



TensorFlow Ops

CS 20: TensorFlow for Deep Learning Research

Lecture 2

1/17/2017

Agenda

Basic operations

Tensor types

Importing data

Lazy loading



Fun with TensorBoard!!!

Your first TensorFlow program

```
import tensorflow as tf

a = tf.constant(2)
b = tf.constant(3)
x = tf.add(a, b)

with tf.Session() as sess:
    print(sess.run(x))
```

Your first TensorFlow program

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with tf.Session() as sess:
    print(sess.run(x))
```

Warning?

The TensorFlow library wasn't compiled to use SSE4.1 instructions, but these are available on your machine and could speed up CPU computations.

Your first TensorFlow program

```
import os
os.environ['TF_CPP_MIN_LOG_LEVEL']='2'
import tensorflow as tf
```

```
a = tf.constant(2)
b = tf.constant(3)
x = tf.add(a, b)
```

```
with tf.Session() as sess:
    print(sess.run(x))
```

No more warning

Visualize it with TensorBoard

```
import tensorflow as tf
```

```
a = tf.constant(2)
```

```
b = tf.constant(3)
```

```
x = tf.add(a, b)
```

Create the summary writer after graph definition and before running your session

```
writer = tf.summary.FileWriter('./graphs', tf.get_default_graph())
```

```
with tf.Session() as sess:
```

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

```
    print(sess.run(x))
```

```
writer.close() # close the writer when you're done using it
```

‘graphs’ or any location where you want to keep your event files

Run it


Go to terminal, run:


```
$ python3 [yourprogram].py
```

```
$ tensorboard --logdir="./graphs" --port 6006
```

6006 or any port you want

Then open your browser and go to: <http://localhost:6006/>

 Fit to screen

 Download PNG

Run simple ▾

(4)

Session ▾

runs (0)

Upload Choose File


☐ Trace inputs


Color ☒ Structure


☐ Device


▾ Close legend.


Graph (* = expandable)


 Namespace* [?](#)


 OpNode [?](#)


 Unconnected series* [?](#)


 Connected series* [?](#)

 Constant [?](#)

 Summary [?](#)

 Dataflow edge [?](#)

 Control dependency edge [?](#)

 Reference edge [?](#)

Main GraphAuxiliary Nodes



Visualize it with TensorBoard

```
import tensorflow as tf

a = tf.constant(2)
b = tf.constant(3)
x = tf.add(a, b)
writer = tf.summary.FileWriter('./graphs', tf.get_default_graph())
writer.close()
```



Visualize it with TensorBoard

```
import tensorflow as tf

a = tf.constant(2)
b = tf.constant(3)
x = tf.add(a, b)
writer = tf.summary.FileWriter('./graphs', tf.get_default_graph())
writer.close()
```



Question:

How to change Const, Const_1 to the names we give the variables?

Explicitly name them

```
import tensorflow as tf

a = tf.constant(2, name='a')
b = tf.constant(3, name='b')
x = tf.add(a, b, name='add')

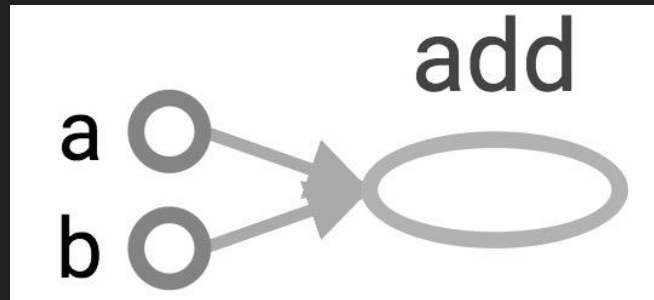
writer = tf.summary.FileWriter('./graphs', tf.get_default_graph())
with tf.Session() as sess:
    print(sess.run(x)) # >> 5
```

Explicitly name them

```
import tensorflow as tf

a = tf.constant(2, name='a')
b = tf.constant(3, name='b')
x = tf.add(a, b, name='add')
```

```
writer = tf.summary.FileWriter('./graphs', tf.get_default_graph())
with tf.Session() as sess:
    print(sess.run(x)) # >> 5
```



**TensorBoard can do much more than just
visualizing your graphs.
Learn to use TensorBoard
well and often!**



Constants, Sequences, Variables, Ops

Constants

```
import tensorflow as tf
```

```
a = tf.constant([2, 2], name='a')
```

```
b = tf.constant([[0, 1], [2, 3]], name='b')
```

```
tf.constant(  
    value,  
    dtype=None,  
    shape=None,  
    name='Const',  
    verify_shape=False  
)
```


Constants

```
import tensorflow as tf

a = tf.constant([2, 2], name='a')
b = tf.constant([[0, 1], [2, 3]], name='b')
x = tf.multiply(a, b, name='mul')
```

Broadcasting similar to NumPy

```
with tf.Session() as sess:
    print(sess.run(x))
```

```
# >> [[0 2]
#      [4 6]]
```

Tensors filled with a specific value

```
tf.zeros(shape, dtype=tf.float32, name=None)
```

creates a tensor of shape and all elements will be zeros

Similar to `numpy.zeros`

```
tf.zeros([2, 3], tf.int32) ==> [[0, 0, 0], [0, 0, 0]]
```

Tensors filled with a specific value

```
tf.zeros_like(input_tensor, dtype=None, name=None, optimize=True)
```

creates a tensor of shape and type (unless type is specified) as the `input_tensor` but all elements are zeros.

Similar to `numpy.zeros_like`

```
# input_tensor is [[0, 1], [2, 3], [4, 5]]
```

```
tf.zeros_like(input_tensor) ==> [[0, 0], [0, 0], [0, 0]]
```

Tensors filled with a specific value

```
tf.ones(shape, dtype=tf.float32, name=None)
```

```
tf.ones_like(input_tensor, dtype=None, name=None, optimize=True)
```

Similar to `numpy.ones`,
`numpy.ones_like`

Tensors filled with a specific value

```
tf.fill(dims, value, name=None)
```

creates a tensor filled with a scalar value.

Similar to NumPy.full

```
tf.fill([2, 3], 8) ==> [[8, 8, 8], [8, 8, 8]]
```

Constants as sequences

```
tf.linspace(start, stop, num, name=None)
```

```
tf.linspace(10.0, 13.0, 4) ==> [10. 11. 12. 13.]
```

```
tf.range(start, limit=None, delta=1, dtype=None, name='range')
```

```
tf.range(3, 18, 3) ==> [3 6 9 12 15]
```

```
tf.range(5) ==> [0 1 2 3 4]
```

NOT THE SAME AS NUMPY SEQUENCES

Tensor objects are not iterable

```
for _ in tf.range(4): # TypeError
```

Randomly Generated Constants

`tf.random_normal`
`tf.truncated_normal`
`tf.random_uniform`
`tf.random_shuffle`
`tf.random_crop`
`tf.multinomial`
`tf.random_gamma`

Randomly Generated Constants

```
tf.set_random_seed(seed)
```


Operations

Category	Examples
Element-wise mathematical operations	Add, Sub, Mul, Div, Exp, Log, Greater, Less, Equal, ...
Array operations	Concat, Slice, Split, Constant, Rank, Shape, Shuffle, ...
Matrix operations	MatMul, MatrixInverse, MatrixDeterminant, ...
Stateful operations	Variable, Assign, AssignAdd, ...
Neural network building blocks	SoftMax, Sigmoid, ReLU, Convolution2D, MaxPool, ...
Checkpointing operations	Save, Restore
Queue and synchronization operations	Enqueue, Dequeue, MutexAcquire, MutexRelease, ...
Control flow operations	Merge, Switch, Enter, Leave, NextIteration

Arithmetic Ops

- `tf.abs`
- `tf.negative`
- `tf.sign`
- `tf.reciprocal`
- `tf.square`
- `tf.round`
- `tf.sqrt`
- `tf.rsqrt`
- `tf.pow`
- `tf.exp`

Pretty standard, quite similar to numpy.

Wizard of Div

```
a = tf.constant([2, 2], name='a')
b = tf.constant([[0, 1], [2, 3]], name='b')
with tf.Session() as sess:
    print(sess.run(tf.div(b, a)))           ⇒ [[0 0] [1 1]]
    print(sess.run(tf.divide(b, a)))        ⇒ [[0. 0.5] [1. 1.5]]
    print(sess.run(tf.truediv(b, a)))       ⇒ [[0. 0.5] [1. 1.5]]
    print(sess.run(tf.floordiv(b, a)))      ⇒ [[0 0] [1 1]]
    print(sess.run(tf.realdiv(b, a)))       ⇒ # Error: only works for real values
    print(sess.run(tf.truncatediv(b, a)))   ⇒ [[0 0] [1 1]]
    print(sess.run(tf.floor_div(b, a)))     ⇒ [[0 0] [1 1]]
```

TensorFlow Data Types

TensorFlow takes Python natives types: boolean, numeric (int, float), strings

```
t_o = 19                                # scalars are treated like 0-d tensors
tf.zeros_like(t_o)                      # ==> 0
tf.ones_like(t_o)                       # ==> 1
```

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tf.zeros_like(t_o)                      # ==> 0
tf.ones_like(t_o)                       # ==> 1
```

```
t_1 = [b"apple", b"peach", b"grape"]    # 1-d arrays are treated like 1-d tensors
tf.zeros_like(t_1)                      # ==> ?????
```

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t_o = 19                                # scalars are treated like 0-d tensors
tf.zeros_like(t_o)                      # ==> 0
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```

```
t_1 = [b"apple", b"peach", b"grape"]    # 1-d arrays are treated like 1-d tensors
tf.zeros_like(t_1)                      # ==> [b" b" b"]
```

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t_1 = [b"apple", b"peach", b"grape"]    # 1-d arrays are treated like 1-d tensors
tf.zeros_like(t_1)                      # ==> [b" b" b"]
tf.ones_like(t_1)                       # ==> ????
```


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t_1 = [b"apple", b"peach", b"grape"]    # 1-d arrays are treated like 1-d tensors
tf.zeros_like(t_1)                       # ==> [b" b" b"]
tf.ones_like(t_1)                        # ==> TypeError: Expected string, got 1 of type 'int' instead.
```

TensorFlow Data Types

TensorFlow takes Python natives types: boolean, numeric (int, float), strings

```
t_o = 19                                # scalars are treated like 0-d tensors
tf.zeros_like(t_o)                      # ==> 0
tf.ones_like(t_o)                       # ==> 1

t_1 = [b"apple", b"peach", b"grape"]    # 1-d arrays are treated like 1-d tensors
tf.zeros_like(t_1)                      # ==> [b" b" b"]
tf.ones_like(t_1)                       # ==> TypeError: Expected string, got 1 of type 'int' instead.

t_2 = [[True, False, False],
        [False, False, True],
        [False, True, False]]           # 2-d arrays are treated like 2-d tensors

tf.zeros_like(t_2)                      # ==> ?????
tf.ones_like(t_2)                       # ==> ?????
```

TensorFlow Data Types

TensorFlow takes Python natives types: boolean, numeric (int, float), strings

```
t_o = 19                                # scalars are treated like 0-d tensors
tf.zeros_like(t_o)                       # ==> 0
tf.ones_like(t_o)                        # ==> 1

t_1 = [b"apple", b"peach", b"grape"]    # 1-d arrays are treated like 1-d tensors
tf.zeros_like(t_1)                       # ==> [b" b" b"]
tf.ones_like(t_1)                        # ==> TypeError: Expected string, got 1 of type 'int' instead.

t_2 = [[True, False, False],
        [False, False, True],
        [False, True, False]]           # 2-d arrays are treated like 2-d tensors

tf.zeros_like(t_2)                       # ==> 3x3 tensor, all elements are False
tf.ones_like(t_2)                        # ==> 3x3 tensor, all elements are True
```

TensorFlow Data Types

- `tf.float16` : 16-bit half-precision floating-point.
- `tf.float32` : 32-bit single-precision floating-point.
- `tf.float64` : 64-bit double-precision floating-point.
- `tf.bfloat16` : 16-bit truncated floating-point.
- `tf.complex64` : 64-bit single-precision complex.
- `tf.complex128` : 128-bit double-precision complex.
- `tf.int8` : 8-bit signed integer.
- `tf.uint8` : 8-bit unsigned integer.
- `tf.uint16` : 16-bit unsigned integer.
- `tf.int16` : 16-bit signed integer.
- `tf.int32` : 32-bit signed integer.
- `tf.int64` : 64-bit signed integer.
- `tf.bool` : Boolean.
- `tf.string` : String.
- `tf.qint8` : Quantized 8-bit signed integer.
- `tf.quint8` : Quantized 8-bit unsigned integer.
- `tf.qint16` : Quantized 16-bit signed integer.
- `tf.quint16` : Quantized 16-bit unsigned integer.
- `tf.qint32` : Quantized 32-bit signed integer.
- `tf.resource` : Handle to a mutable resource.

TF vs NP Data Types

TensorFlow integrates seamlessly with NumPy

```
tf.int32 == np.int32          # ⇒ True
```

Can pass numpy types to TensorFlow ops

```
tf.ones([2, 2], np.float32)  # ⇒ [[1.0 1.0], [1.0 1.0]]
```

For **tf.Session.run(fetches)**: if the requested fetch is a Tensor , output will be a NumPy ndarray.

```
sess = tf.Session()
a = tf.zeros([2, 3], np.int32)
print(type(a))          # ⇒ <class 'tensorflow.python.framework.ops.Tensor'>
a = sess.run(a)
print(type(a))          # ⇒ <class 'numpy.ndarray'>
```

TF vs NP Data Types

TensorFlow integrates seamlessly with NumPy

```
tf.int32 == np.int32          # ⇒ True
```

Can pass numpy types to TensorFlow ops

```
tf.ones([2, 2], np.float32)  # ⇒ [[1.0 1.0], [1.0 1.0]]
```

For **tf.Session.run(fetches)**: if the requested fetch is a Tensor , output will be a NumPy ndarray.

```
sess = tf.Session()
```

```
a = tf.zeros([2, 3], np.int32)
```

```
print(type(a))
```

```
a = sess.run(a)                <<<< Avoid doing this. Use a_out = sess.run(a)
```

```
print(type(a))
```

Use TF DType when possible

- Python native types: TensorFlow has to infer Python type

Use TF DType when possible

- Python native types: TensorFlow has to infer Python type
- NumPy arrays: NumPy is not GPU compatible

What's wrong with constants ...

... other than being constant?

What's wrong with constants?


Constants are stored in the graph definition

Print out the graph def

```
my_const = tf.constant([1.0, 2.0], name="my_const")
```

```
with tf.Session() as sess:  
    print(sess.graph.as_graph_def())
```

```
attr {  
  key: "value"  
  value {  
    tensor {  
      dtype: DT_FLOAT  
      tensor_shape {  
        dim {  
          size: 2  
        }  
      }  
      tensor_content: "\000\000\200?\000\000\000@"  
    }  
  }  
}
```



What's wrong with constants?

This makes loading graphs expensive when constants are big

What's wrong with constants?

This makes loading graphs expensive when constants are big



Only use constants for primitive types.

Use variables or readers for more data that requires more memory

Variables

```
# create variables with tf.Variable
s = tf.Variable(2, name="scalar")
m = tf.Variable([[0, 1], [2, 3]], name="matrix")
W = tf.Variable(tf.zeros([784,10]))
```

Variables

```
# create variables with tf.Variable
s = tf.Variable(2, name="scalar")
m = tf.Variable([[0, 1], [2, 3]], name="matrix")
W = tf.Variable(tf.zeros([784,10]))

# create variables with tf.get_variable
s = tf.get_variable("scalar", initializer=tf.constant(2))
m = tf.get_variable("matrix", initializer=tf.constant([[0, 1], [2, 3]]))
W = tf.get_variable("big_matrix", shape=(784, 10), initializer=tf.zeros_initializer())
```

Variables

```
# create variables with tf.Variable  
s = tf.Variable(2, name="scalar")  
m = tf.Variable([[0, 1], [2, 3]], name="matrix")  
W = tf.Variable(tf.zeros([784,10]))
```



```
# create variables with tf.get_variable  
s = tf.get_variable("scalar", initializer=tf.constant(2))  
m = tf.get_variable("matrix", initializer=tf.constant([[0, 1], [2, 3]]))  
W = tf.get_variable("big_matrix", shape=(784, 10), initializer=tf.zeros_initializer())
```



Variables

```
# create variables with tf.Variable
s = tf.Variable(2, name="scalar")
m = tf.Variable([[0, 1], [2, 3]], name="matrix")
W = tf.Variable(tf.zeros([784,10]))
```

Why tf.constant but tf.Variable?

```
# create variables with tf.get_variable
s = tf.get_variable("scalar", initializer=tf.constant(2))
m = tf.get_variable("matrix", initializer=tf.constant([[0, 1], [2, 3]]))
W = tf.get_variable("big_matrix", shape=(784, 10), initializer=tf.zeros_initializer())
```

Variables

```
# create variables with tf.Variable
s = tf.Variable(2, name="scalar")
m = tf.Variable([[0, 1], [2, 3]], name="matrix")
W = tf.Variable(tf.zeros([784,10]))
```

tf.constant is an op

tf.Variable is a class with many ops

```
# create variables with tf.get_variable
s = tf.get_variable("scalar", initializer=tf.constant(2))
m = tf.get_variable("matrix", initializer=tf.constant([[0, 1], [2, 3]]))
W = tf.get_variable("big_matrix", shape=(784, 10), initializer=tf.zeros_initializer())
```

tf.Variable class

```
# create variables with tf.get_variable
s = tf.get_variable("scalar", initializer=tf.constant(2))
m = tf.get_variable("matrix", initializer=tf.constant([[0, 1], [2, 3]]))
W = tf.get_variable("big_matrix", shape=(784, 10), initializer=tf.zeros_initializer())
```

tf.Variable holds several ops:

```
x = tf.Variable(...)

x.initializer # init op
x.value() # read op
x.assign(...) # write op
x.assign_add(...) # and more
```

tf.Variable class

```
# create variables with tf.get_variable
s = tf.get_variable("scalar", initializer=tf.constant(2))
m = tf.get_variable("matrix", initializer=tf.constant([[0, 1], [2, 3]]))
W = tf.get_variable("big_matrix", shape=(784, 10), initializer=tf.zeros_initializer())

with tf.Session() as sess:
    print(sess.run(W))    >> FailedPreconditionError: Attempting to use uninitialized value Variable
```

You have to initialize your variables

The easiest way is initializing all variables at once:

```
with tf.Session() as sess:
```

```
    sess.run(tf.global_variables_initializer())
```

Initializer is an op. You need to execute it within the context of a session

You have to initialize your variables

The easiest way is initializing all variables at once:

```
with tf.Session() as sess:  
    sess.run(tf.global_variables_initializer())
```

Initialize only a subset of variables:

```
with tf.Session() as sess:  
    sess.run(tf.variables_initializer([a, b]))
```

You have to initialize your variables

The easiest way is initializing all variables at once:

```
with tf.Session() as sess:  
    sess.run(tf.global_variables_initializer())
```

Initialize only a subset of variables:

```
with tf.Session() as sess:  
    sess.run(tf.variables_initializer([a, b]))
```

Initialize a single variable

```
W = tf.Variable(tf.zeros([784,10]))  
with tf.Session() as sess:  
    sess.run(W.initializer)
```

Eval() a variable

```
# W is a random 700 x 100 variable object
W = tf.Variable(tf.truncated_normal([700, 10]))
with tf.Session() as sess:
    sess.run(W.initializer)
    print(W)

>> Tensor("Variable/read:0", shape=(700, 10), dtype=float32)
```


Eval() a variable

```
# W is a random 700 x 100 variable object
W = tf.Variable(tf.truncated_normal([700, 10]))
with tf.Session() as sess:
    sess.run(W.initializer)
    print(W.eval())                # Similar to print(sess.run(W))
```

```
>> [[-0.76781619 -0.67020458  1.15333688 ..., -0.98434633 -1.25692499
      -0.90904623]
      [-0.36763489 -0.65037876 -1.52936983 ...,  0.19320194 -0.38379928
       0.44387451]
      [ 0.12510735 -0.82649058  0.4321366 ..., -0.3816964  0.70466036
       1.33211911]
      ...,
      [ 0.9203397 -0.99590844  0.76853162 ..., -0.74290705  0.37568584
       0.64072722]
      [-0.12753558  0.52571583  1.03265858 ...,  0.59978199 -0.91293705
       -0.02646019]
      [ 0.19076447 -0.62968266 -1.97970271 ..., -1.48389161  0.68170643
       1.46369624]]
```

tf.Variable.assign()

```
W = tf.Variable(10)
W.assign(100)
with tf.Session() as sess:
    sess.run(W.initializer)
    print(W.eval())                # >> ????
```

tf.Variable.assign()

```
W = tf.Variable(10)
W.assign(100)
with tf.Session() as sess:
    sess.run(W.initializer)
    print(W.eval())                # >> 10
```

Ugh, why?

tf.Variable.assign()

```
W = tf.Variable(10)
W.assign(100)
with tf.Session() as sess:
    sess.run(W.initializer)
    print(W.eval())                # >> 10
```

W.assign(100) creates an assign op.
That op needs to be executed in a session
to take effect.

tf.Variable.assign()

```
W = tf.Variable(10)
W.assign(100)
with tf.Session() as sess:
    sess.run(W.initializer)
    print(W.eval())
```

>> 10

```
W = tf.Variable(10)
assign_op = W.assign(100)
with tf.Session() as sess:
    sess.run(W.initializer)
    sess.run(assign_op)
    print(W.eval())
```

>> 100

tf.Variable.assign()

```
# create a variable whose original value is 2
```

```
my_var = tf.Variable(2, name="my_var")
```

```
# assign a * 2 to a and call that op a_times_two
```

```
my_var_times_two = my_var.assign(2 * my_var)
```

```
with tf.Session() as sess:
```

```
    sess.run(my_var.initializer)
```

```
    sess.run(my_var_times_two)
```

```
# >> what's the value of my_var now?
```

tf.Variable.assign()

```
# create a variable whose original value is 2
my_var = tf.Variable(2, name="my_var")
```

```
# assign a * 2 to a and call that op a_times_two
my_var_times_two = my_var.assign(2 * my_var)
```

```
with tf.Session() as sess:
```

```
    sess.run(my_var.initializer)
```

```
    sess.run(my_var_times_two)
```

```
    sess.run(my_var_times_two)
```

```
# >> the value of my_var now is 4
```

```
# >> the value of my_var now is ???
```

tf.Variable.assign()

```
# create a variable whose original value is 2
my_var = tf.Variable(2, name="my_var")
```

```
# assign a * 2 to a and call that op a_times_two
my_var_times_two = my_var.assign(2 * my_var)
```

It assign $2 * \text{my_var}$ to my_var every time my_var_times_two op is executed.

```
with tf.Session() as sess:
    sess.run(my_var.initializer)
    sess.run(my_var_times_two)
    sess.run(my_var_times_two)
    sess.run(my_var_times_two)
```

```
# >> the value of my_var now is 4
# >> the value of my_var now is 8
# >> the value of my_var now is 16
```


assign_add() and assign_sub()

```
my_var = tf.Variable(10)
```

```
With tf.Session() as sess:
```

```
    sess.run(my_var.initializer)
```

```
    # increment by 10
```

```
    sess.run(my_var.assign_add(10)) # >> 20
```

```
    # decrement by 2
```

```
    sess.run(my_var.assign_sub(2)) # >> 18
```

Each session maintains its own copy of variables

```
W = tf.Variable(10)
```

```
sess1 = tf.Session()
```

```
sess2 = tf.Session()
```

```
sess1.run(W.initializer)
```

```
sess2.run(W.initializer)
```

```
print(sess1.run(W.assign_add(10)))      # >> 20
```

```
print(sess2.run(W.assign_sub(2)))      # >> ?
```

Each session maintains its own copy of variables

```
W = tf.Variable(10)
```

```
sess1 = tf.Session()
```

```
sess2 = tf.Session()
```

```
sess1.run(W.initializer)
```

```
sess2.run(W.initializer)
```

```
print(sess1.run(W.assign_add(10)))      # >> 20
```

```
print(sess2.run(W.assign_sub(2)))      # >> 8
```

Each session maintains its own copy of variables

```
W = tf.Variable(10)
```

```
sess1 = tf.Session()
```

```
sess2 = tf.Session()
```

```
sess1.run(W.initializer)
```

```
sess2.run(W.initializer)
```

```
print(sess1.run(W.assign_add(10)))      # >> 20
```

```
print(sess2.run(W.assign_sub(2)))      # >> 8
```

```
print(sess1.run(W.assign_add(100)))    # >> 120
```

```
print(sess2.run(W.assign_sub(50)))    # >> -42
```

```
sess1.close()
```

```
sess2.close()
```

Control Dependencies

```
tf.Graph.control_dependencies(control_inputs)
```

```
# defines which ops should be run first
```

```
# your graph g have 5 ops: a, b, c, d, e
```

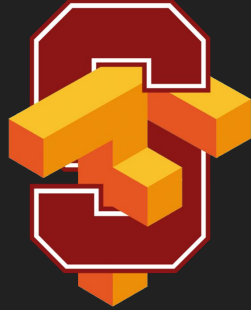
```
g = tf.get_default_graph()
```

```
with g.control_dependencies([a, b, c]):
```

```
    # 'd' and 'e' will only run after 'a', 'b', and 'c' have executed.
```

```
    d = ...
```

```
    e = ...
```



Getting to know each
other?



Placeholder

A quick reminder

A TF program often has 2 phases:

1. Assemble a graph
2. Use a session to execute operations in the graph.

Placeholders

A TF program often has 2 phases:

1. Assemble a graph
2. Use a session to execute operations in the graph.

⇒ Assemble the graph first without knowing the values needed for computation

Placeholders

A TF program often has 2 phases:

1. Assemble a graph
2. Use a session to execute operations in the graph.

⇒ Assemble the graph first without knowing the values needed for computation

Analogy:

Define the function $f(x, y) = 2 * x + y$ without knowing value of x or y .

x, y are placeholders for the actual values.

Why placeholders?

We, or our clients, can later supply their own data when they need to execute the computation.

Placeholders

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

```
# create a placeholder for a vector of 3 elements, type tf.float32
a = tf.placeholder(tf.float32, shape=[3])
```

```
b = tf.constant([5, 5, 5], tf.float32)
```

```
# use the placeholder as you would a constant or a variable
c = a + b # short for tf.add(a, b)
```

```
with tf.Session() as sess:
    print(sess.run(c))                # >> ???
```

Placeholders

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

```
# create a placeholder for a vector of 3 elements, type tf.float32
a = tf.placeholder(tf.float32, shape=[3])
```

```
b = tf.constant([5, 5, 5], tf.float32)
```

```
# use the placeholder as you would a constant or a variable
c = a + b # short for tf.add(a, b)
```

```
with tf.Session() as sess:
    print(sess.run(c))
```

```
# >> InvalidArgumentError: a doesn't an actual value
```

**Supplement the values to placeholders using
a dictionary**

Placeholders

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

```
# create a placeholder for a vector of 3 elements, type tf.float32
a = tf.placeholder(tf.float32, shape=[3])

b = tf.constant([5, 5, 5], tf.float32)

# use the placeholder as you would a constant or a variable
c = a + b # short for tf.add(a, b)

with tf.Session() as sess:
    print(sess.run(c, feed_dict={a: [1, 2, 3]})) # the tensor a is the key, not the string 'a'

# >> [6, 7, 8]
```

Placeholders

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

```
# create a placeholder for a vector of 3 elements, type tf.float32
a = tf.placeholder(tf.float32, shape=[3])
```

```
b = tf.constant([5, 5, 5], tf.float32)
```

```
# use the placeholder as you would a constant or a variable
c = a + b # short for tf.add(a, b)
```

```
with tf.Session() as sess:
    print(sess.run(c, feed_dict={a: [1, 2, 3]}))
```

```
# >> [6, 7, 8]
```

Quirk:

shape=None means that tensor of any shape will be accepted as value for placeholder.

shape=None is easy to construct graphs, but nightmarish for debugging

Placeholders

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

```
# create a placeholder of type float 32-bit, shape is a vector of 3 elements
a = tf.placeholder(tf.float32, shape=[3])
```

```
# create a constant of type float 32-bit, shape is a vector of 3 elements
b = tf.constant([5, 5, 5], tf.float32)
```

```
# use the placeholder as you would a constant or a variable
c = a + b # Short for tf.add(a, b)
```

```
with tf.Session() as sess:
    print(sess.run(c, {a: [1, 2, 3]}))
```

```
# >> [6, 7, 8]
```

Quirk:

shape=None also breaks all following shape inference, which makes many ops not work because they expect certain rank.

Placeholders are valid ops

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

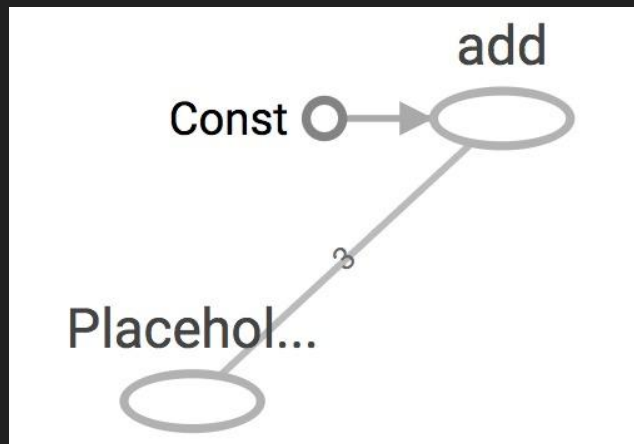
```
# create a placeholder of type float 32-bit, shape is a vector of 3 elements  
a = tf.placeholder(tf.float32, shape=[3])
```

```
# create a constant of type float 32-bit, shape is a vector of 3 elements  
b = tf.constant([5, 5, 5], tf.float32)
```

```
# use the placeholder as you would a constant or a variable  
c = a + b # Short for tf.add(a, b)
```

```
with tf.Session() as sess:  
    print(sess.run(c, {a: [1, 2, 3]}))
```

```
# >> [6, 7, 8]
```



What if want to feed multiple data points in?

You have to do it one at a time

```
with tf.Session() as sess:  
    for a_value in list_of_values_for_a:  
        print(sess.run(c, {a: a_value}))
```

**You can feed_dict any feedable tensor.
Placeholder is just a way to indicate that
something must be fed**

```
tf.Graph.is_feedable(tensor)  
# True if and only if tensor is feedable.
```

Feeding values to TF ops

```
# create operations, tensors, etc (using the default graph)
a = tf.add(2, 5)
b = tf.multiply(a, 3)

with tf.Session() as sess:
    # compute the value of b given a is 15
    sess.run(b, feed_dict={a: 15})
```

```
# >> 45
```

Extremely helpful for testing
Feed in dummy values to test parts of a large graph

The trap of lazy loading*



*I might have made this term up

What's lazy loading?

**Defer creating/initializing an object
until it is needed**

Lazy loading Example

Normal loading

```
x = tf.Variable(10, name='x')
y = tf.Variable(20, name='y')
z = tf.add(x, y)                # create the node before executing the graph

writer = tf.summary.FileWriter('./graphs/normal_loading', tf.get_default_graph())
with tf.Session() as sess:
    sess.run(tf.global_variables_initializer())
    for _ in range(10):
        sess.run(z)
writer.close()
```

Lazy loading Example

Lazy loading

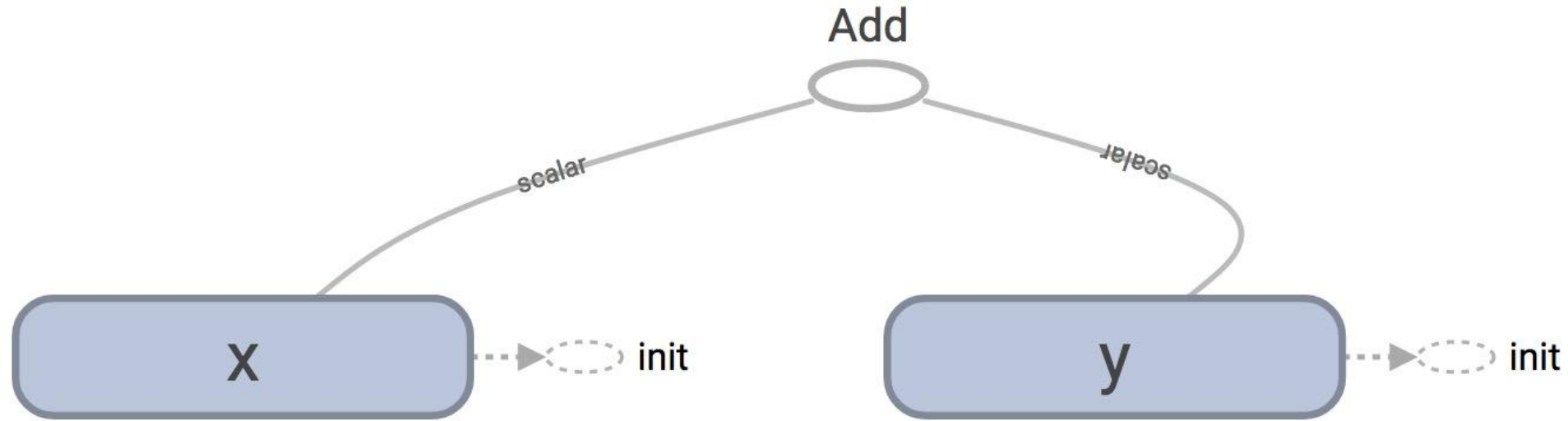
```
x = tf.Variable(10, name='x')
y = tf.Variable(20, name='y')

writer = tf.summary.FileWriter('./graphs/normal_loading', tf.get_default_graph())
with tf.Session() as sess:
    sess.run(tf.global_variables_initializer())
    for _ in range(10):
        sess.run(tf.add(x, y)) # someone decides to be clever to save one line of code
writer.close()
```

**Both give the same value of z
What's the problem?**

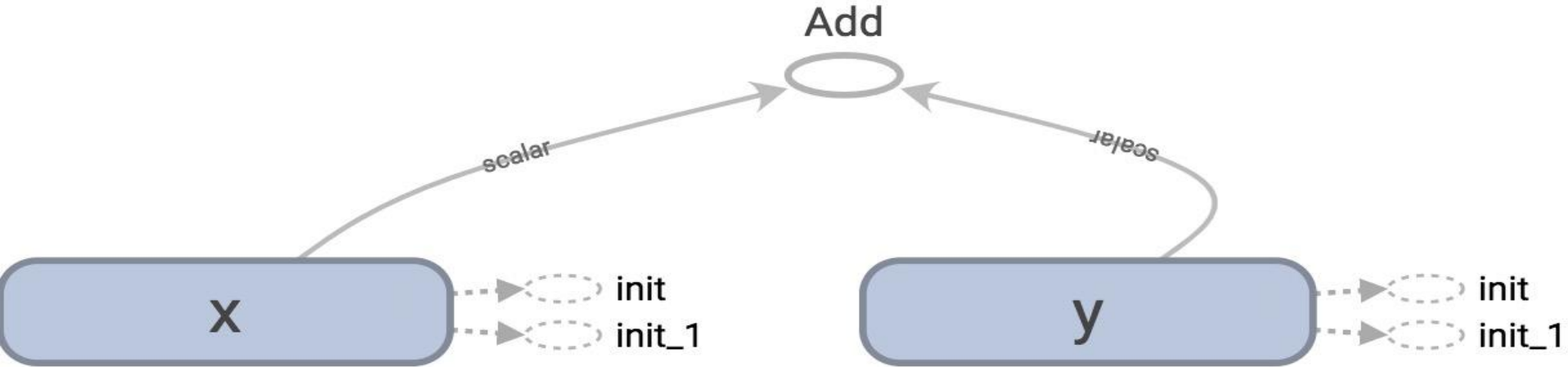
TensorBoard

Normal loading



TensorBoard

Lazy loading



tf.get_default_graph().as_graph_def()

Normal loading

```
node {  
  name: "Add"  
  op: "Add"  
  input: "x/read"  
  input: "y/read"  
  attr {  
    key: "T"  
    value {  
      type: DT_INT32  
    }  
  }  
}
```

Node “Add” added once to the graph definition

tf.get_default_graph().as_graph_def()

Lazy loading

```
node {  
  name: "Add_1"  
  op: "Add"  
  ...  
}  
...  
node {  
  name: "Add_10"  
  op: "Add"  
  ...  
}
```

Node “Add” added 10 times to the graph definition

Or as many times as you want to compute z

**Imagine you want to compute an op
thousands, or millions of times!**

Your graph gets bloated
Slow to load
Expensive to pass around

**One of the most common TF non-bug bugs
I've seen on GitHub**

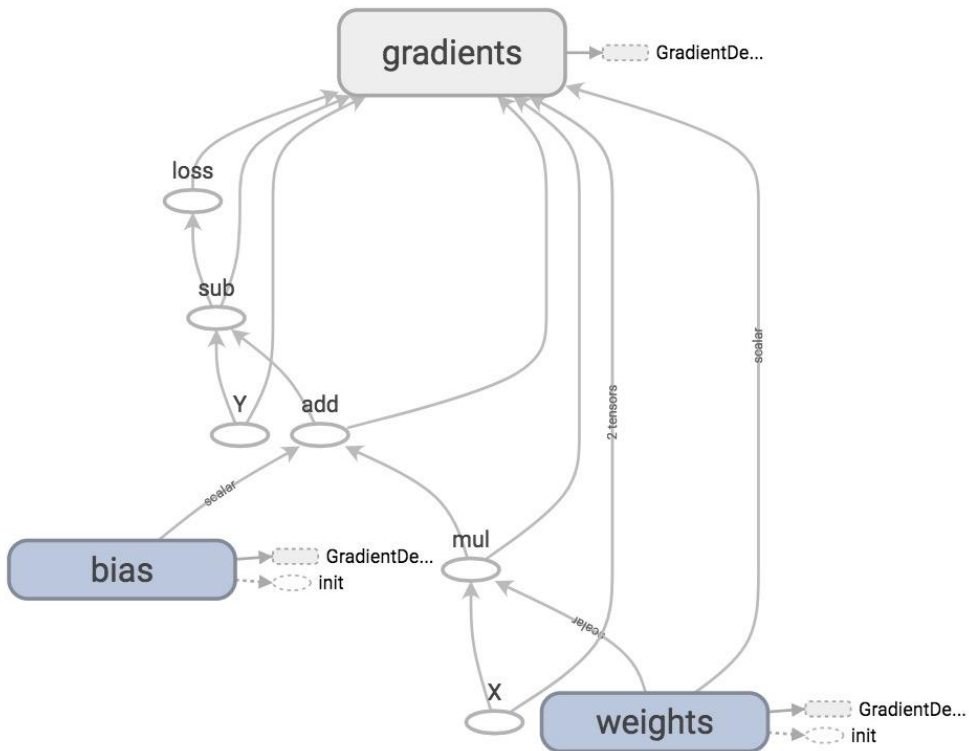
Solution

1. Separate definition of ops from computing/running ops
2. Use Python property to ensure function is also loaded once the first time it is called*

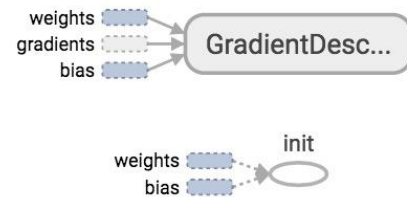
* This is not a Python class so I won't go into it here. But if you don't know how to use this property, you're welcome to ask me!

**Putting it together:
Let's build a machine learning model!**

Main Graph



Auxiliary Nodes



**We will construct this
model next time!!**

Next class

Linear regression

Control Flow

tf.data

Optimizers

Logistic regression on MNIST

Feedback: huyenn@stanford.edu

Thanks!