Tools & Models for Data Science

Deep Learning with TensorFlow

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This Lecture...

- Is meant to de-mystify RNNA6.py
  - RNNA6.py is the code we give you with A6
  - Use this lecture + the Internet when you puzzle over the code

What Is TensorFlow?

- Has many components...
- Including a distributed computation engine
- But for our purposes, it is an automatic differentiation engine
  - That is, you specify an “forward” process (the inference process)
  - And it automatically figures out a gradient descent algorithm (the “backward” or learning process)
  - Even if you have a complicated forward process, it will differentiate it for you
  - Even something complicated like an RNN
  - TF will also allow you to efficiently execute the backward propagation algorithm over data

How to Specific A Forward Process

- You push tensors through various computations TF provides
  - A “tensor” is a generalization of a matrix/vector
  - Can have any number of dimensions
  - Tensors are TF’s most fundamental data type
  - Everything is based off of them

Data Types in TensorFlow

- Use floats (32-bit representation)
  - Support for doubles (64-bit) is not great
  - Added in later in TF
  - The extra bits are just not that important in ML
  - Millions of neurons, working together can withstand a lot of inaccuracy from loss of precision
  - Shorter representation can speed computation

Two Kinds of Tensors in Forward Process

- 1) Placeholders
  - These are tensors whose value will be provided at training time
  - They are inputs into the forward process
  - Declared like

```
inputX = tf.placeholder
  (tf.float32, [batchSize, 256 * maxSeqLen])
```

- `batchSize` = size of mini-batch used
- `256` = one hot encoding (256 characters)
- `maxSeqLen` = max length of line of text
- `[batchSize, 256 * maxSeqLen]` = 2D tensor dimensions

Two Kinds of Tensors in Forward Process

- (2) Variables
  - These are tensors whose value will be learned
  - They are computed during the backward process
  - Declared like

```
b = tf.Variable(np.zeros((1, hiddenUnits)), dtype=tf.float32)
```

- `(1, hiddenUnits)` = initialization dimensions

Constructing the Forward Process

- The forward process is specified by composing operators over tensors
- Example:

```
next_state = tf.tanh(tf.matmul(inputPlusState, W) + b)
```

- In this line of code, operators are “tanh”, “matmul,” and “+”
  - Note: TF does not actually run these operators!
  - It remembers how you composed them
  - And uses those computations to build the backward process later
- `inputPlusState` = characters concatenated with the next state
- `W` = Weight matrix
- `b` = bias
- Recall: The input to a layer is a matrix multiplication of the weights and the outputs from the prior layer

Another Interesting Operation

- The “unstack” operation
- Example:

```
sequenceOfLetters = tf.unstack(inputX, axis=2)
```

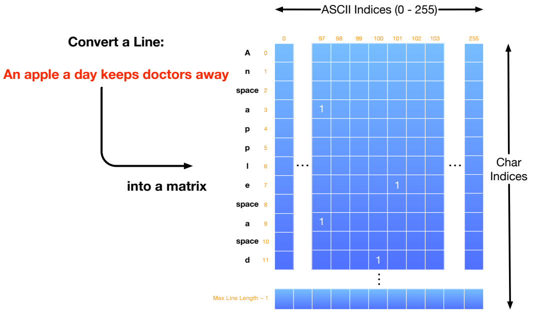
- Takes a d dimension tensor
- And converts it to a list of d, $d-1$ dimension tensors
- Useful if you want to iterate through a tensor
- In RNNA6, we want to iterate through the lines of text

Alternative to Unstack

- Could have “maxSeqLen” different 2-d tensors
- Then would not have to unstack
- But this may be less convenient

Input Data

- Batches of 2D tensors stored as a dictionary
- Key: Line number (sequentially assigned)
- Value: Pair of (class, One-hot-encoding of the character)
- Where
  - Dimension 1: Character in the line
  - Dimension 2: One-hot-encoding of the character
  - Lines are padded to make them the same length



Batches

Convert A Batch of lines:

A batch
of 100 lines

To Sherlock Holmes she is always THE woman. I have seldom heard him mention her under any other name. In his eyes she eclipses and predominates the whole of her sex. It was not that he felt any emotion akin to love for Irene Adler. All emotions, and that

⋮

lenses, would not be more disturbing than a strong emotion in a nature such as his. And yet there was but one woman to him, and that woman was the late Irene Adler, of dubious and questionable memory.

into a 3-D Matrix

Cross Entropy Loss for Classification

- Measures how close a prediction (from a vector of probabilities) is to the actual label
- Probabilities come from a softmax function
- We want high probabilities to go to the correct labels
- Cross entropy is:

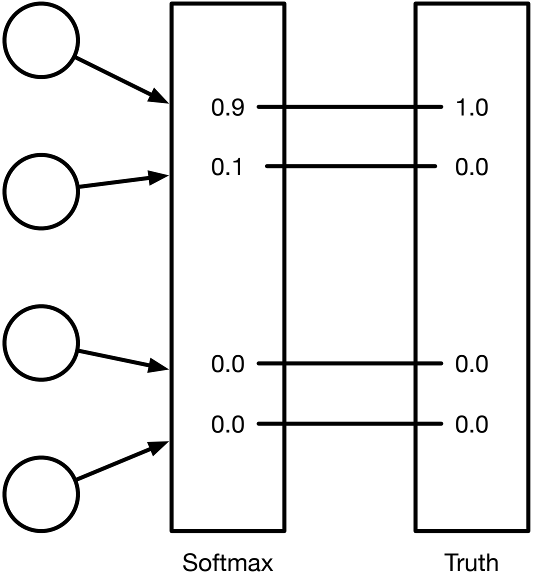
$$H(p,q) = -\sum_{x} p(x) \log q(x)$$

- We want to minimize it!
- Used as the loss function in training

Cross Entropy Loss for Classification

- For probability distribution q spit out by the learner
  - Where (for example) $q(2) = .3$ means the learner thinks there is a $.3$ chance class is 2
  - And an answer distribution p
  - Where $p(i) = 1$ if answer is class i, 0 otherwise
- Cross entropy is:

$$H(p,q) = -\sum_x p(x) \log q(x)$$



Cross-Entropy in TensorFlow

- Trivially implemented in TF
- They give you an operator for it

```
losses = tf.nn.sparse_softmax_cross_entropy_with_logits
          (logits=outputs, labels=inputY)
```

- Input to function (outputs in this case) is output from tanh functions at top of the NN
- There should be one tanh output per class per data point
- Also accepts a vector with the correct labels
- TF does softmax and compares predictions with the truth
- Then computes cross entropy

Learning

- TF has many different gradient-based algorithms to choose from
  - Switching between them means changing one line of code
  - Ex:

```
trainingAlg = tf.train.AdagradOptimizer
     (0.02).minimize(totalLoss)
```

- This (obviously) runs the Adagrad algorithm (look it up!)
- Alternative to gradient descent
- 0.02 is the learning rate

Invoking One Iter of Gradient Descent

```
_totalLoss, _trainingAlg, _currentState,
     _predictions, _outputs = sess.run(
    [totalLoss, trainingAlg, currentState,
     predictions, outputs],
    feed_dict={
         inputX:x,
         inputY:y,
         initialState:_currentState
    })
```

- Args to “run”:
  - “feed_dict” should tell TF what values to use for each placeholder
  - You miss a placeholder? TF will complain
  - List of vars (totalLoss, trainingAlg, etc)... what are they for?
  - Tells TF any Variables whose values you want returned
  - Given back to you as NumPy arrays

Invoking One Iter of Gradient Descent

```
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    })
```

- `sess.run`: 1 iteration
- `_currentState`: numpy matrix of hidden states; all zeros initially, 1st value for hidden states
- Watch the values of the tensors returned

Accessing Variables

- Just ask “run” to return it
  - Like in last slide
  - Or, just use

```
sess.run (W)
```

- Will return last val of W as a NumPy array

Saving Sessions

- When a training session ends, it is gone
- But you can save it

```
saver = tf.train.Saver()
saver.save(sess, 'checkPoint.tf')
```

- Then later can load it up again

```
sess = tf.Session()
saver = tf.train.Saver()
saver.restore(sess, 'checkPoint.tf')
```

- Very useful!!

My Code Doesn't work!

- Make sure your NN is correctly connected
  - Check sizes and shapes of tensors
  - Check the input data
- Monitor the objective function / loss
- Check the initialization (note small variance)
- Check the number of hidden units
- Print out information at each iteration
- Restructure the code to be able to work with it interactively

Questions?