



Eager execution

CS 20: TensorFlow for Deep Learning Research

Lecture 4

1/24/2017

- **Assignment 1 is out! (due 1/31)**
- **Gitter chatroom**

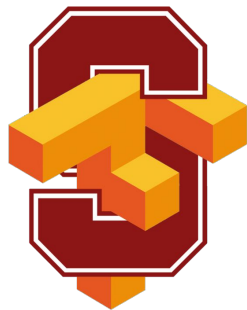
Agenda

Eager execution

Linear regression in eager



Interactive Coding!



Eager Execution

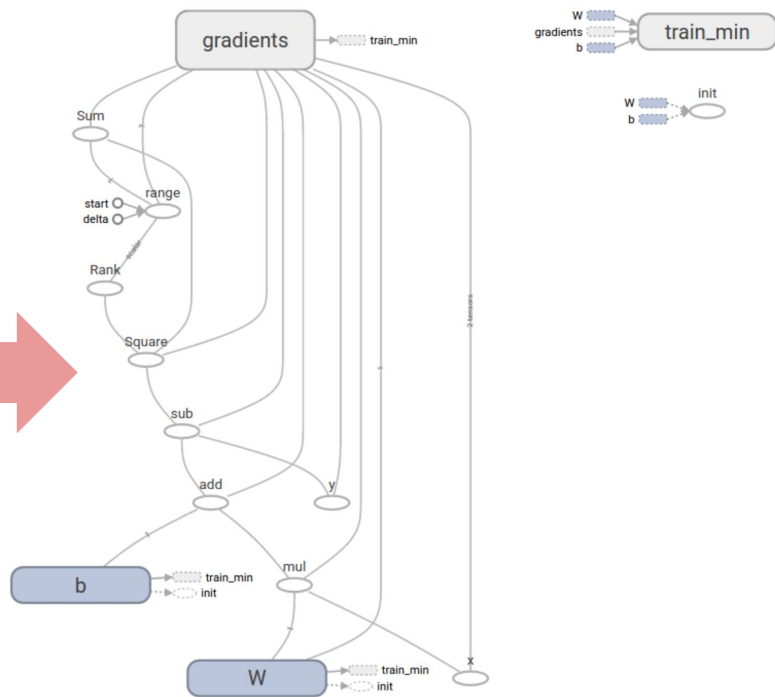
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TensorFlow Today: Declarative (Graphs)

```
import numpy as np
import tensorflow as tf

# Model parameters
W = tf.Variable([.3], tf.float32)
b = tf.Variable([-1.3], tf.float32)
# Model input and output
x = tf.placeholder(tf.float32)
linear_model = W * x + b
y = tf.placeholder(tf.float32)
# loss
loss = tf.reduce_sum(tf.square(linear_model - y)) # sum of the squares
# optimizer
optimizer = tf.train.GradientDescentOptimizer(0.01)
train = optimizer.minimize(loss)
# training data
x_train = [1,2,3,4]
y_train = [0,-1,-2,-3]
# training loop
init = tf.global_variables_initializer()
sess = tf.Session()
sess.run(init) # reset values to wrong
for i in range(1000):
    sess.run(train, {x:x_train, y:y_train})

# evaluate training accuracy
curr_W, curr_b, curr_loss = sess.run([W, b, loss], {x:x_train, y:y_train})
print("W: %s b: %s loss: %s"%(curr_W, curr_b, curr_loss))
```



Graphs are ...

Optimizable

- automatic buffer reuse
- constant folding
- inter-op parallelism
- automatic trade-off between compute and memory

Deployable

- the Graph is an intermediate representation for models

Rewritable

- experiment with automatic device placement or quantization

But graphs are also ...

Difficult to debug

- errors are reported long after graph construction
- execution cannot be debugged with `pdb` or `print` statements

Un-Pythonic

- writing a TensorFlow program is an exercise in metaprogramming
- control flow (e.g., `tf.while_loop`) differs from Python
- can't easily mix graph construction with custom data structures


```
Traceback (most recent call last):
  File "/Users/Akshay/pyenvs/tf-1.50rc1/lib/python3.6/site-packages/tensorflow/python/client/session.py", line 1350, in _do_call
    return fn(*args)
  File "/Users/Akshay/pyenvs/tf-1.50rc1/lib/python3.6/site-packages/tensorflow/python/client/session.py", line 1329, in _run_fn
    status, run_metadata)
  File "/Users/Akshay/pyenvs/tf-1.50rc1/lib/python3.6/site-packages/tensorflow/python/framework/errors_impl.py", line 473, in __exit__
    c_api.TF_GetCode(self.status.status))
tensorflow.python.framework.errors_impl.InvalidArgumentError: indices[0] = 3081 is not in [0, 128]
[[Node: loss/nce_loss/embedding_lookup_1 = Gather[Tindices=DT_INT64, Tparams=DT_FLOAT, _class=["loc:@nce_bias"], validate_indices=true, _device="/job:localhost/replica:0/task:0/device:CPU:0"](nce_bias/read, loss/nce_loss/concat)]]
```

During handling of the above exception, another exception occurred:

```
Traceback (most recent call last):
  File "04_word2vec.py", line 102, in <module>
    main()
  File "04_word2vec.py", line 99, in main
    word2vec(dataset)
  File "04_word2vec.py", line 82, in word2vec
    loss_batch, _ = sess.run([loss, optimizer])
  File "/Users/Akshay/pyenvs/tf-1.50rc1/lib/python3.6/site-packages/tensorflow/python/client/session.py", line 895, in run
    run_metadata_ptr)
  File "/Users/Akshay/pyenvs/tf-1.50rc1/lib/python3.6/site-packages/tensorflow/python/client/session.py", line 1128, in _run
    feed_dict_tensor, options, run_metadata)
  File "/Users/Akshay/pyenvs/tf-1.50rc1/lib/python3.6/site-packages/tensorflow/python/client/session.py", line 1344, in _do_run
    options, run_metadata)
  File "/Users/Akshay/pyenvs/tf-1.50rc1/lib/python3.6/site-packages/tensorflow/python/client/session.py", line 1363, in _do_call
    raise type(e)(node_def, op, message)
tensorflow.python.framework.errors_impl.InvalidArgumentError: indices[0] = 3081 is not in [0, 128]
[[Node: loss/nce_loss/embedding_lookup_1 = Gather[Tindices=DT_INT64, Tparams=DT_FLOAT, _class=["loc:@nce_bias"], validate_indices=true, _device="/job:localhost/replica:0/task:0/device:CPU:0"](nce_bias/read, loss/nce_loss/concat)]]
```

Caused by op 'loss/nce_loss/embedding_lookup_1', defined at:

```
File "04_word2vec.py", line 102, in <module>
    main()
  File "04_word2vec.py", line 99, in main
    word2vec(dataset)
  File "04_word2vec.py", line 65, in word2vec
    num_classes=VOCAB_SIZE, name='loss')
  File "/Users/Akshay/pyenvs/tf-1.50rc1/lib/python3.6/site-packages/tensorflow/python/ops/nn_impl.py", line 1212, in nce_loss
    name=name)
  File "/Users/Akshay/pyenvs/tf-1.50rc1/lib/python3.6/site-packages/tensorflow/python/ops/nn_impl.py", line 1046, in _compute_sampled_logits
    biases, all_ids, partition_strategy=partition_strategy)
  File "/Users/Akshay/pyenvs/tf-1.50rc1/lib/python3.6/site-packages/tensorflow/python/ops/embedding_ops.py", line 325, in embedding_lookup
    transform_fn=None)
  File "/Users/Akshay/pyenvs/tf-1.50rc1/lib/python3.6/site-packages/tensorflow/python/ops/embedding_ops.py", line 150, in _embedding_lookup_and_transform
    result = _clip(_gather(params[0], ids, name=name), ids, max_norm)
  File "/Users/Akshay/pyenvs/tf-1.50rc1/lib/python3.6/site-packages/tensorflow/python/ops/embedding_ops.py", line 54, in _gather
    return array_ops.gather(params, ids, name=name)
  File "/Users/Akshay/pyenvs/tf-1.50rc1/lib/python3.6/site-packages/tensorflow/python/ops/array_ops.py", line 2585, in gather
    params, indices, validate_indices=validate_indices, name=name)
  File "/Users/Akshay/pyenvs/tf-1.50rc1/lib/python3.6/site-packages/tensorflow/python/ops/gen_array_ops.py", line 1864, in gather
    validate_indices=validate_indices, name=name)
  File "/Users/Akshay/pyenvs/tf-1.50rc1/lib/python3.6/site-packages/tensorflow/python/framework/op_def_library.py", line 787, in _apply_op_helper
    op_def=op_def)
  File "/Users/Akshay/pyenvs/tf-1.50rc1/lib/python3.6/site-packages/tensorflow/python/framework/ops.py", line 3160, in create_op
    op_def=op_def)
  File "/Users/Akshay/pyenvs/tf-1.50rc1/lib/python3.6/site-packages/tensorflow/python/framework/ops.py", line 1625, in __init__
    self._traceback = self._graph._extract_stack() # pylint: disable=protected-access
```

```
InvalidArgumentError (see above for traceback): indices[0] = 3081 is not in [0, 128]
[[Node: loss/nce_loss/embedding_lookup_1 = Gather[Tindices=DT_INT64, Tparams=DT_FLOAT, _class=["loc:@nce_bias"], validate_indices=true, _device="/job:localhost/replica:0/task:0/device:CPU:0"](nce_bias/read, loss/nce_loss/concat)]]
```


What if...

You could execute TensorFlow operations **imperatively**,
directly from Python?

Eager Execution

"A NumPy-like library for numerical computation with support for GPU acceleration and automatic differentiation, and a flexible platform for machine learning research and experimentation."

- the eager execution [user guide](#)

Live Demo

```
$python  
import tensorflow # version >= 1.50  
import tensorflow.contrib.eager as tfe  
tfe.enable_eager_execution()
```

Key Advantages

- Compatible with Python debugging tools
 - `pdb.set_trace()` to your heart's content!
- Provides immediate error reporting
- Permits use of Python data structures
 - e.g., for structured input
- Enables easy, Pythonic control flow
 - `if` statements, `for` loops, recursion, oh my!

```
i = tf.constant(0)
while i < 1000:
    i = tf.add(i, 1)
    print("I could do this all day! %d" % i)
```

```
Traceback (most recent call last):
  File "04_word2vec_eager.py", line 83, in <module>
    main()
  File "04_word2vec_eager.py", line 72, in main
    loss_batch, grads = val_and_grad_fn(center_words, target_words)
  File "/Users/Akshay/pyenvs/tf-1.50rc1/lib/python3.6/site-packages/tensorflow/python/eager/backprop.py", line 349, in grad_fn
    end_node = f(*args)
  File "04_word2vec_eager.py", line 51, in word2vec
    num_classes=VOCAB_SIZE))
  File "/Users/Akshay/pyenvs/tf-1.50rc1/lib/python3.6/site-packages/tensorflow/python/ops/nn_impl.py", line 1212, in nce_loss
    name=name)
  File "/Users/Akshay/pyenvs/tf-1.50rc1/lib/python3.6/site-packages/tensorflow/python/ops/nn_impl.py", line 1046, in _compute_sampled_logits
    biases, all_ids, partition_strategy=partition_strategy)
  File "/Users/Akshay/pyenvs/tf-1.50rc1/lib/python3.6/site-packages/tensorflow/python/ops/embedding_ops.py", line 325, in embedding_lookup
    transform_fn=None)
  File "/Users/Akshay/pyenvs/tf-1.50rc1/lib/python3.6/site-packages/tensorflow/python/ops/embedding_ops.py", line 150, in _embedding_lookup_and_transform
    result = _clip(_gather(params[0], ids, name=name), ids, max_norm)
  File "/Users/Akshay/pyenvs/tf-1.50rc1/lib/python3.6/site-packages/tensorflow/python/ops/embedding_ops.py", line 52, in _gather
    return params.sparse_read(ids, name=name)
  File "/Users/Akshay/pyenvs/tf-1.50rc1/lib/python3.6/site-packages/tensorflow/python/ops/resource_variable_ops.py", line 692, in sparse_read
    self._handle, indices, dtype=self.dtype, name=name)
  File "/Users/Akshay/pyenvs/tf-1.50rc1/lib/python3.6/site-packages/tensorflow/python/ops/gen_resource_variable_ops.py", line 250, in resource_gather
    attrs=attrs, ctx=ctx, name=name)
  File "/Users/Akshay/pyenvs/tf-1.50rc1/lib/python3.6/site-packages/tensorflow/python/eager/execute.py", line 66, in quick_execute
    six.raise_from(core._status_to_exception(e.code, message), None)
  File "<string>", line 3, in raise_from
tensorflow.python.framework.errors_impl.InvalidArgumentError: indices[0] = 3081 is not in [0, 128] [Op:ResourceGather] name: nce_loss/embedding_lookup/
```



```
Traceback (most recent call last):
  File "04_word2vec_eager.py", line 83, in <module>
    main()
  File "04_word2vec_eager.py", line 72, in main
    loss_batch, grads = val_and_grad_f
  File "/Users/Akshay/pyenvs/tf-1.50rc
    end_node = f(*args)
  File "04_word2vec_eager.py", line 57,
    num_classes=VOCAB_SIZE))
  File "/Users/Akshay/pyenvs/tf-1.50rc
    name=name)
  File "/Users/Akshay/pyenvs/tf-1.50rc
    biases, all_ids, partition_strateg
  File "/Users/Akshay/pyenvs/tf-1.50rc
    transform_fn=None)
  File "/Users/Akshay/pyenvs/tf-1.50rc
    result = _clipC_gather(params[0],
  File "/Users/Akshay/pyenvs/tf-1.50rc
    return params.sparse_read(ids, nar
  File "/Users/Akshay/pyenvs/tf-1.50rc
    self._handle, indices, dtype=self.
  File "/Users/Akshay/pyenvs/tf-1.50rc
    attrs=_attrs, ctx=_ctx, name=name)
  File "/Users/Akshay/pyenvs/tf-1.50rc
    six.raise_from(core._status_to_exc
  File "<string>", line 3, in raise_fr
tensorflow.python.framework.errors_imp
```



Eager execution
simplifies *your* code

You no longer need to worry about ...

1. placeholders
2. sessions
3. control dependencies
4. "lazy loading"
5. {name, variable, op} scopes

Boilerplate

```
x = tf.placeholder(tf.float32, shape=[1, 1])
```

```
m = tf.matmul(x, x)
```

```
print(m)
```

```
# Tensor("MatMul:0", shape=(1, 1), dtype=float32)
```

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

```
    m_out = sess.run(m, feed_dict={x: [[2.]])
```

```
print(m_out)
```

```
# [[4.]]
```

Code like this...

Boilerplate

```
x = [[2.]] # No need for placeholders!
```

```
m = tf.matmul(x, x)
```

```
print(m) # No sessions!
```

```
# tf.Tensor([[4.]], shape=(1, 1), dtype=float32)
```

Becomes this

"Lazy Loading"

```
x = tf.random_uniform([2, 2])
```

```
with tf.Session() as sess:  
    for i in range(x.shape[0]):  
        for j in range(x.shape[1]):  
            print(sess.run(x[i, j]))
```

*Each iteration
adds nodes to the graph*

~~"Lazy Loading"~~

```
x = tf.random_uniform([2, 2])
```

```
for i in range(x.shape[0]):  
    for j in range(x.shape[1]):  
        print(x[i, j])
```

Tensors Act Like NumPy Arrays

```
x = tf.constant([1.0, 2.0, 3.0])
```

```
# Tensors are backed by NumPy arrays
```

```
assert type(x.numpy()) == np.ndarray
```

```
squared = np.square(x) # Tensors are compatible with NumPy functions
```

```
# Tensors are iterable!
```

```
for i in x:  
    print(i)
```

Caveat: use `tf.equal` to compare Tensors, not `==`

Gradients

Gradients

Automatic differentiation is built into eager execution

Under the hood ...

- Operations are recorded on a **tape**
- The tape is **played back** to compute gradients
 - This is reverse-mode differentiation (backpropagation).

Gradients

```
def square(x):  
    return x ** 2
```

*Differentiate w.r.t. input of
square*

```
grad = tfe.gradients_function(square)
```

```
print(square(3.))      # tf.Tensor(9., shape=(), dtype=float32)
```

```
print(grad(3.))       # [tf.Tensor(6., shape=(), dtype=float32)]
```

Gradients

Use `tfe.Variable` when eager execution is enabled.

```
x = tfe.Variable(2.0)
```

```
def loss(y):
```

```
    return (y - x ** 2) ** 2
```

Differentiate w.r.t. variables used to compute loss

```
grad = tfe.implicit_gradients(loss)
```

```
print(loss(7.)) # tf.Tensor(9., shape=(), dtype=float32)
```

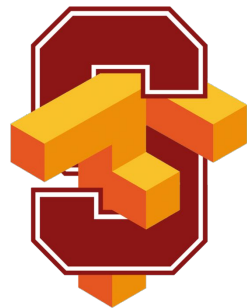
```
print(grad(7.)) # [(<tf.Tensor: -24.0, shape=(), dtype=float32>,  
                  <tf.Variable 'Variable:0' shape=()  
                  dtype=float32, numpy=2.0>)]
```

Gradients

APIs for computing gradients work even when eager execution is not enabled

- `tfe.gradients_function()`
- `tfe.value_and_gradients_function()`
- `tfe.implicit_gradients()`
- `tfe.implicit_value_and_gradients()`

See the [user guide for documentation](#)



Huber Regression with Eager Execution

Interactive Coding

`04_regression_eager_starter.py`

It's not *that* different

A Collection of Operations

TensorFlow = Operation Kernels + Execution

- Graph construction: Execute compositions of operations with Sessions
- Eager execution: Execute compositions with Python

A Collection of Operations

Majority of TF API works regardless of whether eager execution is enabled.

- But, when eager execution is enabled ...
 - prefer `tfe.Variable` under eager execution (compatible with graph construction)
 - manage your own variable storage — variable collections are not supported!
 - use `tf.contrib.summary`
 - use `tfe.Iterator` to iterate over datasets under eager execution
 - prefer object-oriented layers (e.g., `tf.layers.Dense`)
 - functional layers (e.g., `tf.layers.dense`) only work if wrapped in `tfe.make_template`
 - prefer `tfe.py_func` over `tf.py_func`
- See the [user guide](#) for details and updates

What if I like graphs?

Graphs are ...

- Optimizable
 - automatic buffer reuse
 - constant folding
 - inter-op parallelism
 - automatic trade-off between compute and memory
- Deployable
 - the Graph is an *intermediate representation* for models
- Rewritable
 - experiment with automatic device placement or quantization

Imperative to declarative and back

- **Write model definition code once**
 - The same code can execute operations in one Python process and construct graphs in another (see [user guide/examples](#))
- **Checkpoints are compatible**
 - Train eagerly, checkpoint, load in a graph, or vice-versa
- **Create graphs while eager execution is enabled:**
 - `tfe.defun`: "Compile" computation into graphs and execute them.

So when should I use eager execution?

Use eager if you're ...

- **a researcher and want a flexible framework**
 - python control flow and data structures enable experimentation
- **developing a new model**
 - immediate error reporting simplifies debugging
- **new to TensorFlow**
 - eager execution lets you explore the TF API in the Python REPL

Status

- Available in version 1.5 of TensorFlow (`import tf.contrib.eager as tfe`)
- Single GPU, ResNet benchmark performance comparable to graphs
- Under active development
 - Overheads on smaller operations are significant
 - Distributed support is in the works
 - Not all TF APIs are eager-compatible

Further reading

Read the [user guide](#) to learn about ...

- High-level, Keras-like APIs for constructing models
 - `tfe.Network`, `tf.layers.Layer`
- Checkpointing variables
- Summaries and tensorboard
- Custom gradients for numerical stability
- Using GPUs

Check out the [examples folder](#) for idiomatic code

Links

- [Research blog post](#)
- [README](#)
- [User guide](#)
- [Idiomatic model examples](#)
- [Survey paper on autodiff for machine learning](#)
- [Github issues page](#)
 - Found a bug? Want a feature? Create an issue!
- Feedback: akshayka@google.com

Next class

Variable sharing

Manage experiments

Autodiff

Feedback: huyenn@stanford.edu

Thanks!