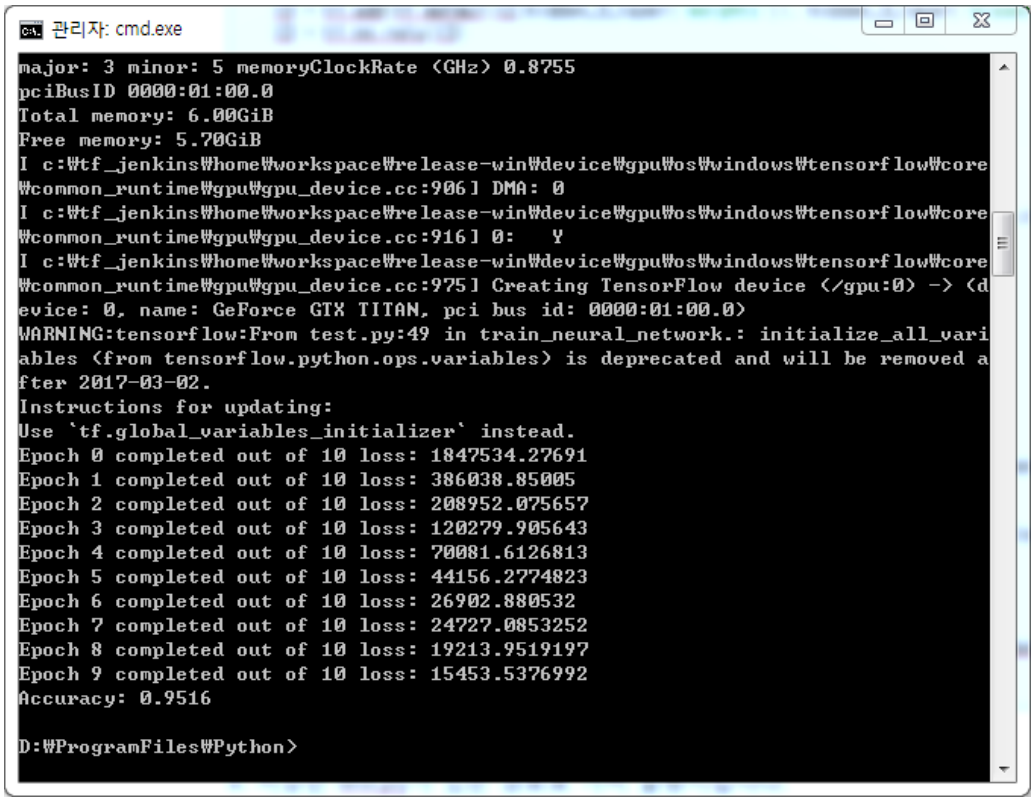
Install TensorFlow

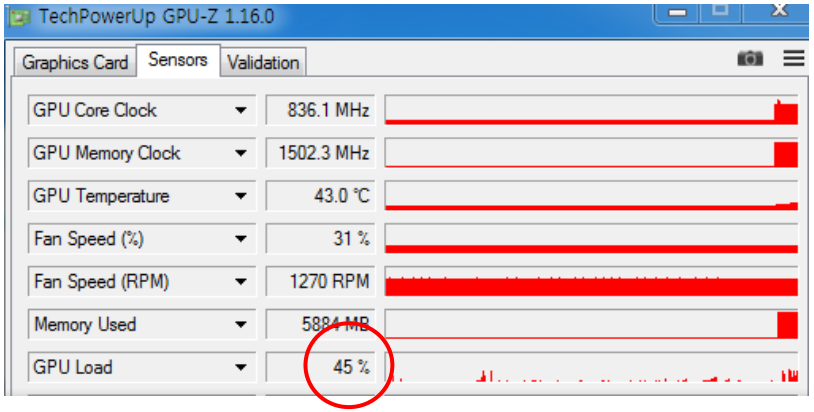


6. quit()을 통해 python 종료

Install TensorFlow

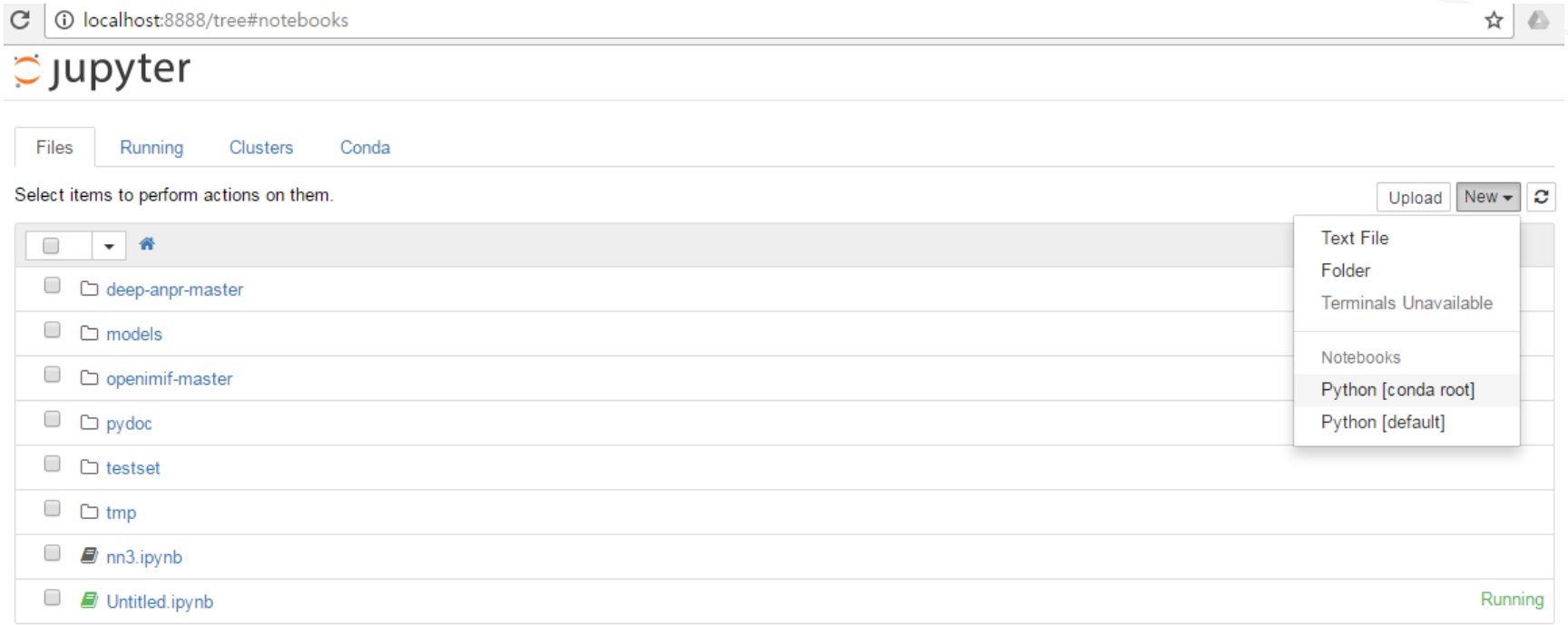
- MNIST 예제를 학습시켜 동작 확인 (3 hidden layer)





Data type

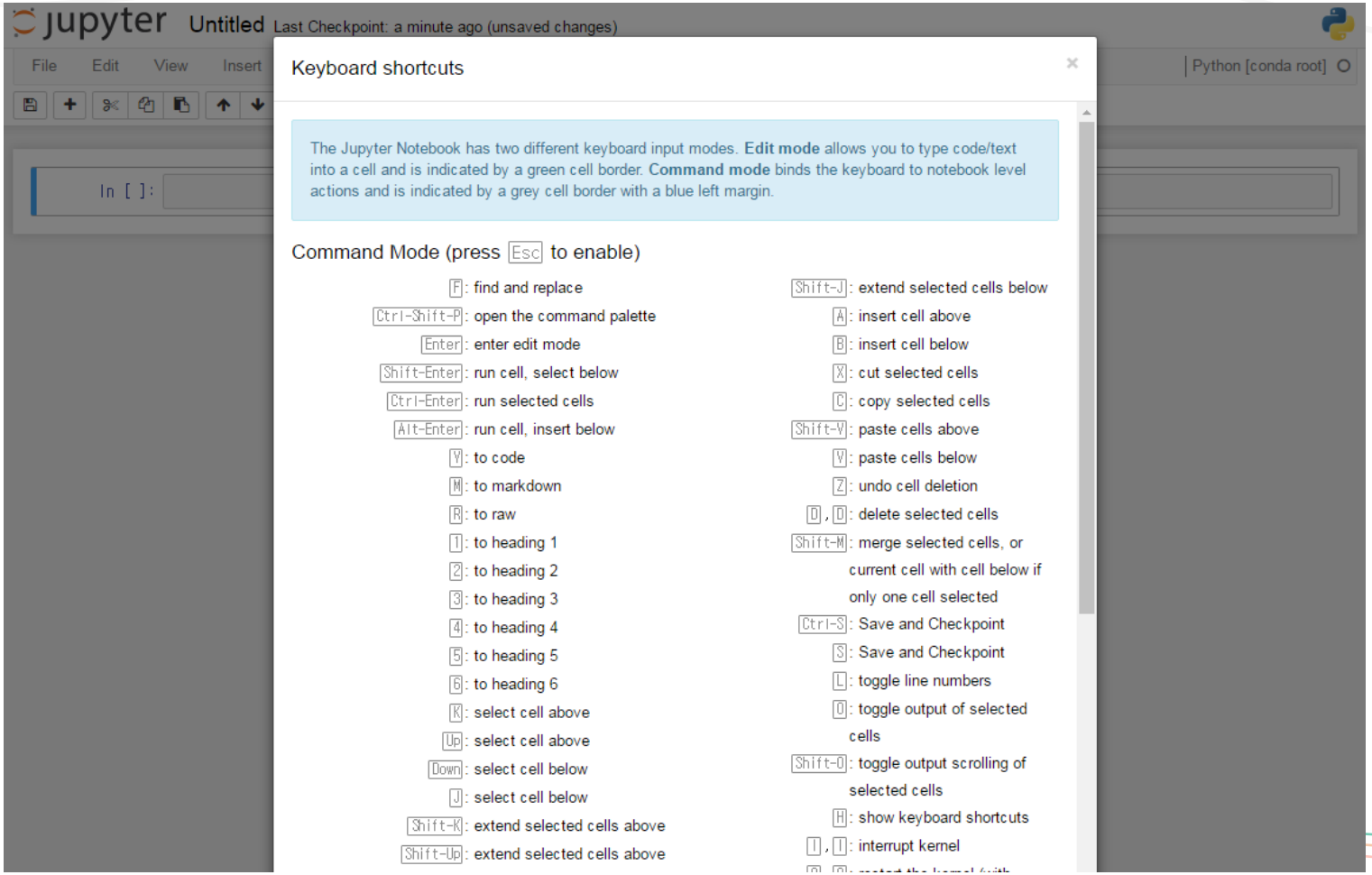
- cmd - jupyter notebook



※주의 : 경로상에 관련 파일이 있지 않을 경우 404 에러 발생

Data type

- jupyter notebook - h



Data type

※ https://www.tensorflow.org/versions/r0.12/api_docs/python/

Inputs and Readers > Placeholders

Members	
`tf.placeholder(dtype, shape=None, name=None)`	Inserts a placeholder for a tensor that will be always fed.

Variables > Variables

Members	
`class tf.Variable`	See the [Variables How To] (../../how_tos/variables/index.md) for a high
`tf.Variable.__init__(initial_value=None, trainable=True, collections=None, validate_shape=True, caching_device=None, name=None, variable_def=None, dtype=None, expected_shape=None, import_scope=None)`	Creates a new variable with value initial_value.

Constants, Sequences, and Random Values > Constant Value Tensors

Members	
`tf.zeros(shape, dtype=tf.float32, name=None)`	Creates a tensor with all elements set to zero.
`tf.zeros_like(tensor, dtype=None, name=None, optimize=True)`	Creates a tensor with all elements set to zero.
`tf.ones(shape, dtype=tf.float32, name=None)`	Creates a tensor with all elements set to 1.
`tf.ones_like(tensor, dtype=None, name=None, optimize=True)`	Creates a tensor with all elements set to 1.
`tf.fill(dims, value, name=None)`	Creates a tensor filled with a scalar value.
`tf.constant(value, dtype=None, shape=None, name='Const', verify_shape=False)`	Creates a constant tensor.

Data type

- Code

```
In [1]: import tensorflow as tf

In [3]: ph = tf.placeholder(dtype = tf.float32, shape=[3,3])
        var = tf.Variable([1, 2, 3, 4, 5], dtype = tf.float32)
        const = tf.constant([10, 20, 30, 40, 50], dtype = tf.float32)

In [5]: print(ph)

        Tensor("Placeholder_1:0", shape=(3, 3), dtype=float32)

In [6]: print(var)

        Tensor("Variable/read:0", shape=(5,), dtype=float32)

In [7]: print(const)

        Tensor("Const:0", shape=(5,), dtype=float32)

In [ ]:
```

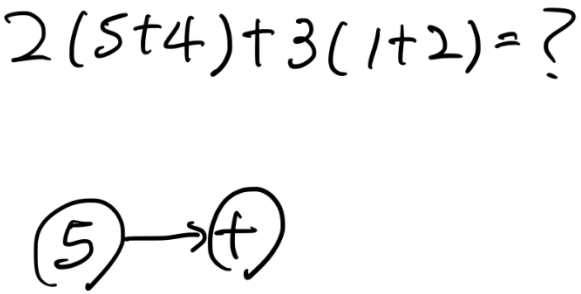
Data type

- 그래프 생성

$2(5+4)+3(1+2)=?$

Data type

- 그래프 생성



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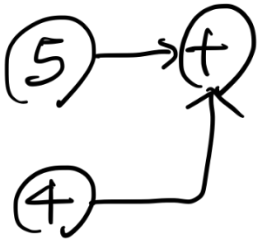

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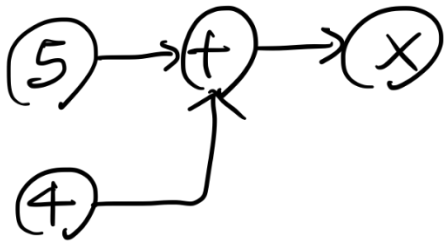

Data type

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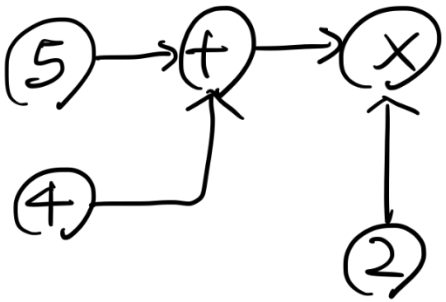

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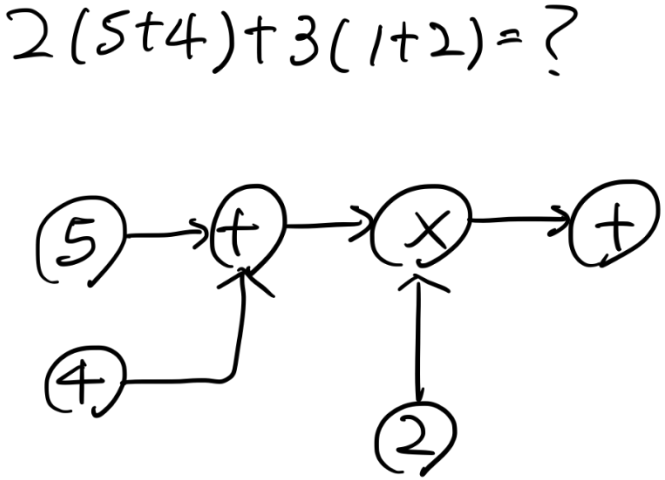

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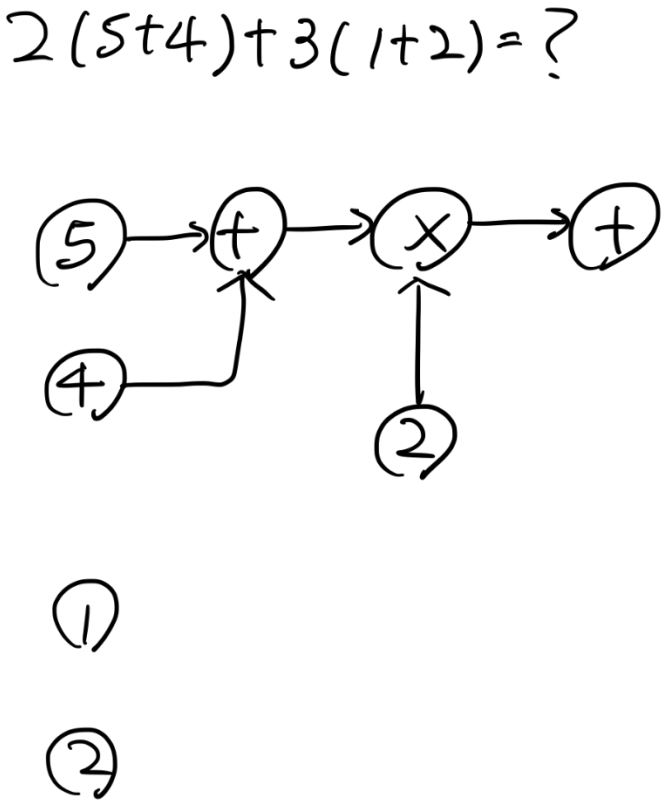

Data type

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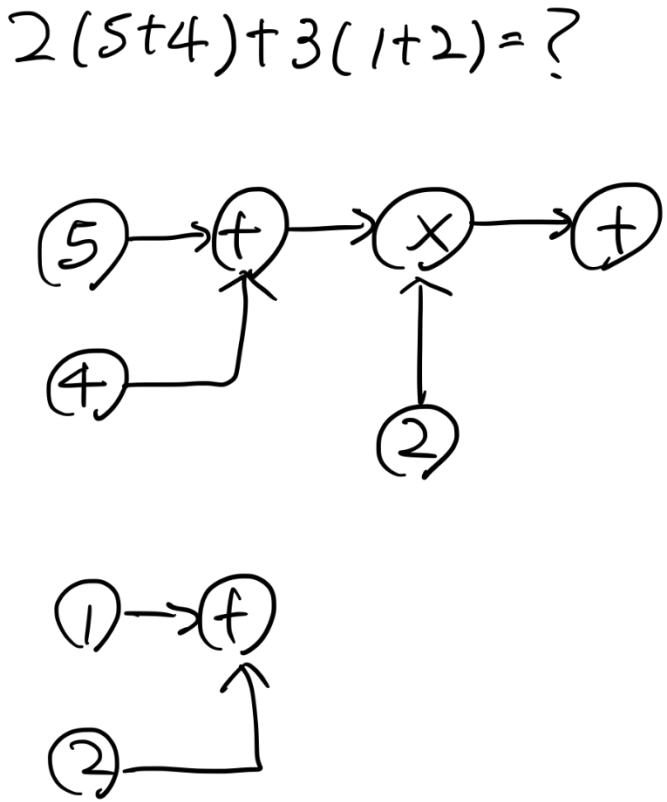

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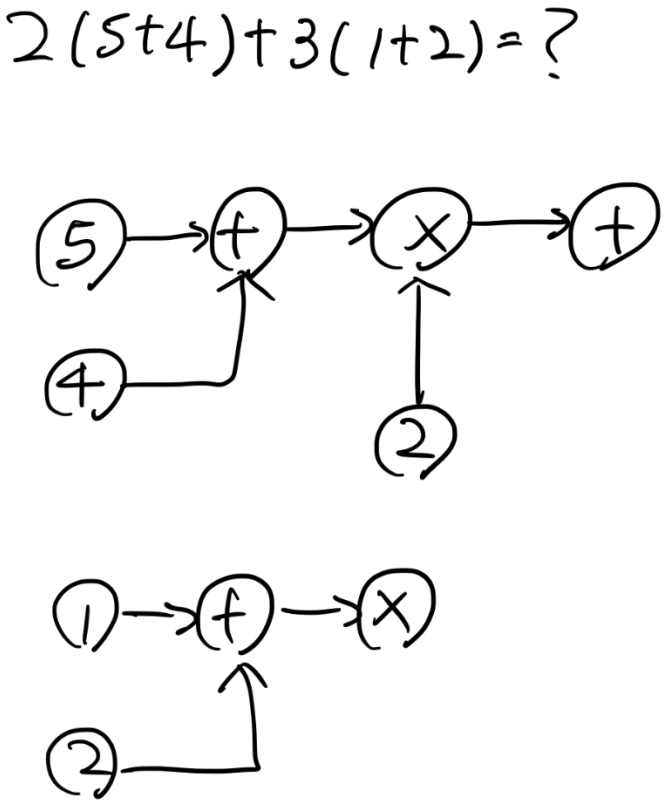

Data type

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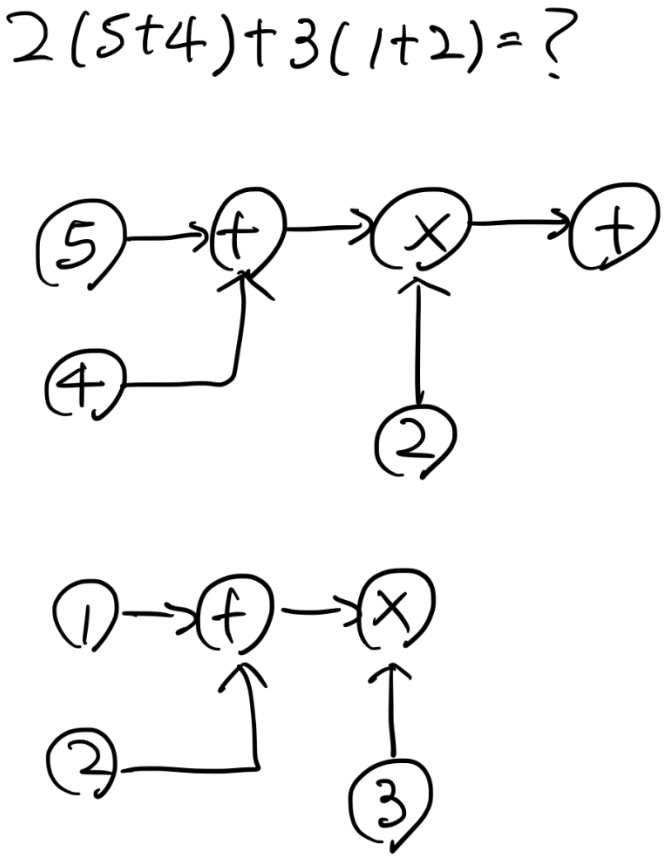

Data type

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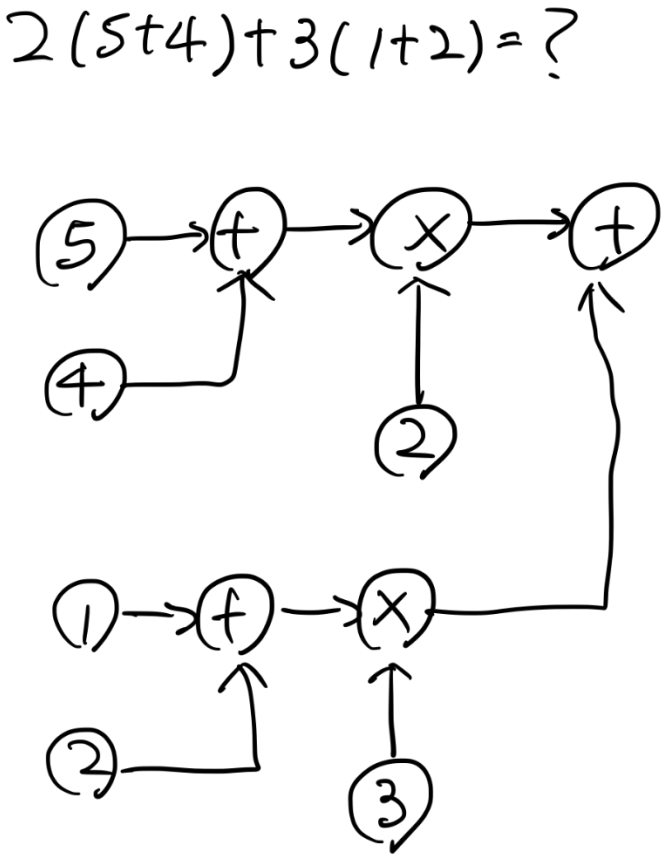

Data type

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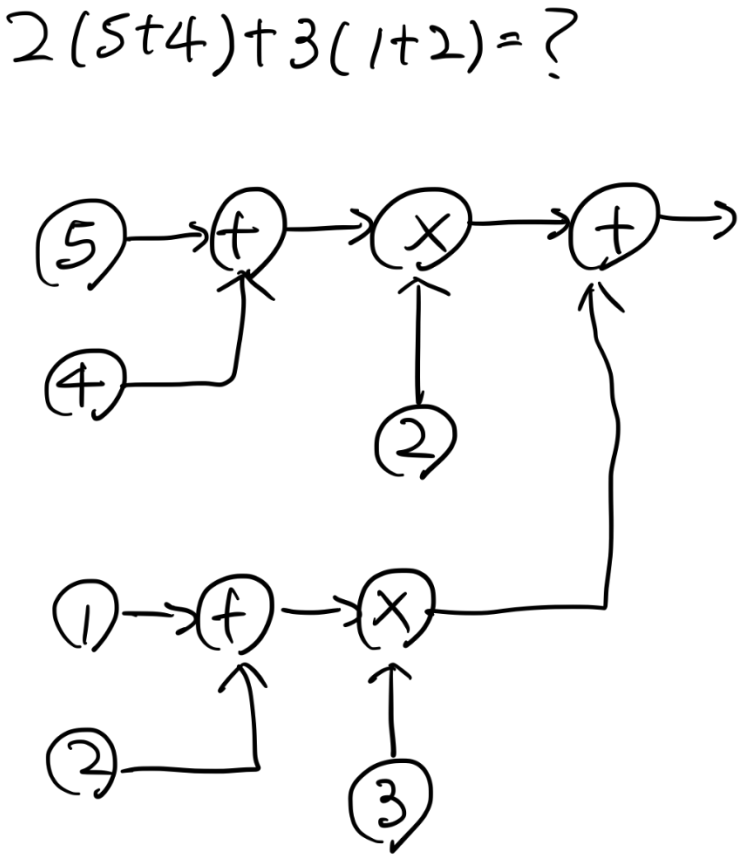

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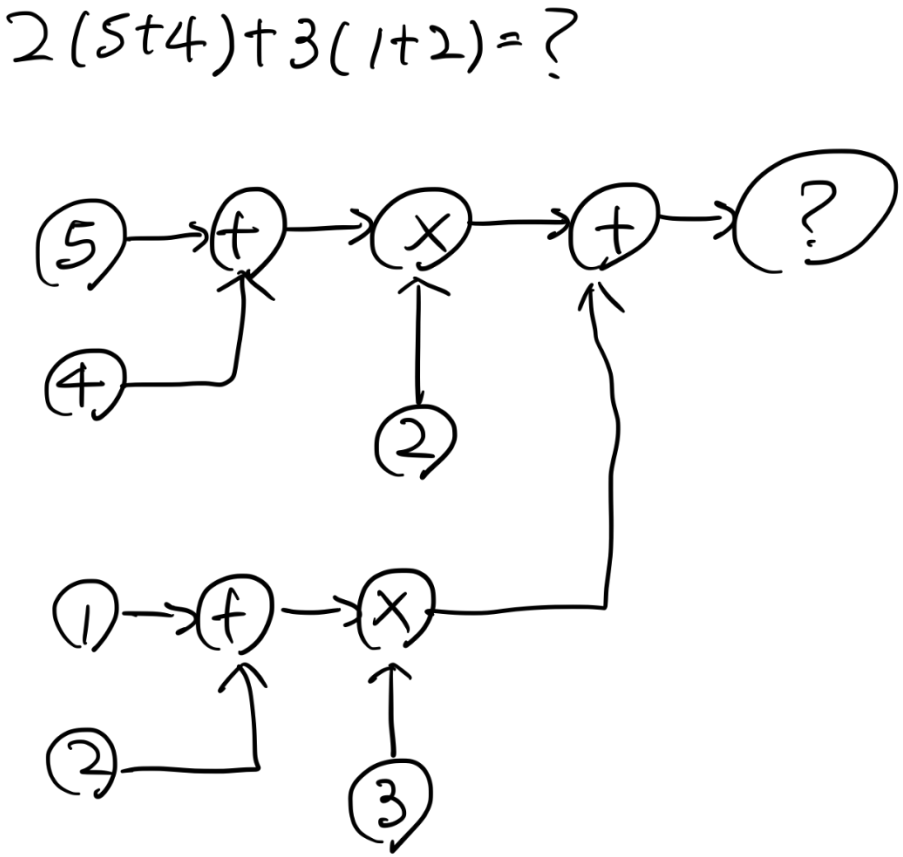
- 그래프 생성



Data type

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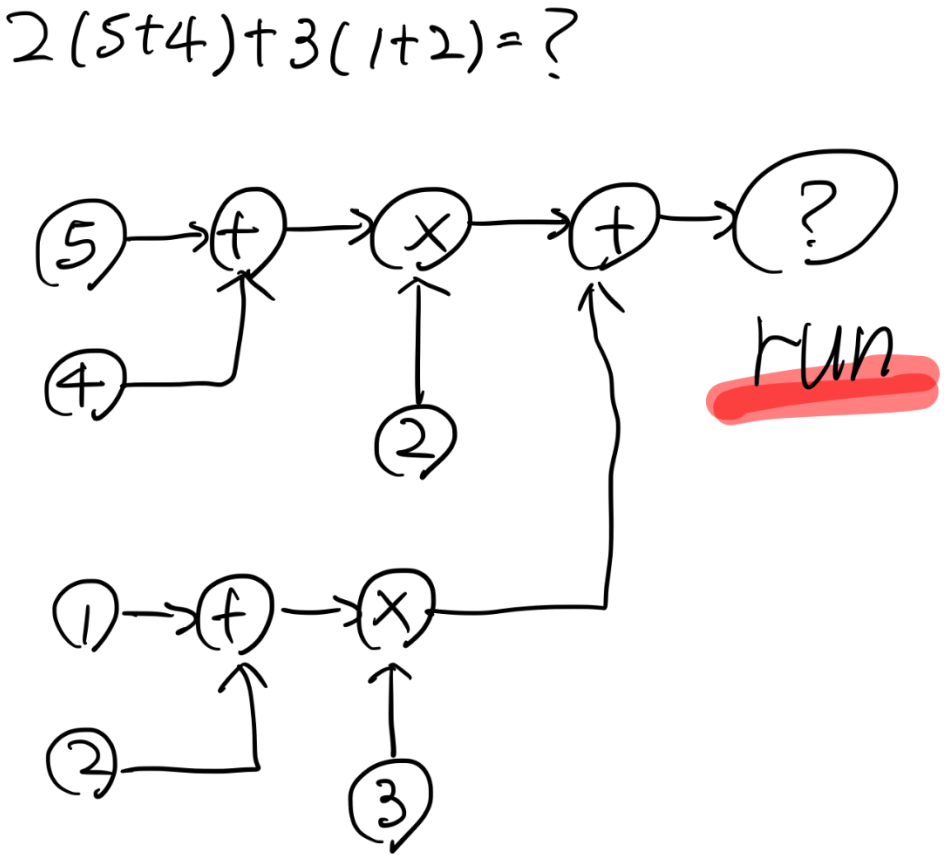

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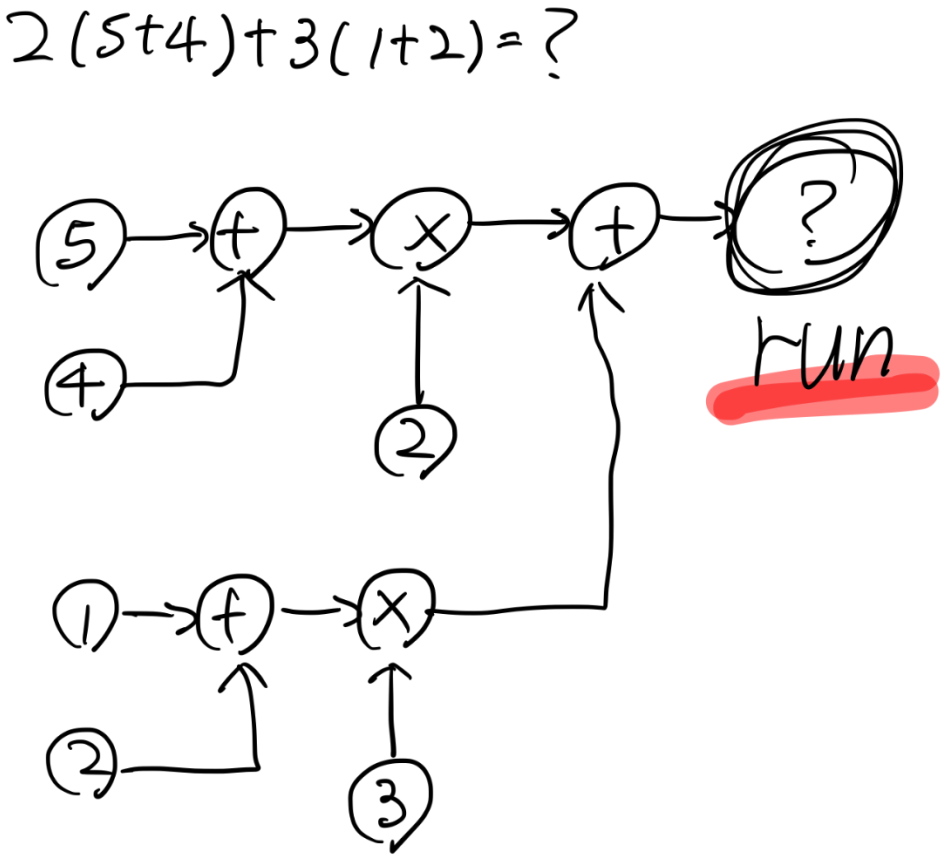

Data type

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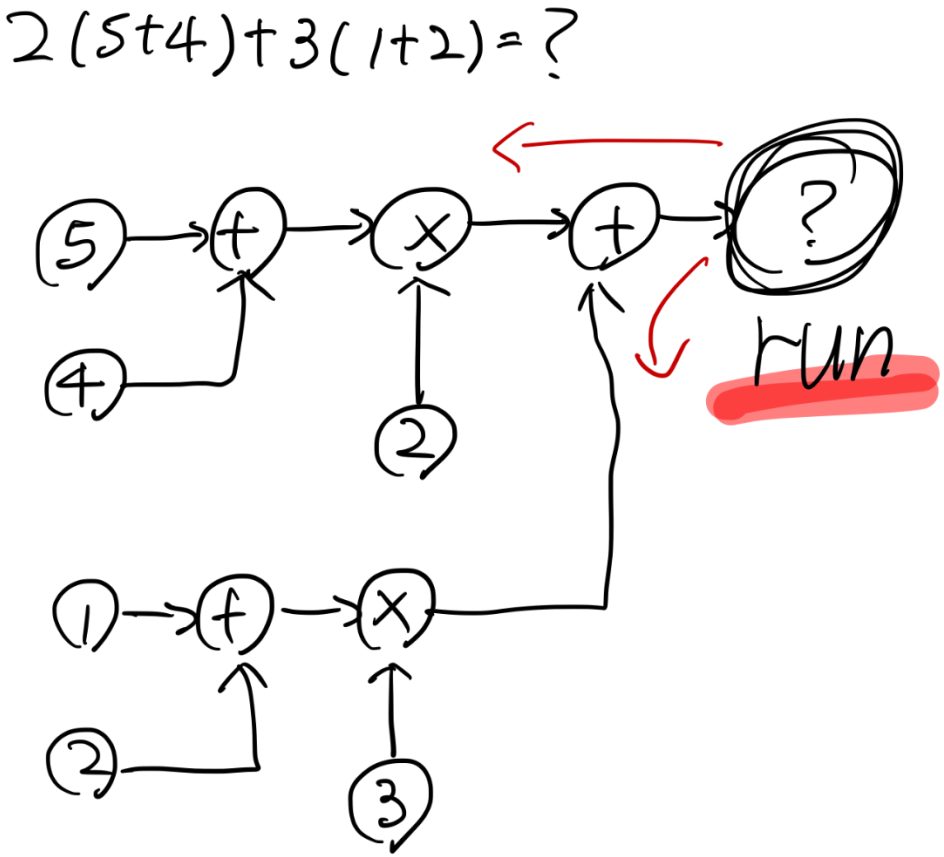
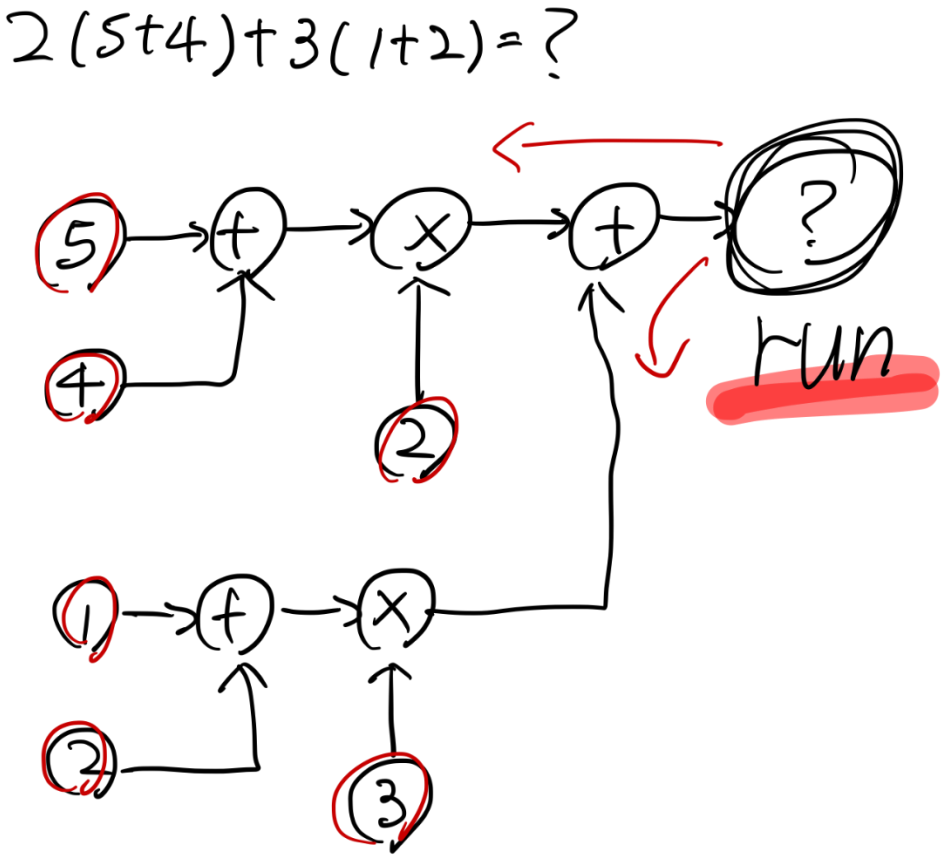


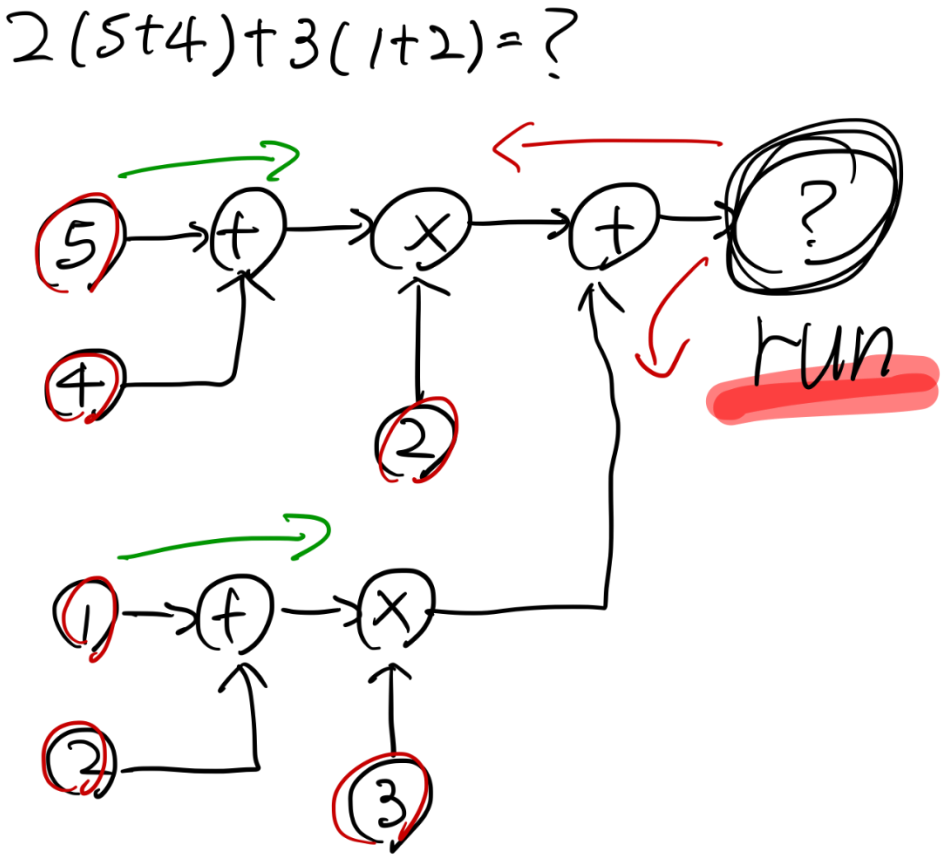
Data type

- 그래프 생성



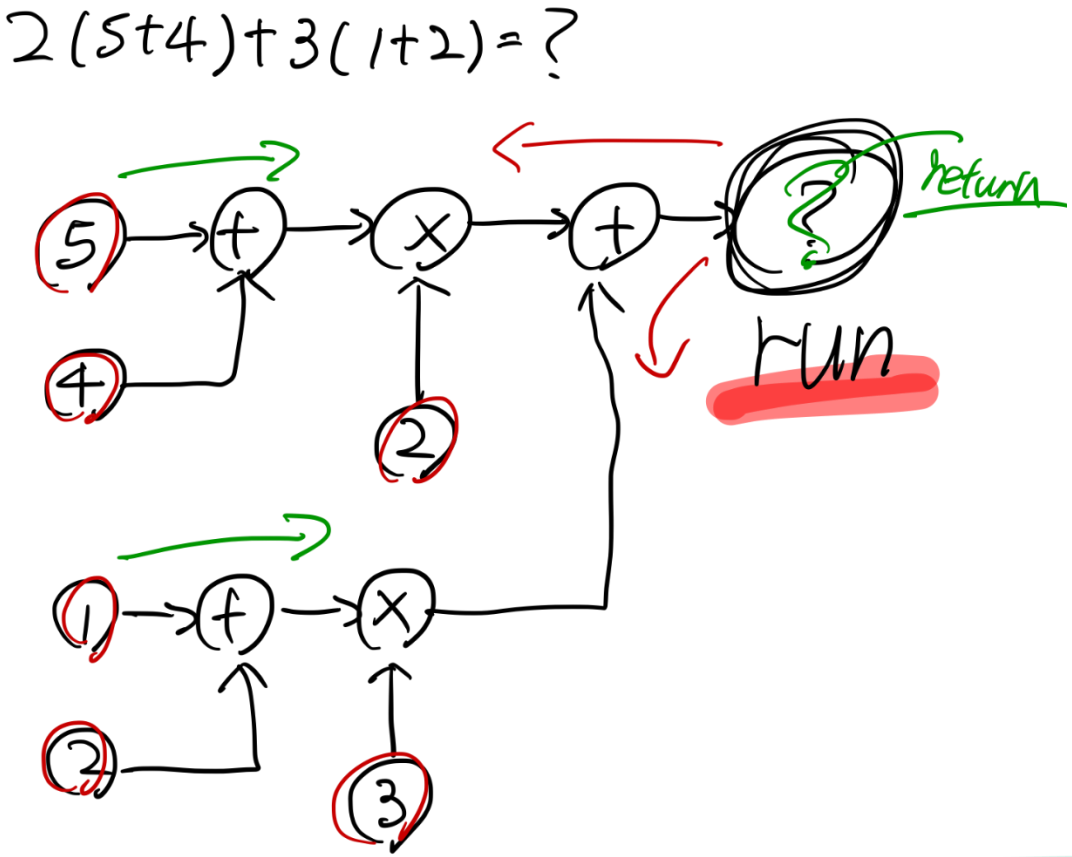
Data type

- 그래프 생성



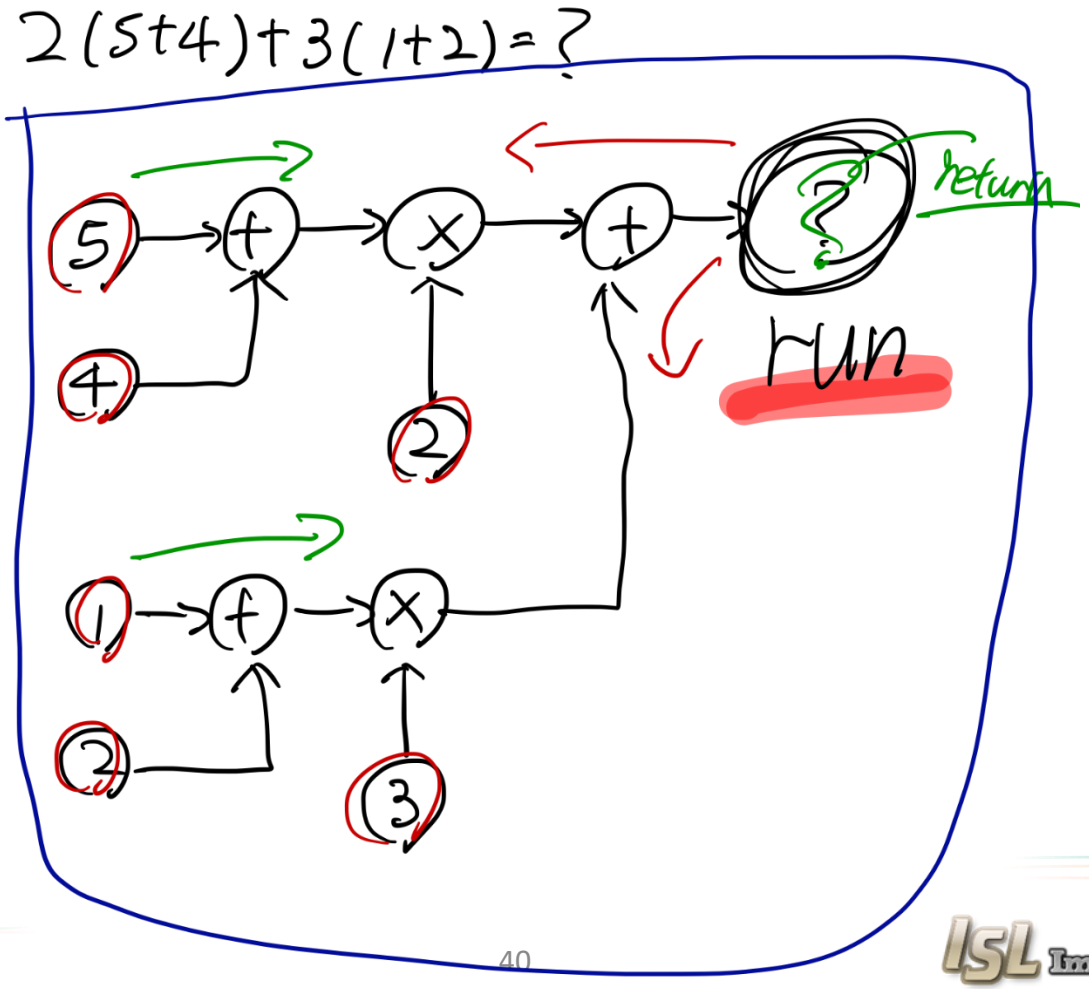
Data type

- 그래프 생성



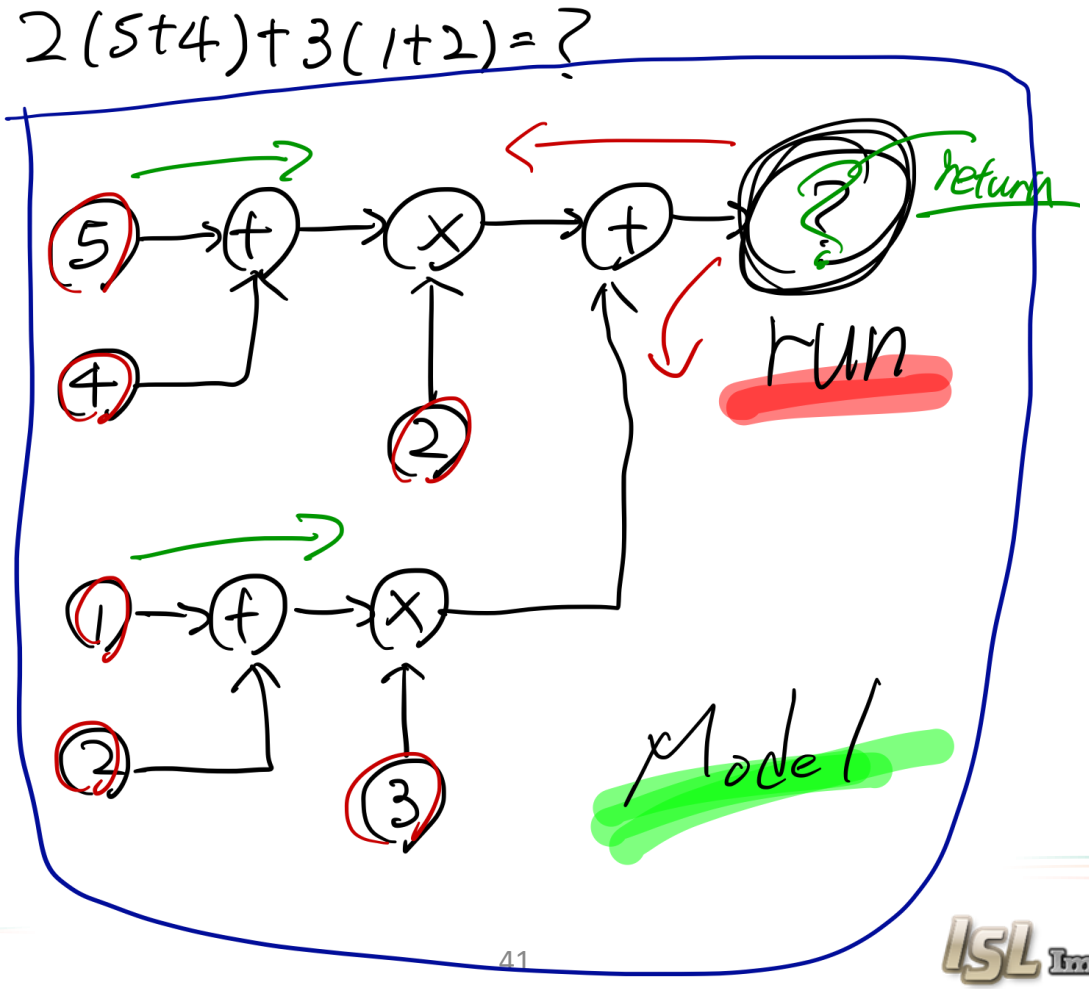
Data type

- 그래프 생성



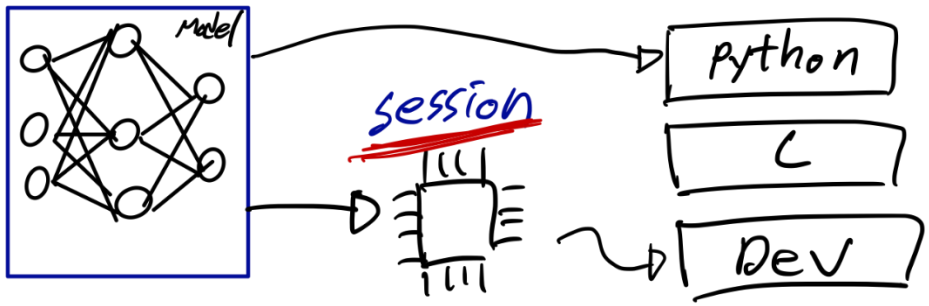
Data type

- 그래프 생성



Data type

- 세션



- Python이 C기반이기 때문에 상호간의 호환성이 좋음
- Python에서 생성된 모델은 디바이스에서 실제 구조가 만들어짐. 이 과정을 '세션에 보낸다.' 또는 '세션에 올린다.' 고 표현함.
- 하드웨어 단계에서 구현되었기 때문에 매우 빠른 연산이 가능해짐 -> TF의 장점

Data type

- 테스트 - constant

In [1]:
```
import tensorflow as tf
```

In [2]:
```
ph = tf.placeholder(dtype = tf.float32, shape=[3,3])
var = tf.Variable([1, 2, 3, 4, 5], dtype = tf.float32)
const = tf.constant([10, 20, 30, 40, 50], dtype = tf.float32)
```

In [3]:
```
print(ph)
```

```
Tensor("Placeholder:0", shape=(3, 3), dtype=float32)
```

In [4]:
```
print(var)
```

```
Tensor("Variable/read:0", shape=(5,), dtype=float32)
```

In [5]:
```
print(const)
```

```
Tensor("Const:0", shape=(5,), dtype=float32)
```

In [6]:
```
a = tf.constant([2])
b = tf.constant([3])
c = tf.constant([5])
d = a*b+c
print(d)
```

```
Tensor("add:0", shape=(1,), dtype=int32)
```

Data type

- 테스트 - constant

In [6]:
```
a = tf.constant([2])
b = tf.constant([3])
c = tf.constant([5])
d = a*b+c
print(d)
```

```
Tensor("add:0", shape=(1,), dtype=int32)
```

In [7]:
```
sess = tf.Session()
res = sess.run(d)
print(res)
```

```
[11]
```

In [ ]:

Data type

- 테스트 - Variable

```
In [7]: sess = tf.Session()
        res = sess.run(d)
        print(res)

        [11]

In [8]: var_a = tf.Variable([2])
        var_b = tf.Variable([10])
        var_c = tf.Variable([7])
        var_d = var_a * var_b + var_c
        print(var_d)

        Tensor("add_1:0", shape=(1,), dtype=int32)
```

Data type

- 테스트 - Variable

```
In [9]: var_res = sess.run(var_d)
---------------------------------------------------------------------------
FailedPreconditionError                    Traceback (most recent call last)
D:₩Anaconda3₩lib₩site-packages₩tensorflow₩python₩client₩session.py in _do_call(sel
   1020     try:
-> 1021       return fn(*args)
   1022     except errors.OpError as e:

D:₩Anaconda3₩lib₩site-packages₩tensorflow₩python₩client₩session.py in _run_fn(sess
etadata)
   1002                                  feed_dict, fetch_list, target_list,
-> 1003                                  status, run_metadata)
   1004

D:₩Anaconda3₩lib₩contextlib.py in __exit__(self, type, value, traceback)
     65             try:
---> 66                 next(self.gen)
     67             except StopIteration:

D:₩Anaconda3₩lib₩site-packages₩tensorflow₩python₩framework₩errors_impl.py in raise
    469           compat.as_text(pywrap_tensorflow.TF_Message(status)),

In [ ]:
```

Variable은 별도의 초기화가 필요함!

Data type

- 테스트 - Variable

```
D:₩Anaconda3₩lib₩site-packages₩tensorflow₩python₩framework₩errors_impl.py in raise
```

```
In [10]: init = tf.global_variables_initializer()
sess.run(init)
var_res = sess.run(var_d)
print(var_res)
```

```
[27]
```

```
In [ ]:
```

Data type

- 테스트 - placeholder

```
value1 = 10
value2 = 50
value3 = 14

ph_d = ph_a * ph_b + ph_c

tensor_map = {ph_a : value1, ph_b : value2, ph_c : value3}

print(ph_a)
print(ph_b)
print(ph_c)
print(ph_d)
```

```
Tensor("Placeholder_1:0", dtype=float32)
Tensor("Placeholder_2:0", dtype=float32)
Tensor("Placeholder_3:0", dtype=float32)
Tensor("add_2:0", dtype=float32)
```

In [12]:

```
ph_res = sess.run(ph_d, feed_dict=tensor_map)
print(ph_res)
```

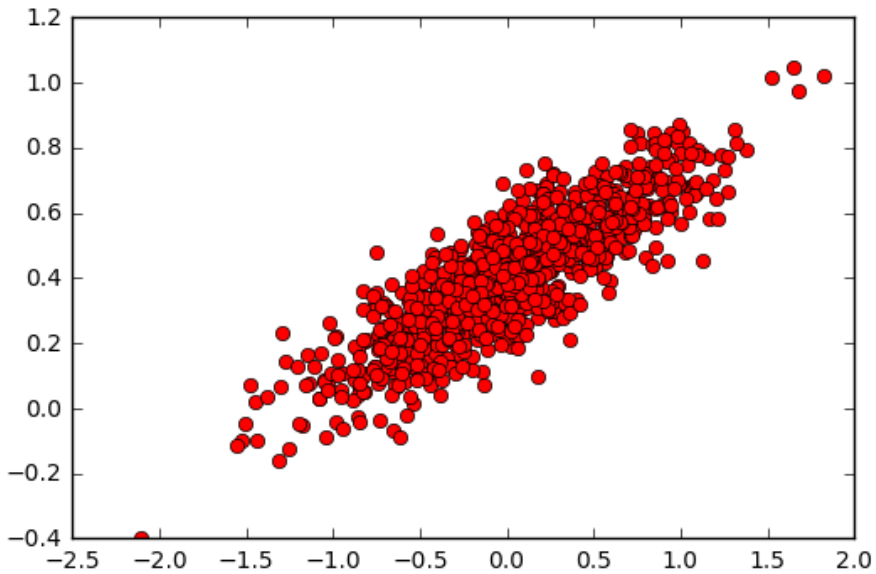
```
514.0
```

In [ ]:

Linear regression + Plot

In [1]:
```
import numpy as np
import matplotlib.pyplot as plt
import tensorflow as tf
```

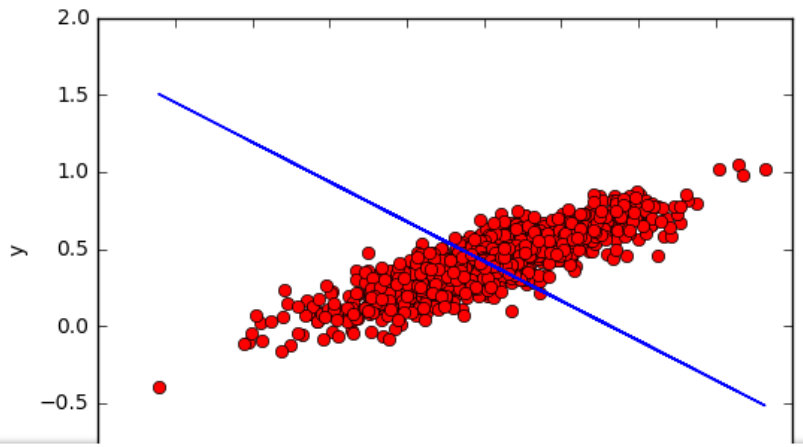
In [5]:
```
num_point = 1000
vectors_set = []
for i in range(num_point):
    x1 = np.random.normal(0.0, 0.55)
    y1 = x1 * 0.3 + 0.4 + np.random.normal(0,0 + 0.1)
    vectors_set.append([x1, y1])

x_data = [v[0] for v in vectors_set]
y_data = [v[1] for v in vectors_set]

plt.plot(x_data, y_data, 'ro')
plt.show()
```



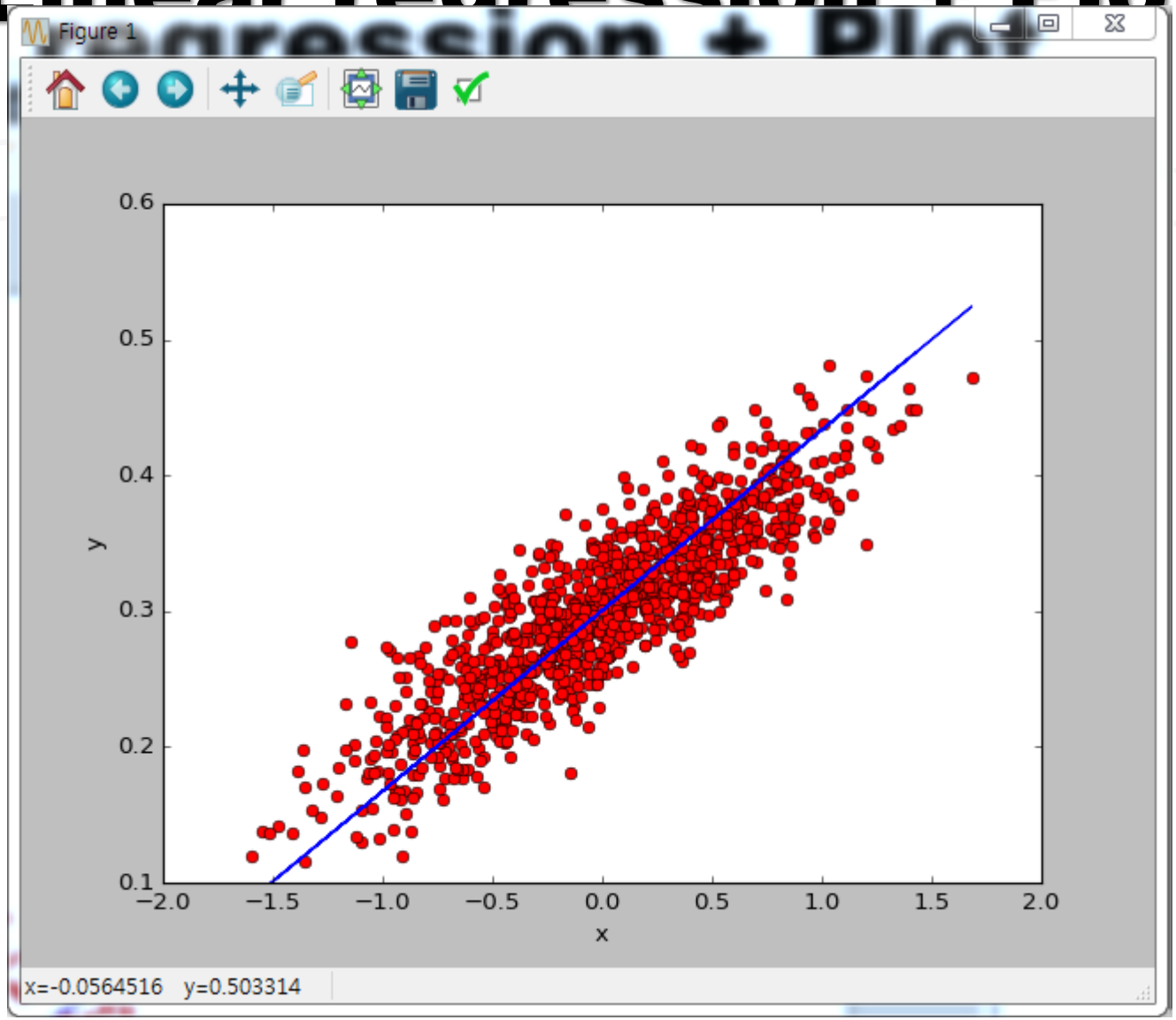
Linear regression + Plot

In [6]:
```
W = tf.Variable(tf.random_uniform([1], -1.0, 1.0))
b = tf.Variable(tf.zeros([1]))
y = W * x_data + b

loss = tf.reduce_mean(tf.square(y - y_data)) # cost function
optimizer = tf.train.GradientDescentOptimizer(0.5) #학습 파라미터
train = optimizer.minimize(loss)
#모델(그래프) 설계 완료

#변수 초기화 및 세션 열기
init = tf.global_variables_initializer()
sess = tf.Session()
sess.run(init)

for step in range(10):
    sess.run(train)
    print(step, sess.run(W), sess.run(b), sess.run(loss))

    #데이터 분포
    plt.plot(x_data, y_data, 'ro')
    #직선(pred)
    plt.plot(x_data, sess.run(W) * x_data + sess.run(b))

    plt.xlabel('x')
    plt.ylabel('y')
    plt.show()
```

```
0 [-0.51449585] [ 0.42089418] 0.212177
```



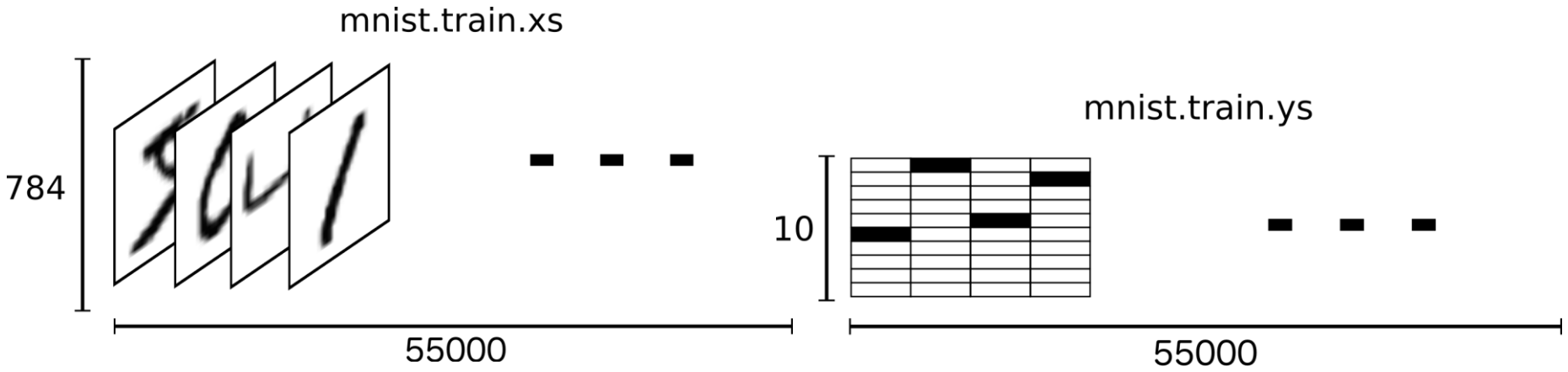
Linear regression + Plot



MNIST

- MNIST

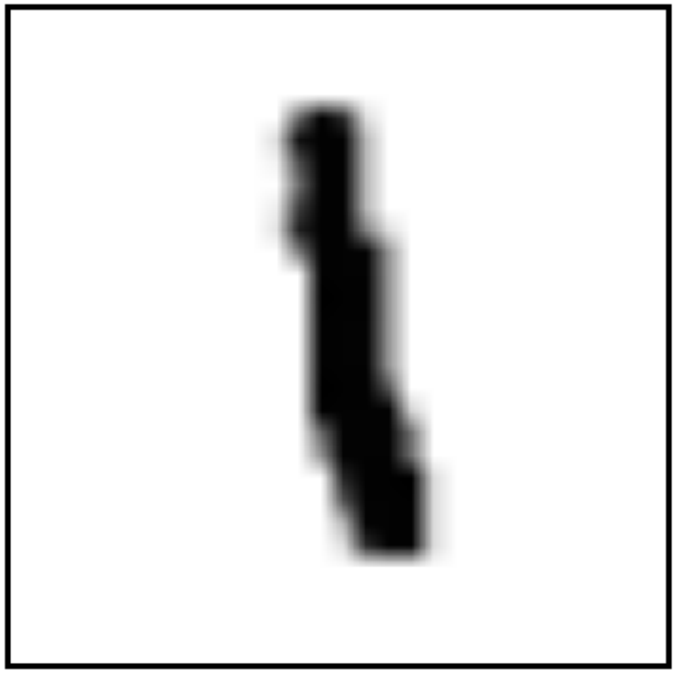
When one learns how to program, there's a tradition that the first thing you do is print "Hello World." Just like programming has Hello World, machine learning has MNIST.



MNIST

- MNIST

When one learns how to program, there's a tradition that the first thing you do is print "Hello World." Just like programming has Hello World, machine learning has MNIST.



$$\simeq \begin{bmatrix}
0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 \\
0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 \\
0 & 0 & 0 & 0 & 0 & 0 & .6 & .8 & 0 & 0 & 0 & 0 & 0 & 0 \\
0 & 0 & 0 & 0 & 0 & 0 & .7 & 1 & 0 & 0 & 0 & 0 & 0 & 0 \\
0 & 0 & 0 & 0 & 0 & 0 & .7 & 1 & 0 & 0 & 0 & 0 & 0 & 0 \\
0 & 0 & 0 & 0 & 0 & 0 & .5 & 1 & .4 & 0 & 0 & 0 & 0 & 0 \\
0 & 0 & 0 & 0 & 0 & 0 & 0 & 1 & .4 & 0 & 0 & 0 & 0 & 0 \\
0 & 0 & 0 & 0 & 0 & 0 & 0 & 1 & .4 & 0 & 0 & 0 & 0 & 0 \\
0 & 0 & 0 & 0 & 0 & 0 & 0 & 1 & .7 & 0 & 0 & 0 & 0 & 0 \\
0 & 0 & 0 & 0 & 0 & 0 & 0 & 1 & 1 & 0 & 0 & 0 & 0 & 0 \\
0 & 0 & 0 & 0 & 0 & 0 & 0 & .9 & 1 & .1 & 0 & 0 & 0 & 0 \\
0 & 0 & 0 & 0 & 0 & 0 & 0 & .3 & 1 & .1 & 0 & 0 & 0 & 0 \\
0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 \\
0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0
\end{bmatrix}$$

MLP

- Input layer - 3 hidden layer – output layer

```
import tensorflow as tf
from tensorflow.examples.tutorials.mnist import input_data
mnist = input_data.read_data_sets("/tmp/data/", one_hot = True)

n_nodes_hl1 = 500
n_nodes_hl2 = 500
n_nodes_hl3 = 500

n_classes = 10
batch_size = 100

x = tf.placeholder('float', [None, 784])
y = tf.placeholder('float')


hidden_1_layer = {'weights':tf.Variable(tf.random_normal([784, n_nodes_hl1])),
                  'biases':tf.Variable(tf.random_normal([n_nodes_hl1]))}

hidden_2_layer = {'weights':tf.Variable(tf.random_normal([n_nodes_hl1, n_nodes_hl2])),
                  'biases':tf.Variable(tf.random_normal([n_nodes_hl2]))}

hidden_3_layer = {'weights':tf.Variable(tf.random_normal([n_nodes_hl2, n_nodes_hl3])),
                  'biases':tf.Variable(tf.random_normal([n_nodes_hl3]))}

output_layer = {'weights':tf.Variable(tf.random_normal([n_nodes_hl3, n_classes])),
                'biases':tf.Variable(tf.random_normal([n_classes])),}


l1 = tf.add(tf.matmul(x,hidden_1_layer['weights']), hidden_1_layer['biases'])
l1 = tf.nn.relu(l1)

l2 = tf.add(tf.matmul(l1,hidden_2_layer['weights']), hidden_2_layer['biases'])
l2 = tf.nn.relu(l2)

l3 = tf.add(tf.matmul(l2,hidden_3_layer['weights']), hidden_3_layer['biases'])
l3 = tf.nn.relu(l3)
```

MLP

- Input layer - 3 hidden layer – output layer

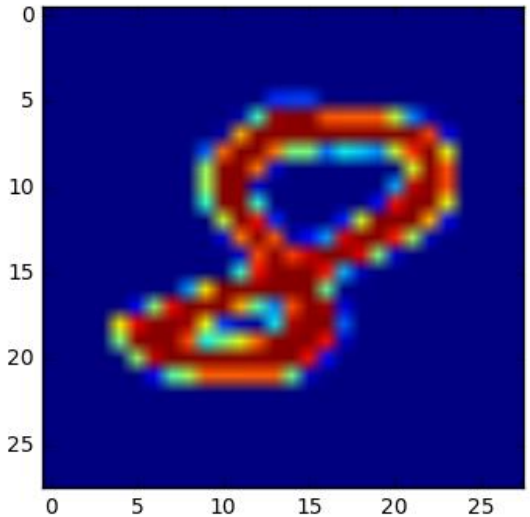
```
output = tf.matmul(l3,output_layer['weights']) + output_layer['biases']


prediction = output
cost = tf.reduce_mean( tf.nn.softmax_cross_entropy_with_logits(prediction,y) )
optimizer = tf.train.AdamOptimizer().minimize(cost)

hm_epochs = 10
sess = tf.Session()
sess.run(tf.global_variables_initializer())

for epoch in range(hm_epochs):
    epoch_loss = 0
    for _ in range(int(mnist.train.num_examples/batch_size)):
        epoch_x, epoch_y = mnist.train.next_batch(batch_size)
        _, c = sess.run([optimizer, cost], feed_dict={x: epoch_x, y: epoch_y})
        epoch_loss += c

    print('Epoch', epoch + 1, 'completed out of',hm_epochs,'loss:',epoch_loss)

correct = tf.equal(tf.argmax(prediction, 1), tf.argmax(y, 1))

accuracy = tf.reduce_mean(tf.cast(correct, 'float'))
print('Accuracy:',sess.run(accuracy, feed_dict = {x:mnist.test.images, y:mnist.test.labels}))
```

```
Extracting /tmp/data/train-images-idx3-ubyte.gz
Extracting /tmp/data/train-labels-idx1-ubyte.gz
Extracting /tmp/data/t10k-images-idx3-ubyte.gz
Extracting /tmp/data/t10k-labels-idx1-ubyte.gz
Epoch 1 completed out of 10 loss: 1607590.13811
Epoch 2 completed out of 10 loss: 395378.241097
Epoch 3 completed out of 10 loss: 212075.841237
Epoch 4 completed out of 10 loss: 124842.024561
Epoch 5 completed out of 10 loss: 73650.398987
Epoch 6 completed out of 10 loss: 45980.5750535
Epoch 7 completed out of 10 loss: 29941.5561811
Epoch 8 completed out of 10 loss: 23685.460072
Epoch 9 completed out of 10 loss: 19176.7452043
Epoch 10 completed out of 10 loss: 17872.4552318
Accuracy: 0.9494
```

MLP

- Input layer - 3 hidden layer – output layer

```
import numpy as np
s = 61
arr = np.array(mnist.test.images[s])
arr.shape = (28, 28)

import matplotlib.pyplot as plt

plt.imshow(arr)
plt.show()

arr.shape = (1, 784)
print('GT   : ', np.argmax(mnist.test.labels[s]))
print('Pred : ',np.argmax(sess.run(output, feed_dict={x:arr})))
```

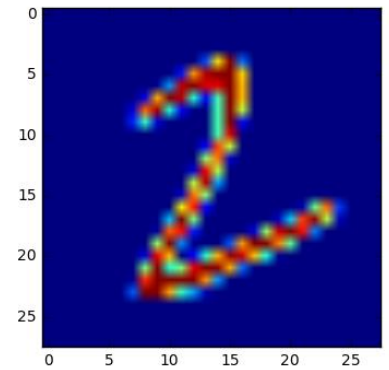



```
GT   : 8
Pred : 8
```

MLP

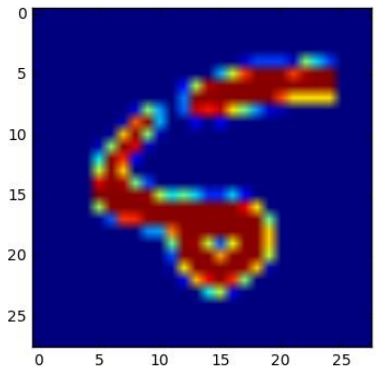
- Failure

```
import numpy as np
s = 38
arr = np.array(mnist.test.images[s])
arr.shape = (28, 28)

import matplotlib.pyplot as plt

plt.imshow(arr)
plt.show()

arr.shape = (1, 784)
print('GT   : ', np.argmax(mnist.test.labels[s]))
print('Pred : ',np.argmax(sess.run(output, feed_dict={x:arr})))
```



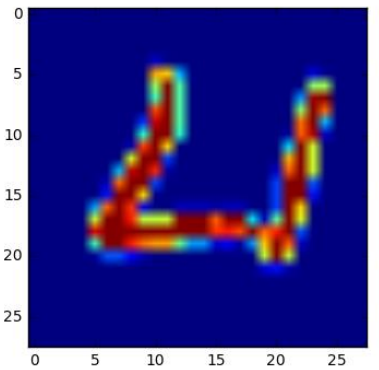
```
GT   : 2
Pred : 1
```

```
import numpy as np
s = 8
arr = np.array(mnist.test.images[s])
arr.shape = (28, 28)

import matplotlib.pyplot as plt

plt.imshow(arr)
plt.show()

arr.shape = (1, 784)
print('GT   : ', np.argmax(mnist.test.labels[s]))
print('Pred : ',np.argmax(sess.run(output, feed_dict={x:arr})))
```



```
GT   : 5
Pred : 6
```

```
import numpy as np
s = 33
arr = np.array(mnist.test.images[s])
arr.shape = (28, 28)

import matplotlib.pyplot as plt

plt.imshow(arr)
plt.show()

arr.shape = (1, 784)
print('GT   : ', np.argmax(mnist.test.labels[s]))
print('Pred : ',np.argmax(sess.run(output, feed_dict={x:arr})))
```

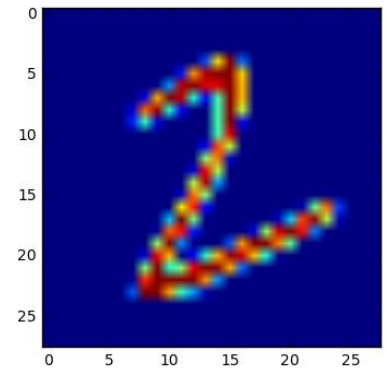


```
GT   : 4
Pred : 0
```

MLP

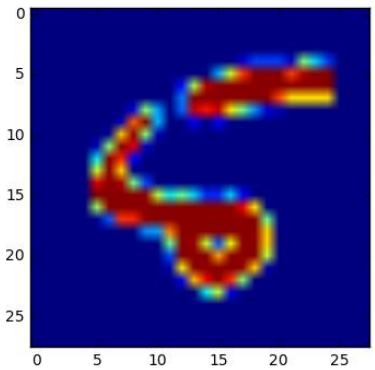
- Failure

```
import numpy as np
s = 38
arr = np.array(mnist.test.images[s])
arr.shape = (28, 28)

import matplotlib.pyplot as plt

plt.imshow(arr)
plt.show()

arr.shape = (1, 784)
print('GT   : ', np.argmax(mnist.test.labels[s]))
print('Pred : ',np.argmax(sess.run(output, feed_dict={x:arr})))
```



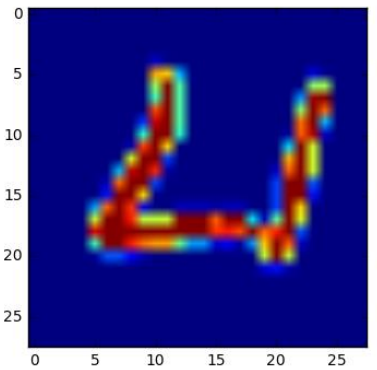
GT : 2
Pred : 1

```
import numpy as np
s = 8
arr = np.array(mnist.test.images[s])
arr.shape = (28, 28)

import matplotlib.pyplot as plt

plt.imshow(arr)
plt.show()

arr.shape = (1, 784)
print('GT   : ', np.argmax(mnist.test.labels[s]))
print('Pred : ',np.argmax(sess.run(output, feed_dict={x:arr})))
```



GT : 5
Pred : 6

```
import numpy as np
s = 33
arr = np.array(mnist.test.images[s])
arr.shape = (28, 28)

import matplotlib.pyplot as plt

plt.imshow(arr)
plt.show()

arr.shape = (1, 784)
print('GT   : ', np.argmax(mnist.test.labels[s]))
print('Pred : ',np.argmax(sess.run(output, feed_dict={x:arr})))
```



GT : 4
Pred : 0

CNN (ConvNet)

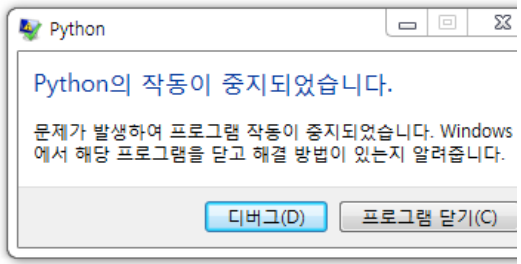
- 버그

In [13]:
```
sess = tf.Session()
sess.run(tf.global_variables_initializer())
```

In [*]:
```
for i in range(20000):#20000
    batch = mnist.train.next_batch(50)
    if i % 1000 == 0:
        train_accuracy = sess.run(accuracy, feed_dict={
                x:batch[0], y_: batch[1], keep_prob: 1.0})
        print("step %d, training accuracy %g"%(i, train_accuracy))
    sess.run(train_step,feed_dict={x: batch[0], y_: batch[1], keep_prob: 0.5})
```

```
step 0, training accuracy 0.12
step 1000, training accuracy 0.94
step 2000, training accuracy 0.96
step 3000, training accuracy 1
step 4000, training accuracy 0.98
step 5000, training accuracy 1
step 6000, training accuracy 0.96
step 7000, training accuracy 1
step 8000, training accuracy 0.98
step 9000, training accuracy 0.96
step 10000, training accuracy 0.98
step 11000, training accuracy 1
step 12000, training accuracy 1
step 13000, training accuracy 1
step 14000, training accuracy 0.98
step 15000, training accuracy 1
step 16000, training accuracy 1
step 17000, training accuracy 1
step 18000, training accuracy 1
step 19000, training accuracy 1
```

CPU버전 삭제로 해결



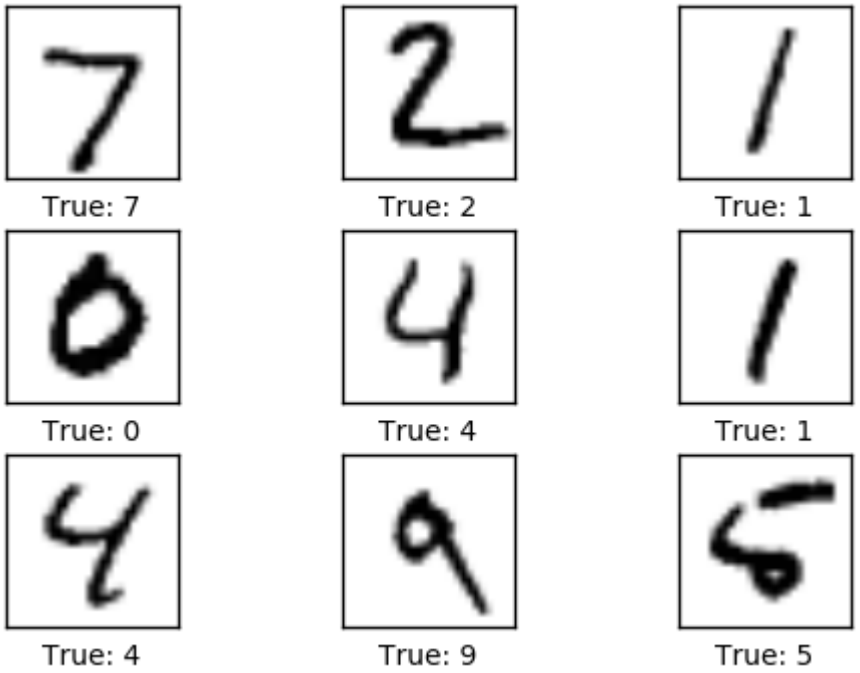
In [*]:
```
print("test accuracy %g"% sess.run(
        accuracy, feed_dict={x: mnist.test.images, y_: mnist.test.labels, keep_prob: 1.0}))
```

CNN (ConvNet)

```
In [12]: cross_entropy = -tf.reduce_sum(y_*tf.log(y_conv))
         train_step = tf.train.AdamOptimizer(1e-4).minimize(cross_entropy)
         correct_prediction = tf.equal(tf.argmax(y_conv,1), tf.argmax(y_,1))
         accuracy = tf.reduce_mean(tf.cast(correct_prediction, "float"))

In [13]: sess = tf.Session()
         sess.run(tf.global_variables_initializer())

In [17]: for i in range(20000):#20000
             batch = mnist.train.next_batch(50)
             if i % 1000 == 0:

In [19]: print("Accuracy : ", sess.run(accuracy, feed_dict={x: mnist.test.images, y_: mnist.test.labels, keep_prob: 1.0}))
         Accuracy :  0.9927

         step 0, training accuracy 0.94
         step 1000, training accuracy 1
         step 2000, training accuracy 1
         step 3000, training accuracy 1
         step 4000, training accuracy 1
         step 5000, training accuracy 0.98
         step 6000, training accuracy 1
         step 7000, training accuracy 1
         step 8000, training accuracy 1
         step 9000, training accuracy 1
         step 10000, training accuracy 1
         step 11000, training accuracy 1
         step 12000, training accuracy 1
         step 13000, training accuracy 1
         step 14000, training accuracy 1
         step 15000, training accuracy 1
         step 16000, training accuracy 1
         step 17000, training accuracy 1
         step 18000, training accuracy 1
         step 19000, training accuracy 1
```

Q&A

example

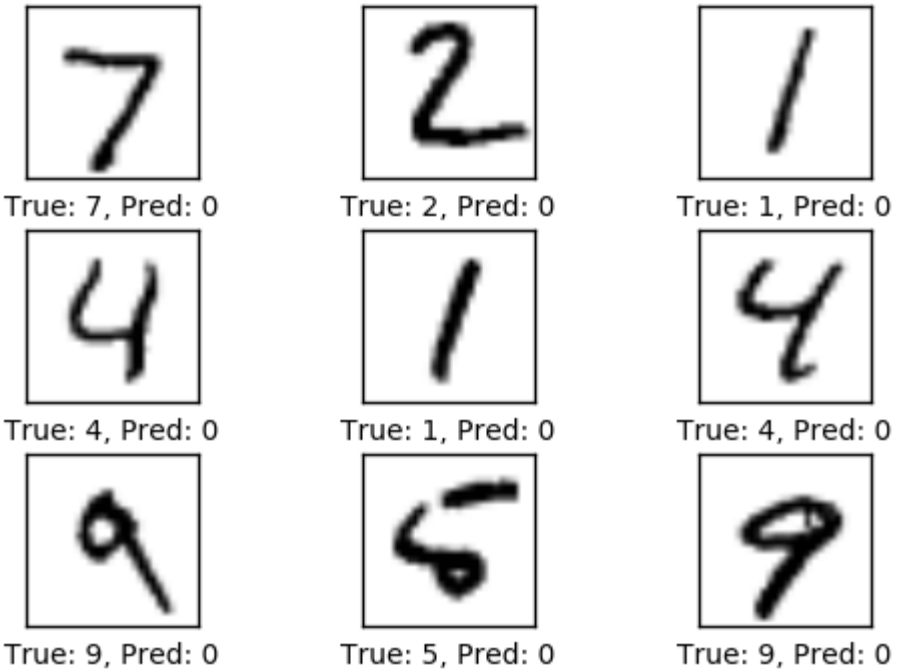


Before any opt

```
print_accuracy()
```

```
Accuracy on test-set: 9.8%
```

```
plot_example_errors()
```



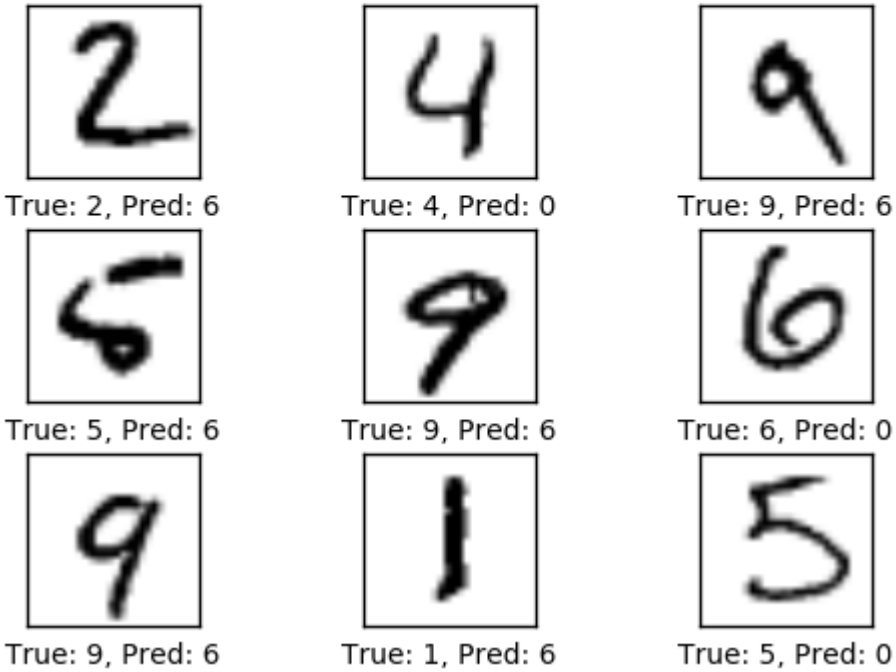
After 1 opt iter

```
optimize(num_iterations=1)
```

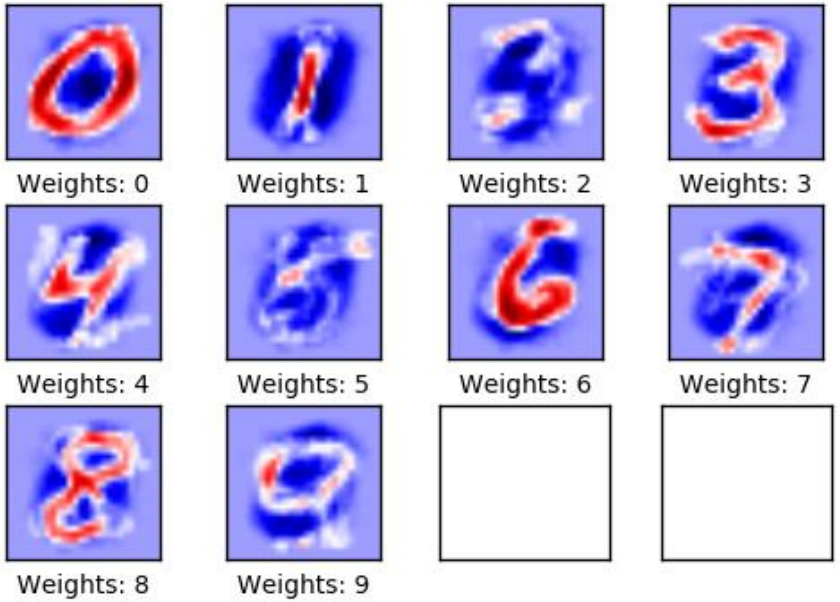
```
print_accuracy()
```

```
Accuracy on test-set: 40.7%
```

```
plot_example_errors()
```




```
plot_weights()
```



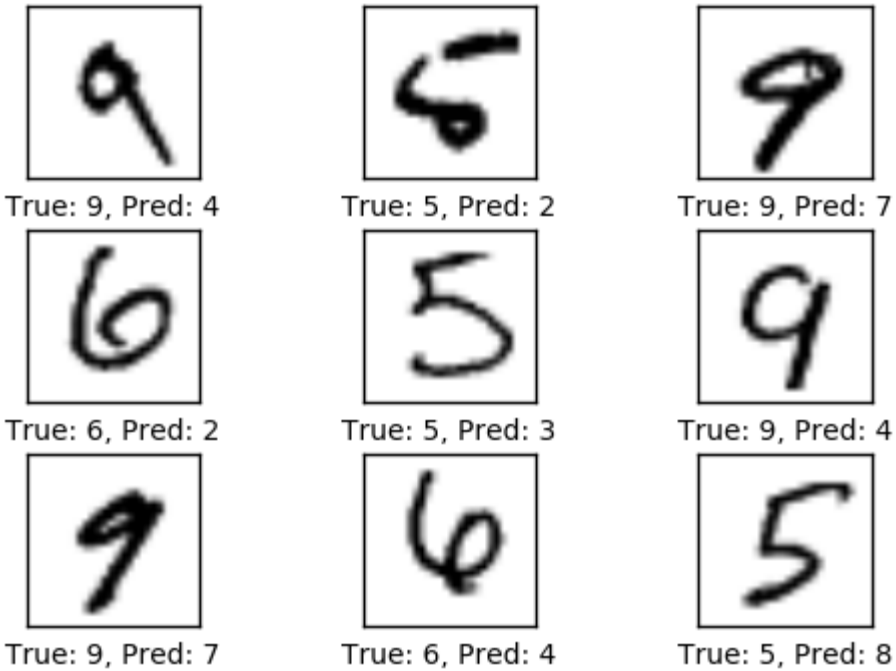
After 10 opt iter

```
# We have already performed 1 iteration.
optimize(num_iterations=9)
```

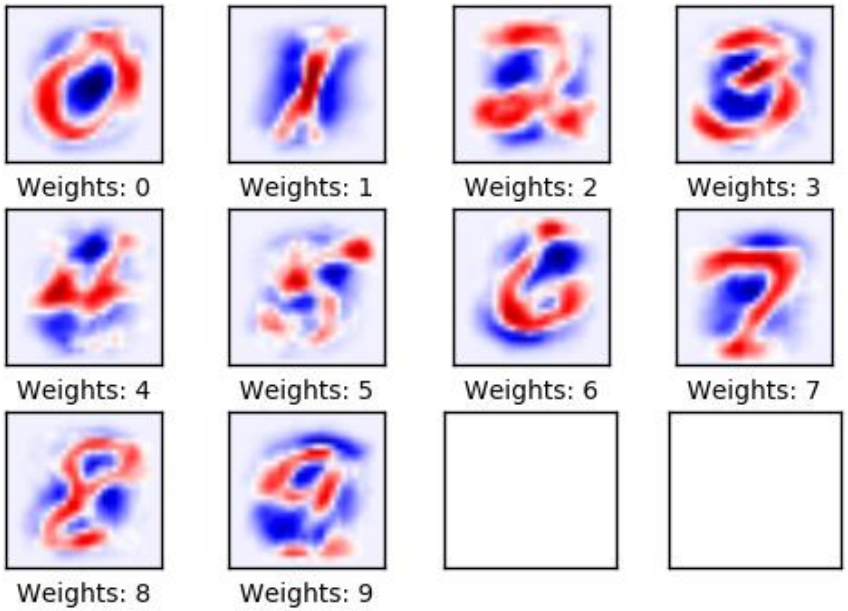
```
print_accuracy()
```

```
Accuracy on test-set: 78.2%
```

```
plot_example_errors()
```




```
plot_weights()
```



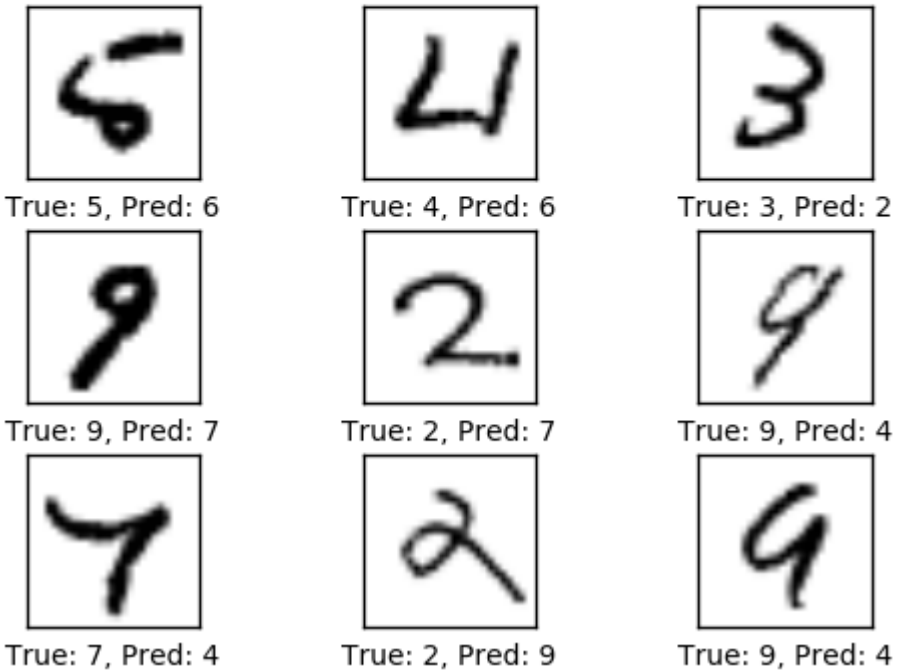
After 1000 opt iter

```
# We have already performed 10 iterations.
optimize(num_iterations=990)
```

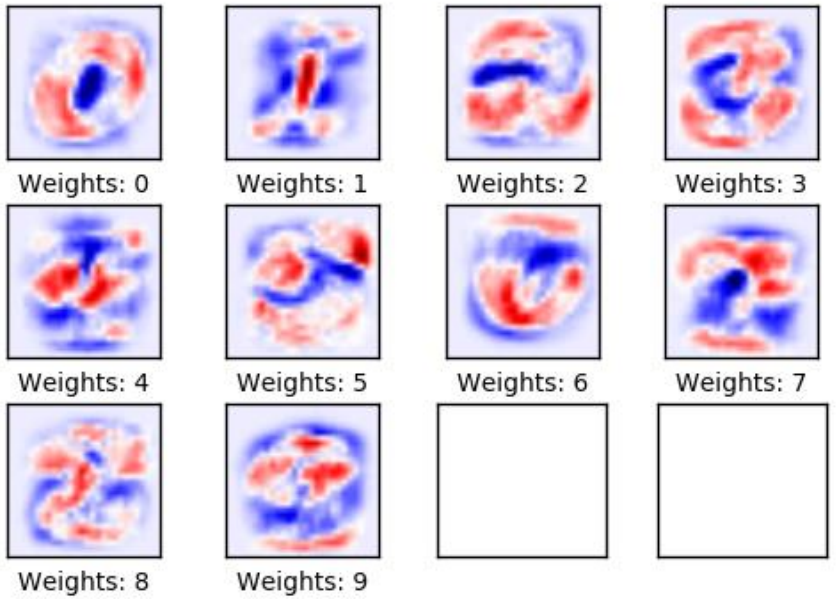
```
print_accuracy()
```

```
Accuracy on test-set: 91.7%
```

```
plot_example_errors()
```




```
plot_weights()
```



After 1000 opt iter

```
print_confusion_matrix()
```

```
[[ 957    0    3    2    0    5   11    1    1    0]
 [   0 1108    2    2    1    2    4    2   14    0]
 [   4    9  914   19   15    5   13   14   35    4]
 [   1    0   16  928    0   28    2   14   13    8]
 [   1    1    3    2  939    0   10    2    6   18]
 [  10    3    3   33   10  784   17    6   19    7]
 [   8    3    3    2   11   14  915    1    1    0]
 [   3    9   21    9    7    1    0  959    2   17]
 [   8    8    8   38   11   40   14   18  825    4]
 [  11    7    1   13   75   13    1   39    4  845]]
```