Basic Models in TensorFlow

CS 20: TensorFlow for Deep Learning Research
Lecture 3
1/19/2017

Agenda

Review

Linear regression on birth/life data

Control Flow

tf.data

Optimizers, gradients

Logistic regression on MNIST

Loss functions

Review

Computation graph

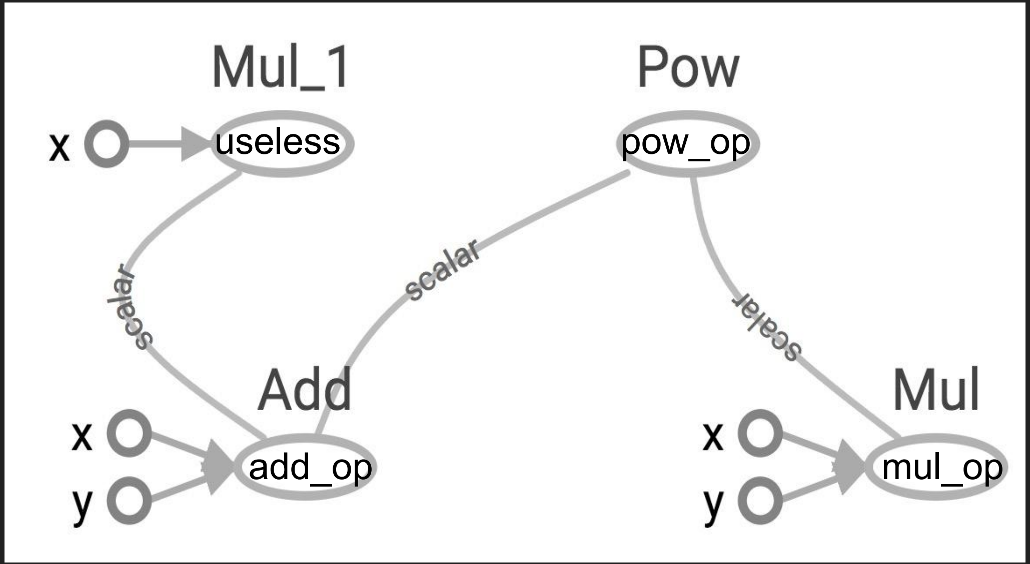
TensorFlow separates definition of computations from their execution

Phase 1: assemble a graph

Phase 2: use a session to execute operations in the graph.

TensorBoard

```
x = 2
y = 3
add_op = tf.add(x, y)
mul_op = tf.multiply(x, y)
useless = tf.multiply(x, add_op)
pow_op = tf.pow(add_op, mul_op)
with tf.Session() as sess:
      z = sess.run(pow_op)
```




```
Create a FileWriter object to write your
graph to event files
```

tf.constant and tf.Variable

Constant values are stored in the graph definition

Sessions allocate memory to store variable values

tf.placeholder and feed_dict

Feed values into placeholders with a dictionary (feed_dict)

Easy to use but poor performance

Avoid lazy loading

1. Separate the assembling of graph and executing ops
2. Use Python attribute to ensure a function is only loaded the first time it's called

Download from the class's GitHub

examples/`03_linreg_starter.py`

examples/`03_logreg_starter.py`

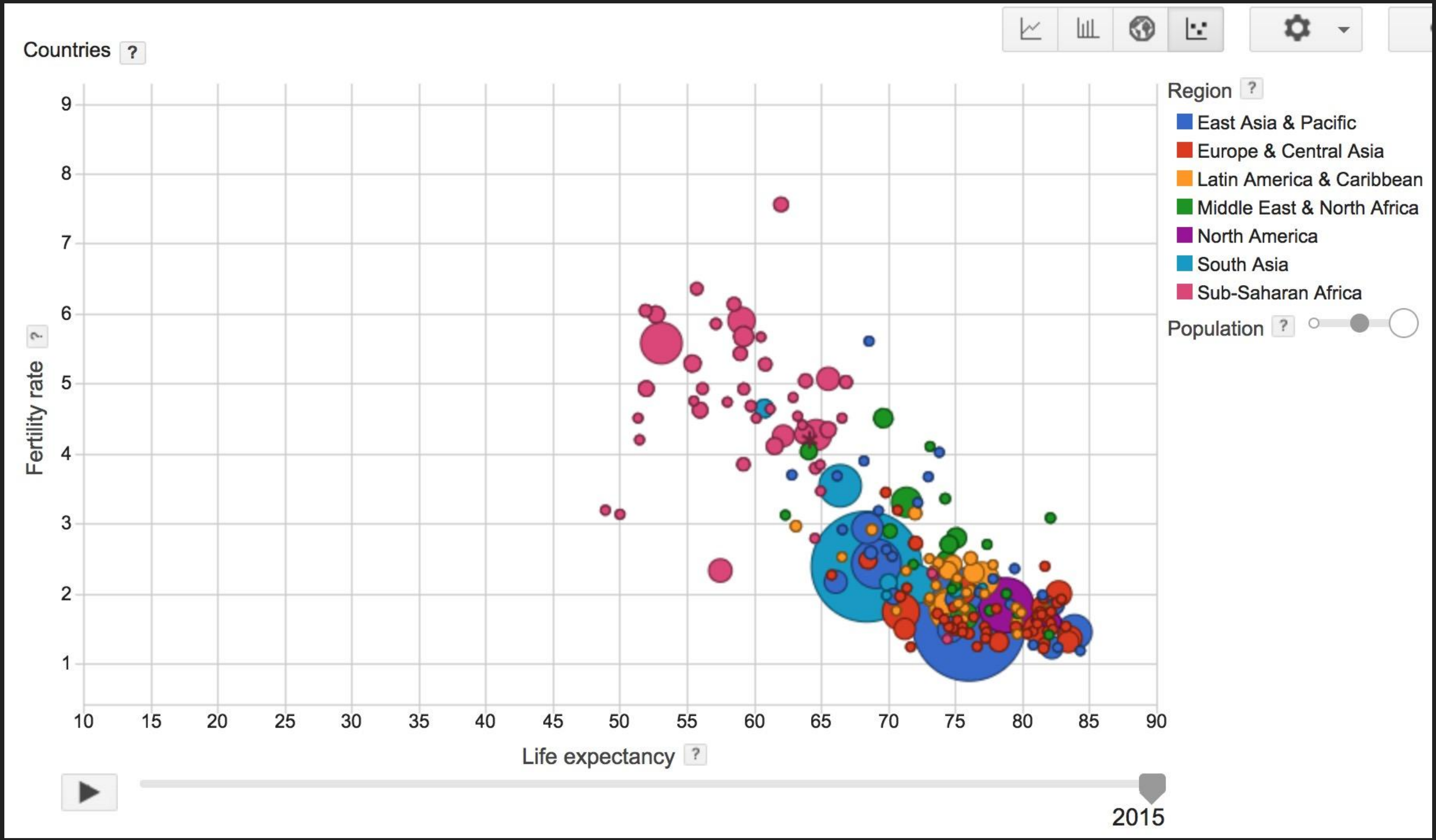
examples/`utils.py`

data/`birth_life_2010.txt`

Linear Regression in TensorFlow

Model the linear relationship between:

- dependent variable Y
- explanatory variables X



Visualization made by Google, based on data collected by World Bank

World Development Indicators dataset

X: birth rate
Y: life expectancy
190 countries

Want

Find a linear relationship between X and Y
to predict Y from X

Model

Inference: Y_predicted = w * X + b

Mean squared error: $E[(y - y\_predicted)^2]$

Interactive Coding

`data/birth_life_2010.txt`

Interactive Coding

`examples/03_linreg_starter.py`

Phase 1: Assemble our graph

Step 1: Read in data

`I already did that for you`

Step 2: Create placeholders for inputs and labels

```
tf.placeholder(dtype, shape=None, name=None)
```

Step 3: Create weight and bias

```
tf.get_variable(
    name,
    shape=None,
    dtype=None,
    initializer=None,
    …
)
```

No need to specify shape if using constant initializer

Step 4: Inference

```
Y_predicted = w * X + b
```

Step 5: Specify loss function

```
loss = tf.square(Y - Y_predicted, name='loss')
```

Step 6: Create optimizer

```
opt = tf.train.GradientDescentOptimizer(learning_rate=0.001)

optimizer = opt.minimize(loss)
```

Phase 2: Train our model

```
Step 1: Initialize variables

Step 2: Run optimizer

(use a feed_dict to feed data into X and Y placeholders)
```

Write log files using a FileWriter

```
writer = tf.summary.FileWriter('./graphs/linear_reg', sess.graph)
```

See it on TensorBoard

```
Step 1: $ python3 03_linreg_starter.py

Step 2: $ tensorboard --logdir='./graphs'
```

TypeError?

TypeError: Fetch argument 841.0 has invalid type <class 'numpy.float32'>, must be a string or Tensor.

(Can not convert a float32 into a Tensor or Operation.)

TypeError

```
for i in range(50): # train the model 100 epochs
    total_loss = 0
    for x, y in data:
        _, loss = sess.run([optimizer, loss], feed_dict={X: x, Y:y}) # Can’t fetch a numpy array
        total_loss += loss
```

TypeError

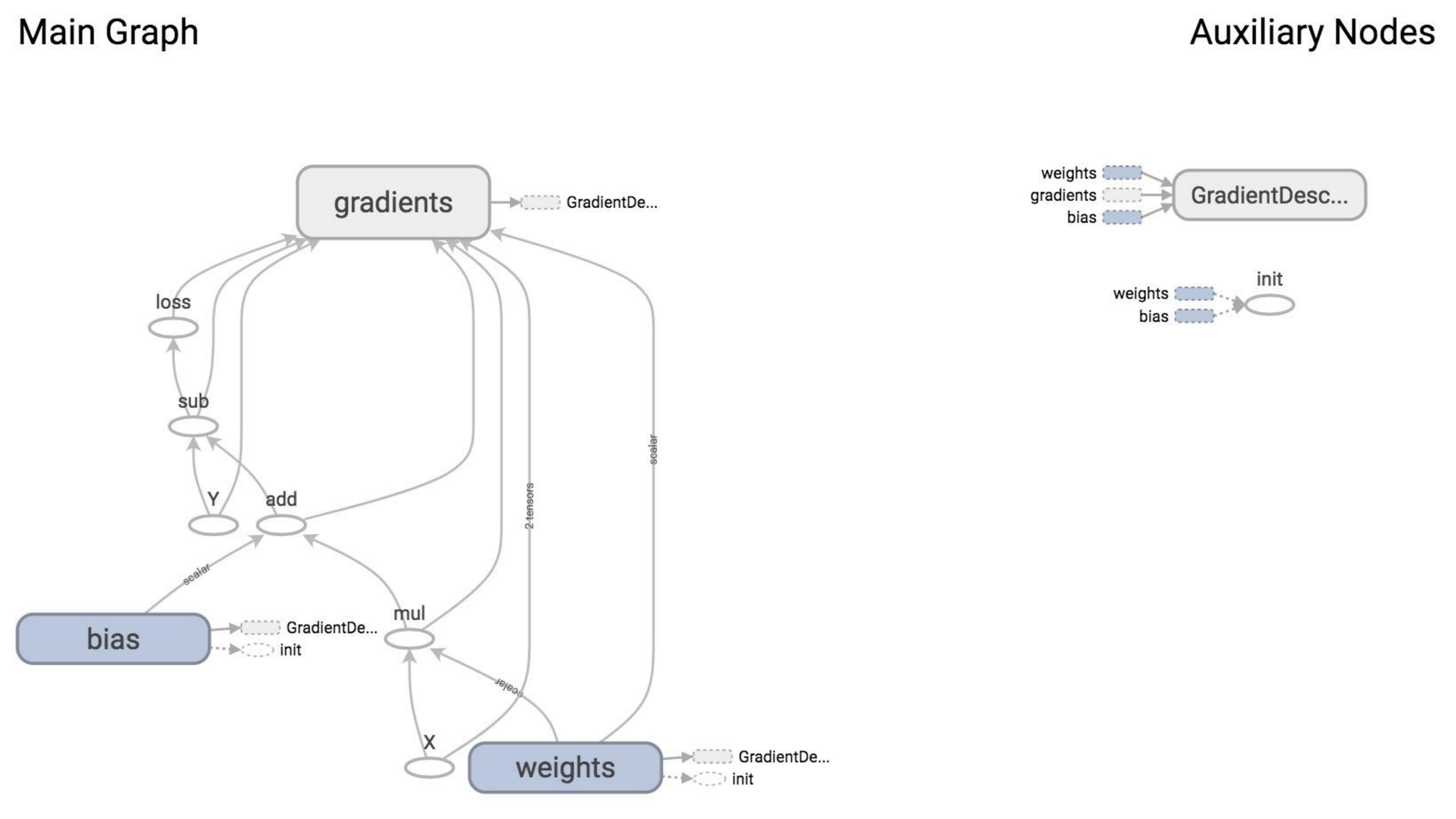
```
for i in range(50): # train the model 100 epochs

      total_loss = 0

      for x, y in data:

            _, loss_ = sess.run([optimizer, loss], feed_dict={X: x, Y:y})

            total_loss += loss_
```



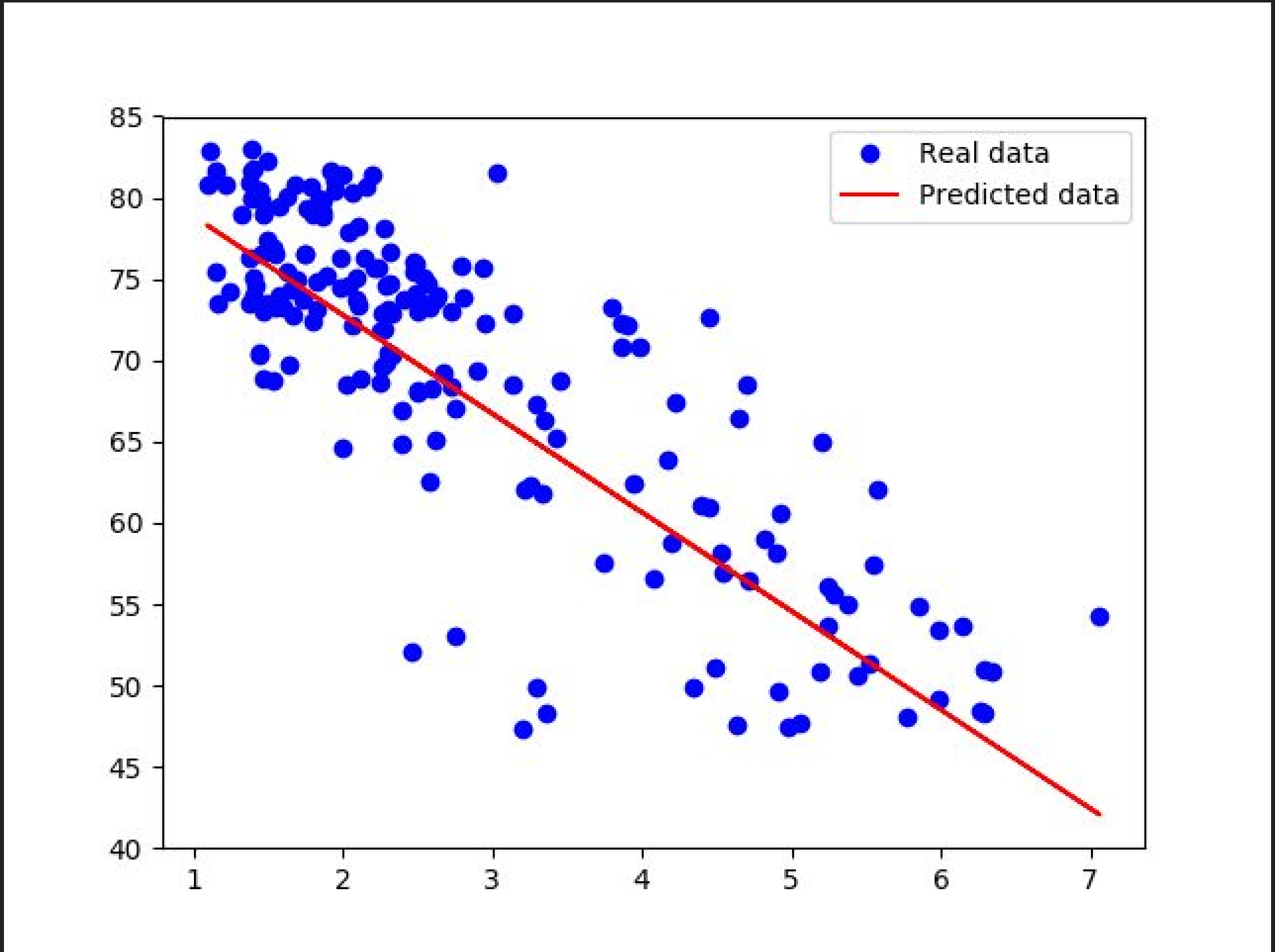
Main Graph
Auxiliary Nodes
gradients
GradientDe...
loss
sub
Y
add
scalar
bias
GradientDe...
init
mul
scalar
X
weights
GradientDe...
init
2 tensors
scalar
weights
gradients
bias
GradientDesc...
init
weights
bias

Plot the results with matplotlib

Step 1: Uncomment the plotting code at the end of your program

Step 2: Run it again

If run into problem of matplotlib in virtual environment, go to GitHub/setup and see the file possible setup problems


Real data
Predicted data
85
80
75
70
65
60
55
50
45
40
1
2
3
4
5
6
7

Huber loss

Robust to outliers

If the difference between the predicted value and the real value is small, square it

If it's large, take its absolute value

$$L_\delta(y, f(x)) = \begin{cases} \frac{1}{2}(y - f(x))^2 & \text{for} |y - f(x)| \le \delta, \\ \delta \, |y - f(x)| - \frac{1}{2}\delta^2 & \text{otherwise.} \end{cases}$$

Implementing Huber loss

Can’t write:

```
if y - y_predicted < delta:
```

$$L_\delta(y, f(x)) = \begin{cases} \frac{1}{2}(y - f(x))^2 & \text{for} |y - f(x)| \le \delta, \\ \delta\,|y - f(x)| - \frac{1}{2}\delta^2 & \text{otherwise.} \end{cases}$$

You can write it if eager mode were enabled. Stay tuned for the next lecture!

Implementing Huber loss

```
tf.cond(pred, fn1, fn2, name=None)
```

$$L_\delta(y, f(x)) = \begin{cases} \frac{1}{2}(y - f(x))^2 & \text{for} |y - f(x)| \le \delta, \\ \delta \, |y - f(x)| - \frac{1}{2}\delta^2 & \text{otherwise.} \end{cases}$$

Implementing Huber loss

```
tf.cond(pred, fn1, fn2, name=None)
```

```
def huber_loss(labels, predictions, delta=14.0):
    residual = tf.abs(labels - predictions)
    def f1(): return 0.5 * tf.square(residual)
    def f2(): return delta * residual - 0.5 * tf.square(delta)
    return tf.cond(residual < delta, f1, f2)
```

$$L_\delta(y, f(x)) = \begin{cases} \frac{1}{2}(y - f(x))^2 & \text{for} |y - f(x)| \le \delta, \\ \delta\,|y - f(x)| - \frac{1}{2}\delta^2 & \text{otherwise.} \end{cases}$$

TF Control Flow

Control Flow Ops	tf.group, tf.count_up_to, tf.cond, tf.case, tf.while_loop, ...
Comparison Ops	tf.equal, tf.not_equal, tf.less, tf.greater, tf.where, ...
Logical Ops	tf.logical_and, tf.logical_not, tf.logical_or, tf.logical_xor
Debugging Ops	tf.is_finite, tf.is_inf, tf.is_nan, tf.Assert, tf.Print, ...

Since TF builds graph before computation, we have to specify all possible subgraphs beforehand. PyTorch's dynamic graphs and TF's eager execution help overcome this

tf.data

Placeholder

Pro: put the data processing outside TensorFlow, making it easy to do in Python

Cons: users often end up processing their data in a single thread and creating data bottleneck that slows execution down.

Placeholder

```
data, n_samples = utils.read_birth_life_data(DATA_FILE)

X = tf.placeholder(tf.float32, name='X')
Y = tf.placeholder(tf.float32, name='Y')
…
with tf.Session() as sess:
       …
     # Step 8: train the model
     for i in range(100): # run 100 epochs
          for x, y in data:
               # Session runs train_op to minimize loss
               sess.run(optimizer, feed_dict={X: x, Y:y})
```

tf.data

Instead of doing inference with placeholders and feeding in data later, do inference directly with data

tf.data

`tf.data.Dataset`

`tf.data.Iterator`

Store data in tf.data.Dataset

```
tf.data.Dataset.from_tensor_slices((features, labels))
```

Store data in tf.data.Dataset

```
tf.data.Dataset.from_tensor_slices((features, labels))

dataset = tf.data.Dataset.from_tensor_slices((data[:,0], data[:,1]))
```

Store data in tf.data.Dataset

```
tf.data.Dataset.from_tensor_slices((features, labels))

dataset = tf.data.Dataset.from_tensor_slices((data[:,0], data[:,1]))

print(dataset.output_types)      # >> (tf.float32, tf.float32)

print(dataset.output_shapes)     # >> (TensorShape([]), TensorShape([]))
```

Can also create Dataset from files

- `tf.data.TextLineDataset(filenames)`
- `tf.data.FixedLengthRecordDataset(filenames)`
- `tf.data.TFRecordDataset(filenames)`

tf.data.Iterator

Create an iterator to iterate through samples in Dataset

tf.data.Iterator

- `iterator = dataset.make_one_shot_iterator()`
- `iterator = dataset.make_initializable_iterator()`

tf.data.Iterator

- `iterator = dataset.make_one_shot_iterator()`
  Iterates through the dataset exactly once. No need to initialization.
- `iterator = dataset.make_initializable_iterator()`
  Iterates through the dataset as many times as we want. Need to initialize with each epoch.

tf.data.Iterator

```
iterator = dataset.make_one_shot_iterator()
X, Y = iterator.get_next()         # X is the birth rate, Y is the life expectancy

with tf.Session() as sess:
      print(sess.run([X, Y]))          # >> [1.822, 74.82825]
      print(sess.run([X, Y]))          # >> [3.869, 70.81949]
      print(sess.run([X, Y]))          # >> [3.911, 72.15066]
```

tf.data.Iterator

```
iterator = dataset.make_initializable_iterator()

...

for i in range(100):
        sess.run(iterator.initializer)
        total_loss = 0
        try:
            while True:
                sess.run([optimizer])
        except tf.errors.OutOfRangeError:
            pass
```

Handling data in TensorFlow

```
dataset = dataset.shuffle(1000)

dataset = dataset.repeat(100)

dataset = dataset.batch(128)

dataset = dataset.map(lambda x: tf.one_hot(x, 10))
# convert each elem of dataset to one_hot vector
```

Does tf.data really perform better?

Does tf.data really perform better?

With placeholder: 9.05271519 seconds

With tf.data: 6.12285947 seconds

How does TensorFlow know what variables to update?

Optimizers

Optimizer

```
optimizer = tf.train.GradientDescentOptimizer(learning_rate=0.01).minimize(loss)

_, l = sess.run([optimizer, loss], feed_dict={X: x, Y:y})
```

Optimizer

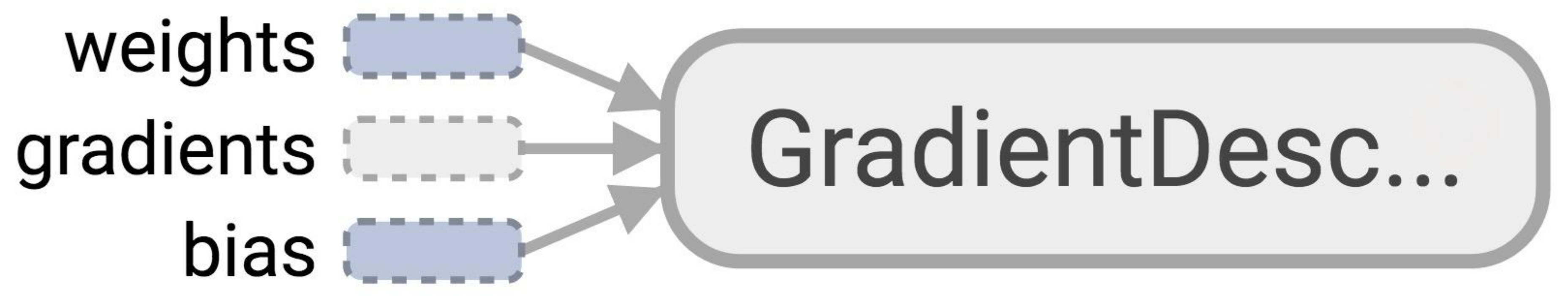
```
optimizer = tf.train.GradientDescentOptimizer(learning_rate=0.001).minimize(loss)

_, l = sess.run([optimizer, loss], feed_dict={X: x, Y:y})
```

Session looks at all trainable variables that loss depends on and update them

Optimizer

Session looks at all trainable variables that optimizer depends on and update them



Trainable variables

```
tf.Variable(initial_value=None, trainable=True,...)
```

Specify if a variable should be trained or not
By default, all variables are trainable

List of optimizers in TF

```
tf.train.GradientDescentOptimizer

tf.train.AdagradOptimizer

tf.train.MomentumOptimizer

tf.train.AdamOptimizer

tf.train.FtrlOptimizer

tf.train.RMSPropOptimizer

...
```

“Advanced” optimizers work better when tuned, but are generally harder to tune

Discussion question

1. How to know that our model is correct?
2. How to improve our model?

Assignment 1

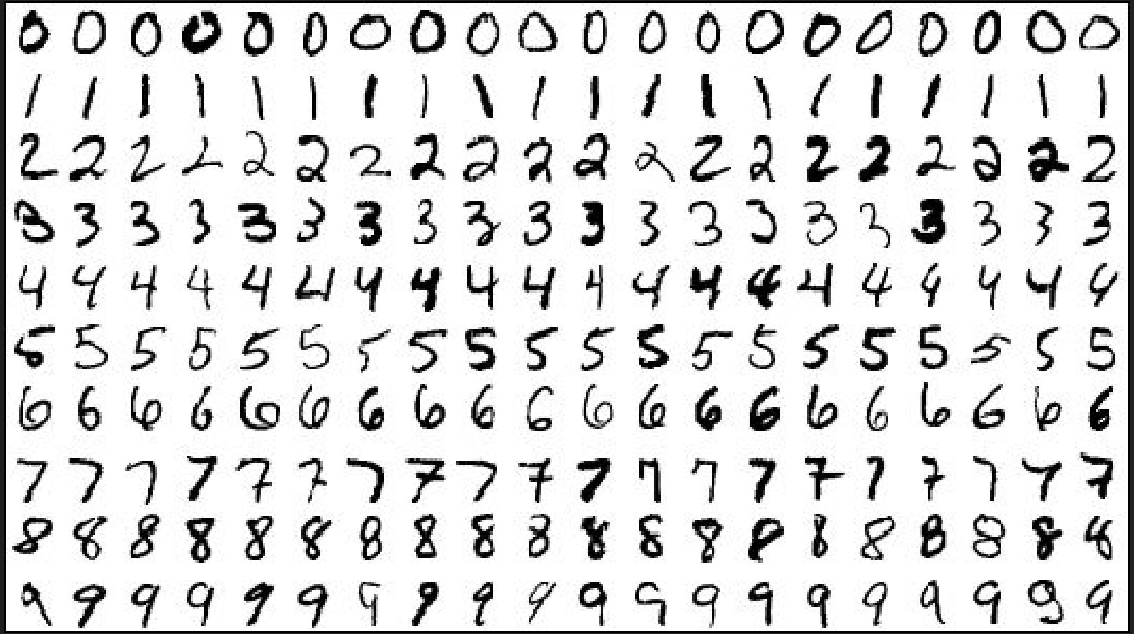
Out tomorrow
Due 1/31
Optional Interactive Grading

Logistic Regression in TensorFlow


Then he separated the
light from the darkness
The first logistic
regression model

MNIST Database

Each image is a 28x28 array, flattened out to be a 1-d tensor of size 784



MNIST

X: image of a handwritten digit
Y: the digit value
Recognize the digit in the image

MNIST

X: image of a handwritten digit
Y: the digit value

Model

```
Inference: Y_predicted = softmax(X * w + b)

Cross entropy loss: -log(Y_predicted)
```

Process data

```
from tensorflow.examples.tutorials.mnist import input_data
MNIST = input_data.read_data_sets('data/mnist', one_hot=True)
```

Process data

```
from tensorflow.examples.tutorials.mnist import input_data
MNIST = input_data.read_data_sets('data/mnist', one_hot=True)

MNIST.train: 55,000 examples
MNIST.validation: 5,000 examples
MNIST.test: 10,000 examples
```

Process data

```
from tensorflow.examples.tutorials.mnist import input_data
MNIST = input_data.read_data_sets('data/mnist', one_hot=True)

MNIST.train: 55,000 examples
MNIST.validation: 5,000 examples
MNIST.test: 10,000 examples
```

No immediate way to convert Python generators to tf.data.Dataset

Process data

```
mnist_folder = 'data/mnist'
utils.download_mnist(mnist_folder)
train, val, test = utils.read_mnist(mnist_folder, flatten=True)
```

Create datasets

```
mnist_folder = 'data/mnist'
utils.download_mnist(mnist_folder)
train, val, test = utils.read_mnist(mnist_folder, flatten=True)

train_data = tf.data.Dataset.from_tensor_slices(train)
train_data = train_data.shuffle(10000) # optional
test_data = tf.data.Dataset.from_tensor_slices(test)
```

Create iterator

```
mnist_folder = 'data/mnist'
utils.download_mnist(mnist_folder)
train, val, test = utils.read_mnist(mnist_folder, flatten=True)

train_data = tf.data.Dataset.from_tensor_slices(train)
train_data = train_data.shuffle(10000) # optional
test_data = tf.data.Dataset.from_tensor_slices(test)

iterator = train_data.make_initializable_iterator()
```

Create iterator

```
mnist_folder = 'data/mnist'
utils.download_mnist(mnist_folder)
train, val, test = utils.read_mnist(mnist_folder, flatten=True)

train_data = tf.data.Dataset.from_tensor_slices(train)
train_data = train_data.shuffle(10000) # optional
test_data = tf.data.Dataset.from_tensor_slices(test)

iterator = train_data.make_initializable_iterator()
img, label = iterator.get_next()
…
```

Problem?

Create iterator

```
mnist_folder = 'data/mnist'
utils.download_mnist(mnist_folder)
train, val, test = utils.read_mnist(mnist_folder, flatten=True)

train_data = tf.data.Dataset.from_tensor_slices(train)
train_data = train_data.shuffle(10000) # optional
test_data = tf.data.Dataset.from_tensor_slices(test)

iterator = train_data.make_initializable_iterator()
img, label = iterator.get_next()
…
```

```
>> Can only do inference with train_data.
>> Need to build another subgraph with another iterator for test_data!!!
```

Create iterator

```
mnist_folder = 'data/mnist'
utils.download_mnist(mnist_folder)
train, val, test = utils.read_mnist(mnist_folder, flatten=True)

train_data = tf.data.Dataset.from_tensor_slices(train)
train_data = train_data.shuffle(10000) # optional
test_data = tf.data.Dataset.from_tensor_slices(test)

iterator = tf.data.Iterator.from_structure(train_data.output_types,
                                           train_data.output_shapes)
img, label = iterator.get_next()

train_init = iterator.make_initializer(train_data)  # initializer for train_data
test_init = iterator.make_initializer(test_data)    # initializer for train_data
```

Initialize iterator with the dataset you want

```
with tf.Session() as sess:
    ...
    for i in range(n_epochs):
        sess.run(train_init)                # use train_init during training loop
        try:
            while True:
                _, l = sess.run([optimizer, loss])
        except tf.errors.OutOfRangeError:
            pass
```

Initialize iterator with the dataset you want

```
with tf.Session() as sess:
    ...
    for i in range(n_epochs):
        sess.run(train_init)
        try:
            while True:
                _, l = sess.run([optimizer, loss])
        except tf.errors.OutOfRangeError:
            pass

    # test the model
    sess.run(test_init)                     # use test_init during testing
    try:
        while True:
            sess.run(accuracy)
    except tf.errors.OutOfRangeError:
        pass
```

Phase 1: Assemble our graph

Step 1: Read in data

I already did that for you

Step 2: Create datasets and iterator

```
train_data = tf.data.Dataset.from_tensor_slices(train)
train_data = train_data.shuffle(10000) # optional
train_data = train_data.batch(batch_size)

test_data = tf.data.Dataset.from_tensor_slices(test)
test_data = test_data.batch(batch_size)
```

Step 2: Create datasets and iterator

```
iterator =
tf.data.Iterator.from_structure(train_data.output_types,
                                  train_data.output_shapes)
img, label = iterator.get_next()

train_init = iterator.make_initializer(train_data)
test_init = iterator.make_initializer(test_data)
```

Step 3: Create weights and biases

use `tf.get_variable()`

Step 4: Build model to predict Y

```
logits = tf.matmul(img, w) + b
```

We don’t do softmax here, as we’ll do softmax together with cross_entropy loss.
It’s more efficient to compute gradients w.r.t. logits than w.r.t. softmax

Step 5: Specify loss function

```
entropy = tf.nn.softmax_cross_entropy_with_logits(labels=label,
                        logits=logits)

loss = tf.reduce_mean(entropy)
```

Step 6: Create optimizer

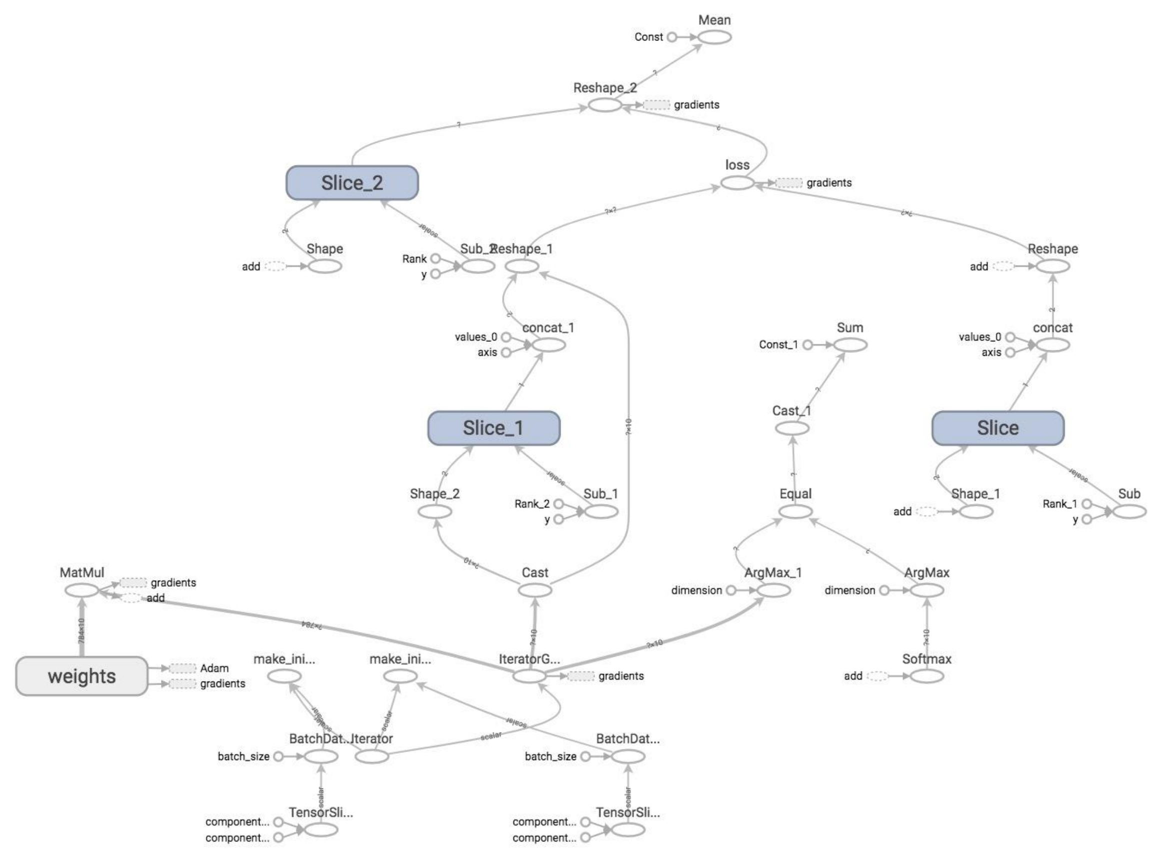
```
tf.train.AdamOptimizer(learning_rate=0.01).minimize(loss)
```

Phase 2: Train our model

```
Step 1: Initialize variables

  Step 2: Run optimizer op
```

TensorBoard it



Next class

Structure your model in TensorFlow

Example: word2vec

Eager execution

Feedback: huyenn@stanford.edu

Thanks!