With TF 1.0!

Lab 9

NN for XOR

Sung Kim <hunkim+ml@gmail.com>

Code: https://github.com/hunkim/DeepLearningZeroToAll/

Call for comments

Please feel free to add comments directly on these slides

Other slides: https://goo.gl/jPtWNt

Picture from http://www.tssablog.org/archives/3280

With TF 1.0!

Lab 9-1

NN for XOR

Sung Kim <hunkim+ml@gmail.com>

Code: https://github.com/hunkim/DeepLearningZeroToAll/

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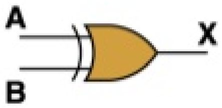
zeran4 #11 1 commit / 5 ++ / 4 --	jennykang #2 19 commits / 940 ++ / 253 --
GzuPark #3 14 commits / 41 ++ / 31 --	kkweon #4 5 commits / 372 ++ / 296 --
BlueMelon715 #5 4 commits / 45 ++ / 34 --	jin-chong #6 2 commits / 4 ++ / 4 --
FuZer #7 2 commits / 37 ++ / 30 --	cynthia #8 1 commit / 28 ++ / 28 --
keon #9 1 commit / 3 ++ / 3 --	allieus #10 1 commit / 55 ++ / 59 --

XOR data set

Boolean Expression

$$X = A \oplus B$$

Logic Diagram Symbol



Truth Table

A	B	X
0	0	0
0	1	1
1	0	1
1	1	0

```
x_data = np.array([[0, 0], [0, 1], [1, 0], [1, 1]], dtype=np.float32)
y_data = np.array([[0],    [1],    [1],    [0]], dtype=np.float32)
```

http://templ25.mandaringardencity.com/xor-gate-truth-table-2/

XOR with logistic regression?

```python
x_data = np.array([[0, 0], [0, 1], [1, 0], [1, 1]], dtype=np.float32)
y_data = np.array([[0], [1], [1], [0]], dtype=np.float32)

X = tf.placeholder(tf.float32)
Y = tf.placeholder(tf.float32)
W = tf.Variable(tf.random_normal([2, 1]), name='weight')
b = tf.Variable(tf.random_normal([1]), name='bias')

# Hypothesis using sigmoid: tf.div(1., 1. + tf.exp(tf.matmul(X, W)))
hypothesis = tf.sigmoid(tf.matmul(X, W) + b)

# cost/loss function
cost = -tf.reduce_mean(Y * tf.log(hypothesis) + (1 - Y) * tf.log(1 - hypothesis))
train = tf.train.GradientDescentOptimizer(learning_rate=0.1).minimize(cost)

# Accuracy computation
# True if hypothesis>0.5 else False
predicted = tf.cast(hypothesis > 0.5, dtype=tf.float32)
accuracy = tf.reduce_mean(tf.cast(tf.equal(predicted, Y), dtype=tf.float32))

# Launch graph
with tf.Session() as sess:
   # Initialize TensorFlow variables
   sess.run(tf.global_variables_initializer())

   for step in range(10001):
       sess.run(train, feed_dict={X: x_data, Y: y_data})
       if step % 100 == 0:
           print(step, sess.run(cost, feed_dict={X: x_data, Y: y_data}), sess.run(W))

   # Accuracy report
   h, c, a = sess.run([hypothesis, predicted, accuracy], feed_dict={X: x_data, Y: y_data})
   print("\nHypothesis: ", h, "\nCorrect: ", c, "\nAccuracy: ", a)
```

https://github.com/hunkim/DeepLearningZeroToAll/blob/master/lab-09-1-xor.py

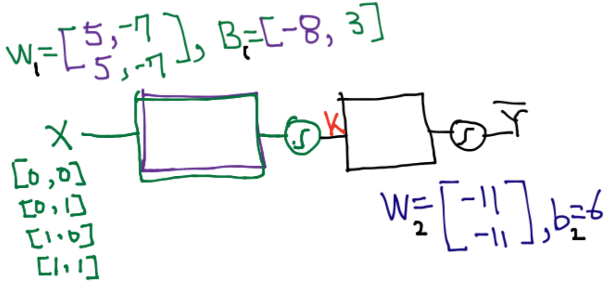
```python
x_data = np.array([[0, 0], [0, 1], [1, 0], [1, 1]], dtype=np.float32)
y_data = np.array([[0], [1], [1], [0]], dtype=np.float32)

X = tf.placeholder(tf.float32)
Y = tf.placeholder(tf.float32)
W = tf.Variable(tf.random_normal([2, 1]), name='weight')
b = tf.Variable(tf.random_normal([1]), name='bias')

# Hypothesis using sigmoid: tf.div(1., 1. + tf.exp(tf.matmul(X, W)))
hypothesis = tf.sigmoid(tf.matmul(X, W) + b)

# cost/loss function
cost = -tf.reduce_mean(Y * tf.log(hypothesis) + (1 - Y) * tf.log(1 - hypothesis))
train = tf.train.GradientDescentOptimizer(learning_rate=0.1).minimize(cost)

# Accuracy computation
# True if hypothesis>0.5 else False
predicted = tf.cast(hypothesis > 0.5, dtype=tf.float32)
accuracy = tf.reduce_mean(tf.cast(tf.equal(predicted, Y), dtype=tf.float32))

# Launch graph
with tf.Session() as sess:
   # Initialize TensorFlow variables
   sess.run(tf.global_variables_initializer())

   for step in range(10001):
       sess.run(train, feed_dict={X: x_data, Y: y_data})
       if step % 100 == 0:
           print(step, sess.run(cost, feed_dict={X: x_data, Y: y_data}), sess.run(W))

   # Accuracy report
   h, c, a = sess.run([hypothesis, predicted, accuracy], feed_dict={X: x_data, Y: y_data})
   print("\nHypothesis: ", h, "\nCorrect: ", c, "\nAccuracy: ", a)
```

XOR with logistic regression? But it doesn't work!

Hypothesis:
[[0.5]
[0.5]
[0.5]
[0.5]]
Correct:
[[0.]
[0.]
[0.]
[0.]]
Accuracy: 0.5

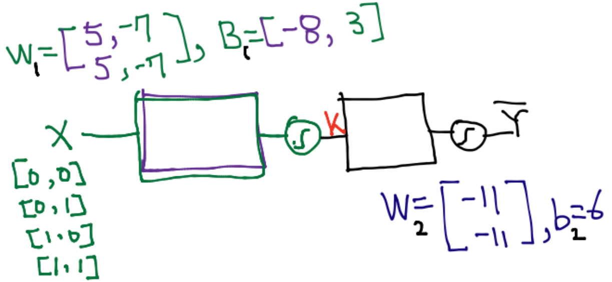
https://github.com/hunkim/DeepLearningZeroToAll/blob/master/lab-09-1-xor.py

Neural Net




```python
W = tf.Variable(tf.random_normal([2, 1]), name='weight')
b = tf.Variable(tf.random_normal([1]), name='bias')

# Hypothesis using sigmoid: tf.div(1., 1. + tf.exp(tf.matmul(X, W)))
hypothesis = tf.sigmoid(tf.matmul(X, W) + b)
```

Neural Net




```python
W = tf.Variable(tf.random_normal([2, 1]), name='weight')
b = tf.Variable(tf.random_normal([1]), name='bias')

# Hypothesis using sigmoid: tf.div(1., 1. + tf.exp(tf.matmul(X, W)))
hypothesis = tf.sigmoid(tf.matmul(X, W) + b)
```

```python
W1 = tf.Variable(tf.random_normal([2, 2]), name='weight1')
b1 = tf.Variable(tf.random_normal([2]), name='bias1')
layer1 = tf.sigmoid(tf.matmul(X, W1) + b1)

W2 = tf.Variable(tf.random_normal([2, 1]), name='weight2')
b2 = tf.Variable(tf.random_normal([1]), name='bias2')
hypothesis = tf.sigmoid(tf.matmul(layer1, W2) + b2)
```

https://github.com/hunkim/DeepLearningZeroToAll/blob/master/lab-09-2-xor-nn.py

NN for XOR

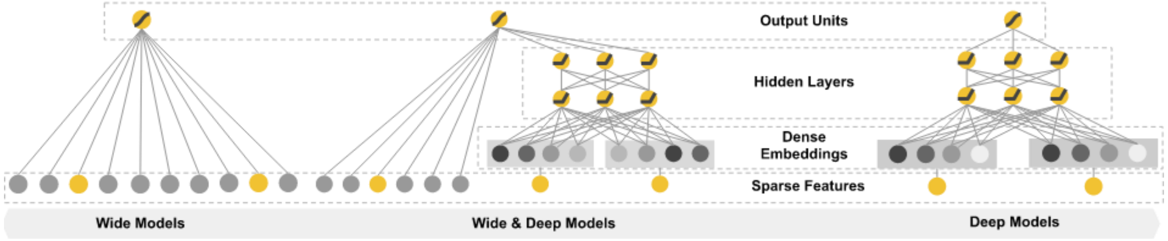
```python
x_data = np.array([[0, 0], [0, 1], [1, 0], [1, 1]], dtype=np.float32)
y_data = np.array([[0], [1], [1], [0]], dtype=np.float32)
X = tf.placeholder(tf.float32)
Y = tf.placeholder(tf.float32)

W1 = tf.Variable(tf.random_normal([2, 2]), name='weight1')
b1 = tf.Variable(tf.random_normal([2]), name='bias1')
layer1 = tf.sigmoid(tf.matmul(X, W1) + b1)

W2 = tf.Variable(tf.random_normal([2, 1]), name='weight2')
b2 = tf.Variable(tf.random_normal([1]), name='bias2')
hypothesis = tf.sigmoid(tf.matmul(layer1, W2) + b2)

# cost/loss function
cost = -tf.reduce_mean(Y * tf.log(hypothesis) + (1 - Y) * tf.log(1 - hypothesis))
train = tf.train.GradientDescentOptimizer(learning_rate=0.1).minimize(cost)
# Accuracy computation
# True if hypothesis>0.5 else False
predicted = tf.cast(hypothesis > 0.5, dtype=tf.float32)
accuracy = tf.reduce_mean(tf.cast(tf.equal(predicted, Y), dtype=tf.float32))
# Launch graph
with tf.Session() as sess:
   # Initialize TensorFlow variables
   sess.run(tf.global_variables_initializer())
   for step in range(10001):
       sess.run(train, feed_dict={X: x_data, Y: y_data})
       if step % 100 == 0:
           print(step, sess.run(cost, feed_dict={X: x_data, Y: y_data}), sess.run([W1, W2]))

   # Accuracy report
   h, c, a = sess.run([hypothesis, predicted, accuracy],
                      feed_dict={X: x_data, Y: y_data})
   print("\nHypothesis: ", h, "\nCorrect: ", c, "\nAccuracy: ", a)
```

```
Hypothesis:
[[ 0.01338218]
[ 0.98166394]
[ 0.98809403]
[ 0.01135799]]
Correct:
[[ 0.]
[ 1.]
[ 1.]
[ 0.]]
Accuracy:  1.0
```

https://github.com/hunkim/DeepLearningZeroToAll/blob/master/lab-09-2-xor-nn.py

Wide NN for XOR

```
W1 = tf.Variable(tf.random_normal([2, 10]), name='weight1')
b1 = tf.Variable(tf.random_normal([10]), name='bias1')
layer1 = tf.sigmoid(tf.matmul(X, W1) + b1)

W2 = tf.Variable(tf.random_normal([10, 1]), name='weight2')
b2 = tf.Variable(tf.random_normal([1]), name='bias2')
hypothesis = tf.sigmoid(tf.matmul(layer1, W2) + b2)
```



[2,10], [10,1]

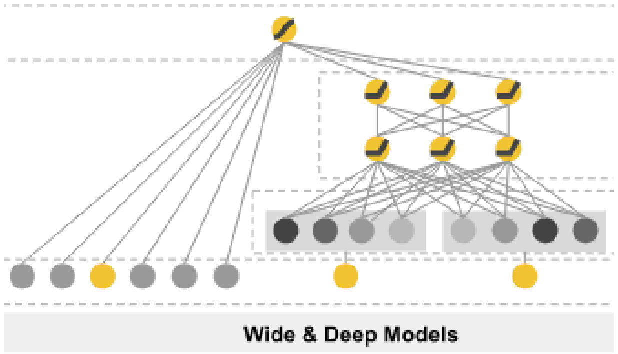
Hypothesis:
[[0.00358802]
 [0.99366933]
 [0.99204296]
 [0.0095663]]
Correct:
[[0.]
 [1.]
 [1.]
 [0.]]
Accuracy: 1.0

[2,2], [2,1]

Hypothesis:
[[0.01338218]
[0.98166394]
[0.98809403]
[0.01135799]]
Correct:
[[0.]
[1.]
[1.]
[0.]]
Accuracy: 1.0

https://github.com/hunkim/DeepLearningZeroToAll/blob/master/lab-09-3-xor-nn-wide-deep.py

Deep NN for XOR




```
W1 = tf.Variable(tf.random_normal([2, 10]), name='weight1')
b1 = tf.Variable(tf.random_normal([10]), name='bias1')
layer1 = tf.sigmoid(tf.matmul(X, W1) + b1)

W2 = tf.Variable(tf.random_normal([10, 10]), name='weight2')
b2 = tf.Variable(tf.random_normal([10]), name='bias2')
layer2 = tf.sigmoid(tf.matmul(layer1, W2) + b2)

W3 = tf.Variable(tf.random_normal([10, 10]), name='weight3')
b3 = tf.Variable(tf.random_normal([10]), name='bias3')
layer3 = tf.sigmoid(tf.matmul(layer2, W3) + b3)

W4 = tf.Variable(tf.random_normal([10, 1]), name='weight4')
b4 = tf.Variable(tf.random_normal([1]), name='bias4')
hypothesis = tf.sigmoid(tf.matmul(layer3, W4) + b4)
```

4 layers

```
Hypothesis:
[[  7.80e-04]
 [  9.99e-01]
 [  9.98e-01]
 [  1.55e-03]]
Correct:
[[ 0.]
 [ 1.]
 [ 1.]
 [ 0.]]
Accuracy:  1.0
```

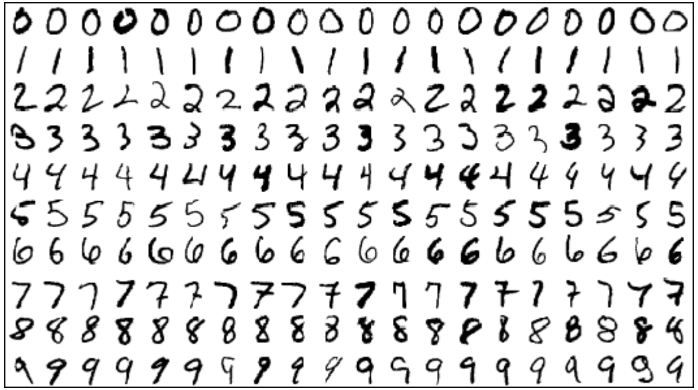
2 layers

```
Hypothesis:
[[ 0.01338218]
 [ 0.98166394]
 [ 0.98809403]
 [ 0.01135799]]
Correct:
[[ 0.]
 [ 1.]
 [ 1.]
 [ 0.]]
Accuracy:  1.0
```

https://github.com/hunkim/DeepLearningZeroToAll/blob/master/lab-09-3-xor-nn-wide-deep.py

Exercise

- Wide and Deep NN for MNIST



With TF 1.0!

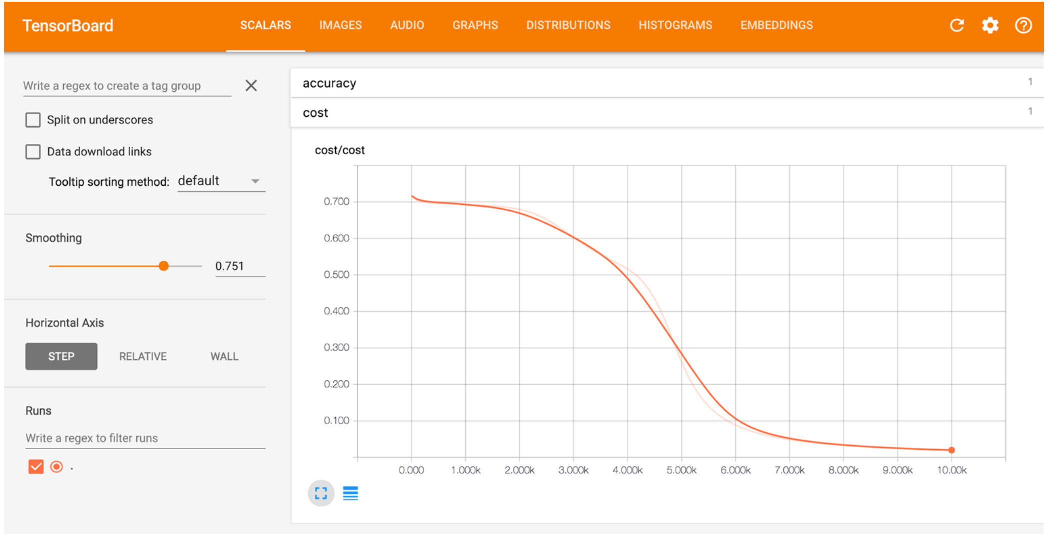
Lab 9-2

Tensorboard for XOR NN

Sung Kim <hunkim+ml@gmail.com>
Code: https://github.com/hunkim/DeepLearningZeroToAll/

TensorBoard: TF logging/debugging tool

- Visualize your TF graph
- Plot quantitative metrics
- Show additional data

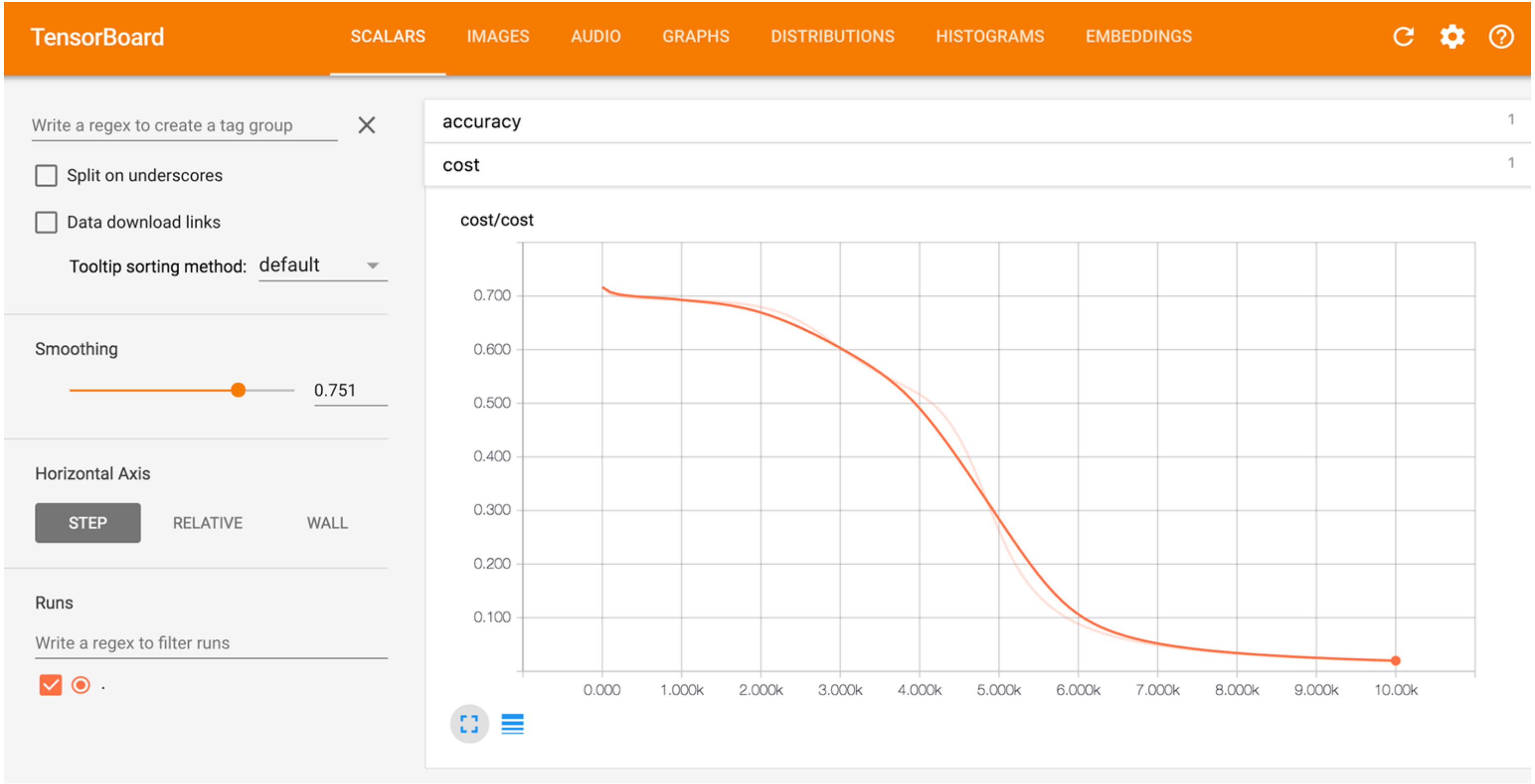


https://www.tensorflow.org/get_started/summaries_and_tensorboard

Old fashion: print, print, print

```
9400 0.0151413 [array([[ 6.21692038,  6.05913448],
       [-6.33773184, -5.75189114]], dtype=float32), array([[ 9.93581772],
       [-9.43034935]], dtype=float32)]
9500 0.014909 [array([[ 6.22498751,  6.07049847],
       [-6.34637976, -5.76352596]], dtype=float32), array([[ 9.96414757],
       [-9.45942593]], dtype=float32)]
9600 0.0146836 [array([[ 6.23292685,  6.08166742],
       [-6.35489035, -5.77496052]], dtype=float32), array([[ 9.99207973],
       [-9.48807526]], dtype=float32)]
9700 0.0144647 [array([[ 6.24074268,  6.09264851],
       [-6.36326933, -5.78619957]], dtype=float32), array([[ 10.01962471],
       [ -9.51631165]], dtype=float32)]
9800 0.0142521 [array([[ 6.24843407,  6.10344648],
       [-6.37151814, -5.79724932]], dtype=float32), array([[ 10.04679298],
       [ -9.54414845]], dtype=float32)]
9900 0.0140456 [array([[ 6.25601053,  6.11406422],
       [-6.3796401 , -5.80811596]], dtype=float32), array([[ 10.07359505],
       [ -9.57159519]], dtype=float32)]
10000 0.0138448 [array([[ 6.26347113,  6.12451124],
       [-6.38764334, -5.81880617]], dtype=float32), array([[ 10.10004139],
       [ -9.59866238]], dtype=float32)]
```

New way!



TensorBoard
SCALARS
IMAGES
AUDIO
GRAPHS
DISTRIBUTIONS
HISTOGRAMS
EMBEDDINGS
Write a regex to create a tag group
Split on underscores
Data download links
Tooltip sorting method: default
Smoothing
0.751
Horizontal Axis
STEP
RELATIVE
WALL
Runs
Write a regex to filter runs
accuracy
1
cost
1
cost/cost
0.700
0.600
0.500
0.400
0.300
0.200
0.100
0.000
1.000k
2.000k
3.000k
4.000k
5.000k
6.000k
7.000k
8.000k
9.000k
10.00k

5 steps of using TensorBoard

1. From TF graph, decide which tensors you want to log

```
w2_hist = tf.summary.histogram("weights2", W2)
cost_summ = tf.summary.scalar("cost", cost)
```

2. Merge all summaries

```
summary = tf.summary.merge_all()
```

3. Create writer and add graph

```
# Create summary writer
writer = tf.summary.FileWriter('./logs')
writer.add_graph(sess.graph)
```

4. Run summary merge and add_summary

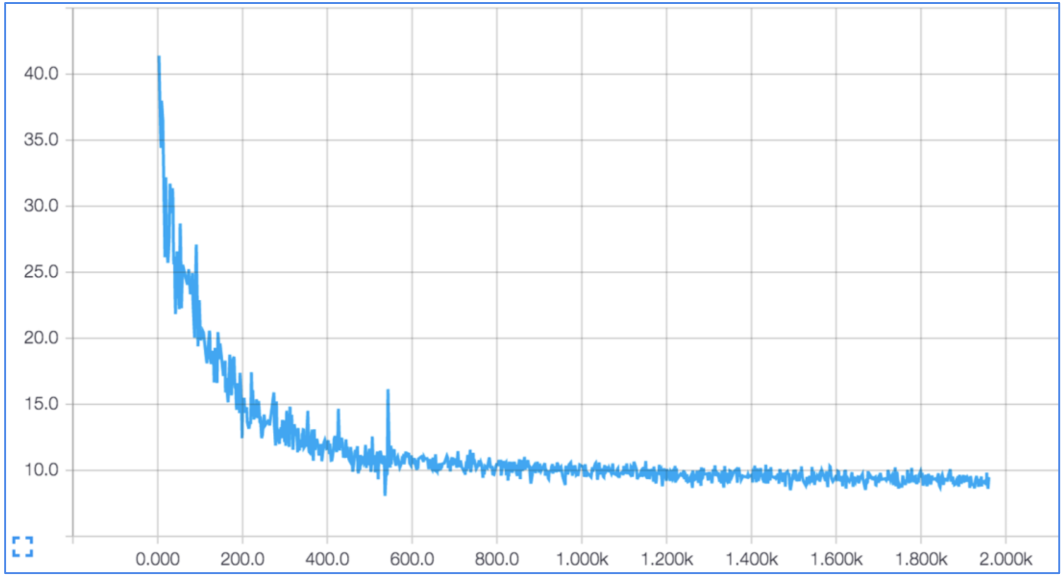
```
s, _ = sess.run([summary, optimizer], feed_dict=feed_dict)
writer.add_summary(s, global_step=global_step)
```

5. Launch TensorBoard

```
tensorboard --logdir=./logs
```

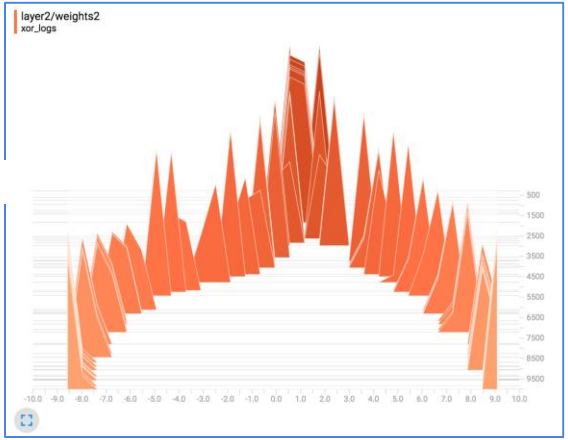
Scalar tensors

```
cost_summ = tf.summary.scalar("cost", cost)
```



Histogram (multi-dimensional tensors)

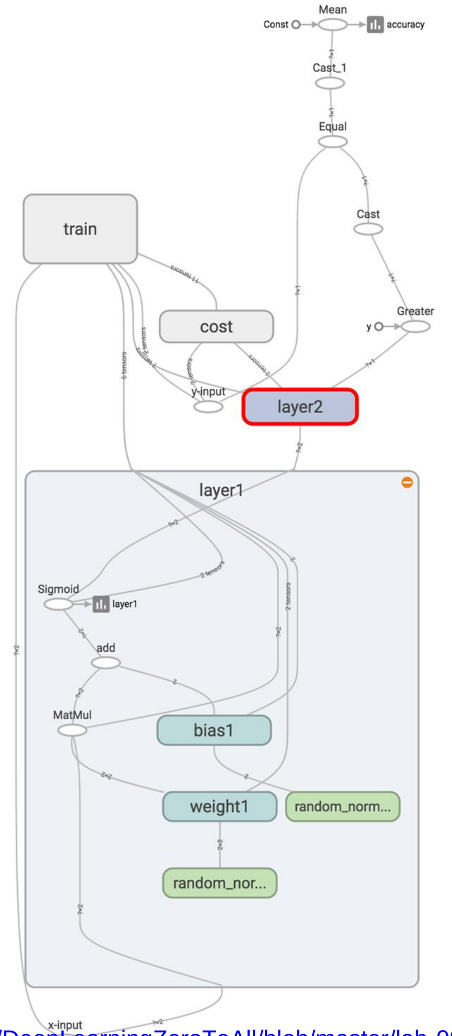
```
W2 = tf.Variable(tf.random_normal([2, 1]), name='weight2')
b2 = tf.Variable(tf.random_normal([1]), name='bias2')
hypothesis = tf.sigmoid(tf.matmul(layer1, W2) + b2)

w2_hist = tf.summary.histogram("weights2", W2)
b2_hist = tf.summary.histogram("biases2", b2)
hypothesis_hist = tf.summary.histogram("hypothesis", hypothesis)
```



https://github.com/hunkim/DeepLearningZeroToAll/blob/master/lab-09-4-xor_tensorboard.py

Add scope for better graph hierarchy

```
with tf.name_scope("layer1") as scope:
   W1 = tf.Variable(tf.random_normal([2, 2]), name='weight1')
   b1 = tf.Variable(tf.random_normal([2]), name='bias1')
   layer1 = tf.sigmoid(tf.matmul(X, W1) + b1)

   w1_hist = tf.summary.histogram("weights1", W1)
   b1_hist = tf.summary.histogram("biases1", b1)
   layer1_hist = tf.summary.histogram("layer1", layer1)


with tf.name_scope("layer2") as scope:
   W2 = tf.Variable(tf.random_normal([2, 1]), name='weight2')
   b2 = tf.Variable(tf.random_normal([1]), name='bias2')
   hypothesis = tf.sigmoid(tf.matmul(layer1, W2) + b2)

   w2_hist = tf.summary.histogram("weights2", W2)
   b2_hist = tf.summary.histogram("biases2", b2)
   hypothesis_hist = tf.summary.histogram("hypothesis", hypothesis
```



https://github.com/hunkim/DeepLearningZeroToAll/blob/master/lab-09-4-xor_tensorboard.py

2 3 Merge summaries and create writer after creating session

```
# Summary
summary = tf.summary.merge_all()

# initialize
sess = tf.Session()
sess.run(tf.global_variables_initializer())

# Create summary writer
writer = tf.summary.FileWriter(TB_SUMMARY_DIR)
writer.add_graph(sess.graph) # Add graph in the tensorboard
```

https://github.com/hunkim/DeepLearningZeroToAll/blob/master/lab-09-4-xor_tensorboard.py

④ Run merged summary and write (add summary)

```
s, _ = sess.run([summary, optimizer], feed_dict=feed_dict)
writer.add_summary(s, global_step=global_step)
global_step += 1
```

https://github.com/hunkim/DeepLearningZeroToAll/blob/master/lab-09-4-xor_tensorboard.py

5 Launch tensorboard (local)

```
writer = tf.summary.FileWriter("./logs/xor_logs")
```

```
$ tensorboard —logdir=./logs/xor_logs
```

Starting TensorBoard b'41' on port 6006

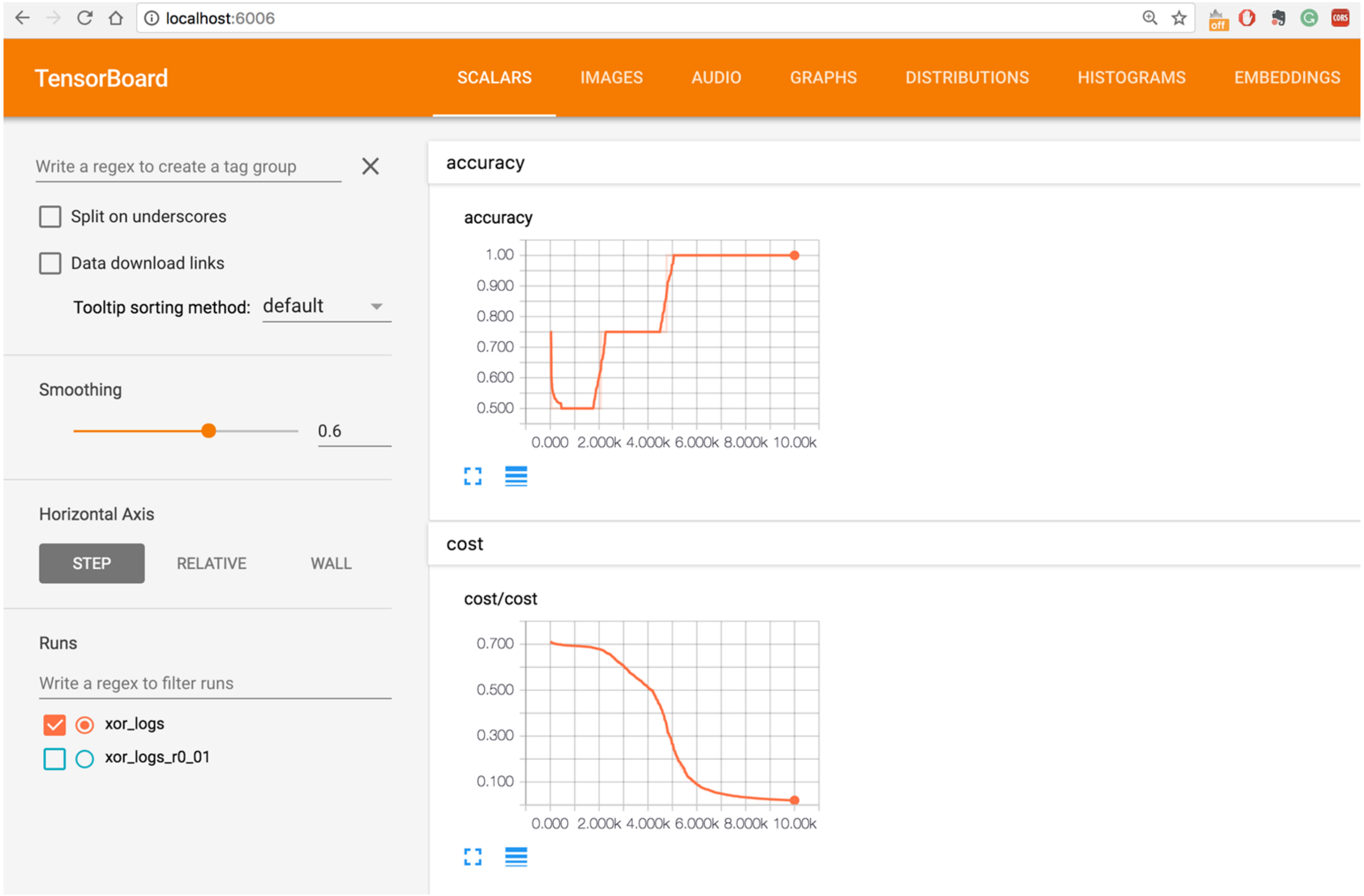
(You can navigate to http://127.0.0.1:6006)

❺ Launch tensorboard (remote server)

```
ssh -L local_port:127.0.0.1:remote_port username@server.com
```

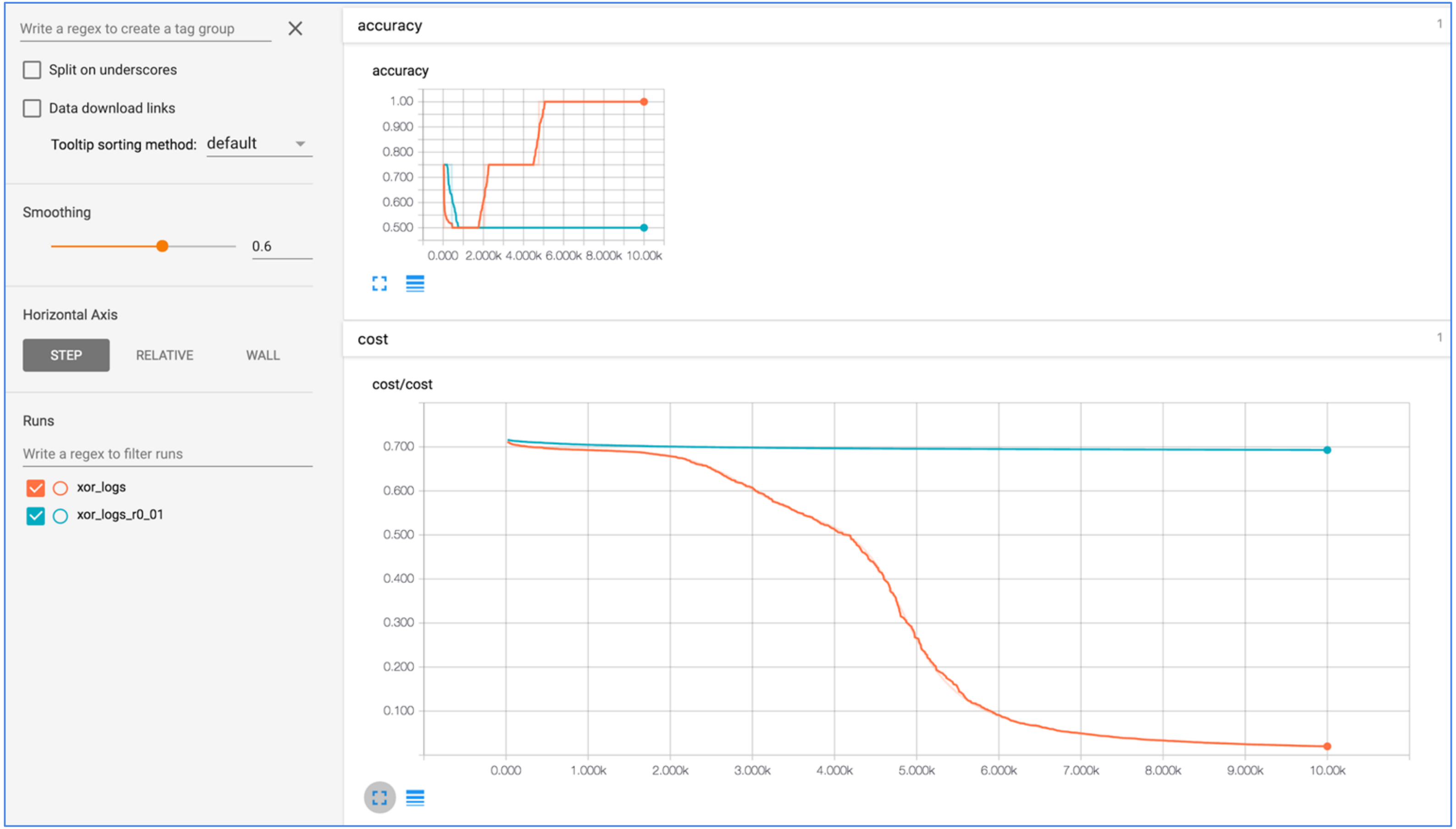
```
local>  $ ssh -L 7007:121.0.0.0:6006 hunkim@server.com
server> $ tensorboard —logdir=./logs/xor_logs
```

(You can navigate to http://127.0.0.1:7007)


localhost:6006
TensorBoard
SCALARS
IMAGES
AUDIO
GRAPHS
DISTRIBUTIONS
HISTOGRAMS
EMBEDDINGS
Write a regex to create a tag group
Split on underscores
Data download links
Tooltip sorting method: default
Smoothing
0.6
Horizontal Axis
STEP
RELATIVE
WALL
Runs
Write a regex to filter runs
xor_logs
xor_logs_r0_01
accuracy
accuracy
1.00
0.900
0.800
0.700
0.600
0.500
0.000 2.000k 4.000k 6.000k 8.000k 10.00k
cost
cost/cost
0.700
0.500
0.300
0.100
0.000 2.000k 4.000k 6.000k 8.000k 10.00k

Multiple runs

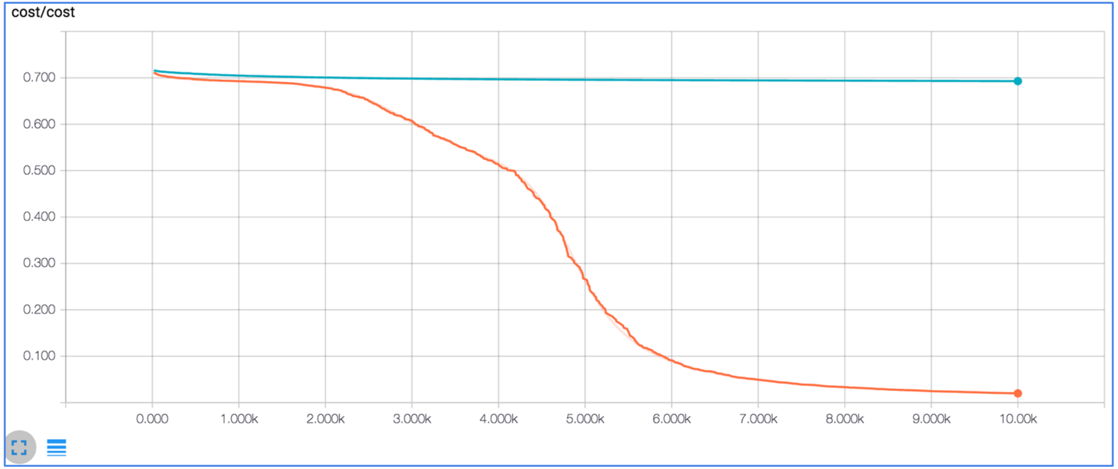
`learning_rate=0.1 VS learning_rate=0.01`



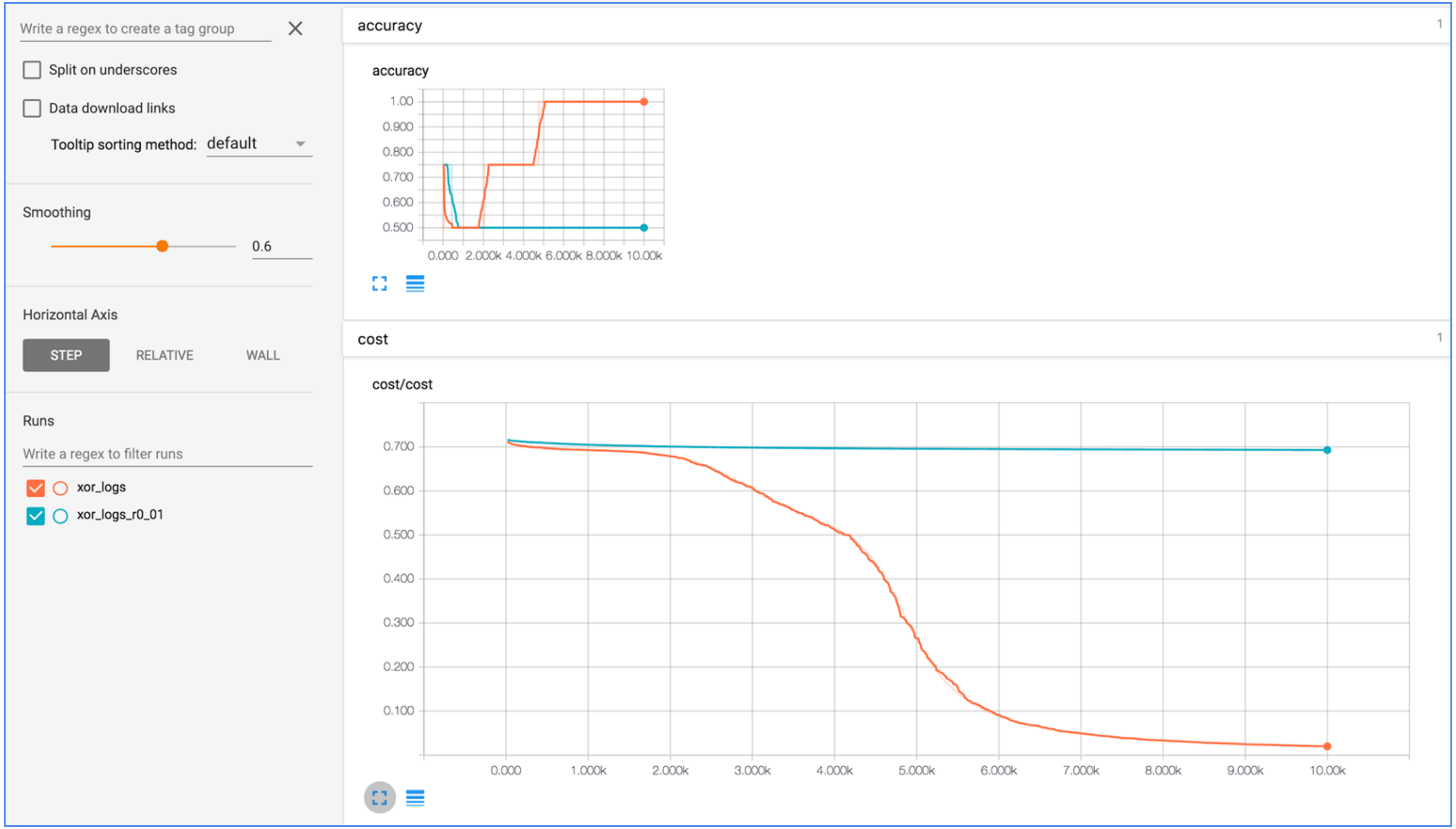
Multiple runs

```
tensorboard —logdir=./logs/xor_logs
   train = tf.train.GradientDescentOptimizer(learning_rate=0.1).minimize(cost)
   ...
   writer = tf.summary.FileWriter("./logs/xor_logs")
tensorboard —logdir=./logs/xor_logs_r0_01
   train = tf.train.GradientDescentOptimizer(learning_rate=0.01).minimize(cost)
   ...
   writer = tf.summary.FileWriter(“"./logs/xor_logs_r0_01"”)
```

```
tensorboard —logdir=./logs
```



Multiple runs



5 steps of using TensorBoard

1 From TF graph, decide which tensors you want to log

```
w2_hist = tf.summary.histogram("weights2", W2)
cost_summ = tf.summary.scalar("cost", cost)
```

2 Merge all summaries

```
summary = tf.summary.merge_all()
```

3 Create writer and add graph

```
# Create summary writer
writer = tf.summary.FileWriter('./logs')
writer.add_graph(sess.graph)
```

4 Run summary merge and add_summary

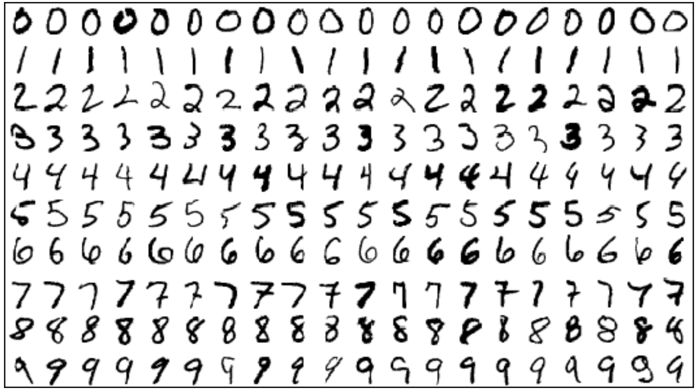
```
s, _ = sess.run([summary, optimizer], feed_dict=feed_dict)
writer.add_summary(s, global_step=global_step)
```

5 Launch TensorBoard

```
tensorboard --logdir=./logs
```

Exercise

- Wide and Deep NN for MNIST
- Add tensorboard



With TF 1.0!

Lab 9-2-E

Tensorboard for MNIST

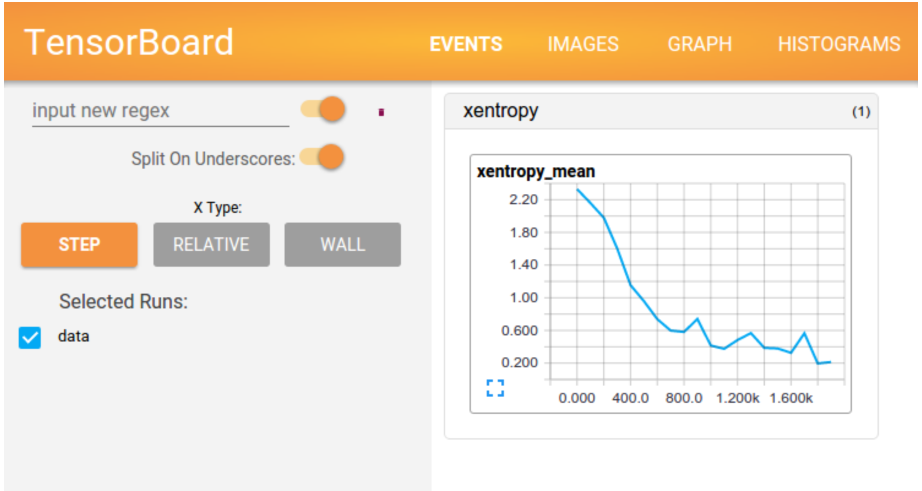
Sung Kim <hunkim+ml@gmail.com>
Code: https://github.com/hunkim/DeepLearningZeroToAll/

Visualizing your Deep learning using TensorBoard (TensorFlow)

Sung Kim <hunkim+ml@gmail.com>

TensorBoard: TF logging/debugging tool

- Visualize your TF graph
- Plot quantitative metrics
- Show additional data

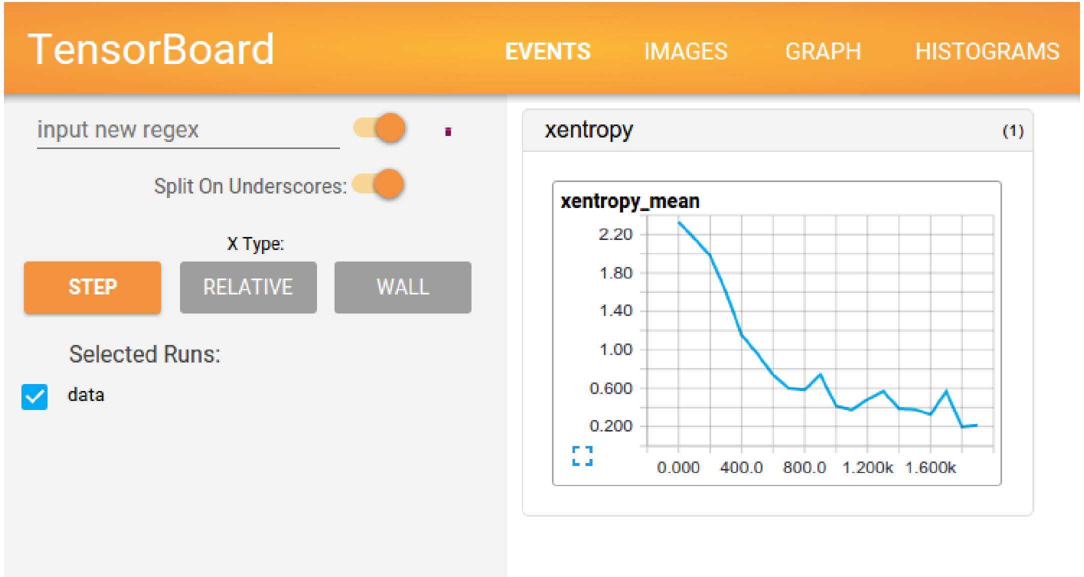


https://www.tensorflow.org/get_started/summaries_and_tensorboard

Old fashion: print, print, print

```
2000 [0.69364417, array([[ 0.50981331,  0.50592244],
       [ 0.37054271,  0.37088916],
       [ 0.6810087 ,  0.38607275],
       [ 0.54717511,  0.26581794]], dtype=float32), array([[ 0.50861073],
       [ 0.51602864],
       [ 0.4826754 ],
       [ 0.49036184]], dtype=float32), array([[ 0.71915275, -0.48754135],
       [-0.56914777, -0.55209494]], dtype=float32), array([[-0.44138899],
       [ 0.23536676]], dtype=float32), array([ 0.03925836,  0.02369077], dtype=float32), array([ 0.14039496], dtype=float32)]
4000 [0.69332385, array([[ 0.52235132,  0.50927138],
       [ 0.38598102,  0.37814924],
       [ 0.69650716,  0.39592981],
       [ 0.56881481,  0.27748841]], dtype=float32), array([[ 0.50748861],
       [ 0.51554251],
       [ 0.48338425],
       [ 0.49113813]], dtype=float32), array([[ 0.74125487, -0.45954311],
       [-0.55370271, -0.53450096]], dtype=float32), array([[-0.42565805],
       [ 0.19686614]], dtype=float32), array([ 0.08946501,  0.03708982], dtype=float32), array([ 0.15204136], dtype=float32)]
6000 [0.69306737, array([[ 0.53439337,  0.51197231],
       [ 0.39961013,  0.38383543],
       [ 0.71191686,  0.40380618],
       [ 0.58899951,  0.2868301 ]], dtype=float32), array([[ 0.50660294],
       [ 0.51538038],
```

New way!


TensorBoard
EVENTS
IMAGES
GRAPH
HISTOGRAMS
input new regex
Split On Underscores:
X Type:
STEP
RELATIVE
WALL
Selected Runs:
data
xentropy
(1)
xentropy_mean
2.20
1.80
1.40
1.00
0.600
0.200
0.000
400.0
800.0
1.200k
1.600k

5 steps of using TensorBoard

1. From TF graph, decide which tensors you want to log

```
with tf.variable_scope('layer1') as scope:
    tf.summary.image('input', x_image, 3)
    tf.summary.histogram("layer", L1)
    tf.summary.scalar("loss", cost)
```

2. Merge all summaries

```
summary = tf.summary.merge_all()
```

3. Create writer and add graph

```
# Create summary writer
writer = tf.summary.FileWriter(TB_SUMMARY_DIR)
writer.add_graph(sess.graph)
```

4. Run summary merge and add_summary

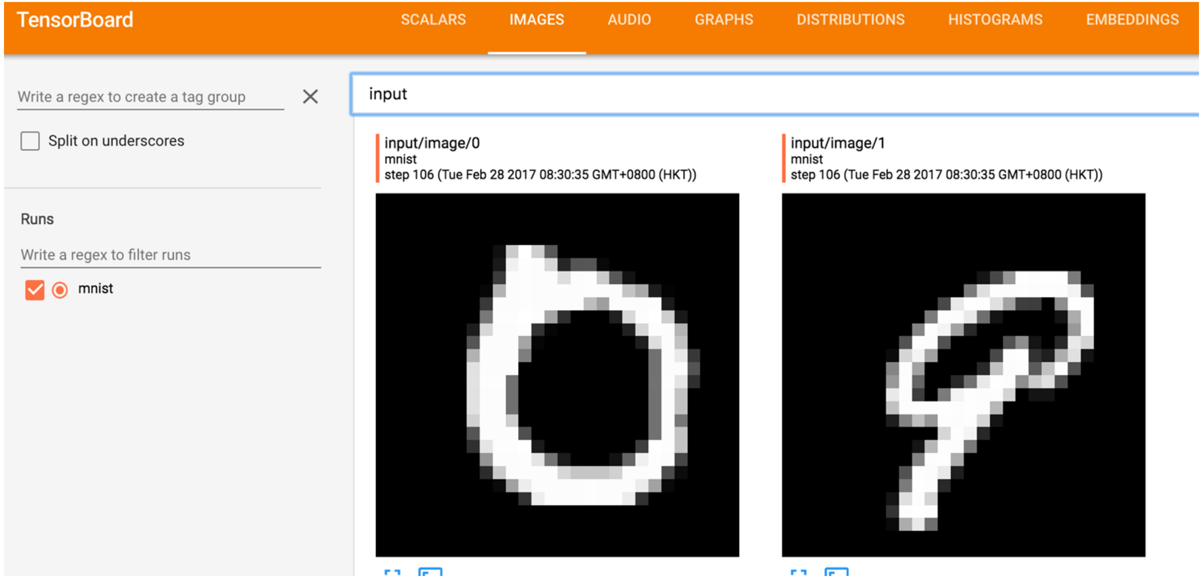
```
s, _ = sess.run([summary, optimizer], feed_dict=feed_dict)
writer.add_summary(s, global_step=global_step)
```

5. Launch TensorBoard

```
tensorboard --logdir=/tmp/mnist_logs
```

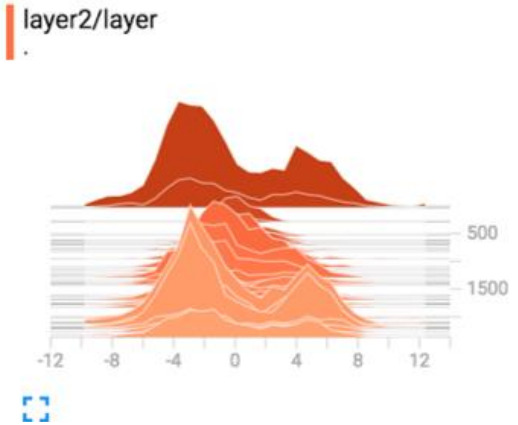
Image Input

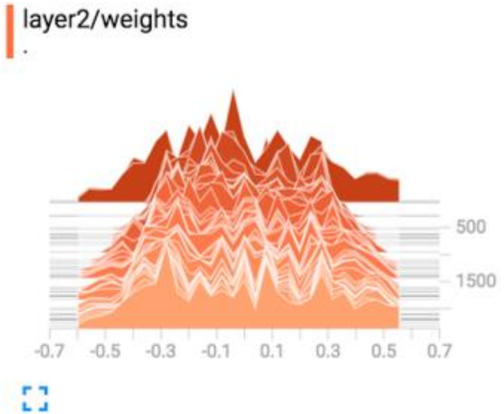
```
# Image input
x_image = tf.reshape(X, [-1, 28, 28, 1])
tf.summary.image('input', x_image, 3)
```



Histogram (multi-dimensional tensors)

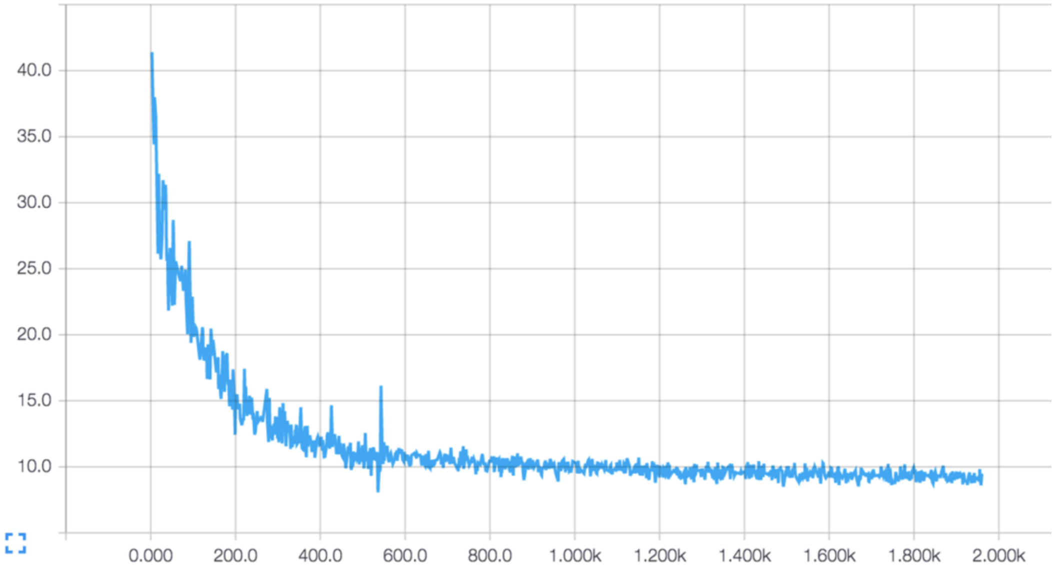
```
with tf.variable_scope('layer1') as scope:
    W1 = tf.get_variable("W", shape=[784, 512])
    b1 = tf.Variable(tf.random_normal([512]))
    L1 = tf.nn.relu(tf.matmul(X, W1) + b1)
    L1 = tf.nn.dropout(L1, keep_prob=keep_prob)

    tf.summary.histogram("X", X)
    tf.summary.histogram("weights", W1)
    tf.summary.histogram("bias", b1)
    tf.summary.histogram("layer", L1)
```





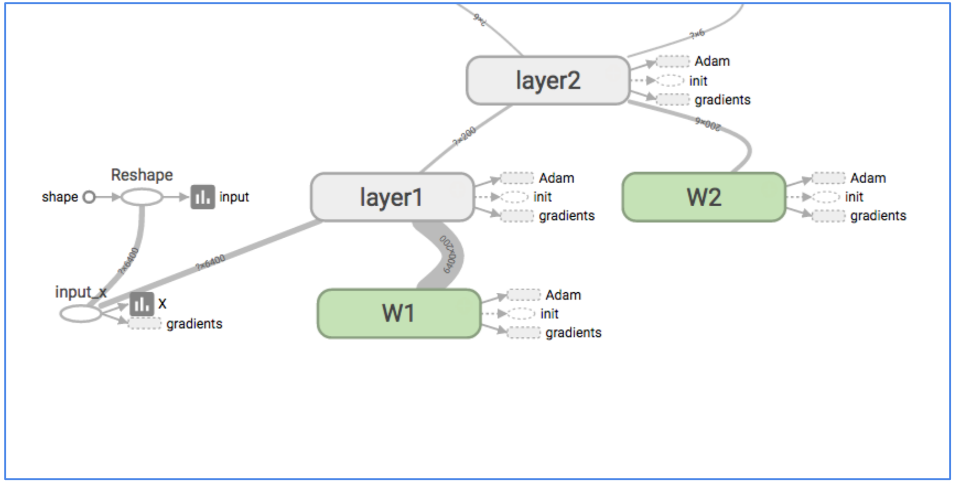
Scalar tensors

```
tf.summary.scalar("loss", cost)
```



Add scope for better hierarchy

```
with tf.variable_scope('layer1') as scope:
  W1 = tf.get_variable("W", shape=[784, 512],...
  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)

  tf.summary.histogram("X", X)
  tf.summary.histogram("weights", W1)
  tf.summary.histogram("bias", b1)
  tf.summary.histogram("layer", L1)

with tf.variable_scope('layer2') as scope:
   ...

with tf.variable_scope('layer3') as scope:
   ...

with tf.variable_scope('layer4') as scope:
   ...

with tf.variable_scope('layer5') as scope:
   ...
```



2 Merge summaries and create writer
3 after creating session

```
# Summary
summary = tf.summary.merge_all()

# initialize
sess = tf.Session()
sess.run(tf.global_variables_initializer())

# Create summary writer
writer = tf.summary.FileWriter(TB_SUMMARY_DIR)
writer.add_graph(sess.graph)
```

Run merged summary and write (add summary)

```
s, _ = sess.run([summary, optimizer], feed_dict=feed_dict)
writer.add_summary(s, global_step=global_step)
global_step += 1
```

Launch tensorboard (local)

```
writer = tf.summary.FileWriter("/tmp/mnist_logs")
```

```
$ tensorboard –logdir=/tmp/mnist_logs
```

Starting TensorBoard b'41' on port 6006
(You can navigate to http://127.0.0.1:6006)

Launch tensorboard (remote server)

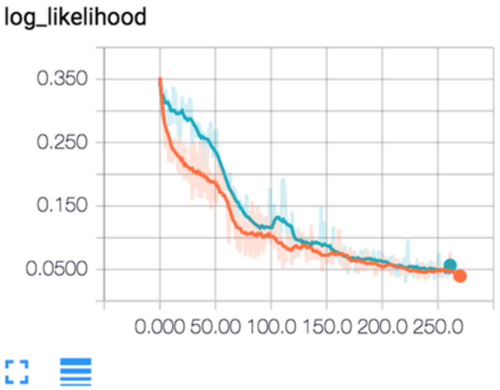
```
ssh -L local_port:127.0.0.1:remote_port username@server.com
```

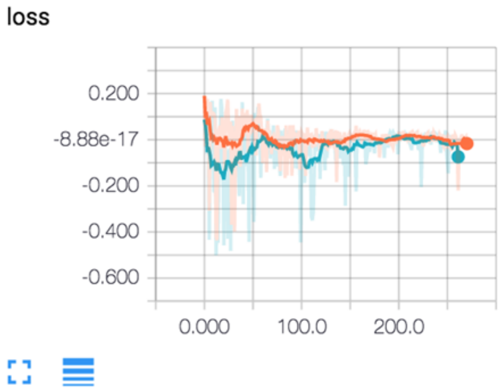
```
local>  $ ssh -L 7007:127.0.0.1:6006 hunkim@server.com
server> $ tensorboard —logdir=/tmp/mnist_logs
```

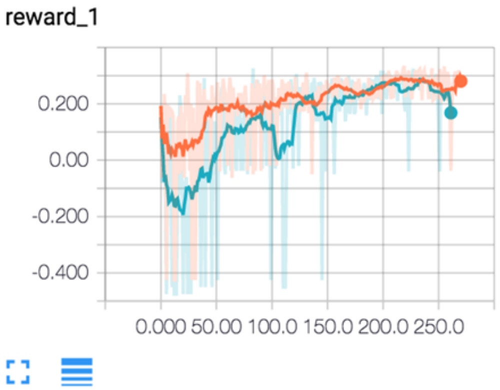
(You can navigate to http://127.0.0.1:7007)

Multiple runs

```
tensorboard –logdir=/tmp/mnist_logs/run1
    writer = tf.summary.FileWriter(“/tmp/mnist_logs/run1”)
tensorboard –logdir=/tmp/mnist_logs/run2
    writer = tf.summary.FileWriter(“/tmp/mnist_logs/run1”)

tensorboard –logdir=/tmp/mnist_logs
```







5 steps of using TensorBoard

1. From TF graph, decide which tensors you want to log

```
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    tf.summary.scalar("loss", cost)
```

2. Merge all summaries

```
summary = tf.summary.merge_all()
```

3. Create writer and add graph

```
# Create summary writer
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writer.add_graph(sess.graph)
```

4. Run summary merge and add_summary

```
s, _ = sess.run([summary, optimizer], feed_dict=feed_dict)
writer.add_summary(s, global_step=global_step)
```

5. Launch TensorBoard

```
tensorboard --logdir=/tmp/mnist_logs
```

With TF 1.0!

Lab 9-3 (optional)

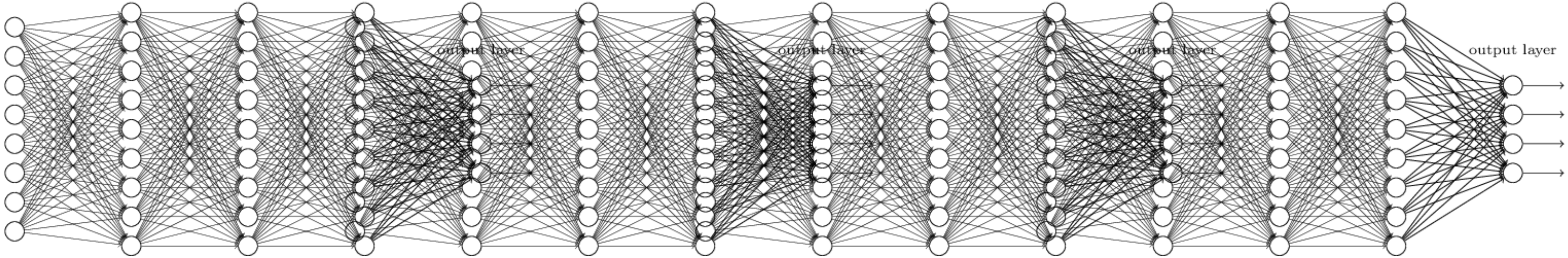
NN Backpropagation

Sung Kim <hunkim+ml@gmail.com>
Code: https://github.com/hunkim/DeepLearningZeroToAll/

https://github.com/hunkim/DeepLearningZeroToAll/

sxjscience #12 1 commit / 350 ++ / 0 --	jennykang #2 19 commits / 940 ++ / 253 --	GzuPark #3 15 commits / 49 ++ / 39 --	kkweon #4 12 commits / 1,087 ++ / 340 --
BlueMelon715 #5 5 commits / 55 ++ / 44 --	jihobak #6 3 commits / 244 ++ / 1,289 --	FuZer #7 2 commits / 37 ++ / 30 --	jin-chong #8 2 commits / 4 ++ / 4 --
zeran4 #9 1 commit / 5 ++ / 4 --	cynthia #10 1 commit / 28 ++ / 28 --	kaka120011 #11 1 commit / 1 ++ / 1 --	keon #12 1 commit / 3 ++ / 3 --
allieus #13 1 commit / 55 ++ / 59 --	togheppi #14 1 commit / 1,280 ++ / 0 --	davinnovation #15 1 commit / 64 ++ / 0 --	skyer9 #16 1 commit / 94 ++ / 69 --
redongjun #17 1 commit / 78 ++ / 0 --	bkRyusim #18 1 commit / 1 ++ / 1 --	maestrojeong #19 1 commit / 50 ++ / 0 --	mjc92 #13 1 commit / 1,215 ++ / 0 --

How to train?



Gradient descent algorithm

$$W := W - \alpha \frac{1}{m} \sum_{i=1}^{m} (Wx^{(i)} - y^{(i)}) x^{(i)}$$

$$w = w - \alpha \frac{\partial E}{\partial w}$$

Tensorflow

$$w = w - \alpha \frac{\partial E}{\partial w}$$


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

“Yes you should understand backprop”

- “If you try to ignore how it works under the hood because *TensorFlow automagically makes my networks learn*”
  - “You will not be ready to wrestle with the dangers it presents”
  - “You will be much less effective at building and debugging neural networks.”
- “The good news is that backpropagation is not that difficult to understand”
  - “if presented properly.”

https://medium.com/@karpathy/yes-you-should-understand-backprop-e2f06eab496b

Back propagation (chain rule)

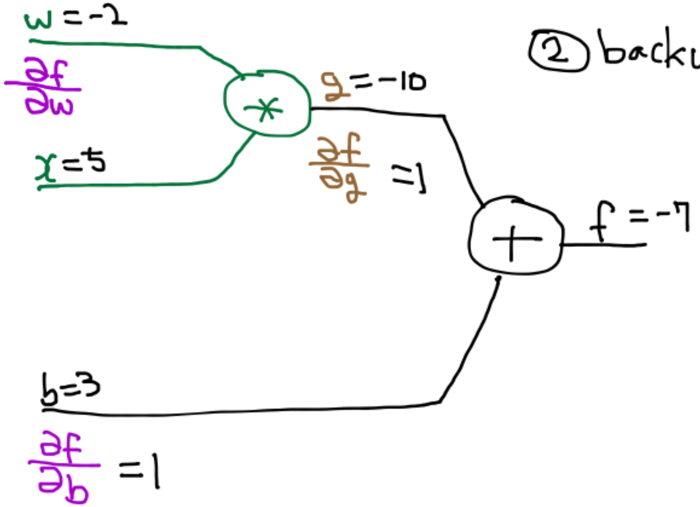
$f = wx + b$, $g = wx$, $f = g + b$, $\frac{\partial f}{\partial g} = 1$, $\frac{\partial f}{\partial b} = 1$

$\frac{\partial g}{\partial w} = x$

① forward ($w=-2$, $x=5$, $b=3$)

② backward

$$\frac{\partial f}{\partial w} = \frac{\partial f}{\partial g}\frac{\partial g}{\partial w} = 1 * x = 5$$

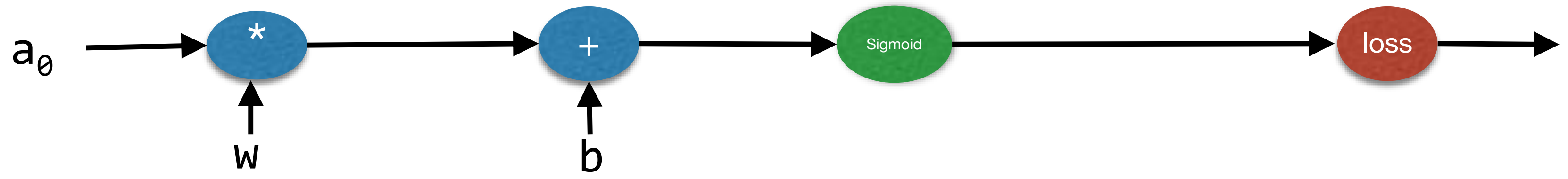


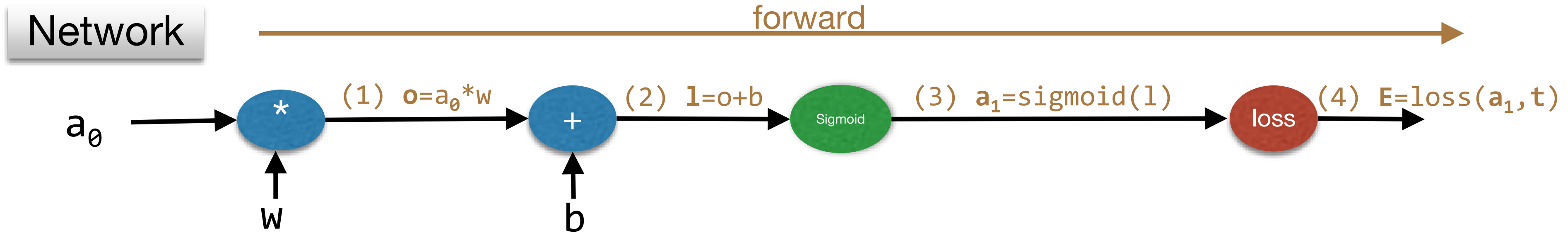
Back propagation (chain rule)

$$\frac{\partial f}{\partial w} = \frac{\partial f}{\partial g}\frac{\partial g}{\partial w} = 1 * x = 5$$

http://cs231n.stanford.edu/

Logistic Regression Network



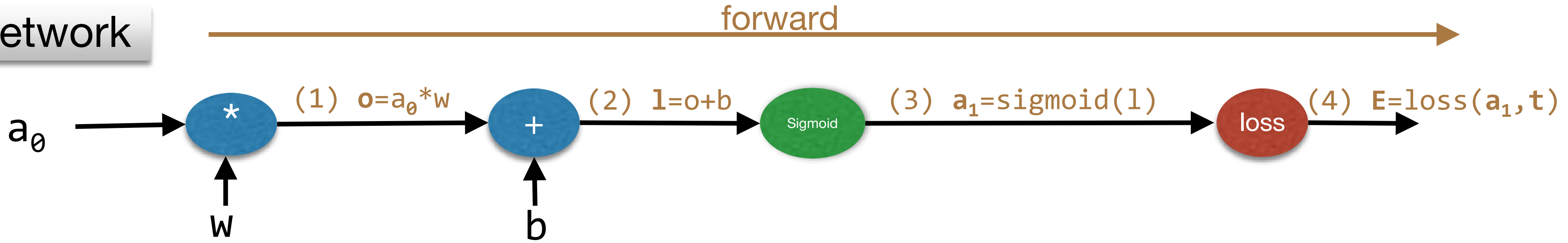


$$a_1 = sigmoid(a_0 * w + b)$$

$$E = loss(a_1, t) = -\sum t * log(a_1) + (1 - t) * log(1 - a_1)$$

Forward pass, OK? Just follow (1), (2), (3) and (4)

Network

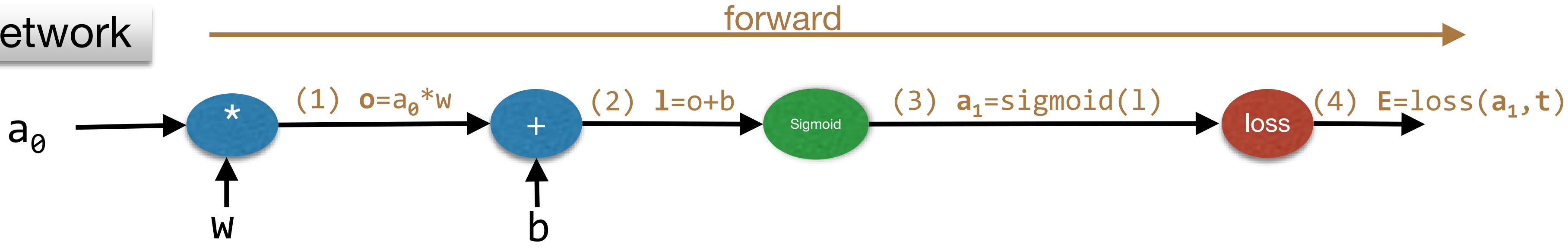


$$a_1 = sigmoid(a_0 * w + b)$$

$$E = loss(a_1, t) = -\sum t * log(a_1) + (1 - t) * log(1 - a_1)$$

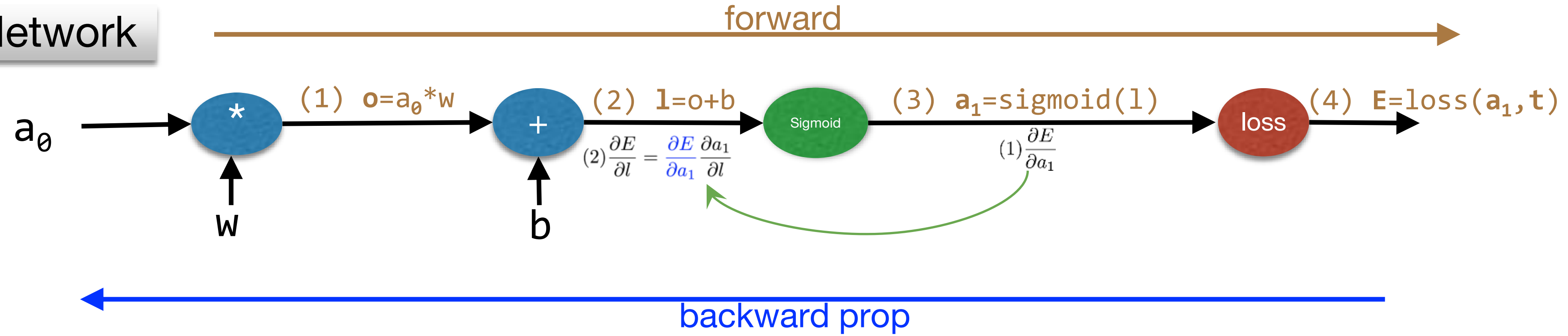
$$\boxed{a_0 = 0.1, t = 0, w = 0.1, b = 0.3}$$

Network



$$w = w - \alpha \frac{\partial E}{\partial w}$$

Network



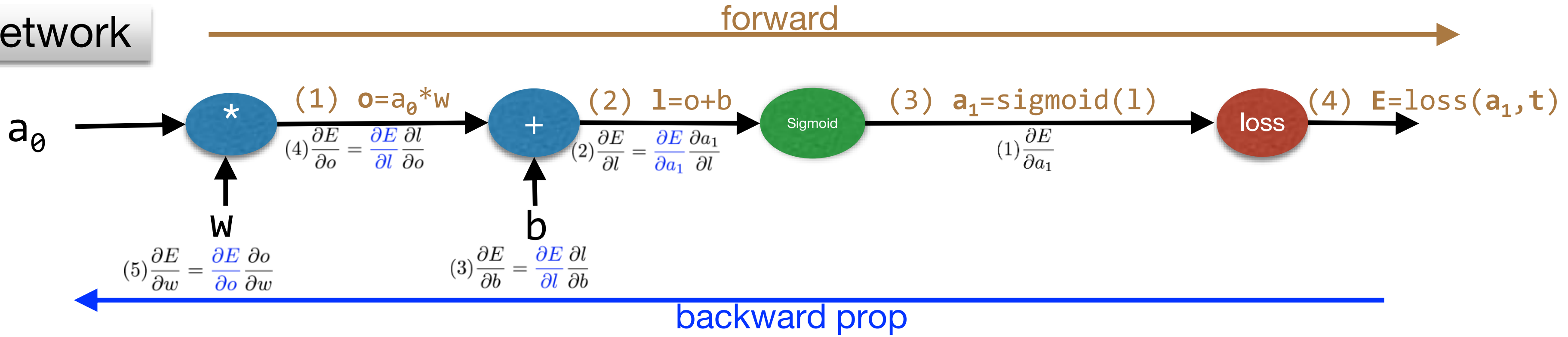
$$w = w - \alpha \frac{\partial E}{\partial w}$$

Let's do back propagation!

$(1)\frac{\partial E}{\partial a_1}$ will be given. What would be $(2)\frac{\partial E}{\partial l}$?

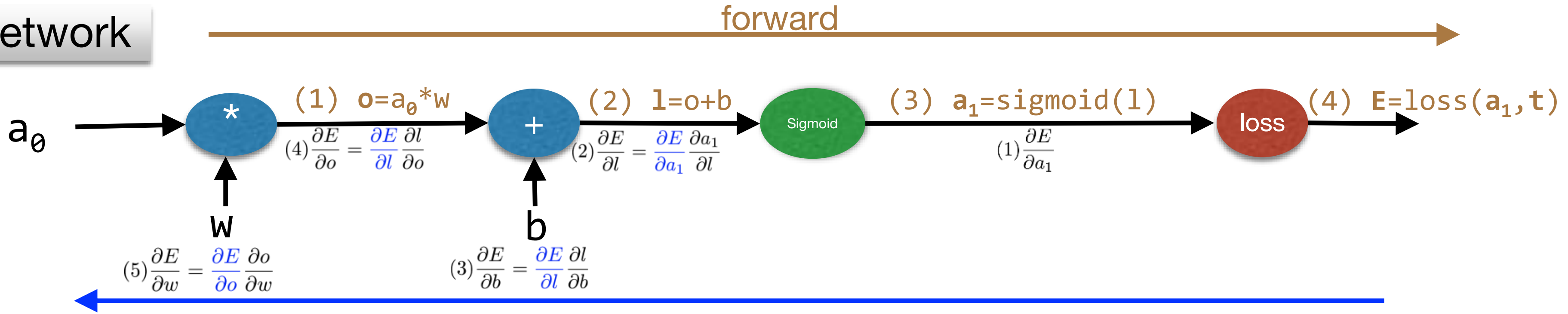
We can use the chain rule.

Network



In the same manner, we can get back prop (4), (3), (1) and (1)!

Network



Gate derivatives

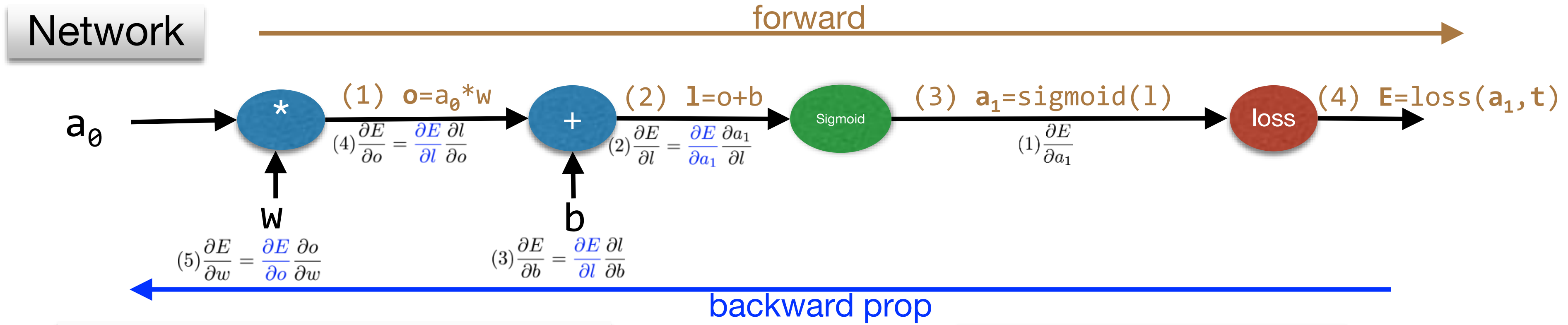
$$o = aw, \quad \frac{\partial o}{\partial w} = a, \quad \frac{\partial o}{\partial a} = w$$

$$l = o + b, \quad \frac{\partial l}{\partial o} = 1, \quad \frac{\partial l}{\partial b} = 1$$

$$E = -\sum t log(a) + (1-t) log(1-a), \quad \frac{\partial E}{\partial a} = \frac{a-t}{a(1-a)}$$

$$a = sigmoid(l) = \frac{1}{1+e^{-l}}, \quad \frac{\partial a}{\partial l} = a(1-a)$$

These derivatives for each gate will be given.
We can just use them in the chain rule.



Derivatives (chain rule)

$$(1)\ \frac{\partial E}{\partial a_1} = \frac{a_1 - t}{a_1(1-a_1)}$$

$$(2)\ \frac{\partial E}{\partial l} = \frac{\partial E}{\partial a_1}\frac{\partial a_1}{\partial l}$$

Given from the pre computed derivative

Gate derivatives

$$o = aw,\ \frac{\partial o}{\partial w} = a,\ \frac{\partial o}{\partial a} = w$$

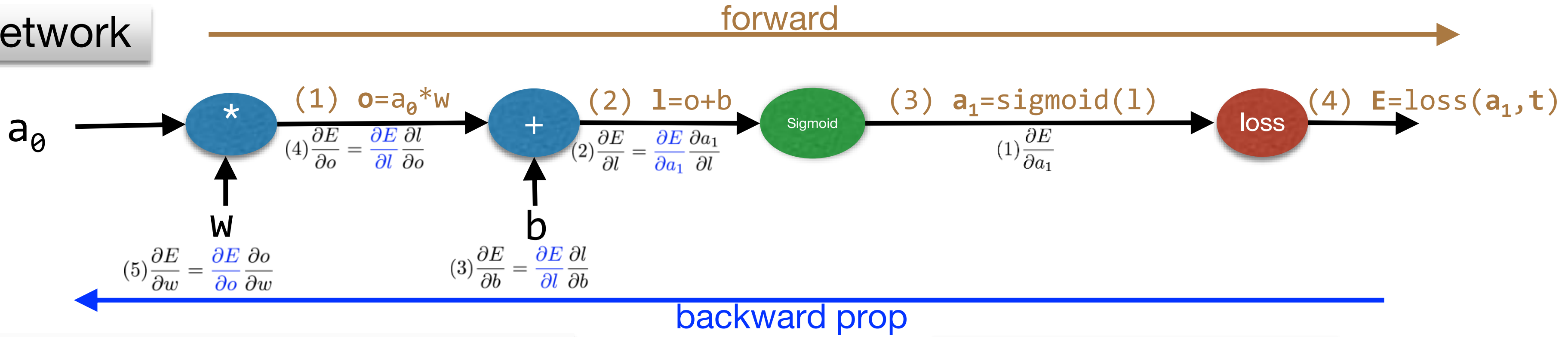
$$l = o + b,\ \frac{\partial l}{\partial o} = 1,\ \frac{\partial l}{\partial b} = 1$$

$$E = -\sum tlog(a) + (1-t)log(1-a),\ \frac{\partial E}{\partial a} = \frac{a-t}{a(1-a)}$$

$$a = sigmoid(l) = \frac{1}{1+e^{-l}},\ \frac{\partial a}{\partial l} = a(1-a)$$

Just apply them one by one and solve each derivative one by one!

Network



Derivatives (chain rule)

$$(1)\ \frac{\partial E}{\partial a_1} = \frac{a_1 - t}{a_1(1-a_1)}$$

Given from the pre computed derivative

$$(2)\ \frac{\partial E}{\partial l} = \frac{\partial E}{\partial a_1}\frac{\partial a_1}{\partial l} = \frac{a_1 - t}{a_1(1-a_1)} * a_1(1-a_1) = a_1 - t$$

Given

Gate derivatives

$$o = aw,\quad \frac{\partial o}{\partial w} = a,\quad \frac{\partial o}{\partial a} = w$$

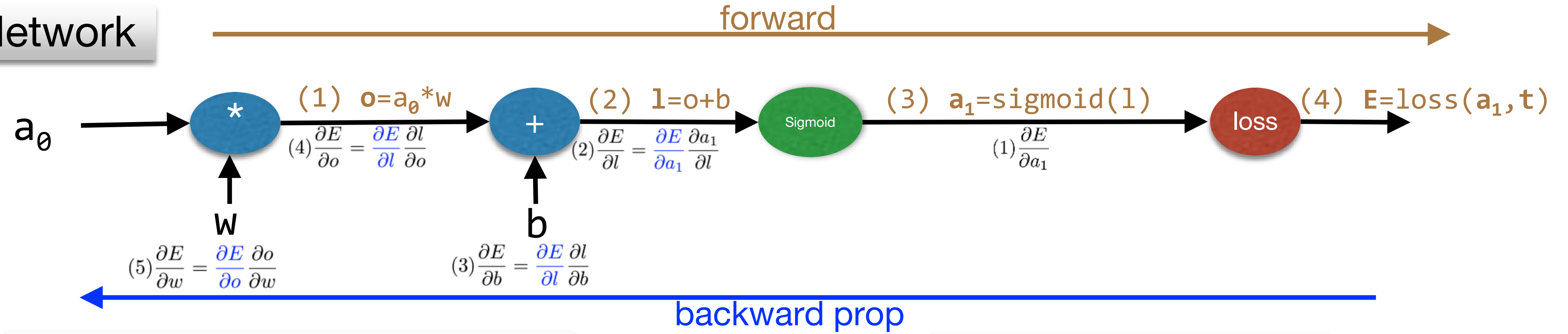
$$l = o + b,\quad \frac{\partial l}{\partial o} = 1,\quad \frac{\partial l}{\partial b} = 1$$

$$E = -\sum t log(a) + (1-t) log(1-a),\quad \frac{\partial E}{\partial a} = \frac{a-t}{a(1-a)}$$

$$a = sigmoid(l) = \frac{1}{1+e^{-l}},\quad \frac{\partial a}{\partial l} = a(1-a)$$

Just apply them one by one and solve each derivative one by one!

Network



Derivatives (chain rule)

$$(1)\frac{\partial E}{\partial a_1} = \frac{a_1 - t}{a_1(1-a_1)}$$

$$(2)\frac{\partial E}{\partial l} = \frac{\partial E}{\partial a_1}\frac{\partial a_1}{\partial l} = \frac{a_1 - t}{a_1(1-a_1)} * a_1(1-a_1) = a_1 - t$$

Given from the pre computed derivative

Given

$$(3)\frac{\partial E}{\partial b} = \frac{\partial E}{\partial l}\frac{\partial l}{\partial b} = \frac{\partial E}{\partial l} * 1 = a_1 - t$$

$$(4)\frac{\partial E}{\partial o} = \frac{\partial E}{\partial l}\frac{\partial l}{\partial o} = \frac{\partial E}{\partial l} * 1 = a_1 - t$$

$$(5)\frac{\partial E}{\partial w} = \frac{\partial E}{\partial o}\frac{\partial o}{\partial w} = \frac{\partial E}{\partial o} a_0 = (a_1 - t)a_0$$

Gate derivatives

$$o = aw, \quad \frac{\partial o}{\partial w} = a, \quad \frac{\partial o}{\partial a} = w$$

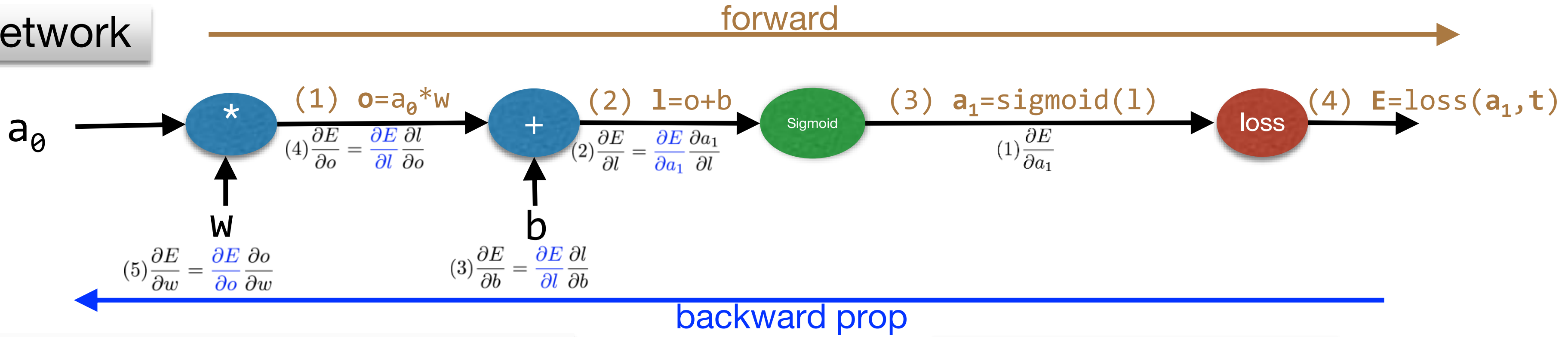
$$l = o + b, \quad \frac{\partial l}{\partial o} = 1, \quad \frac{\partial l}{\partial b} = 1$$

$$E = -\sum t\log(a) + (1-t)\log(1-a), \quad \frac{\partial E}{\partial a} = \frac{a-t}{a(1-a)}$$

$$a = sigmoid(l) = \frac{1}{1+e^{-l}}, \quad \frac{\partial a}{\partial l} = a(1-a)$$

Just apply them one by one and solve each derivative one by one!

Network



Derivatives (chain rule)

$$(1)\,\frac{\partial E}{\partial a_1} = \frac{a_1 - t}{a_1(1-a_1)}$$

$$(2)\,\frac{\partial E}{\partial l} = \frac{\partial E}{\partial a_1}\frac{\partial a_1}{\partial l} = \frac{a_1 - t}{a_1(1-a_1)} * a_1(1-a_1) = a_1 - t$$

$$(3)\,\frac{\partial E}{\partial b} = \frac{\partial E}{\partial l}\frac{\partial l}{\partial b} = \frac{\partial E}{\partial l} * 1 = a_1 - t$$

$$(4)\,\frac{\partial E}{\partial o} = \frac{\partial E}{\partial l}\frac{\partial l}{\partial o} = \frac{\partial E}{\partial l} * 1 = a_1 - t$$

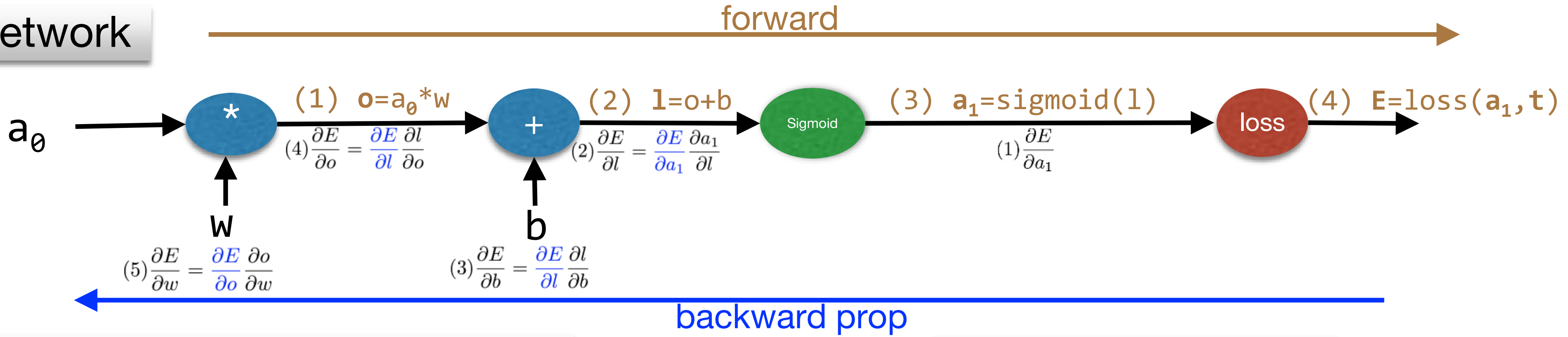
$$(5)\,\frac{\partial E}{\partial w} = \frac{\partial E}{\partial o}\frac{\partial o}{\partial w} = a_0^T\frac{\partial E}{\partial o} = a_0^T(a_1 - t)$$

Matrix

$$\frac{\partial E}{\partial W} = \frac{\partial E}{\partial O}\frac{\partial O}{\partial W} = A^T\frac{\partial E}{\partial O}, where\ O = AW$$

For Matrix: http://cs231n.github.io/optimization-2/#staged

Network



Derivatives (chain rule)

$$(1)\frac{\partial E}{\partial a_1} = \frac{a_1 - t}{a_1(1-a_1)}$$

$$(2)\frac{\partial E}{\partial l} = \frac{\partial E}{\partial a_1}\frac{\partial a_1}{\partial l} = \frac{a_1 - t}{a_1(1-a_1)} * a_1(1-a_1) = a_1 - t$$

$$(3)\frac{\partial E}{\partial b} = \frac{\partial E}{\partial l}\frac{\partial l}{\partial b} = \frac{\partial E}{\partial l} * 1 = a_1 - t$$

$$(4)\frac{\partial E}{\partial o} = \frac{\partial E}{\partial l}\frac{\partial l}{\partial o} = \frac{\partial E}{\partial l} * 1 = a_1 - t$$

$$(5)\frac{\partial E}{\partial w} = \frac{\partial E}{\partial o}\frac{\partial o}{\partial w} = a_0^T\frac{\partial E}{\partial o} = a_0^T(a_1 - t)$$

Matrix

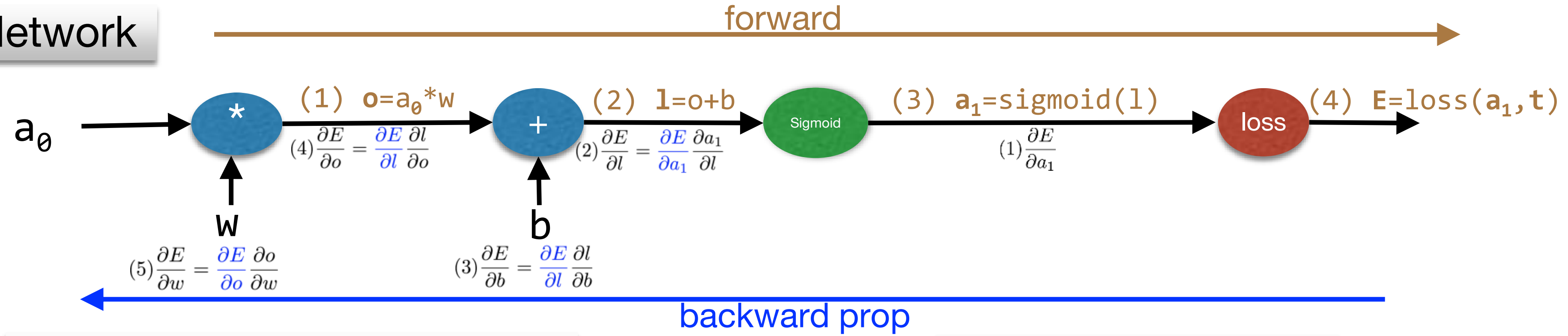
$$\frac{\partial E}{\partial W} = \frac{\partial E}{\partial O}\frac{\partial O}{\partial W} = A^T\frac{\partial E}{\partial O}, where\ O = AW$$

Network update (learning rate, alpha)

$$w = w - \alpha\frac{\partial E}{\partial w}$$

$$b = b - \alpha\frac{\partial E}{\partial b}$$

Network



Derivatives (chain rule)

$$(1)\frac{\partial E}{\partial a_1} = \frac{a_1 - t}{a_1(1-a_1)}$$

$$(2)\frac{\partial E}{\partial l} = \frac{\partial E}{\partial a_1}\frac{\partial a_1}{\partial l} = \frac{a_1 - t}{a_1(1-a_1)} * a_1(1-a_1) = a_1 - t$$

$$(3)\frac{\partial E}{\partial b} = \frac{\partial E}{\partial l}\frac{\partial l}{\partial b} = \frac{\partial E}{\partial l} * 1 = a_1 - t$$

$$(4)\frac{\partial E}{\partial o} = \frac{\partial E}{\partial l}\frac{\partial l}{\partial o} = \frac{\partial E}{\partial l} * 1 = a_1 - t$$

$$(5)\frac{\partial E}{\partial w} = \frac{\partial E}{\partial o}\frac{\partial o}{\partial w} = a_0^T\frac{\partial E}{\partial o} = a_0^T(a_1 - t)$$

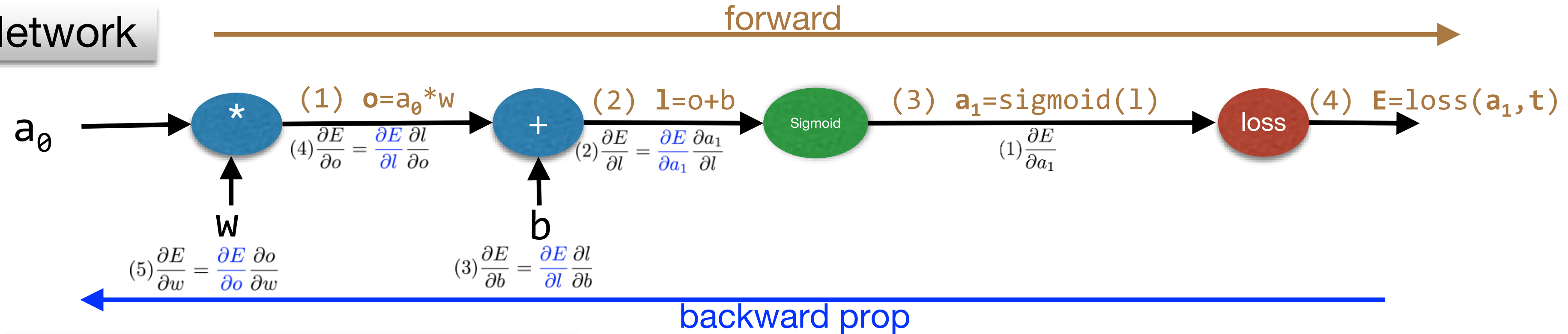
Done! Let's update our network using derivatives!

Network update (learning rate, alpha)

$$w = w - \alpha\frac{\partial E}{\partial w}$$

$$b = b - \alpha\frac{\partial E}{\partial b}$$

Network



Derivatives (chain rule)

$$E = -\sum t log(a) + (1-t) log(1-a), \quad \frac{\partial E}{\partial a} = \frac{a-t}{a(1-a)}$$

$$a = sigmoid(l) = \frac{1}{1+e^{-l}}, \quad \frac{\partial a}{\partial l} = a(1-a)$$

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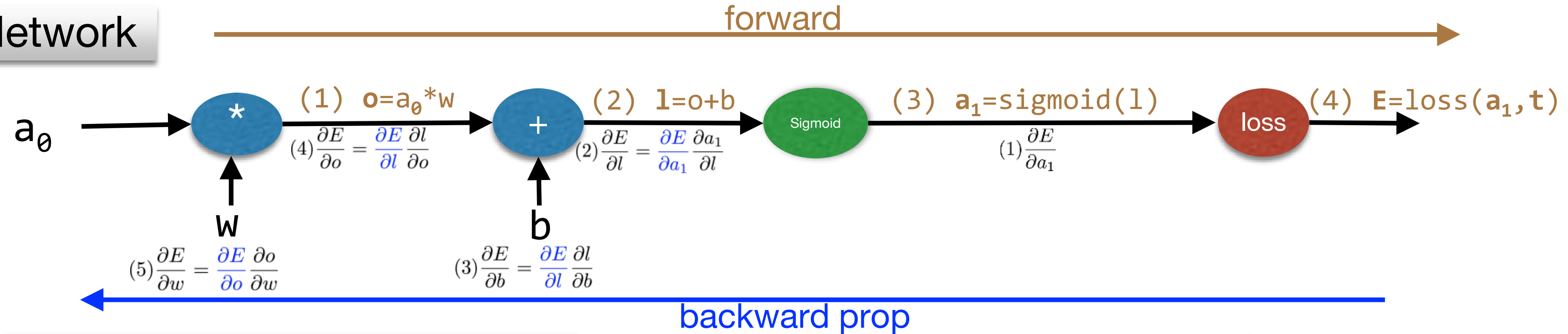
```
d_a1 = (a1 - t) / (a1 * (1. - t) + 1e-7)
d_sigma = a1 * (1 - a1) # sigma prime
d_l = d_a1 * d_sigma  # (a1 - t)
d_b = d_l * 1
d_o = d_1 * 1
d_W = tf.matmul(tf.transpose(a0), d_o)
```

Network



Derivatives (chain rule)

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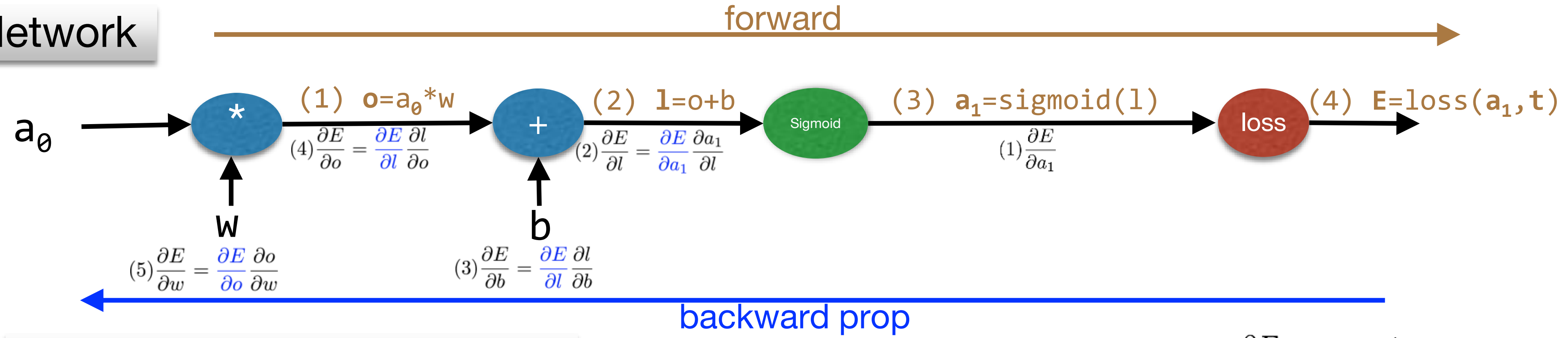
d_sigma = a1 * (1 - a1) # sigma prime
d_l = d_a1 * d_sigma  # (a1 - t)
d_b = d_l * 1
d_o = d_1 * 1
d_W = tf.matmul(tf.transpose(a0), d_o)
# Updating network using gradients
learning_rate = 0.01
train_step = [
    tf.assign(W, W - learning_rate * d_W),
    tf.assign(b, b - learning_rate * d_b)]
```

Network



Derivatives (chain rule)

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d_l = d_a1 * d_sigma  # (a1 - t)
d_b = d_l * 1
d_o = d_1 * 1
d_W = tf.matmul(tf.transpose(a0), d_o)
# Updating network using gradients
learning_rate = 0.01
train_step = [
  tf.assign(W, W - learning_rate * d_W / N), # sample size
  tf.assign(b, b - learning_rate * tf.reduce_sum(d_b))]
```

Exercise

- See more backprop code samples at https://github.com/hunkim/DeepLearningZeroToAll
- `https://github.com/hunkim/DeepLearningZeroToAll/blob/master/lab-09-7-sigmoid_back_prop.py`

- Solve XOR using NN backprop