

Nick McClure

TensorFlow Machine Learning Cookbook

Explore machine learning concepts using the latest numerical computing library – TensorFlow – with the help of this comprehensive cookbook



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BIRMINGHAM - MUMBAI

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Preface

TensorFlow was open sourced in November of 2015 by Google, and since then it has become the most starred machine learning repository on GitHub. TensorFlow's popularity is due to the approach of creating computational graphs, automatic differentiation, and customizability. Because of these features, TensorFlow is a very powerful and adaptable tool that can be used to solve many different machine learning problems.

This book addresses many machine learning algorithms, applies them to real situations and data, and shows how to interpret the results.

What this book covers

Chapter 1, Getting Started with TensorFlow, covers the main objects and concepts in TensorFlow. We introduce tensors, variables, and placeholders. We also show how to work with matrices and various mathematical operations in TensorFlow. At the end of the chapter we show how to access the data sources used in the rest of the book.

Chapter 2, The TensorFlow Way, establishes how to connect all the algorithm components from *Chapter 1* into a computational graph in multiple ways to create a simple classifier. Along the way, we cover computational graphs, loss functions, back propagation, and training with data.

Chapter 3, Linear Regression, focuses on using TensorFlow for exploring various linear regression techniques, such as Deming, lasso, ridge, elastic net, and logistic regression. We show how to implement each in a TensorFlow computational graph.

Chapter 4, Support Vector Machines, introduces support vector machines (SVMs) and shows how to use TensorFlow to implement linear SVMs, non-linear SVMs, and multi-class SVMs.

Chapter 5, Nearest Neighbor Methods, shows how to implement nearest neighbor techniques using numerical metrics, text metrics, and scaled distance functions. We use nearest neighbor techniques to perform record matching among addresses and to classify hand-written digits from the MNIST database.

Chapter 6, Neural Networks, covers how to implement neural networks in TensorFlow, starting with the operational gates and activation function concepts. We then show a shallow neural network and show how to build up various different types of layers. We end the chapter by teaching TensorFlow to play tic-tac-toe via a neural network method.

Chapter 7, Natural Language Processing, illustrates various text processing techniques with TensorFlow. We show how to implement the bag-of-words technique and TF-IDF for text. We then introduce neural network text representations with CBOW and skip-gram and use these techniques for Word2Vec and Doc2Vec for making real-world predictions.

Chapter 8, Convolutional Neural Networks, expands our knowledge of neural networks by illustrating how to use neural networks on images with convolutional neural networks (CNNs). We show how to build a simple CNN for MNIST digit recognition and extend it to color images in the CIFAR-10 task. We also illustrate how to extend prior trained image recognition models for custom tasks. We end the chapter by explaining and showing the stylenet/neural style and deep-dream algorithms in TensorFlow.

Chapter 9, Recurrent Neural Networks, explains how to implement recurrent neural networks (RNNs) in TensorFlow. We show how to do text-spam prediction, and expand the RNN model to do text generation based on Shakespeare. We also train a sequence to sequence model for German-English translation. We finish the chapter by showing the usage of Siamese RNN networks for record matching on addresses.

Chapter 10, Taking TensorFlow to Production, gives tips and examples on moving TensorFlow to a production environment and how to take advantage of multiple processing devices (for example GPUs) and setting up TensorFlow distributed on multiple machines.

Chapter 11, More with TensorFlow, show the versatility of TensorFlow by illustrating how to do k-means, genetic algorithms, and solve a system of ordinary differential equations (ODEs). We also show the various uses of Tensorboard, and how to view computational graph metrics.

What you need for this book

The recipes in this book use TensorFlow, which is available at <https://www.tensorflow.org/> and are based on Python 3, available at <https://www.python.org/downloads/>. Most of the recipes will require the use of an Internet connection to download the necessary data.

Who this book is for

The TensorFlow Machine Learning Cookbook is for users that have some experience with machine learning and some experience with Python programming. Users with an extensive machine learning background may find the TensorFlow code enlightening, and users with an extensive Python programming background may find the explanations helpful.

Sections

In this book, you will find several headings that appear frequently (Getting ready, How to do it..., How it works..., There's more..., and See also).

To give clear instructions on how to complete a recipe, we use these sections as follows:

Getting ready

This section tells you what to expect in the recipe, and describes how to set up any software or any preliminary settings required for the recipe.

How to do it...

This section contains the steps required to follow the recipe.

How it works...

This section usually consists of a detailed explanation of what happened in the previous section.

There's more...

This section consists of additional information about the recipe in order to make the reader more knowledgeable about the recipe.

See also

This section provides helpful links to other useful information for the recipe.

Conventions

In this book, there are many styles of text that distinguish between the types of information. Code words in text are shown as follows: "We then set the `batch_size` variable."

A block of code is set as follows:

```
embedding_mat = tf.Variable(tf.random_uniform([vocab_size, embedding_size], -1.0, 1.0))
embedding_output = tf.nn.embedding_lookup(embedding_mat, x_data_ph)
```

Some code blocks will have output associated with that code, and we note this in the code block as follows:

```
print('Training Accuracy: {}' .format(accuracy))
```

Which results in the following output:

```
Training Accuracy: 0.878171
```

Important words are shown in bold.



Warnings or important notes appear in a box like this.



Tips and tricks appear like this.

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1

Getting Started with TensorFlow

In this chapter, we will cover basic recipes in order to understand how TensorFlow works and how to access data for this book and additional resources. By the end of the chapter, you should have knowledge of the following:

- ▶ How TensorFlow Works
- ▶ Declaring Variables and Tensors
- ▶ Using Placeholders and Variables
- ▶ Working with Matrices
- ▶ Declaring Operations
- ▶ Implementing Activation Functions
- ▶ Working with Data Sources
- ▶ Additional Resources

Introduction

Google's TensorFlow engine has a unique way of solving problems. This unique way allows us to solve machine learning problems very efficiently. Machine learning is used in almost all areas of life and work, but some of the more famous areas are computer vision, speech recognition, language translations, and healthcare. We will cover the basic steps to understand how TensorFlow operates and eventually build up to production code techniques later in the book. These fundamentals are important in order to understand the recipes in the rest of this book.

How TensorFlow Works

At first, computation in TensorFlow may seem needlessly complicated. But there is a reason for it: because of how TensorFlow treats computation, developing more complicated algorithms is relatively easy. This recipe will guide us through the pseudocode of a TensorFlow algorithm.

Getting ready

Currently, TensorFlow is supported on Linux, Mac, and Windows. The code for this book has been created and run on a Linux system, but should run on any other system as well. The code for the book is available on GitHub at https://github.com/nfmccclure/tensorflow_cookbookTensorFlow. Throughout this book, we will only concern ourselves with the Python library wrapper of TensorFlow, although most of the original core code for TensorFlow is written in C++. This book will use Python 3.4+ (<https://www.python.org>) and TensorFlow 0.12 (<https://www.tensorflow.org>). TensorFlow has a 1.0.0 alpha version available on the official GitHub site, and the code in this book has been reviewed to be compatible with that version as well. While TensorFlow can run on the CPU, most algorithms run faster if processed on the GPU, and it is supported on graphics cards with Nvidia Compute Capability v4.0+ (v5.1 recommended). Popular GPUs for TensorFlow are Nvidia Tesla architectures and Pascal architectures with at least 4 GB of video RAM. To run on a GPU, you will also need to download and install the Nvidia Cuda Toolkit and also v 5.x+ (<https://developer.nvidia.com/cuda-downloads>). Some of the recipes will rely on a current installation of the Python packages: Scipy, Numpy, and Scikit-Learn. These accompanying packages are also all included in the Anaconda package (<https://www.continuum.io/downloads>).

How to do it...

Here we will introduce the general flow of TensorFlow algorithms. Most recipes will follow this outline:

1. **Import or generate datasets:** All of our machine-learning algorithms will depend on datasets. In this book, we will either generate data or use an outside source of datasets. Sometimes it is better to rely on generated data because we will just want to know the expected outcome. Most of the time, we will access public datasets for the given recipe and the details on accessing these are given in section 8 of this chapter.
2. **Transform and normalize data:** Normally, input datasets do not come in the shape TensorFlow would expect so we need to transform TensorFlow them to the accepted shape. The data is usually not in the correct dimension or type that our algorithms expect. We will have to transform our data before we can use it. Most algorithms also expect normalized data and we will do this here as well. TensorFlow has built-in functions that can normalize the data for you as follows:

```
data = tf.nn.batch_norm_with_global_normalization(...)
```

3. **Partition datasets into train, test, and validation sets:** We generally want to test our algorithms on different sets that we have trained on. Also, many algorithms require hyperparameter tuning, so we set aside a validation set for determining the best set of hyperparameters.
4. **Set algorithm parameters (hyperparameters):** Our algorithms usually have a set of parameters that we hold constant throughout the procedure. For example, this can be the number of iterations, the learning rate, or other fixed parameters of our choosing. It is considered good form to initialize these together so the reader or user can easily find them, as follows:

```
learning_rate = 0.01
batch_size = 100
iterations = 1000
```

5. **Initialize variables and placeholders:** TensorFlow depends on knowing what it can and cannot modify. TensorFlow will modify/adjust the variables and weight/bias during optimization to minimize a `loss` function. To accomplish this, we feed in data through placeholders. We need to initialize both of these variables and placeholders with size and type, so that TensorFlow knows what to expect. TensorFlow also needs to know the type of data to expect: for most of this book, we will use `float32`. TensorFlow also provides `float64` and `float16`. Note that the more bytes used for precision results in slower algorithms, but the less we use results in less precision. See the following code:

```
a_var = tf.constant(42)
x_input = tf.placeholder(tf.float32, [None, input_size])
y_input = tf.placeholder(tf.float32, [None, num_classes])
```

6. **Define the model structure:** After we have the data, and have initialized our variables and placeholders, we have to define the model. This is done by building a computational graph. TensorFlow chooses what operations and values must be the variables and placeholders to arrive at our model outcomes. We talk more in depth about computational graphs in the *Operations in a Computational Graph* TensorFlow recipe in *Chapter 2, The TensorFlow Way*. Our model for this example will be a linear model:

```
y_pred = tf.add(tf.mul(x_input, weight_matrix), b_matrix)
```

7. **Declare the loss functions:** After defining the model, we must be able to evaluate the output. This is where we declare the `loss` function. The `loss` function is very important as it tells us how far off our predictions are from the actual values. The different types of `loss` functions are explored in greater detail, in the *Implementing Back Propagation* recipe in *Chapter 2, The TensorFlow Way*:

```
loss = tf.reduce_mean(tf.square(y_actual - y_pred))
```

8. **Initialize and train the model:** Now that we have everything in place, we need to create an instance of our graph, feed in the data through the placeholders, and let TensorFlow change the variables to better predict our training data. Here is one way to initialize the computational graph:

```
with tf.Session(graph=graph) as session:  
    ...  
    session.run(...)  
    ...
```

Note that we can also initiate our graph with:

```
session = tf.Session(graph=graph)  
session.run(...)
```

9. **Evaluate the model:** Once we have built and trained the model, we should evaluate the model by looking at how well it does with new data through some specified criteria. We evaluate on the train and test set and these evaluations will allow us to see if the model is underfit or overfit. We will address these in later recipes.
10. **Tune hyperparameters:** Most of the time, we will want to go back and change some of the hyperparameters, based on the model performance. We then repeat the previous steps with different hyperparameters and evaluate the model on the validation set.
11. **Deploy/predict new outcomes:** It is also important to know how to make predictions on new, unseen, data. We can do this with all of our models, once we have them trained.

How it works...

In TensorFlow, we have to set up the data, variables, placeholders, and model before we tell the program to train and change the variables to improve the predictions. TensorFlow accomplishes this through the computational graphs. These computational graphs are a directed graphs with no recursion, which allows for computational parallelism. We create a loss function for TensorFlow to minimize. TensorFlow accomplishes this by modifying the variables in the computational graph. TensorFlow knows how to modify the variables because it keeps track of the computations in the model and automatically computes the gradients for every variable. Because of this, we can see how easy it can be to make changes and try different data sources.

See also

- ▶ A great place to start is to go through the official documentation of the TensorFlow Python API section at https://www.tensorflow.org/api_docs/python/
- ▶ There are also tutorials available at: <https://www.tensorflow.org/tutorials/>

Declaring Tensors

Tensors are the primary data structure that TensorFlow uses to operate on the computational graph. We can declare these tensors as variables and or feed them in as placeholders. First we must know how to create tensors.

Getting ready

When we create a tensor and declare it to be a variable, TensorFlow creates several graph structures in our computation graph. It is also important to point out that just by creating a tensor, TensorFlow is not adding anything to the computational graph. TensorFlow does this only after creating available out of the tensor. See the next section on variables and placeholders for more information.

How to do it...

Here we will cover the main ways to create tensors in TensorFlow:

1. Fixed tensors:
 - ❑ Create a zero filled tensor. Use the following:

```
zero_tsr = tf.zeros([row_dim, col_dim])
```
 - ❑ Create a one filled tensor. Use the following:

```
ones_tsr = tf.ones([row_dim, col_dim])
```
 - ❑ Create a constant filled tensor. Use the following:

```
filled_tsr = tf.fill([row_dim, col_dim], 42)
```
 - ❑ Create a tensor out of an existing constant. Use the following:

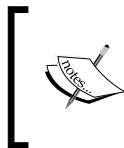
```
constant_tsr = tf.constant([1,2,3])
```



Note that the `tf.constant()` function can be used to broadcast a value into an array, mimicking the behavior of `tf.fill()` by writing `tf.constant(42, [row_dim, col_dim])`

2. Tensors of similar shape:
 - ❑ We can also initialize variables based on the shape of other tensors, as follows:

```
zeros_similar = tf.zeros_like(constant_tsr)
ones_similar = tf.ones_like(constant_tsr)
```



Note, that since these tensors depend on prior tensors, we must initialize them in order. Attempting to initialize all the tensors all at once will result in an error. See the section *There's more...* at the end of the next chapter on variables and placeholders.

3. Sequence tensors:

- ❑ TensorFlow allows us to specify tensors that contain defined intervals. The following functions behave very similarly to the `range()` outputs and numpy's `linspace()` outputs. See the following function:
`linear_tsr = tf.linspace(start=0, stop=1, start=3)`
- ❑ The resulting tensor is the sequence [0.0, 0.5, 1.0]. Note that this function includes the specified stop value. See the following function:
`integer_seq_tsr = tf.range(start=6, limit=15, delta=3)`
- ❑ The result is the sequence [6, 9, 12]. Note that this function does not include the limit value.

4. Random tensors:

- ❑ The following generated random numbers are from a uniform distribution:
`randunif_tsr = tf.random_uniform([row_dim, col_dim], minval=0, maxval=1)`
- ❑ Note that this random uniform distribution draws from the interval that includes the `minval` but not the `maxval` (`minval <= x < maxval`).
- ❑ To get a tensor with random draws from a normal distribution, as follows:
`randnorm_tsr = tf.random_normal([row_dim, col_dim], mean=0.0, stddev=1.0)`
- ❑ There are also times when we wish to generate normal random values that are assured within certain bounds. The `truncated_normal()` function always picks normal values within two standard deviations of the specified mean. See the following:
`runcnorm_tsr = tf.truncated_normal([row_dim, col_dim], mean=0.0, stddev=1.0)`

- We might also be interested in randomizing entries of arrays. To accomplish this, there are two functions that help us: `random_shuffle()` and `random_crop()`. See the following:

```
shuffled_output = tf.random_shuffle(input_tensor)
cropped_output = tf.random_crop(input_tensor, crop_size)
```

- Later on in this book, we will be interested in randomly cropping an image of size (height, width, 3) where there are three color spectrums. To fix a dimension in the `cropped_output`, you must give it the maximum size in that dimension:

```
cropped_image = tf.random_crop(my_image, [height/2, width/2, 3])
```

How it works...

Once we have decided on how to create the tensors, then we may also create the corresponding variables by wrapping the tensor in the `Variable()` function, as follows. More on this in the next section:

```
my_var = tf.Variable(tf.zeros([row_dim, col_dim]))
```

There's more...

We are not limited to the built-in functions. We can convert any `numpy` array to a Python list, or constant to a tensor using the function `convert_to_tensor()`. Note that this function also accepts tensors as an input in case we wish to generalize a computation inside a function.

Using Placeholders and Variables

Placeholders and variables are key tools for using computational graphs in TensorFlow. We must understand the difference and when to best use them to our advantage.

Getting ready

One of the most important distinctions to make with the data is whether it is a placeholder or a variable. Variables are the parameters of the algorithm and TensorFlow keeps track of how to change these to optimize the algorithm. Placeholders are objects that allow you to feed in data of a specific type and shape and depend on the results of the computational graph, such as the expected outcome of a computation.

How to do it...

The main way to create a variable is by using the `Variable()` function, which takes a tensor as an input and outputs a variable. This is the declaration and we still need to initialize the variable. Initializing is what puts the variable with the corresponding methods on the computational graph. Here is an example of creating and initializing a variable:

```
my_var = tf.Variable(tf.zeros([2,3]))
sess = tf.Session()
initialize_op = tf.global_variables_initializer()
sess.run(initialize_op)
```

To see what the computational graph looks like after creating and initializing a variable, see the next part in this recipe.

Placeholders are just holding the position for data to be fed into the graph. Placeholders get data from a `feed_dict` argument in the session. To put a placeholder in the graph, we must perform at least one operation on the placeholder. We initialize the graph, declare `x` to be a placeholder, and define `y` as the identity operation on `x`, which just returns `x`. We then create data to feed into the `x` placeholder and run the identity operation. It is worth noting that TensorFlow will not return a self-referenced placeholder in the feed dictionary. The code is shown here and the resulting graph is shown in the next section:

```
sess = tf.Session()
x = tf.placeholder(tf.float32, shape=[2,2])
y = tf.identity(x)
x_vals = np.random.rand(2,2)
sess.run(y, feed_dict={x: x_vals})
# Note that sess.run(x, feed_dict={x: x_vals}) will result in a self-referencing error.
```

How it works...

The computational graph of initializing a variable as a tensor of zeros is shown in the following figure:

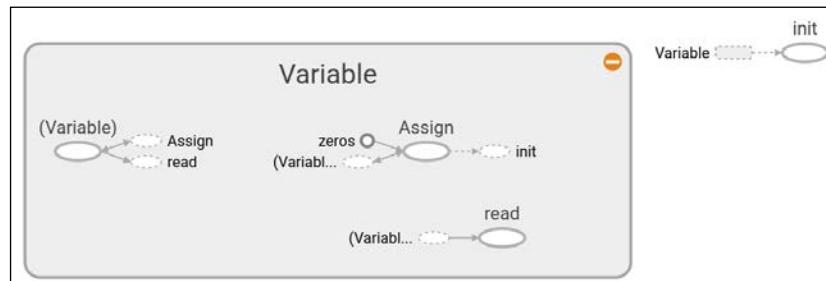


Figure 1: Variable

In *Figure 1*, we can see what the computational graph looks like in detail with just one variable, initialized to all zeros. The grey shaded region is a very detailed view of the operations and constants involved. The main computational graph with less detail is the smaller graph outside of the grey region in the upper right corner. For more details on creating and visualizing graphs, see *Chapter 10, Taking TensorFlow to Production*, section 1.

Similarly, the computational graph of feeding a numpy array into a placeholder can be seen in the following figure:

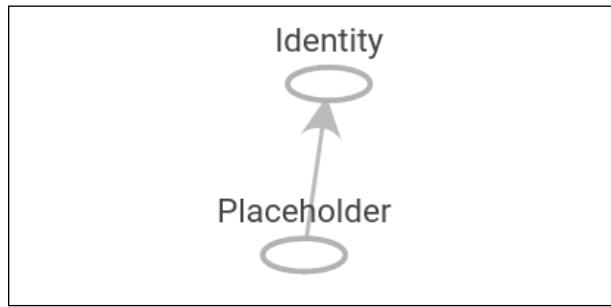


Figure 2: Here is the computational graph of a placeholder initialized. The grey shaded region is a very detailed view of the operations and constants involved. The main computational graph with less detail is the smaller graph outside of the grey region in the upper right.

There's more...

During the run of the computational graph, we have to tell TensorFlow when to initialize the variables we have created. TensorFlow must be informed about when it can initialize the variables. While each variable has an `initializer` method, the most common way to do this is to use the `helper` function, which is `global_variables_initializer()`. This function creates an operation in the graph that initializes all the variables we have created, as follows:

```
initializer_op = tf.global_variables_initializer()
```

But if we want to initialize a variable based on the results of initializing another variable, we have to initialize variables in the order we want, as follows:

```
sess = tf.Session()
first_var = tf.Variable(tf.zeros([2,3]))
sess.run(first_var.initializer)
second_var = tf.Variable(tf.zeros_like(first_var))
# Depends on first_var
sess.run(second_var.initializer)
```

Working with Matrices

Understanding how TensorFlow works with matrices is very important to understanding the flow of data through computational graphs.

Getting ready

Many algorithms depend on matrix operations. TensorFlow gives us easy-to-use operations to perform such matrix calculations. For all of the following examples, we can create a graph session by running the following code:

```
import tensorflow as tf
sess = tf.Session()
```

How to do it...

1. **Creating matrices:** We can create two-dimensional matrices from numpy arrays or nested lists, as we described in the earlier section on tensors. We can also use the tensor creation functions and specify a two-dimensional shape for functions such as `zeros()`, `ones()`, `truncated_normal()`, and so on. TensorFlow also allows us to create a diagonal matrix from a one-dimensional array or list with the function `diag()`, as follows:

```
identity_matrix = tf.diag([1.0, 1.0, 1.0])
A = tf.truncated_normal([2, 3])
B = tf.fill([2,3], 5.0)
C = tf.random_uniform([3,2])
D = tf.convert_to_tensor(np.array([[1., 2., 3.], [-3., -7.,
-1.],[0., 5., -2.]]))
print(sess.run(identity_matrix))
[[ 1.  0.  0.]
 [ 0.  1.  0.]
 [ 0.  0.  1.]]
print(sess.run(A))
[[ 0.96751703  0.11397751 -0.3438891 ]
 [-0.10132604 -0.8432678   0.29810596]]
print(sess.run(B))
[[ 5.  5.  5.]
 [ 5.  5.  5.]]
print(sess.run(C))
[[ 0.33184157  0.08907614]
 [ 0.53189191  0.67605299]
 [ 0.95889051  0.67061249]]
```

```
print(sess.run(D))  
[[ 1.  2.  3.]  
 [-3. -7. -1.]  
 [ 0.  5. -2.]]
```

 Note that if we were to run `sess.run(C)` again, we would reinitialize the random variables and end up with different random values.

2. Addition and subtraction uses the following function:

```
print(sess.run(A+B))  
[[ 4.61596632  5.39771316  4.4325695 ]  
 [ 3.26702736  5.14477345  4.98265553]]  
print(sess.run(B-B))  
[[ 0.  0.  0.]  
 [ 0.  0.  0.]]  
Multiplication  
print(sess.run(tf.matmul(B, identity_matrix)))  
[[ 5.  5.  5.]  
 [ 5.  5.  5.]]
```

3. Also, the function `matmul()` has arguments that specify whether or not to transpose the arguments before multiplication or whether each matrix is sparse.
4. Transpose the arguments as follows:

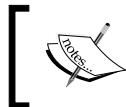
```
print(sess.run(tf.transpose(C)))  
[[ 0.67124544  0.26766731  0.99068872]  
 [ 0.25006068  0.86560275  0.58411312]]
```

5. Again, it is worth mentioning the reinitializing that gives us different values than before.
6. For the determinant, use the following:

```
print(sess.run(tf.matrix_determinant(D)))  
-38.0
```

□ Inverse:

```
print(sess.run(tf.matrix_inverse(D)))  
[[-0.5         -0.5         -0.5         ]  
 [ 0.15789474  0.05263158  0.21052632]  
 [ 0.39473684  0.13157895  0.02631579]]
```



Note that the inverse method is based on the Cholesky decomposition if the matrix is symmetric positive definite or the LU decomposition otherwise.



7. Decompositions:

- For the Cholesky decomposition, use the following:

```
print(sess.run(tf.cholesky(identity_matrix)))  
[[ 1.  0.  1.]  
 [ 0.  1.  0.]  
 [ 0.  0.  1.]]
```

8. For Eigenvalues and eigenvectors, use the following code:

```
print(sess.run(tf.self_adjoint_eig(D))  
[[ -10.65907521 -0.22750691  2.88658212]  
 [  0.21749542   0.63250104 -0.74339638]  
 [  0.84526515   0.2587998   0.46749277]  
 [ -0.4880805    0.73004459  0.47834331]]
```

Note that the function `self_adjoint_eig()` outputs the eigenvalues in the first row and the subsequent vectors in the remaining vectors. In mathematics, this is known as the Eigen decomposition of a matrix.

How it works...

TensorFlow provides all the tools for us to get started with numerical computations and adding such computations to our graphs. This notation might seem quite heavy for simple matrix operations. Remember that we are adding these operations to the graph and telling TensorFlow what tensors to run through those operations. While this might seem verbose now, it helps to understand the notations in later chapters, when this way of computation will make it easier to accomplish our goals.

Declaring Operations

Now we must learn about the other operations we can add to a TensorFlow graph.

Getting ready

Besides the standard arithmetic operations, TensorFlow provides us with more operations that we should be aware of. We need to know how to use them before proceeding. Again, we can create a graph session by running the following code:

```
import tensorflow as tf
sess = tf.Session()
```

How to do it...

TensorFlow has the standard operations on tensors: `add()`, `sub()`, `mul()`, and `div()`. Note that all of these operations in this section will evaluate the inputs element-wise unless specified otherwise:

1. TensorFlow provides some variations of `div()` and relevant functions.
2. It is worth mentioning that `div()` returns the same type as the inputs. This means it really returns the floor of the division (akin to Python 2) if the inputs are integers. To return the Python 3 version, which casts integers into floats before dividing and always returning a float, TensorFlow provides the function `truediv()` function, as shown as follows:

```
print(sess.run(tf.div(3,4)))
0
print(sess.run(tf.truediv(3,4)))
0.75
```

3. If we have floats and want an integer division, we can use the function `floordiv()`. Note that this will still return a float, but rounded down to the nearest integer. The function is shown as follows:

```
print(sess.run(tf.floordiv(3.0,4.0)))
0.0
```

4. Another important function is `mod()`. This function returns the remainder after the division. It is shown as follows:

```
print(sess.run(tf.mod(22.0, 5.0)))
2.0
```

5. The cross-product between two tensors is achieved by the `cross()` function. Remember that the cross-product is only defined for two three-dimensional vectors, so it only accepts two three-dimensional tensors. The function is shown as follows:

```
print(sess.run(tf.cross([1., 0., 0.], [0., 1., 0.])))  
[ 0.  0.  1.0]
```

6. Here is a compact list of the more common math functions. All of these functions operate elementwise.

<code>abs()</code>	Absolute value of one input tensor
<code>ceil()</code>	Ceiling function of one input tensor
<code>cos()</code>	Cosine function of one input tensor
<code>exp()</code>	Base e exponential of one input tensor
<code>floor()</code>	Floor function of one input tensor
<code>inv()</code>	Multiplicative inverse (1/x) of one input tensor
<code>log()</code>	Natural logarithm of one input tensor
<code>maximum()</code>	Element-wise max of two tensors
<code>minimum()</code>	Element-wise min of two tensors
<code>neg()</code>	Negative of one input tensor
<code>pow()</code>	The first tensor raised to the second tensor element-wise
<code>round()</code>	Rounds one input tensor
<code>rsqrt()</code>	One over the square root of one tensor
<code>sign()</code>	Returns -1, 0, or 1, depending on the sign of the tensor
<code>sin()</code>	Sine function of one input tensor
<code>sqrt()</code>	Square root of one input tensor
<code>square()</code>	Square of one input tensor

7. **Specialty mathematical functions:** There are some special math functions that get used in machine learning that are worth mentioning and TensorFlow has built in functions for them. Again, these functions operate element-wise, unless specified otherwise:

digamma ()	Psi function, the derivative of the lgamma () function
erf ()	Gaussian error function, element-wise, of one tensor
erfc ()	Complimentary error function of one tensor
igamma ()	Lower regularized incomplete gamma function
igammac ()	Upper regularized incomplete gamma function
lbeta ()	Natural logarithm of the absolute value of the beta function
lgamma ()	Natural logarithm of the absolute value of the gamma function
squared_difference ()	Computes the square of the differences between two tensors

How it works...

It is important to know what functions are available to us to add to our computational graphs. Mostly, we will be concerned with the preceding functions. We can also generate many different custom functions as compositions of the preceding functions, as follows:

```
# Tangent function (tan(pi/4)=1)
print(sess.run(tf.div(tf.sin(3.1416/4.), tf.cos(3.1416/4.))))
1.0
```

There's more...

If we wish to add other operations to our graphs that are not listed here, we must create our own from the preceding functions. Here is an example of an operation not listed previously that we can add to our graph. We choose to add a custom polynomial function, $3x^2 - x + 10$:

```
def custom_polynomial(value):
    return(tf.sub(3 * tf.square(value), value) + 10)
print(sess.run(custom_polynomial(11)))
362
```

Implementing Activation Functions

Getting ready

When we start to use neural networks, we will use activation functions regularly because activation functions are a mandatory part of any neural network. The goal of the activation function is to adjust weight and bias. In TensorFlow, activation functions are non-linear operations that act on tensors. They are functions that operate in a similar way to the previous mathematical operations. Activation functions serve many purposes, but a few main concepts is that they introduce a non-linearity into the graph while normalizing the outputs. Start a TensorFlow graph with the following commands:

```
import tensorflow as tf
sess = tf.Session()
```

How to do it...

The activation functions live in the **neural network (nn)** library in TensorFlow. Besides using built-in activation functions, we can also design our own using TensorFlow operations. We can import the predefined activation functions (`import tensorflow.nn as nn`) or be explicit and write `.nn` in our function calls. Here, we choose to be explicit with each function call:

1. The rectified linear unit, known as ReLU, is the most common and basic way to introduce a non-linearity into neural networks. This function is just `max(0, x)`. It is continuous but not smooth. It appears as follows:

```
print(sess.run(tf.nn.relu([-3., 3., 10.])))
[ 0.  3.  10.]
```

2. There will be times when we wish to cap the linearly increasing part of the preceding ReLU activation function. We can do this by nesting the `max(0, x)` function into a `min()` function. The implementation that TensorFlow has is called the ReLU6 function. This is defined as `min(max(0, x), 6)`. This is a version of the hard-sigmoid function and is computationally faster, and does not suffer from vanishing (infinitesimally near zero) or exploding values. This will come in handy when we discuss deeper neural networks in *Chapters 8, Convolutional Neural Networks* and *Chapter 9, Recurrent Neural Networks*. It appears as follows:

```
print(sess.run(tf.nn.relu6([-3., 3., 10.])))
[ 0.  3.  6.]
```

3. The sigmoid function is the most common continuous and smooth activation function. It is also called a logistic function and has the form $1/(1+\exp(-x))$. The sigmoid is not often used because of the tendency to zero-out the back propagation terms during training. It appears as follows:

```
print(sess.run(tf.nn.sigmoid([-1., 0., 1.])))  
[ 0.26894143  0.5           0.7310586 ]
```



We should be aware that some activation functions are not zero centered, such as the sigmoid. This will require us to zero-mean the data prior to using it in most computational graph algorithms.



4. Another smooth activation function is the hyper tangent. The hyper tangent function is very similar to the sigmoid except that instead of having a range between 0 and 1, it has a range between -1 and 1. The function has the form of the ratio of the hyperbolic sine over the hyperbolic cosine. But another way to write this is $((\exp(x)-\exp(-x))/(\exp(x)+\exp(-x)))$. It appears as follows:

```
print(sess.run(tf.nn.tanh([-1., 0., 1.])))  
[-0.76159418  0.           0.76159418 ]
```

5. The softsign function also gets used as an activation function. The form of this function is $x/(\text{abs}(x) + 1)$. The softsign function is supposed to be a continuous approximation to the sign function. It appears as follows:

```
print(sess.run(tf.nn.softsign([-1., 0., -1.])))  
[-0.5  0.   0.5]
```

6. Another function, the softplus, is a smooth version of the ReLU function. The form of this function is $\log(\exp(x) + 1)$. It appears as follows:

```
print(sess.run(tf.nn.softplus([-1., 0., -1.])))  
[ 0.31326166  0.69314718  1.31326163]
```



The softplus goes to infinity as the input increases whereas the softsign goes to 1. As the input gets smaller, however, the softplus approaches zero and the softsign goes to -1.



7. The **Exponential Linear Unit (ELU)** is very similar to the softplus function except that the bottom asymptote is -1 instead of 0. The form is $(\exp(x)+1)$ if $x < 0$ else x . It appears as follows:

```
print(sess.run(tf.nn.elu([-1., 0., -1.])))  
[-0.63212055  0.           1.           ]
```

How it works...

These activation functions are the way that we introduce nonlinearities in neural networks or other computational graphs in the future. It is important to note where in our network we are using activation functions. If the activation function has a range between 0 and 1 (sigmoid), then the computational graph can only output values between 0 and 1.

If the activation functions are inside and hidden between nodes, then we want to be aware of the effect that the range can have on our tensors as we pass them through. If our tensors were scaled to have a mean of zero, we will want to use an activation function that preserves as much variance as possible around zero. This would imply we want to choose an activation function such as the hyperbolic tangent (tanh) or softsign. If the tensors are all scaled to be positive, then we would ideally choose an activation function that preserves variance in the positive domain.

There's more...

Here are two graphs that illustrate the different activation functions. The following figure shows the following functions ReLU, ReLU6, softplus, exponential LU, sigmoid, softsign, and the hyperbolic tangent:

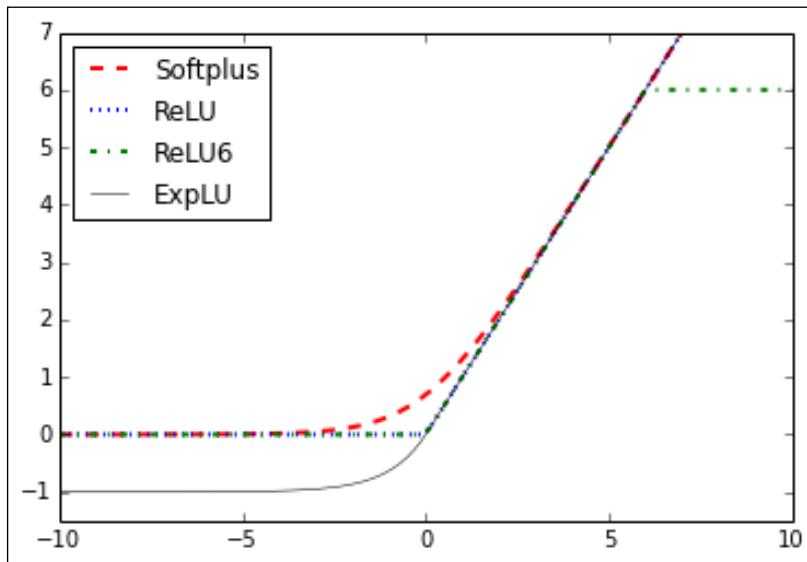


Figure 3: Activation functions of softplus, ReLU, ReLU6, and exponential LU

In *Figure 3*, we can see four of the activation functions, softplus, ReLU, ReLU6, and exponential LU. These functions flatten out to the left of zero and linearly increase to the right of zero, with the exception of ReLU6, which has a maximum value of 6:

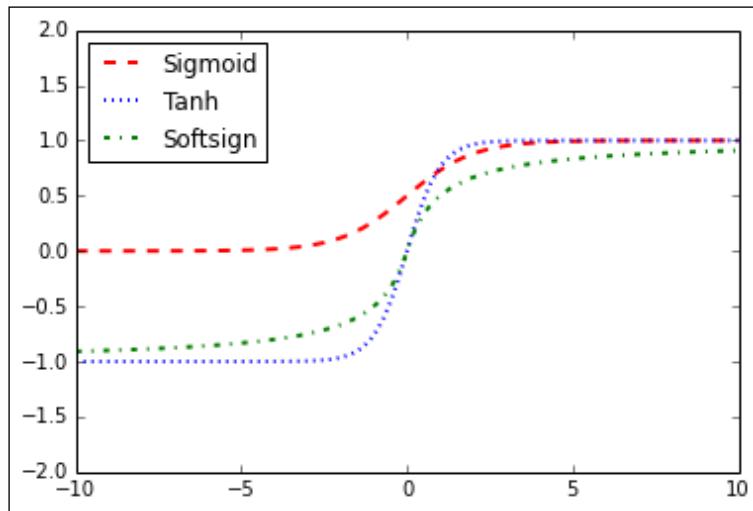


Figure 4: Sigmoid, hyperbolic tangent (tanh), and softsign activation function

In *Figure 4*, we have the activation functions sigmoid, hyperbolic tangent (tanh), and softsign. These activation functions are all smooth and have a S shape. Note that there are two horizontal asymptotes for these functions.

Working with Data Sources

For most of this book, we will rely on the use of datasets to fit machine learning algorithms. This section has instructions on how to access each of these various datasets through TensorFlow and Python.

Getting ready

In TensorFlow some of the datasets that we will use are built in to Python libraries, some will require a Python script to download, and some will be manually downloaded through the Internet. Almost all of these datasets require an active Internet connection to retrieve data.

How to do it...

1. **Iris data:** This dataset is arguably the most classic dataset used in machine learning and maybe all of statistics. It is a dataset that measures sepal length, sepal width, petal length, and petal width of three different types of iris flowers: *Iris setosa*, *Iris virginica*, and *Iris versicolor*. There are 150 measurements overall, 50 measurements of each species. To load the dataset in Python, we use Scikit Learn's dataset function, as follows:

```
from sklearn import datasets
iris = datasets.load_iris()
print(len(iris.data))
150
print(len(iris.target))
150
print(iris.target[0]) # Sepal length, Sepal width, Petal length,
Petal width
[ 5.1 3.5 1.4 0.2]
print(set(iris.target)) # I. setosa, I. virginica, I. versicolor
{0, 1, 2}
```

2. **Birth weight data:** The University of Massachusetts at Amherst has compiled many statistical datasets that are of interest (1). One such dataset is a measure of child birth weight and other demographic and medical measurements of the mother and family history. There are 189 observations of 11 variables. Here is how to access the data in Python:

```
import requests
birthdata_url = 'https://www.umass.edu/statdata/statdata/data/
lowbwt.dat'
birth_file = requests.get(birthdata_url)
birth_data = birth_file.text.split('\\r\\n') [5:]
birth_header = [x for x in birth_data[0].split( ' ') if len(x)>=1]
birth_data = [[float(x) for x in y.split( '' ) if len(x)>=1] for y
in birth_data[1:] if len(y)>=1]
print(len(birth_data))
189
print(len(birth_data[0]))
11
```

3. **Boston Housing data:** Carnegie Mellon University maintains a library of datasets in their Statlib Library. This data is easily accessible via The University of California at Irvine's Machine-Learning Repository (2). There are 506 observations of house worth along with various demographic data and housing attributes (14 variables). Here is how to access the data in Python:

```
import requests
housing_url = 'https://archive.ics.uci.edu/ml/machine-learning-
databases/housing/housing.data'
housing_header = ['CRIM', 'ZN', 'INDUS', 'CHAS', 'NOX', 'RM',
'AGE', 'DIS', 'RAD', 'TAX', 'PTRATIO', 'B', 'LSTAT', 'MEDV0']
housing_file = requests.get(housing_url)
housing_data = [[float(x) for x in y.split(' ') if len(x)>=1] for
y in housing_file.text.split('\n') if len(y)>=1]
print(len(housing_data))
506
print(len(housing_data[0]))
14
```

4. **MNIST handwriting data: MNIST (Mixed National Institute of Standards and Technology)** is a subset of the larger NIST handwriting database. The MNIST handwriting dataset is hosted on Yann LeCun's website (<https://yann.lecun.com/exdb/mnist/>). It is a database of 70,000 images of single digit numbers (0-9) with about 60,000 annotated for a training set and 10,000 for a test set. This dataset is used so often in image recognition that TensorFlow provides built-in functions to access this data. In machine learning, it is also important to provide validation data to prevent overfitting (target leakage). Because of this TensorFlow, sets aside 5,000 of the train set into a validation set. Here is how to access the data in Python:

```
from tensorflow.examples.tutorials.mnist import input_data
mnist = input_data.read_data_sets("MNIST_data/", "one_hot=True")
print(len(mnist.train.images))
55000
print(len(mnist.test.images))
10000
print(len(mnist.validation.images))
5000
print(mnist.train.labels[1,:]) # The first label is a 3!!!
[ 0.  0.  0.  1.  0.  0.  0.  0.  0.]
```

5. **Spam-ham text data.** UCI's machine learning data set library (2) also holds a spam-ham text message dataset. We can access this .zip file and get the spam-ham text data as follows:

```
import requests
import io
from zipfile import ZipFile
zip_url = 'http://archive.ics.uci.edu/ml/machine-learning-
databases/00228/smsspamcollection.zip'
r = requests.get(zip_url)
z = ZipFile(io.BytesIO(r.content))
file = z.read('SMSSpamCollection')
text_data = file.decode()
text_data = text_data.encode('ascii', errors='ignore')
text_data = text_data.decode().split('\n')
text_data = [x.split('\t') for x in text_data if len(x)>=1]
[text_data_target, text_data_train] = [list(x) for x in zip(*text_
data)]
print(len(text_data_train))
5574
print(set(text_data_target))
{'ham', 'spam'}
print(text_data_train[1])
Ok lar... Joking wif u oni...
```

6. **Movie review data:** Bo Pang from Cornell has released a movie review dataset that classifies reviews as good or bad (3). You can find the data on the website, <http://www.cs.cornell.edu/people/pabo/movie-review-data/>. To download, extract, and transform this data, we run the following code:

```
import requests
import io
import tarfile
movie_data_url = 'http://www.cs.cornell.edu/people/pabo/movie-
review-data/rt-polaritydata.tar.gz'
r = requests.get(movie_data_url)
# Stream data into temp object
stream_data = io.BytesIO(r.content)
tmp = io.BytesIO()
while True:
    s = stream_data.read(16384)
    if not s:
        break
    tmp.write(s)
stream_data.close()
tmp.seek(0)
```

```
# Extract tar file
tar_file = tarfile.open(fileobj=tmp, mode="r:gz")
pos = tar_file.extractfile('rt-polaritydata/rt-polarity.pos')
neg = tar_file.extractfile('rt-polaritydata/rt-polarity.neg')
# Save pos/neg reviews (Also deal with encoding)
pos_data = []
for line in pos:
    pos_data.append(line.decode('ISO-8859-1').
                    encode('ascii',errors='ignore').decode())
neg_data = []
for line in neg:
    neg_data.append(line.decode('ISO-8859-1').
                    encode('ascii',errors='ignore').decode())
tar_file.close()
print(len(pos_data))
5331
print(len(neg_data))
5331
# Print out first negative review
print(neg_data[0])
simpistic , silly and tedious .
```

7. **CIFAR-10 image data:** The Canadian Institute For Advanced Research has released an image set that contains 80 million labeled colored images (each image is scaled to 32x32 pixels). There are 10 different target classes (airplane, automobile, bird, and so on). The CIFAR-10 is a subset that has 60,000 images. There are 50,000 images in the training set, and 10,000 in the test set. Since we will be using this dataset in multiple ways, and because it is one of our larger datasets, we will not run a script each time we need it. To get this dataset, please navigate to <http://www.cs.toronto.edu/~kriz/cifar.html>, and download the CIFAR-10 dataset. We will address how to use this dataset in the appropriate chapters.
8. **The works of Shakespeare text data:** Project Gutenberg (5) is a project that releases electronic versions of free books. They have compiled all of the works of Shakespeare together and here is how to access the text file through Python:

```
import requests
shakespeare_url = 'http://www.gutenberg.org/cache/epub/100/pg100.txt'
# Get Shakespeare text
response = requests.get(shakespeare_url)
shakespeare_file = response.content
# Decode binary into string
shakespeare_text = shakespeare_file.decode('utf-8')
```

- ```
Drop first few descriptive paragraphs.
shakespeare_text = shakespeare_text[7675:]
print(len(shakespeare_text)) # Number of characters
5582212
```
9. **English-German sentence translation data:** The Tatoeba project (<http://tatoeba.org>) collects sentence translations in many languages. Their data has been released under the Creative Commons License. From this data, ManyThings.org (<http://www.manythings.org>) has compiled sentence-to-sentence translations in text files available for download. Here we will use the English-German translation file, but you can change the URL to whatever languages you would like to use:

```
import requests
import io
from zipfile import ZipFile
sentence_url = 'http://www.manythings.org/anki/deu-eng.zip'
r = requests.get(sentence_url)
z = ZipFile(io.BytesIO(r.content))
file = z.read('deu.txt')
Format Data
eng_ger_data = file.decode()
eng_ger_data = eng_ger_data.encode('ascii','',errors='ignore')
eng_ger_data = eng_ger_data.decode().split('\n')
eng_ger_data = [x.split('\t') for x in eng_ger_data if len(x)>=1]
[english_sentence, german_sentence] = [list(x) for x in zip(*eng_ger_data)]
print(len(english_sentence))
137673
print(len(german_sentence))
137673
print(eng_ger_data[10])
['I won!, 'Ich habe gewonnen!']
```

## How it works...

When it comes time to use one of these datasets in a recipe, we will refer you to this section and assume that the data is loaded in such a way as described in the preceding text. If further data transformation or pre-processing is needed, then such code will be provided in the recipe itself.

## See also

- ▶ Hosmer, D.W., Lemeshow, S., and Sturdivant, R. X. (2013). Applied Logistic Regression: 3rd Edition. <https://www.umass.edu/statdata/statdata/data/lowbwt.txt>
- ▶ Lichman, M. (2013). UCI Machine Learning Repository. <http://archive.ics.uci.edu/ml>. Irvine, CA: University of California, School of Information and Computer Science.
- ▶ Bo Pang, Lillian Lee, and Shivakumar Vaithyanathan, Thumbs up? Sentiment Classification using Machine Learning Techniques, Proceedings of EMNLP 2002. <http://www.cs.cornell.edu/people/pabo/movie-review-data/>
- ▶ Krizhevsky. (2009). Learning Multiple Layers of Features from Tiny Images. <http://www.cs.toronto.edu/~kriz/cifar.html>
- ▶ Project Gutenberg. Accessed April 2016. <http://www.gutenberg.org/>.

## Additional Resources

Here we will provide additional links, documentation sources, and tutorials that are of great assistance to learning and using TensorFlow.

## Getting ready

When learning how to use TensorFlow, it helps to know where to turn to for assistance or pointers. This section lists resources to get TensorFlow running and to troubleshoot problems.

## How to do it...

Here is a list of TensorFlow resources:

1. The code for this book is available online at [https://github.com/nfmcclure/tensorflow\\_cookbook](https://github.com/nfmcclure/tensorflow_cookbook).
2. The official TensorFlow Python API documentation is located at [https://www.tensorflow.org/api\\_docs/python](https://www.tensorflow.org/api_docs/python). Here there is documentation and examples of all of the functions, objects, and methods in TensorFlow. Note the version number r0.8' in the link and realize that a more current version may be available.
3. TensorFlow's official tutorials are very thorough and detailed. They are located at <https://www.tensorflow.org/tutorials/index.html>. They start covering image recognition models, and work through Word2Vec, RNN models, and sequence-to-sequence models. They also have additional tutorials on generating fractals and solving a PDE system. Note that they are continually adding more tutorials and examples to this collection.

4. TensorFlow's official GitHub repository is available via <https://github.com/tensorflow/tensorflow>. Here you can view the open-sourced code and even fork or clone the most current version of the code if you want. You can also see current filed issues if you navigate to the issues directory.
5. A public Docker container that is kept current by TensorFlow is available on Dockerhub at: <https://hub.docker.com/r/tensorflow/tensorflow/>
6. A downloadable virtual machine that contains TensorFlow installed on an Ubuntu 15.04 OS is available as well. This option is great for running the UNIX version of TensorFlow on a Windows PC. The VM is available through a Google Document request form at: [https://docs.google.com/forms/d/1mUztUlK6\\_z31BbMW5ihXaYH1hBcbDd94mERe-8XHyoI/viewform](https://docs.google.com/forms/d/1mUztUlK6_z31BbMW5ihXaYH1hBcbDd94mERe-8XHyoI/viewform). It is about a 2 GB download and requires VMWare player to run. VMWare player is a product made by VMWare and is free for personal use and is available at: <https://www.vmware.com/go/downloadplayer/>. This virtual machine is maintained by David Winters (1).
7. A great source for community help is Stack Overflow. There is a tag for TensorFlow. This tag seems to be growing in interest as TensorFlow is gaining more popularity. To view activity on this tag, visit <http://stackoverflow.com/questions/tagged/Tensorflow>
8. While TensorFlow is very agile and can be used for many things, the most common usage of TensorFlow is deep learning. To understand the basis for deep learning, how the underlying mathematics works, and to develop more intuition on deep learning, Google has created an online course available on Udacity. To sign up and take the video lecture course visit <https://www.udacity.com/course/deep-learning--ud730>.
9. TensorFlow has also made a site where you can visually explore training a neural network while changing the parameters and datasets. Visit <http://playground.tensorflow.org/> to explore how different settings affect the training of neural networks.
10. Geoffrey Hinton teaches an online course, *Neural Networks for Machine Learning*, through Coursera. Visit <https://www.coursera.org/learn/neural-networks>
11. Stanford University has an online syllabus and detailed course notes for *Convolutional Neural Networks for Visual Recognition*. Visit <http://cs231n.stanford.edu/>

## See also

- ▶ Winters, D. [https://docs.google.com/forms/d/1mUztUlK6\\_z31BbMW5ihXaYH1hBcbDd94mERe-8XHyoI/viewform](https://docs.google.com/forms/d/1mUztUlK6_z31BbMW5ihXaYH1hBcbDd94mERe-8XHyoI/viewform)

# 2

## The TensorFlow Way

In this chapter, we will introduce the key components of how TensorFlow operates. Then we will tie it together to create a simple classifier and evaluate the outcomes. By the end of the chapter you should have learned about the following:

- ▶ Operations in a Computational Graph
- ▶ Layering Nested Operations
- ▶ Working with Multiple Layers
- ▶ Implementing Loss Functions
- ▶ Implementing Back Propagation
- ▶ Working with Batch and Stochastic Training
- ▶ Combining Everything Together
- ▶ Evaluating Models

### Introduction

Now that we have introduced how TensorFlow creates tensors, uses variables and placeholders, we will introduce how to act on these objects in a computational graph. From this, we can set up a simple classifier and see how well it performs.



Also, remember that all the code from this book is available online on GitHub at [https://github.com/nfmccclure/tensorflow\\_cookbook](https://github.com/nfmccclure/tensorflow_cookbook).

## Operations in a Computational Graph

Now that we can put objects into our computational graph, we will introduce operations that act on such objects.

### Getting ready

To start a graph, we load TensorFlow and create a session, as follows:

```
import tensorflow as tf
sess = tf.Session()
```

### How to do it...

In this example, we will combine what we have learned and feed in each number in a list to an operation in a graph and print the output:

1. First we declare our tensors and placeholders. Here we will create a numpy array to feed into our operation:

```
import numpy as np
x_vals = np.array([1., 3., 5., 7., 9.])
x_data = tf.placeholder(tf.float32)
m_const = tf.constant(3.)
my_product = tf.mul(x_data, m_const)
for x_val in x_vals:
 print(sess.run(my_product, feed_dict={x_data: x_val}))
3.0
9.0
15.0
21.0
27.0
```

## How it works...

Steps 1 and 2 create the data and operations on the computational graph. Then, in step 3, we feed the data through the graph and print the output. Here is what the computational graph looks like:

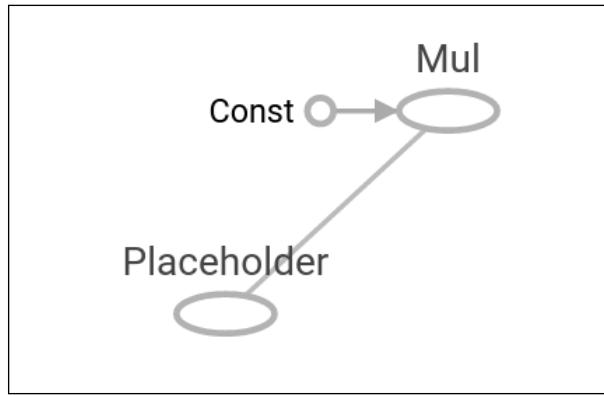


Figure 1: Here we can see in the graph that the placeholder, `x_data`, along with our multiplicative constant, feeds into the multiplication operation.

## Layering Nested Operations

In this recipe, we will learn how to put multiple operations on the same computational graph.

### Getting ready

It's important to know how to chain operations together. This will set up layered operations in the computational graph. For a demonstration we will multiply a placeholder by two matrices and then perform addition. We will feed in two matrices in the form of a three-dimensional numpy array:

```
import tensorflow as tf
sess = tf.Session()
```

## How to do it...

It is also important to note how the data will change shape as it passes through. We will feed in two numpy arrays of size 3x5. We will multiply each matrix by a constant of size 5x1, which will result in a matrix of size 3x1. We will then multiply this by 1x1 matrix resulting in a 3x1 matrix again. Finally, we add a 3x1 matrix at the end, as follows:

1. First we create the data to feed in and the corresponding placeholder:

```
my_array = np.array([[1., 3., 5., 7., 9.],
 [-2., 0., 2., 4., 6.],
 [-6., -3., 0., 3., 6.]])
x_vals = np.array([my_array, my_array + 1])
x_data = tf.placeholder(tf.float32, shape=(3, 5))
```

2. Next we create the constants that we will use for matrix multiplication and addition:

```
m1 = tf.constant([[1.], [0.], [-1.], [2.], [4.]])
m2 = tf.constant([[2.]])
a1 = tf.constant([[10.]])
```

3. Now we declare the operations and add them to the graph:

```
prod1 = tf.matmul(x_data, m1)
prod2 = tf.matmul(prod1, m2)
add1 = tf.add(prod2, a1)
```

4. Finally, we feed the data through our graph:

```
for x_val in x_vals:
 print(sess.run(add1, feed_dict={x_data: x_val}))
[[102.]
 [66.]
 [58.]]
[[114.]
 [78.]
 [70.]]
```

## How it works...

The computational graph we just created can be visualized with Tensorboard. Tensorboard is a feature of TensorFlow that allows us to visualize the computational graphs and values in that graph. These features are provided natively, unlike other machine learning frameworks. To see how this is done, see the *Visualizing graphs in Tensorboard* recipe in *Chapter 11, More with TensorFlow*. Here is what our layered graph looks like:

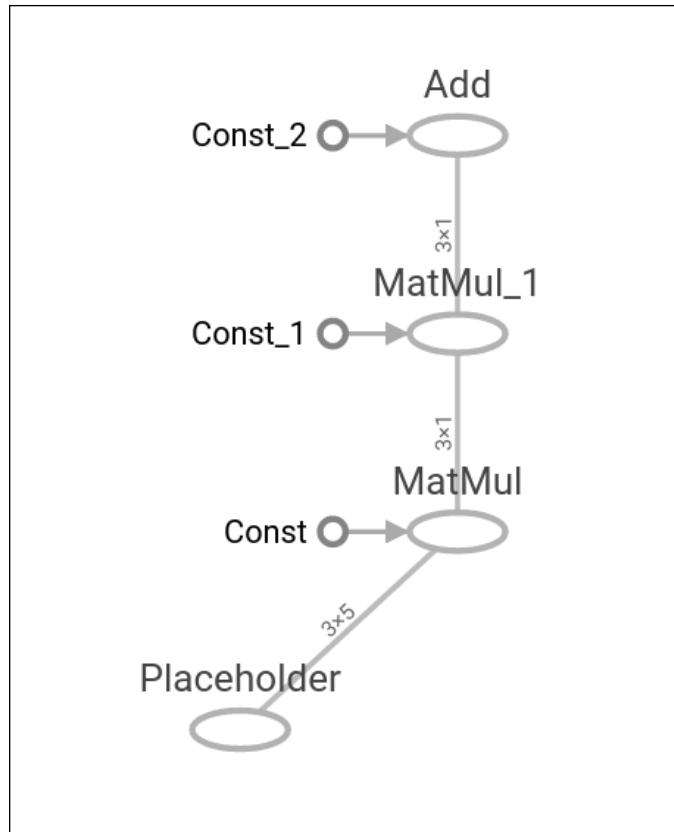


Figure 2: In this computational graph you can see the data size as it propagates upward through the graph.

### There's more...

We have to declare the data shape and know the outcome shape of the operations before we run data through the graph. This is not always the case. There may be a dimension or two that we do not know beforehand or that can vary. To accomplish this, we designate the dimension that can vary or is unknown as value none. For example, to have the prior data placeholder have an unknown amount of columns, we would write the following line:

```
x_data = tf.placeholder(tf.float32, shape=(3, None))
```

This allows us to break matrix multiplication rules and we must still obey the fact that the multiplying constant must have the same corresponding number of rows. We can either generate this dynamically or reshape the `x_data` as we feed data in our graph. This will come in handy in later chapters when we are feeding data in multiple batches.

## Working with Multiple Layers

Now that we have covered multiple operations, we will cover how to connect various layers that have data propagating through them.

### Getting ready

In this recipe, we will introduce how to best connect various layers, including custom layers. The data we will generate and use will be representative of small random images. It is best to understand these types of operation on a simple example and how we can use some built-in layers to perform calculations. We will perform a small moving window average across a 2D image and then flow the resulting output through a custom operation layer.

In this section, we will see that the computational graph can get large and hard to look at. To address this, we will also introduce ways to name operations and create scopes for layers. To start, load `numpy` and `tensorflow` and create a graph, using the following:

```
import tensorflow as tf
import numpy as np
sess = tf.Session()
```

### How to do it...

1. First we create our sample 2D image with `numpy`. This image will be a 4x4 pixel image. We will create it in four dimensions; the first and last dimension will have a size of one. Note that some TensorFlow image functions will operate on four-dimensional images. Those four dimensions are image number, height, width, and channel, and to make it one image with one channel, we set two of the dimensions to 1, as follows:

```
x_shape = [1, 4, 4, 1]
x_val = np.random.uniform(size=x_shape)
```

2. Now we have to create the placeholder in our graph where we can feed in the sample image, as follows:

```
x_data = tf.placeholder(tf.float32, shape=x_shape)
```

- To create a moving window average across our  $4 \times 4$  image, we will use a built-in function that will convolute a constant across a window of the shape  $2 \times 2$ . This function is quite common to use in image processing and in TensorFlow, the function we will use is `conv2d()`. This function takes a piecewise product of the window and a filter we specify. We must also specify a stride for the moving window in both directions. Here we will compute four moving window averages, the top left, top right, bottom left, and bottom right four pixels. We do this by creating a  $2 \times 2$  window and having strides of length 2 in each direction. To take the average, we will convolute the  $2 \times 2$  window with a constant of 0.25., as follows:

```
my_filter = tf.constant(0.25, shape=[2, 2, 1, 1])
my_strides = [1, 2, 2, 1]
mov_avg_layer= tf.nn.conv2d(x_data, my_filter, my_strides,
 padding='SAME', name='Moving'_Avg_
 Window')
```



To figure out the output size of a convolutional layer, we can use the following formula:  $Output = (W-F+2P)/S+1$ , where  $W$  is the input size,  $F$  is the filter size,  $P$  is the padding of zeros, and  $S$  is the stride.

- Note that we are also naming this layer `Moving_Avg_Window` by using the `name` argument of the function.
- Now we define a custom layer that will operate on the  $2 \times 2$  output of the moving window average. The custom function will first multiply the input by another  $2 \times 2$  matrix tensor, and then add one to each entry. After this we take the `sigmoid` of each element and return the  $2 \times 2$  matrix. Since matrix multiplication only operates on two-dimensional matrices, we need to drop the extra dimensions of our image that are of size 1. TensorFlow can do this with the built-in function `squeeze()`. Here we define the new layer:

```
def custom_layer(input_matrix):
 input_matrix_sqeezed = tf.squeeze(input_matrix)
 A = tf.constant([[1., 2.], [-1., 3.]])
 b = tf.constant(1., shape=[2, 2])
 temp1 = tf.matmul(A, input_matrix_sqeezed)
 temp = tf.add(temp1, b) # Ax + b
 return(tf.sigmoid(temp))
```

- Now we have to place the new layer on the graph. We will do this with a named scope so that it is identifiable and collapsible/expandable on the computational graph, as follows:

```
with tf.name_scope('Custom_Layer') as scope:
 custom_layer1 = custom_layer(mov_avg_layer)
```

- Now we just feed in the  $4 \times 4$  image in the placeholder and tell TensorFlow to run the graph, as follows:

```
print(sess.run(custom_layer1, feed_dict={x_data: x_val}))
[[0.91914582 0.96025133]
 [0.87262219 0.9469803]]
```

## How it works...

The visualized graph looks better with the naming of operations and scoping of layers. We can collapse and expand the custom layer because we created it in a named scope. In the following figure, see the collapsed version on the left and the expanded version on the right:

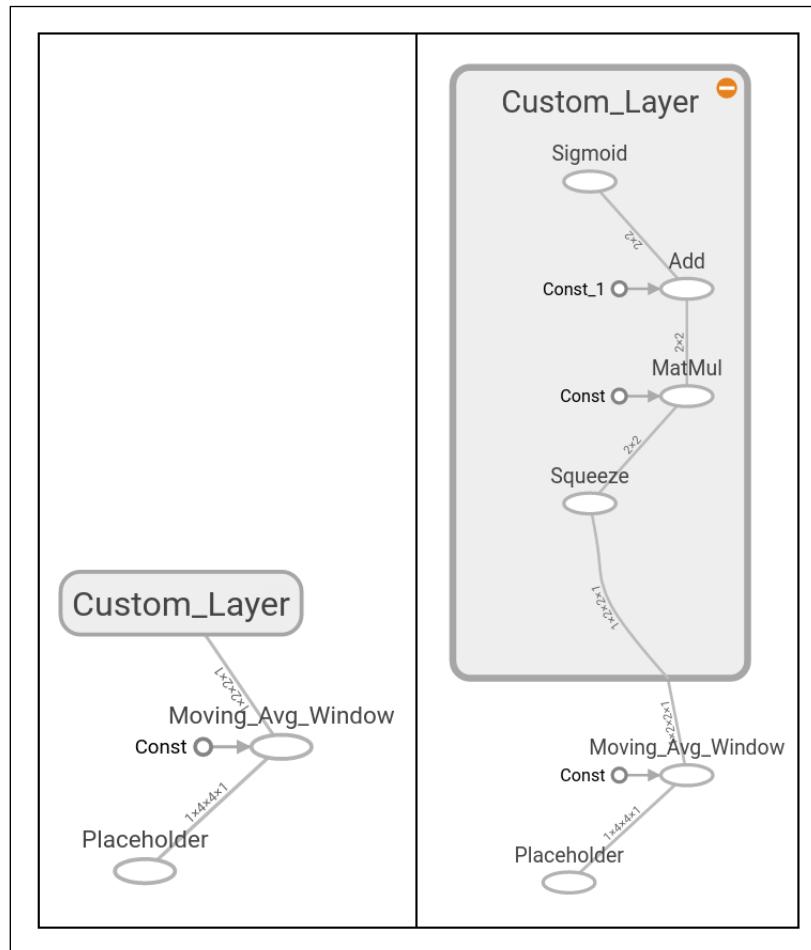


Figure 3: Computational graph with two layers. The first layer is named as `Moving_Avg_Window`, and the second is a collection of operations called `Custom_Layer`. It is collapsed on the left and expanded on the right.

## Implementing Loss Functions

Loss functions are very important to machine learning algorithms. They measure the distance between the model outputs and the target (truth) values. In this recipe, we show various loss function implementations in TensorFlow.

### Getting ready

In order to optimize our machine learning algorithms, we will need to evaluate the outcomes. Evaluating outcomes in TensorFlow depends on specifying a `loss` function. A `loss` function tells TensorFlow how good or bad the predictions are compared to the desired result. In most cases, we will have a set of data and a target on which to train our algorithm. The `loss` function compares the target to the prediction and gives a numerical distance between the two.

For this recipe, we will cover the main `loss` functions that we can implement in TensorFlow.

To see how the different `loss` functions operate, we will plot them in this recipe. We will first start a computational graph and load `matplotlib`, a python plotting library, as follows:

```
import matplotlib.pyplot as plt
import tensorflow as tf
```

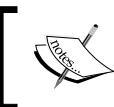
### How to do it...

First we will talk about `loss` functions for regression, that is, predicting a continuous dependent variable. To start, we will create a sequence of our predictions and a target as a tensor. We will output the results across 500 `x`-values between -1 and 1. See the next section for a plot of the outputs. Use the following code:

```
x_vals = tf.linspace(-1., 1., 500)
target = tf.constant(0.)
```

1. The L2 norm `loss` is also known as the Euclidean `loss` function. It is just the square of the distance to the target. Here we will compute the `loss` function as if the target is zero. The L2 norm is a great `loss` function because it is very curved near the target and algorithms can use this fact to converge to the target more slowly, the closer it gets., as follows:

```
l2_y_vals = tf.square(target - x_vals)
l2_y_out = sess.run(l2_y_vals)
```



TensorFlow has a built-in form of the L2 norm, called `nn.l2_loss()`. This function is actually half the L2-norm above. In other words, it is same as previously but divided by 2.

2. The L1 norm loss is also known as the absolute loss function. Instead of squaring the difference, we take the absolute value. The L1 norm is better for outliers than the L2 norm because it is not as steep for larger values. One issue to be aware of is that the L1 norm is not smooth at the target and this can result in algorithms not converging well. It appears as follows:

```
l1_y_vals = tf.abs(target - x_vals)
l1_y_out = sess.run(l1_y_vals)
```

3. Pseudo-Huber loss is a continuous and smooth approximation to the Huber loss function. This loss function attempts to take the best of the L1 and L2 norms by being convex near the target and less steep for extreme values. The form depends on an extra parameter, delta, which dictates how steep it will be. We will plot two forms, delta1 = 0.25 and delta2 = 5 to show the difference, as follows:

```
delta1 = tf.constant(0.25)
phuber1_y_vals = tf.mul(tf.square(delta1), tf.sqrt(1. +
 tf.square((target - x_vals)/delta1)) - 1.)
phuber1_y_out = sess.run(phuber1_y_vals)
delta2 = tf.constant(5.)
phuber2_y_vals = tf.mul(tf.square(delta2), tf.sqrt(1. +
 tf.square((target - x_vals)/delta2)) - 1.)
phuber2_y_out = sess.run(phuber2_y_vals)
```

4. Classification loss functions are used to evaluate loss when predicting categorical outcomes.
5. We will need to redefine our predictions (x\_vals) and target. We will save the outputs and plot them in the next section. Use the following:

```
x_vals = tf.linspace(-3., 5., 500)
target = tf.constant(1.)
targets = tf.fill([500], 1.)
```

6. Hinge loss is mostly used for support vector machines, but can be used in neural networks as well. It is meant to compute a loss between with two target classes, 1 and -1. In the following code, we are using the target value 1, so the as closer our predictions as near are to 1, the lower the loss value:

```
hinge_y_vals = tf.maximum(0., 1. - tf.mul(target, x_vals))
hinge_y_out = sess.run(hinge_y_vals)
```

7. Cross-entropy loss for a binary case is also sometimes referred to as the logistic loss function. It comes about when we are predicting the two classes 0 or 1. We wish to measure a distance from the actual class (0 or 1) to the predicted value, which is usually a real number between 0 and 1. To measure this distance, we can use the cross entropy formula from information theory, as follows:

```
xentropy_y_vals = - tf.mul(target, tf.log(x_vals)) - tf.mul((1. - target), tf.log(1. - x_vals))
xentropy_y_out = sess.run(xentropy_y_vals)
```

8. Sigmoid cross entropy loss is very similar to the previous loss function except we transform the x-values by the sigmoid function before we put them in the cross entropy loss, as follows:

```
xentropy_sigmoid_y_vals = tf.nn.sigmoid_cross_entropy_with_
logits(x_vals, targets)
xentropy_sigmoid_y_out = sess.run(xentropy_sigmoid_y_vals)
```

9. Weighted cross entropy loss is a weighted version of the sigmoid cross entropy loss. We provide a weight on the positive target. For an example, we will weight the positive target by 0.5, as follows:

```
weight = tf.constant(0.5)
xentropy_weighted_y_vals = tf.nn.weighted_cross_entropy_with_
logits(x_vals, targets, weight)
xentropy_weighted_y_out = sess.run(xentropy_weighted_y_vals)
```

10. Softmax cross-entropy loss operates on non-normalized outputs. This function is used to measure a loss when there is only one target category instead of multiple. Because of this, the function transforms the outputs into a probability distribution via the softmax function and then computes the loss function from a true probability distribution, as follows:

```
unscaled_logits = tf.constant([[1., -3., 10.]])
target_dist = tf.constant([[0.1, 0.02, 0.88]])
softmax_xentropy = tf.nn.softmax_cross_entropy_with_
logits(unscaled_logits, target_dist)
print(sess.run(softmax_xentropy))
[1.16012561]
```

11. Sparse softmax cross-entropy loss is the same as previously, except instead of the target being a probability distribution, it is an index of which category is true. Instead of a sparse all-zero target vector with one value of one, we just pass in the index of which category is the true value, as follows:

```
unscaled_logits = tf.constant([[1., -3., 10.]])
sparse_target_dist = tf.constant([2])
sparse_xentropy = tf.nn.sparse_softmax_cross_entropy_with_
logits(unscaled_logits, sparse_target_dist)
print(sess.run(sparse_xentropy))
[0.00012564]
```

## How it works...

Here is how to use `matplotlib` to plot the regression loss functions:

```
x_array = sess.run(x_vals)
plt.plot(x_array, l2_y_out, 'b-', label='L2 Loss')
plt.plot(x_array, l1_y_out, 'r--', label='L1 Loss')
plt.plot(x_array, phuber1_y_out, 'k-.', label='P-Huber Loss (0.25)')
plt.plot(x_array, phuber2_y_out, 'g:', label='P'-Huber Loss (5.0)')
plt.ylim(-0.2, 0.4)
plt.legend(loc='lower right', prop={'size': 11})
plt.show()
```

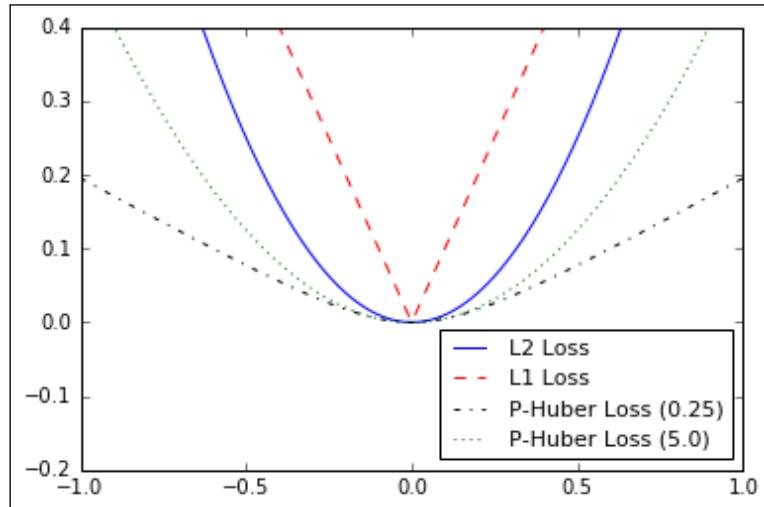


Figure 4: Plotting various regression loss functions.

And here is how to use `matplotlib` to plot the various classification loss functions:

```
x_array = sess.run(x_vals)
plt.plot(x_array, hinge_y_out, 'b-', label='Hinge Loss')
plt.plot(x_array, xentropy_y_out, 'r--', label='Cross Entropy Loss')
plt.plot(x_array, xentropy_sigmoid_y_out, 'k-.', label='Cross Entropy Sigmoid Loss')
plt.plot(x_array, xentropy_weighted_y_out, g:', label='Weighted Cross Entropy Loss (x0.5)')
plt.ylim(-1.5, 3)
plt.legend(loc='lower right', prop={'size': 11})
plt.show()
```

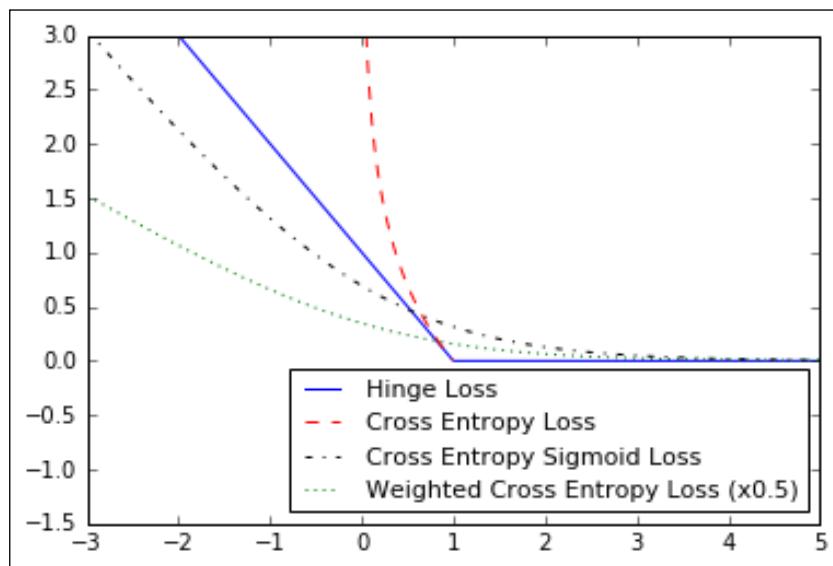


Figure 5: Plots of classification loss functions.

### There's more...

Here is a table summarizing the different loss functions that we have described:

| Loss function | Use            | Benefits                            | Disadvantages                       |
|---------------|----------------|-------------------------------------|-------------------------------------|
| L2            | Regression     | More stable                         | Less robust                         |
| L1            | Regression     | More robust                         | Less stable                         |
| Pseudo-Huber  | Regression     | More robust and stable              | One more parameter                  |
| Hinge         | Classification | Creates a max margin for use in SVM | Unbounded loss affected by outliers |

| Loss function | Use            | Benefits    | Disadvantages               |
|---------------|----------------|-------------|-----------------------------|
| Cross-entropy | Classification | More stable | Unbounded loss, less robust |

The remaining classification loss functions all have to do with the type of cross-entropy loss. The cross-entropy sigmoid loss function is for use on unscaled logits and is preferred over computing the sigmoid, and then the cross entropy, because TensorFlow has better built-in ways to handle numerical edge cases. The same goes for softmax cross entropy and sparse softmax cross entropy.



Most of the classification loss functions described here are for two class predictions. This can be extended to multiple classes via summing the cross entropy terms over each prediction/target.



There are also many other metrics to look at when evaluating a model. Here is a list of some more to consider:

| Model metric                             | Description                                                                                                                                          |
|------------------------------------------|------------------------------------------------------------------------------------------------------------------------------------------------------|
| R-squared (coefficient of determination) | For linear models, this is the proportion of variance in the dependent variable that is explained by the independent data.                           |
| RMSE (root mean squared error)           | For continuous models, measures the difference between predictions and actual via the square root of the average squared error.                      |
| Confusion matrix                         | For categorical models, we look at a matrix of predicted categories versus actual categories. A perfect model has all the counts along the diagonal. |
| Recall                                   | For categorical models, this is the fraction of true positives over all predicted positives.                                                         |
| Precision                                | For categorical models, this is the fraction of true positives over all actual positives.                                                            |
| F-score                                  | For categorical models, this is the harmonic mean of precision and recall.                                                                           |

## Implementing Back Propagation

One of the benefits of using TensorFlow, is that it can keep track of operations and automatically update model variables based on back propagation. In this recipe, we will introduce how to use this aspect to our advantage when training machine learning models.

### Getting ready

Now we will introduce how to change our variables in the model in such a way that a `loss` function is minimized. We have learned about how to use objects and operations, and create `loss` functions that will measure the distance between our predictions and targets. Now we just have to tell TensorFlow how to back propagate errors through our computational graph to update the variables and minimize the `loss` function. This is done via declaring an optimization function. Once we have an optimization function declared, TensorFlow will go through and figure out the back propagation terms for all of our computations in the graph. When we feed data in and minimize the `loss` function, TensorFlow will modify our variables in the graph accordingly.

For this recipe, we will do a very simple regression algorithm. We will sample random numbers from a normal, with mean `1` and standard deviation `0.1`. Then we will run the numbers through one operation, which will be to multiply them by a variable, `A`. From this, the `loss` function will be the L2 norm between the output and the target, which will always be the value `10`. Theoretically, the best value for `A` will be the number `10` since our data will have mean `1`.

The second example is a very simple binary classification algorithm. Here we will generate 100 numbers from two normal distributions,  $N(-1,1)$  and  $N(3,1)$ . All the numbers from  $N(-1, 1)$  will be in target class `0`, and all the numbers from  $N(3, 1)$  will be in target class `1`. The model to differentiate these numbers will be a `sigmoid` function of a translation. In other words, the model will be `sigmoid(x + A)` where `A` is a variable we will fit. Theoretically, `A` will be equal to `-1`. We arrive at this number because if `m1` and `m2` are the means of the two normal functions, the value added to them to translate them equidistant to zero will be  $-(m_1+m_2)/2$ . We will see how TensorFlow can arrive at that number in the second example.

While specifying a good learning rate helps the convergence of algorithms, we must also specify a type of optimization. From the preceding two examples, we are using standard gradient descent. This is implemented with the TensorFlow function `GradientDescentOptimizer()`.

## How to do it...

Here is how the regression example works:

1. We start by loading the numerical Python package, numpy and tensorflow:

```
import numpy as np
import tensorflow as tf
```

2. Now we start a graph session:

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

3. Next we create the data, placeholders, and the A variable:

```
x_vals = np.random.normal(1, 0.1, 100)
y_vals = np.repeat(10., 100)
x_data = tf.placeholder(shape=[1], dtype=tf.float32)
y_target = tf.placeholder(shape=[1], dtype=tf.float32)
A = tf.Variable(tf.random_normal(shape=[1]))
```

4. We add the multiplication operation to our graph:

```
my_output = tf.mul(x_data, A)
```

5. Next we add our L2 loss function between the multiplication output and the target data:

```
loss = tf.square(my_output - y_target)
```

6. Before we can run anything, we have to initialize the variables:

```
init = tf.initialize_all_variables()
sess.run(init)
```

7. Now we have to declare a way to optimize the variables in our graph. We declare an optimizer algorithm. Most optimization algorithms need to know how far to step in each iteration. This distance is controlled by the learning rate. If our learning rate is too big, our algorithm might overshoot the minimum, but if our learning rate is too small, our algorithm might take too long to converge; this is related to the *vanishing and exploding gradient problem*. The learning rate has a big influence on convergence and we will discuss this at the end of the section. While here we use the standard gradient descent algorithm, there are many different optimization algorithms that operate differently and can do better or worse depending on the problem. For a great overview of different optimization algorithms, see the paper by Sebastian Ruder in the See Also section at the end of this recipe:

```
my_opt = tf.train.GradientDescentOptimizer(learning_rate=0.02)
train_step = my_opt.minimize(loss)
```



There is much theory on what learning rates are best. This is one of the harder things to know and figure out in machine learning algorithms. Good papers to read about how learning rates are related to specific optimization algorithms are listed in the *There's more...* section at the end of this recipe.

8. The final step is to loop through our training algorithm and tell TensorFlow to train many times. We will do this 101 times and print out results every 25th iteration. To train, we will select a random x and y entry and feed it through the graph. TensorFlow will automatically compute the loss, and slightly change the A bias to minimize the loss:

```
for i in range(100):
 rand_index = np.random.choice(100)
 rand_x = [x_vals[rand_index]]
 rand_y = [y_vals[rand_index]]
 sess.run(train_step, feed_dict={x_data: rand_x, y_target:
rand_y})
 if (i+1)%25==0:
 print('Step #' + str(i+1) + ' A = ' + str(sess.run(A)))
 print('Loss = ' + str(sess.run(loss, feed_dict={x_data:
rand_x, y_target: rand_y})))
Here is the output:
Step #25 A = [6.23402166]
Loss = 16.3173
Step #50 A = [8.50733757]
Loss = 3.56651
Step #75 A = [9.37753201]
Loss = 3.03149
Step #100 A = [9.80041122]
Loss = 0.0990248
```

9. Now we will introduce the code for the simple classification example. We can use the same TensorFlow script if we reset the graph first. Remember we will attempt to find an optimal translation, A that will translate the two distributions to the origin and the sigmoid function will split the two into two different classes.
10. First we reset the graph and reinitialize the graph session:

```
from tensorflow.python.framework import ops
ops.reset_default_graph()
sess = tf.Session()
```

11. Next we will create the data from two different normal distributions,  $N(-1, 1)$  and  $N(3, 1)$ . We will also generate the target labels, placeholders for the data, and the bias variable, A:

```
x_vals = np.concatenate((np.random.normal(-1, 1, 50), np.random.normal(3, 1, 50)))
y_vals = np.concatenate((np.repeat(0., 50), np.repeat(1., 50)))
x_data = tf.placeholder(shape=[1], dtype=tf.float32)
y_target = tf.placeholder(shape=[1], dtype=tf.float32)
A = tf.Variable(tf.random_normal(mean=10, shape=[1]))
```



Note that we initialized A to around the value 10, far from the theoretical value of -1. We did this on purpose to show how the algorithm converges from the value 10 to the optimal value, -1.

12. Next we add the translation operation to the graph. Remember that we do not have to wrap this in a `sigmoid` function because the `loss` function will do that for us:

```
my_output = tf.add(x_data, A)
```

13. Because the specific `loss` function expects batches of data that have an extra dimension associated with them (an added dimension which is the batch number), we will add an extra dimension to the output with the function, `expand_dims()`. In the next section we will discuss how to use variable sized batches in training. For now, we will again just use one random data point at a time:

```
my_output_expanded = tf.expand_dims(my_output, 0)
y_target_expanded = tf.expand_dims(y_target, 0)
```

14. Next we will initialize our one variable, A:

```
init = tf.initialize_all_variables()
sess.run(init)
```

15. Now we declare our `loss` function. We will use a cross entropy with unscaled logits that transforms them with a `sigmoid` function. TensorFlow has this all in one function for us in the neural network package called `nn.sigmoid_cross_entropy_with_logits()`. As stated before, it expects the arguments to have specific dimensions, so we have to use the expanded outputs and targets accordingly:

```
xentropy = tf.nn.sigmoid_cross_entropy_with_logits(my_output_
expanded, y_target_expanded)
```

16. Just like the regression example, we need to add an optimizer function to the graph so that TensorFlow knows how to update the bias variable in the graph:

```
my_opt = tf.train.GradientDescentOptimizer(0.05)
train_step = my_opt.minimize(xentropy)
```

17. Finally, we loop through a randomly selected data point several hundred times and update the variable `A` accordingly. Every 200 iterations, we will print out the value of `A` and the loss:

```
for i in range(1400):
 rand_index = np.random.choice(100)
 rand_x = [x_vals[rand_index]]
 rand_y = [y_vals[rand_index]]

 sess.run(train_step, feed_dict={x_data: rand_x, y_target:
rand_y})
 if (i+1)%200==0:
 print('Step #' + str(i+1) + ' A = ' + str(sess.run(A)))
 print('Loss = ' + str(sess.run(xentropy, feed_dict={x_
data: rand_x, y_target: rand_y})))
Step #200 A = [3.59597969]
Loss = [[0.00126199]]
Step #400 A = [0.50947344]
Loss = [[0.01149425]]
Step #600 A = [-0.50994617]
Loss = [[0.14271219]]
Step #800 A = [-0.76606178]
Loss = [[0.18807337]]
Step #1000 A = [-0.90859312]
Loss = [[0.02346182]]
Step #1200 A = [-0.86169094]
Loss = [[0.05427232]]
Step #1400 A = [-1.08486211]
Loss = [[0.04099189]]
```

## How it works...

As a recap, for both examples, we did the following:

1. Created the data.
2. Initialized placeholders and variables.
3. Created a loss function.
4. Defined an optimization algorithm.
5. And finally, iterated across random data samples to iteratively update our variables.

## There's more...

We've mentioned before that the optimization algorithm is sensitive to the choice of the learning rate. It is important to summarize the effect of this choice in a concise manner:

| Learning rate size    | Advantages/Disadvantages                    | Uses                                                           |
|-----------------------|---------------------------------------------|----------------------------------------------------------------|
| Smaller learning rate | Converges slower but more accurate results. | If solution is unstable, try lowering the learning rate first. |
| Larger learning rate  | Less accurate, but converges faster.        | For some problems, helps prevent solutions from stagnating.    |

Sometimes the standard gradient descent algorithm can get stuck or slow down significantly. This can happen when the optimization is stuck in the flat spot of a saddle. To combat this, there is another algorithm that takes into account a momentum term, which adds on a fraction of the prior step's gradient descent value. TensorFlow has this built in with the `MomentumOptimizer()` function.

Another variant is to vary the optimizer step for each variable in our models. Ideally, we would like to take larger steps for smaller moving variables and shorter steps for faster changing variables. We will not go into the mathematics of this approach, but a common implementation of this idea is called the Adagrad algorithm. This algorithm takes into account the whole history of the variable gradients. Again, the function in TensorFlow for this is called `AdagradOptimizer()`.

Sometimes, Adagrad forces the gradients to zero too soon because it takes into account the whole history. A solution to this is to limit how many steps we use. Doing this is called the Adadelta algorithm. We can apply this by using the function `AdadeltaOptimizer()`.

There are a few other implementations of different gradient descent algorithms. For these, we would refer the reader to the TensorFlow documentation at: [https://www.tensorflow.org/api\\_docs/python/train/optimizers](https://www.tensorflow.org/api_docs/python/train/optimizers).

## See also

For some references on optimization algorithms and learning rates, see the following papers and articles:

- ▶ Kingma, D., Jimmy, L. *Adam: A Method for Stochastic Optimization*. ICLR 2015.  
<https://arxiv.org/pdf/1412.6980.pdf>
- ▶ Ruder, S. *An Overview of Gradient Descent Optimization Algorithms*. 2016.  
<https://arxiv.org/pdf/1609.04747v1.pdf>
- ▶ Zeiler, M. *ADADelta: An Adaptive Learning Rate Method*. 2012. <http://www.matthewzeiler.com/pubs/googleTR2012/googleTR2012.pdf>

# Working with Batch and Stochastic Training

While TensorFlow updates our model variables according to the prior described back propagation, it can operate on anywhere from one datum observation to a large group of data at once. Operating on one training example can make for a very erratic learning process, while using a too large batch can be computationally expensive. Choosing the right type of training is crucial to getting our machine learning algorithms to converge to a solution.

## Getting ready

In order for TensorFlow to compute the variable gradients for back propagation to work, we have to measure the loss on a sample or multiple samples. Stochastic training is only putting through one randomly sampled data-target pair at a time, just like we did in the previous recipe. Another option is to put a larger portion of the training examples in at a time and average the loss for the gradient calculation. Batch training size can vary up to and including the whole dataset at once. Here we will show how to extend the prior regression example, which used stochastic training to batch training.

We will start by loading `numpy`, `matplotlib`, and `tensorflow` and start a graph session, as follows:

```
import matplotlib as plt
import numpy as np
import tensorflow as tf
sess = tf.Session()
```

## How to do it...

1. We will start by declaring a batch size. This will be how many data observations we will feed through the computational graph at one time:

```
batch_size = 20
```

2. Next we declare the data, placeholders, and the variable in the model. The change we make here is tothat we change the shape of the placeholders. They are now two dimensions, where the first dimension is `None`, and second will be the number of data points in the batch. We could have explicitly set it to 20, but we can generalize and use the `None` value. Again, as mentioned in *Chapter 1, Getting Started with TensorFlow*, we still have to make sure that the dimensions work out in the model and this does not allow us to perform any illegal matrix operations:

```
x_vals = np.random.normal(1, 0.1, 100)
y_vals = np.repeat(10., 100)
x_data = tf.placeholder(shape=[None, 1], dtype=tf.float32)
y_target = tf.placeholder(shape=[None, 1], dtype=tf.float32)
A = tf.Variable(tf.random_normal(shape=[1,1]))
```

3. Now we add our operation to the graph, which will now be matrix multiplication instead of regular multiplication. Remember that matrix multiplication is not communicative so we have to enter the matrices in the correct order in the `matmul()` function:

```
my_output = tf.matmul(x_data, A)
```

4. Our loss function will change because we have to take the mean of all the L2 losses of each data point in the batch. We do this by wrapping our prior loss output in TensorFlow's `reduce_mean()` function:

```
loss = tf.reduce_mean(tf.square(my_output - y_target))
```

5. We declare our optimizer just like we did before:

```
my_opt = tf.train.GradientDescentOptimizer(0.02)
train_step = my_opt.minimize(loss)
```

6. Finally, we will loop through and iterate on the training step to optimize the algorithm. This part is different than before because we want to be able to plot the loss over versus stochastic training convergence. So we initialize a list to store the `loss` function every five intervals:

```
loss_batch = []
for i in range(100):
 rand_index = np.random.choice(100, size=batch_size)
 rand_x = np.transpose([x_vals[rand_index]])
 rand_y = np.transpose([y_vals[rand_index]])
```

```
sess.run(train_step, feed_dict={x_data: rand_x, y_target: rand_y})
if (i+1)%5==0:
 print('Step #' + str(i+1) + ' A = ' + str(sess.run(A)))
 temp_loss = sess.run(loss, feed_dict={x_data: rand_x, y_target: rand_y})
 print('Loss = ' + str(temp_loss))
 loss_batch.append(temp_loss)
```

7. Here is the final output of the 100 iterations. Notice that the value of A has an extra dimension because it now has to be a 2D matrix:

```
Step #100 A = [[9.86720943]]
Loss = 0.
```

## How it works...

Batch training and stochastic training differ in their optimization method and their convergence. Finding a good batch size can be difficult. To see how convergence differs between batch and stochastic, here is the code to plot the batch loss from above. There is also a variable here that contains the stochastic loss, but that computation follows from the prior section in this chapter. Here is the code to save and record the stochastic loss in the training loop. Just substitute this code in the prior recipe:

```
loss_stochastic = []
for i in range(100):
 rand_index = np.random.choice(100)
 rand_x = [x_vals[rand_index]]
 rand_y = [y_vals[rand_index]]
 sess.run(train_step, feed_dict={x_data: rand_x, y_target: rand_y})
 if (i+1)%5==0:
 print('Step #' + str(i+1) + ' A = ' + str(sess.run(A)))
 temp_loss = sess.run(loss, feed_dict={x_data: rand_x, y_target: rand_y})
 print('Loss = ' + str(temp_loss))
 loss_stochastic.append(temp_loss)
```

Here is the code to produce the plot of both the stochastic and batch loss for the same regression problem:

```
plt.plot(range(0, 100, 5), loss_stochastic, 'b-', label='Stochastic Loss')
plt.plot(range(0, 100, 5), loss_batch, 'r--', label='Batch' Loss,
size=20)
plt.legend(loc='upper right', prop={'size': 11})
plt.show()
```

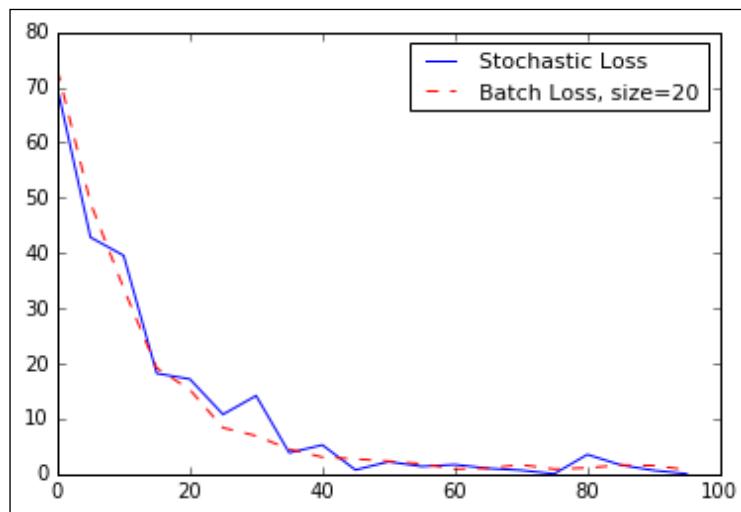


Figure 6: Stochastic loss and batch loss (batch size = 20) plotted over 100 iterations. Note that the batch loss is much smoother and the stochastic loss is much more erratic.

### There's more...

| Type of training | Advantages                                      | Disadvantages                                 |
|------------------|-------------------------------------------------|-----------------------------------------------|
| Stochastic       | Randomness may help move out of local minimums. | Generally, needs more iterations to converge. |
| Batch            | Finds minimums quicker.                         | Takes more resources to compute.              |

## Combining Everything Together

In this section, we will combine everything we have illustrated so far and create a classifier on the iris dataset.

### Getting ready

The iris data set is described in more detail in the *Working with Data Sources* recipe in *Chapter 1, Getting Started with TensorFlow*. We will load this data, and do a simple binary classifier to predict whether a flower is the species *Iris setosa* or not. To be clear, this dataset has three classes of species, but we will only predict whether it is a single species (*I. setosa*) or not, giving us a binary classifier. We will start by loading the libraries and data, then transform the target accordingly.

### How to do it...

1. First we load the libraries needed and initialize the computational graph. Note that we also load `matplotlib` here, because we would like to plot the resulting line after:

```
import matplotlib.pyplot as plt
import numpy as np
from sklearn import datasets
import tensorflow as tf
sess = tf.Session()
```

2. Next we load the iris data. We will also need to transform the target data to be just 1 or 0 if the target is setosa or not. Since the iris data set marks setosa as a zero, we will change all targets with the value 0 to 1, and the other values all to 0. We will also only use two features, petal length and petal width. These two features are the third and fourth entry in each x-value:

```
iris = datasets.load_iris()
binary_target = np.array([1. if x==0 else 0. for x in iris.target])
iris_2d = np.array([[x[2], x[3]] for x in iris.data])
```

3. Let's declare our batch size, data placeholders, and model variables. Remember that the data placeholders for variable batch sizes have `None` as the first dimension:

```
batch_size = 20
x1_data = tf.placeholder(shape=[None, 1], dtype=tf.float32)
x2_data = tf.placeholder(shape=[None, 1], dtype=tf.float32)
y_target = tf.placeholder(shape=[None, 1], dtype=tf.float32)
A = tf.Variable(tf.random_normal(shape=[1, 1]))
b = tf.Variable(tf.random_normal(shape=[1, 1]))
```



Note that we can increase the performance (speed) of the algorithm by decreasing the bytes for floats by using `dtype=tf.float32` instead.



4. Here we define the linear model. The model will take the form  $x2=x1*A+b$ . And if we want to find points above or below that line, we see whether they are above or below zero when plugged into the equation  $x2-x1*A-b$ . We will do this by taking the sigmoid of that equation and predicting 1 or 0 from that equation. Remember that TensorFlow has loss functions with the sigmoid built in, so we just need to define the output of the model prior to the sigmoid function:

```
my_mult = tf.matmul(x2_data, A)
my_add = tf.add(my_mult, b)
my_output = tf.sub(x1_data, my_add)
```

5. Now we add our sigmoid cross-entropy loss function with TensorFlow's built in function, `sigmoid_cross_entropy_with_logits()`:

```
xentropy = tf.nn.sigmoid_cross_entropy_with_logits(my_output, y_target)
```

6. We also have to tell TensorFlow how to optimize our computational graph by declaring an optimizing method. We will want to minimize the cross-entropy loss. We will also choose 0.05 as our learning rate:

```
my_opt = tf.train.GradientDescentOptimizer(0.05)
train_step = my_opt.minimize(xentropy)
```

7. Now we create a variable initialization operation and tell TensorFlow to execute it:

```
init = tf.initialize_all_variables()
sess.run(init)
```

8. Now we will train our linear model with 1000 iterations. We will feed in the three data points that we require: petal length, petal width, and the target variable. Every 200 iterations we will print the variable values:

```
for i in range(1000):
 rand_index = np.random.choice(len(iris_2d), size=batch_size)
 rand_x = iris_2d[rand_index]
 rand_x1 = np.array([[x[0]] for x in rand_x])
 rand_x2 = np.array([[x[1]] for x in rand_x])
 rand_y = np.array([[y] for y in binary_target[rand_index]])
 sess.run(train_step, feed_dict={x1_data: rand_x1, x2_data:
 rand_x2, y_target: rand_y})
 if (i+1)%200==0:
```

```
 print('Step #' + str(i+1) + ' A = ' + str(sess.run(A)) +
' , b = ' + str(sess.run(b)))
Step #200 A = [[8.67285347]], b = [[-3.47147632]]
Step #400 A = [[10.25393486]], b = [[-4.62928772]]
Step #600 A = [[11.152668]], b = [[-5.4077611]]
Step #800 A = [[11.81016064]], b = [[-5.96689034]]
Step #1000 A = [[12.41202831]], b = [[-6.34769201]]
```

9. The next set of commands extracts the model variables, and plots the line on a graph. The resulting graph is in the next section:

```
[[slope]] = sess.run(A)
[[intercept]] = sess.run(b)
x = np.linspace(0, 3, num=50)
ablineValues = []
for i in x:
 ablineValues.append(slope*i+intercept)
setosa_x = [a[1] for i,a in enumerate(iris_2d) if binary_
target[i]==1]
setosa_y = [a[0] for i,a in enumerate(iris_2d) if binary_
target[i]==1]
non_setosa_x = [a[1] for i,a in enumerate(iris_2d) if binary_
target[i]==0]
non_setosa_y = [a[0] for i,a in enumerate(iris_2d) if binary_
target[i]==0]
plt.plot(setosa_x, setosa_y, 'rx', ms=10, mew=2, label='setosa')
plt.plot(non_setosa_x, non_setosa_y, 'ro', label='Non-setosa')
plt.plot(x, ablineValues, 'b-')
plt.xlim([0.0, 2.7])
plt.ylim([0.0, 7.1])
plt.suptitle('Linear Separator For I.setosa', fontsize=20)
plt.xlabel('Petal Length')
plt.ylabel('Petal Width')
plt.legend(loc='lower right')
plt.show()
```

## How it works...

Our goal was to fit a line between the *I.setosa* points and the other two species using only petal width and petal length. If we plot the points and the resulting line, we see that we have achieved the following:

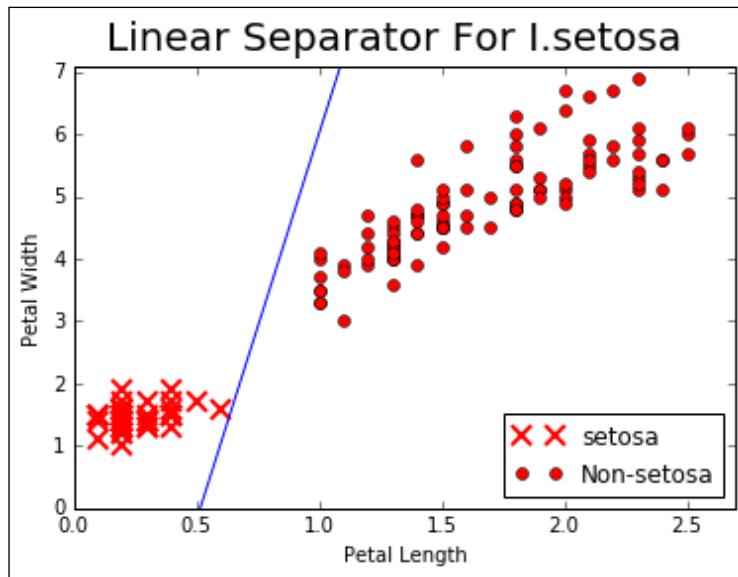


Figure 7: Plot of *I.setosa* and non-setosa for petal width vs petal length. The solid line is the linear separator that we achieved after 1,000 iterations.

## There's more...

While we achieved our objective of separating the two classes with a line, it may not be the best model for separating two classes. In *Chapter 4, Support Vector Machines* we will discuss support vector machines, which is a better way of separating two classes in a feature space.

## See also

For more information on the iris dataset, see the Wikipedia entry, [https://en.wikipedia.org/wiki/Iris\\_flower\\_data\\_set](https://en.wikipedia.org/wiki/Iris_flower_data_set). For information about the Scikit Learn iris dataset implementation, see the documentation at [http://scikit-learn.org/stable/auto\\_examples/datasets/plot\\_iris\\_dataset.html](http://scikit-learn.org/stable/auto_examples/datasets/plot_iris_dataset.html).

## Evaluating Models

We have learned how to train a regression and classification algorithm in TensorFlow. After this is accomplished, we must be able to evaluate the model's predictions to determine how well it did.

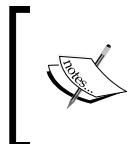
### Getting ready

Evaluating models is very important and every subsequent model will have some form of model evaluation. Using TensorFlow, we must build this feature into the computational graph and call it during and/or after our model is training.

Evaluating models during training gives us insight into the algorithm and may give us hints to debug it, improve it, or change models entirely. While evaluation during training isn't always necessary, we will show how to do this with both regression and classification.

After training, we need to quantify how the model performs on the data. Ideally, we have a separate training and test set (and even a validation set) on which we can evaluate the model.

When we want to evaluate a model, we will want to do so on a large batch of data points. If we have implemented batch training, we can reuse our model to make a prediction on such a batch. If we have implemented stochastic training, we may have to create a separate evaluator that can process data in batches.



If we included a transformation on our model output in the `loss` function, for example, `sigmoid_cross_entropy_with_logits()`, we must take that into account when computing predictions for accuracy calculations. Don't forget to include this in our evaluation of the model.

### How to do it...

Regression models attempt to predict a continuous number. The target is not a category, but a desired number. To evaluate these regression predictions against the actual targets, we need an aggregate measure of the distance between the two. Most of the time, a meaningful `loss` function will satisfy these criteria. Here is how to change the simple regression algorithm from above into printing out the `loss` in the training loop and evaluating the `loss` at the end. For an example, we will revisit and rewrite our regression example in the prior *Implementing Back Propagation* recipe in this chapter.

Classification models predict a category based on numerical inputs. The actual targets are a sequence of 1s and 0s and we must have a measure of how close we are to the truth from our predictions. The `loss` function for classification models usually isn't that helpful in interpreting how well our model is doing. Usually, we want some sort of classification accuracy, which is commonly the percentage of correctly predicted categories. For this example, we will use the classification example from the prior *Implementing Back Propagation* recipe in this chapter.

## How it works...

First we will show how to evaluate the simple regression model that simply fits a constant multiplication to the target of 10, as follows:

1. First we start by loading the libraries, creating the graph, data, variables, and placeholders. There is an additional part to this section that is very important. After we create the data, we will split the data into training and testing datasets randomly. This is important because we will always test our models if they are predicting well or not. Evaluating the model both on the training data and test data also lets us see whether the model is overfitting or not:

```
import matplotlib.pyplot as plt
import numpy as np
import tensorflow as tf
sess = tf.Session()
x_vals = np.random.normal(1, 0.1, 100)
y_vals = np.repeat(10., 100)
x_data = tf.placeholder(shape=[None, 1], dtype=tf.float32)
y_target = tf.placeholder(shape=[None, 1], dtype=tf.float32)
batch_size = 25
train_indices = np.random.choice(len(x_vals), round(len(x_vals)*0.8), replace=False)
test_indices = np.array(list(set(range(len(x_vals))) - set(train_indices)))
x_vals_train = x_vals[train_indices]
x_vals_test = x_vals[test_indices]
y_vals_train = y_vals[train_indices]
y_vals_test = y_vals[test_indices]
A = tf.Variable(tf.random_normal(shape=[1,1]))
```

2. Now we declare our model, loss function, and optimization algorithm. We will also initialize the model variable A. Use the following code:

```
my_output = tf.matmul(x_data, A)
loss = tf.reduce_mean(tf.square(my_output - y_target))
init = tf.initialize_all_variables()
sess.run(init)
my_opt = tf.train.GradientDescentOptimizer(0.02)
train_step = my_opt.minimize(loss)
```

3. We run the training loop just as we would before, as follows:

```
for i in range(100):
 rand_index = np.random.choice(len(x_vals_train), size=batch_size)
 rand_x = np.transpose([x_vals_train[rand_index]])
 rand_y = np.transpose([y_vals_train[rand_index]])
 sess.run(train_step, feed_dict={x_data: rand_x, y_target: rand_y})
 if (i+1)%25==0:
 print('Step #' + str(i+1) + ' A = ' + str(sess.run(A)))
 print('Loss = ' + str(sess.run(loss, feed_dict={x_data: rand_x, y_target: rand_y})))
Step #25 A = [[6.39879179]]
Loss = 13.7903
Step #50 A = [[8.64770794]]
Loss = 2.53685
Step #75 A = [[9.40029907]]
Loss = 0.818259
Step #100 A = [[9.6809473]]
Loss = 1.10908
```

4. Now, to evaluate the model, we will output the MSE (loss function) on the training and test sets, as follows:

```
mse_test = sess.run(loss, feed_dict={x_data: np.transpose([x_vals_test]), y_target: np.transpose([y_vals_test])})
mse_train = sess.run(loss, feed_dict={x_data: np.transpose([x_vals_train]), y_target: np.transpose([y_vals_train])})
print('MSE' on test:' + str(np.round(mse_test, 2)))
print('MSE' on train:' + str(np.round(mse_train, 2)))
MSE on test:1.35
MSE on train:0.88
```

5. For the classification example, we will do something very similar. This time, we will need to create our own accuracy function that we can call at the end. One reason for this is because our loss function has the sigmoid built in and we will need to call the sigmoid separately and test it to see if our classes are correct.
6. In the same script, we can just reload the graph and create our data, variables, and placeholders. Remember that we will also need to separate the data and targets into training and testing sets. Use the following code:

```
from tensorflow.python.framework import ops
ops.reset_default_graph()
sess = tf.Session()
batch_size = 25
x_vals = np.concatenate((np.random.normal(-1, 1, 50), np.random.
normal(2, 1, 50)))
y_vals = np.concatenate((np.repeat(0., 50), np.repeat(1., 50)))
x_data = tf.placeholder(shape=[1, None], dtype=tf.float32)
y_target = tf.placeholder(shape=[1, None], dtype=tf.float32)
train_indices = np.random.choice(len(x_vals), round(len(x_
vals)*0.8), replace=False)
test_indices = np.array(list(set(range(len(x_vals))) - set(train_.
indices)))
x_vals_train = x_vals[train_indices]
x_vals_test = x_vals[test_indices]
y_vals_train = y_vals[train_indices]
y_vals_test = y_vals[test_indices]
A = tf.Variable(tf.random_normal(mean=10, shape=[1]))
```

7. We will now add the model and the loss function to the graph, initialize variables, and create the optimization procedure, as follows:

```
my_output = tf.add(x_data, A)
init = tf.initialize_all_variables()
sess.run(init)
xentropy = tf.reduce_mean(tf.nn.sigmoid_cross_entropy_with_
logits(my_output, y_target))
my_opt = tf.train.GradientDescentOptimizer(0.05)
train_step = my_opt.minimize(xentropy)
```

8. Now we run our training loop, as follows:

```
for i in range(1800):
 rand_index = np.random.choice(len(x_vals_train), size=batch_.
size)
 rand_x = [x_vals_train[rand_index]]
 rand_y = [y_vals_train[rand_index]]
 sess.run(train_step, feed_dict={x_data: rand_x, y_target:
rand_y})
```

```
if (i+1)%200==0:
 print('Step #' + str(i+1) + ' A = ' + str(sess.run(A)))
 print('Loss = ' + str(sess.run(xentropy, feed_dict={x_
data: rand_x, y_target: rand_y})))
Step #200 A = [6.64970636]
Loss = 3.39434
Step #400 A = [2.2884655]
Loss = 0.456173
Step #600 A = [0.29109824]
Loss = 0.312162
Step #800 A = [-0.20045301]
Loss = 0.241349
Step #1000 A = [-0.33634067]
Loss = 0.376786
Step #1200 A = [-0.36866501]
Loss = 0.271654
Step #1400 A = [-0.3727718]
Loss = 0.294866
Step #1600 A = [-0.39153299]
Loss = 0.202275
Step #1800 A = [-0.36630616]
Loss = 0.358463
```

9. To evaluate the model, we will create our own prediction operation. We wrap the prediction operation in a squeeze function because we want to make the predictions and targets the same shape. Then we test for equality with the equal function. After that, we are left with a tensor of true and false values that we cast to float32 and take the mean of them. This will result in an accuracy value. We will evaluate this function for both the training and testing sets, as follows:

```
y_prediction = tf.squeeze(tf.round(tf.nn.sigmoid(tf.add(x_data,
A))))
correct_prediction = tf.equal(y_prediction, y_target)
accuracy = tf.reduce_mean(tf.cast(correct_prediction, tf.float32))
acc_value_test = sess.run(accuracy, feed_dict={x_data: [x_vals_
test], y_target: [y_vals_test]})
acc_value_train = sess.run(accuracy, feed_dict={x_data: [x_vals_
train], y_target: [y_vals_train]})
print('Accuracy' on train set: ' + str(acc_value_train))
print('Accuracy' on test set: ' + str(acc_value_test))
Accuracy on train set: 0.925
Accuracy on test set: 0.95
```

10. Many times, seeing the model results (accuracy, MSE, and so on) will help us to evaluate the model. We can easily graph the model and data here because it is one-dimensional. Here is how to visualize the model and data with two separate histograms using matplotlib:

```
A_result = sess.run(A)
bins = np.linspace(-5, 5, 50)
plt.hist(x_vals[0:50], bins, alpha=0.5, label='N'(-1,1),
color='white')
plt.hist(x_vals[50:100], bins[0:50], alpha=0.5, label='N'(2,1),
color='red')
plt.plot((A_result, A_result), (0, 8), 'k--', linewidth=3,
label='A = ' + str(np.round(A_result, 2)))
plt.legend(loc='upper right')
plt.title('Binary' Classifier, Accuracy=' + str(np.round(acc_
value, 2)))
plt.show()
```

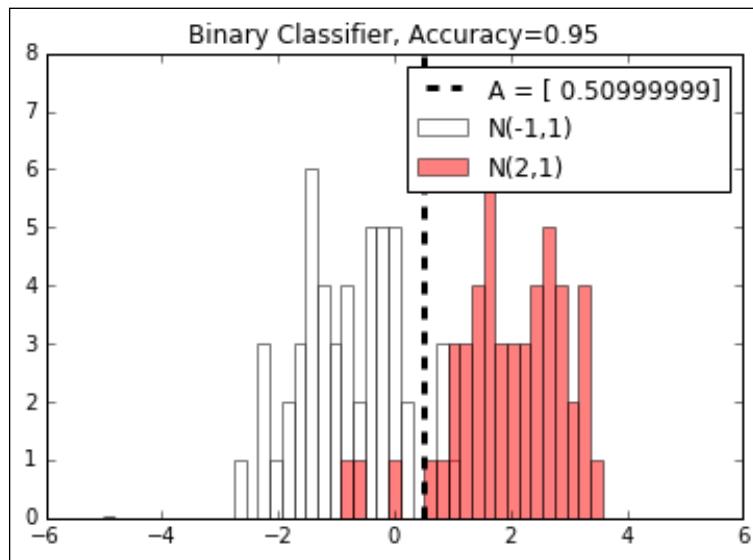


Figure 8: Visualization of data and the end model, A. The two normal values are centered at -1 and 2, making the theoretical best split at 0.5. Here the model found the best split very close to that number.

# 3

## Linear Regression

In this chapter, we will cover the basic recipes for understanding how TensorFlow works and how to access data for this book and additional resources. We will cover the following areas:

- ▶ Using the Matrix Inverse Method
- ▶ Implementing a Decomposition Method
- ▶ Learning the TensorFlow Way of Regression
- ▶ Understanding Loss Functions in Linear Regression
- ▶ Implementing Deming Regression
- ▶ Implementing Lasso and Ridge Regression
- ▶ Implementing Elastic Net Regression
- ▶ Implementing Regression Logistic Regression

### Introduction

Linear regression may be one of the most important algorithms in statistics, machine learning, and science in general. It's one of the most used algorithms and it is very important to understand how to implement it and its various flavors. One of the advantages that linear regression has over many other algorithms is that it is very interpretable. We end up with a number for each feature that directly represents how that feature influences the target or dependent variable. In this chapter, we will introduce how linear regression can be classically implemented, and then move on to how to best implement it in TensorFlow. Remember that all the code is available at GitHub online at [https://github.com/nfmccclure/tensorflow\\_cookbook](https://github.com/nfmccclure/tensorflow_cookbook).

## Using the Matrix Inverse Method

In this recipe, we will use TensorFlow to solve two dimensional linear regressions with the matrix inverse method.

### Getting ready

Linear regression can be represented as a set of matrix equations, say  $Ax = b$ . Here we are interested in solving the coefficients in matrix  $x$ . We have to be careful if our observation matrix (design matrix)  $A$  is not square. The solution to solving  $x$  can be expressed as  $x = (A^T A)^{-1} A^T b$ . To show this is indeed the case, we will generate two-dimensional data, solve it in TensorFlow, and plot the result.

### How to do it...

- First we load the necessary libraries, initialize the graph, and create the data, as follows:

```
import matplotlib.pyplot as plt
import numpy as np
import tensorflow as tf
sess = tf.Session()
x_vals = np.linspace(0, 10, 100)
y_vals = x_vals + np.random.normal(0, 1, 100)
```

- Next we create the matrices to use in the inverse method. We create the  $A$  matrix first, which will be a column of x-data and a column of 1s. Then we create the  $b$  matrix from the y-data. Use the following code:

```
x_vals_column = np.transpose(np.matrix(x_vals))
ones_column = np.transpose(np.matrix(np.repeat(1, 100)))
A = np.column_stack((x_vals_column, ones_column))
b = np.transpose(np.matrix(y_vals))
```

- We then turn our  $A$  and  $b$  matrices into tensors, as follows:

```
A_tensor = tf.constant(A)
b_tensor = tf.constant(b)
```

- Now that we have our matrices set up , we can use TensorFlow to solve this via the matrix inverse method, as follows:

```
tA_A = tf.matmul(tf.transpose(A_tensor), A_tensor)
tA_A_inv = tf.matrix_inverse(tA_A)
product = tf.matmul(tA_A_inv, tf.transpose(A_tensor))
solution = tf.matmul(product, b_tensor)
solution_eval = sess.run(solution)
```

5. We now extract the coefficients from the solution, the slope and the  $y$ -intercept, as follows:

```
slope = solution_eval[0][0]
y_intercept = solution_eval[1][0]
print('slope: ' + str(slope))
print('y_intercept: ' + str(y_intercept))

slope: 0.955707151739
y_intercept: 0.174366829314

best_fit = []
for i in x_vals:
 best_fit.append(slope*i+y_intercept)
plt.plot(x_vals, y_vals, 'o', label='Data')
plt.plot(x_vals, best_fit, 'r-', label='Best fit line',
linewidth=3)
plt.legend(loc='upper left')
plt.show()
```

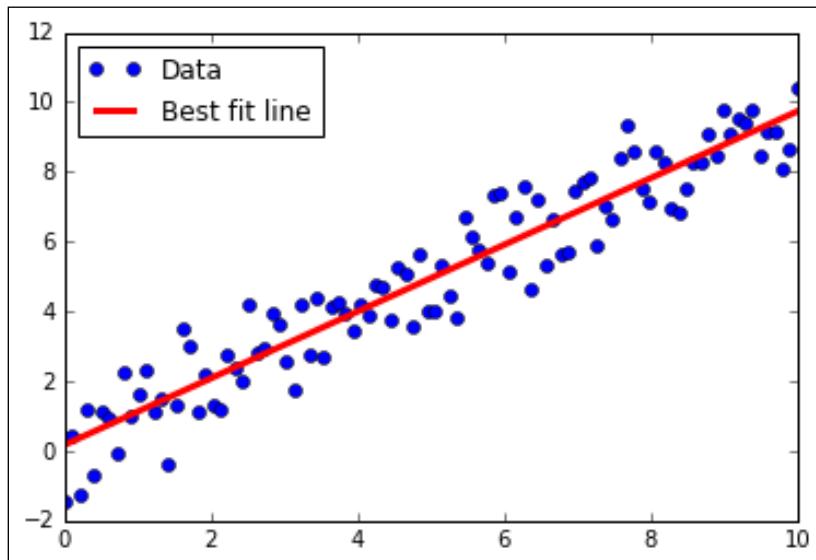


Figure 1: Data points and a best-fit line obtained via the matrix inverse method.

## How it works...

Unlike prior recipes, or most recipes in this book, the solution here is found exactly through matrix operations. Most TensorFlow algorithms that we will use are implemented via a training loop and take advantage of automatic back propagation to update model variables. Here, we illustrate the versatility of TensorFlow by implementing a direct solution to fitting a model to data.

## Implementing a Decomposition Method

For this recipe, we will implement a matrix decomposition method for linear regression. Specifically we will use the Cholesky decomposition, for which relevant functions exist in TensorFlow.

### Getting ready

Implementing inverse methods in the previous recipe can be numerically inefficient in most cases, especially when the matrices get very large. Another approach is to decompose the  $A$  matrix and perform matrix operations on the decompositions instead. One such approach is to use the built-in Cholesky decomposition method in TensorFlow. One reason people are so interested in decomposing a matrix into more matrices is because the resulting matrices will have assured properties that allow us to use certain methods efficiently. The Cholesky decomposition decomposes a matrix into a lower and upper triangular matrix, say  $L$  and  $L'$ , such that these matrices are transpositions of each other. For further information on the properties of this decomposition, there are many resources available that describe it and how to arrive at it. Here we will solve the system,  $Ax = b$ , by writing it as  $LL'x = b$ . We will first solve  $Ly = b$  and then solve  $L'x = y$  to arrive at our coefficient matrix,  $x$ .

## How to do it...

1. We will set up the system exactly in the same way as the previous recipe. We will import libraries, initialize the graph, and create the data. Then we will obtain our  $A$  matrix and  $b$  matrix in the same way as before:

```
import matplotlib.pyplot as plt
import numpy as np
import tensorflow as tf
from tensorflow.python.framework import ops
ops.reset_default_graph()
sess = tf.Session()
x_vals = np.linspace(0, 10, 100)
y_vals = x_vals + np.random.normal(0, 1, 100)
x_vals_column = np.transpose(np.matrix(x_vals))
ones_column = np.transpose(np.matrix(np.repeat(1, 100)))
A = np.column_stack((x_vals_column, ones_column))
b = np.transpose(np.matrix(y_vals))
A_tensor = tf.constant(A)
b_tensor = tf.constant(b)
```

2. Next we will find the Cholesky decomposition of our square matrix,  $A^T A$ :



Note that the TensorFlow function, `cholesky()`, only returns the lower diagonal part of the decomposition. This is fine, as the upper diagonal matrix is just the lower one, transposed.

```
tA_A = tf.matmul(tf.transpose(A_tensor), A_tensor)
L = tf.cholesky(tA_A)
tA_b = tf.matmul(tf.transpose(A_tensor), b)
sol1 = tf.matrix_solve(L, tA_b)
sol2 = tf.matrix_solve(tf.transpose(L), sol1)
```

3. Now that we have the solution, we extract the coefficients:

```
solution_eval = sess.run(sol2)
slope = solution_eval[0][0]
y_intercept = solution_eval[1][0]
print('slope: ' + str(slope))
print('y_intercept: ' + str(y_intercept))

slope: 0.956117676145
y_intercept: 0.136575513864

best_fit = []
for i in x_vals:
 best_fit.append(slope*i+y_intercept)
plt.plot(x_vals, y_vals, 'o', label='Data')
plt.plot(x_vals, best_fit, 'r-', label='Best fit line',
linewidth=3)
plt.legend(loc='upper left')
plt.show()
```

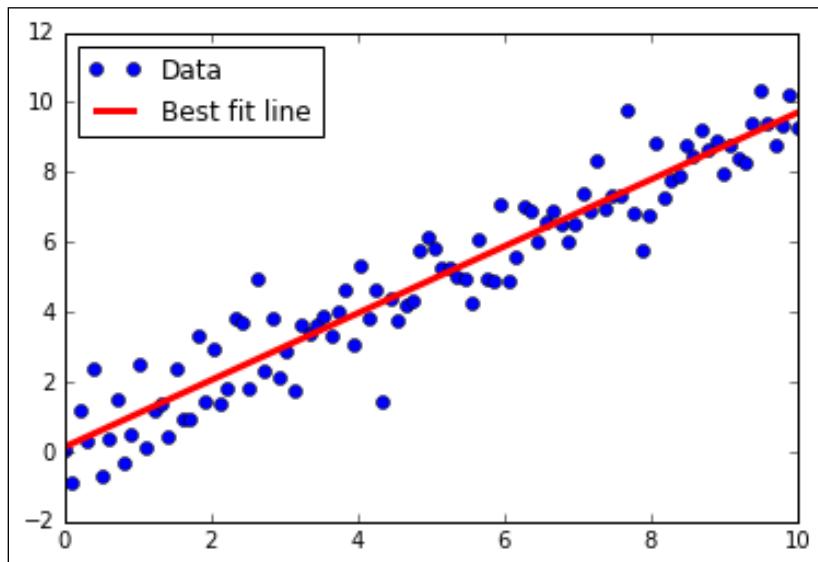


Figure 2: Data points and best-fit line obtained via Cholesky decomposition.

## How it works...

As you can see, we arrive at a very similar answer to the prior recipe. Keep in mind that this way of decomposing a matrix, then performing our operations on the pieces, is sometimes much more efficient and numerically stable.

# Learning The TensorFlow Way of Linear Regression

## Getting ready

In this recipe, we will loop through batches of data points and let TensorFlow update the slope and y-intercept. Instead of generated data, we will us the iris dataset that is built in to the Scikit Learn. Specifically, we will find an optimal line through data points where the x-value is the petal width and the y-value is the sepal length. We choose these two because there appears to be a linear relationship between them, as we will see in the graphs at the end. We will also talk more about the effects of different loss functions in the next section, but for this recipe we will use the L2 loss function.

## How to do it...

1. We start by loading the necessary libraries, creating a graph, and loading the data:

```
import matplotlib.pyplot as plt
import numpy as np
import tensorflow as tf
from sklearn import datasets
from tensorflow.python.framework import ops
ops.reset_default_graph()
sess = tf.Session()
iris = datasets.load_iris()

x_vals = np.array([x[3] for x in iris.data])
y_vals = np.array([y[0] for y in iris.data])
```

2. We then declare our learning rate, batch size, placeholders, and model variables:

```
learning_rate = 0.05
batch_size = 25
x_data = tf.placeholder(shape=[None, 1], dtype=tf.float32)
y_target = tf.placeholder(shape=[None, 1], dtype=tf.float32)
A = tf.Variable(tf.random_normal(shape=[1,1]))
b = tf.Variable(tf.random_normal(shape=[1,1]))
```

3. Next, we write the formula for the linear model,  $y=Ax+b$ :

```
model_output = tf.add(tf.matmul(x_data, A), b)
```

4. Then we declare our L2 loss function (which includes the mean over the batch), initialize the variables, and declare our optimizer. Note that we chose 0.05 as our learning rate:

```
loss = tf.reduce_mean(tf.square(y_target - model_output))
init = tf.global_variables_initializer()
sess.run(init)
my_opt = tf.train.GradientDescentOptimizer(learning_rate)
train_step = my_opt.minimize(loss)
```

5. We can now loop through and train the model on randomly selected batches. We will run it for 100 loops and print out the variable and loss values every 25 iterations. Note that here we are also saving the loss of every iteration so that we can view it afterwards:

```
loss_vec = []
for i in range(100):
 rand_index = np.random.choice(len(x_vals), size=batch_size)
 rand_x = np.transpose([x_vals[rand_index]])
 rand_y = np.transpose([y_vals[rand_index]])
 sess.run(train_step, feed_dict={x_data: rand_x, y_target:
rand_y})
 temp_loss = sess.run(loss, feed_dict={x_data: rand_x, y_
target: rand_y})
 loss_vec.append(temp_loss)
 if (i+1)%25==0:
 print('Step #' + str(i+1) + ' A = ' + str(sess.run(A)) + '
b = ' + str(sess.run(b)))
 print('Loss = ' + str(temp_loss))
Step #25 A = [[2.17270374]] b = [[2.85338426]]
Loss = 1.08116
Step #50 A = [[1.70683455]] b = [[3.59916329]]
Loss = 0.796941
Step #75 A = [[1.32762754]] b = [[4.08189011]]
Loss = 0.466912
Step #100 A = [[1.15968263]] b = [[4.38497639]]
Loss = 0.281003
```

6. Next we will extract the coefficients we found and create a best-fit line to put in the graph:

```
[slope] = sess.run(A)
[y_intercept] = sess.run(b)
best_fit = []
for i in x_vals:
 best_fit.append(slope*i+y_intercept)
```

7. Here we will create two plots. The first will be the data with the found line overlaid. The second is the L2 loss function over the 100 iterations:

```
plt.plot(x_vals, y_vals, 'o', label='Data Points')
plt.plot(x_vals, best_fit, 'r-', label='Best fit line',
linewidth=3)
plt.legend(loc='upper left')
plt.title('Sepal Length vs Pedal Width')
plt.xlabel('Pedal Width')
plt.ylabel('Sepal Length')
plt.show()
plt.plot(loss_vec, 'k-')
plt.title('L2 Loss per Generation')
plt.xlabel('Generation')
plt.ylabel('L2 Loss')
plt.show()
```

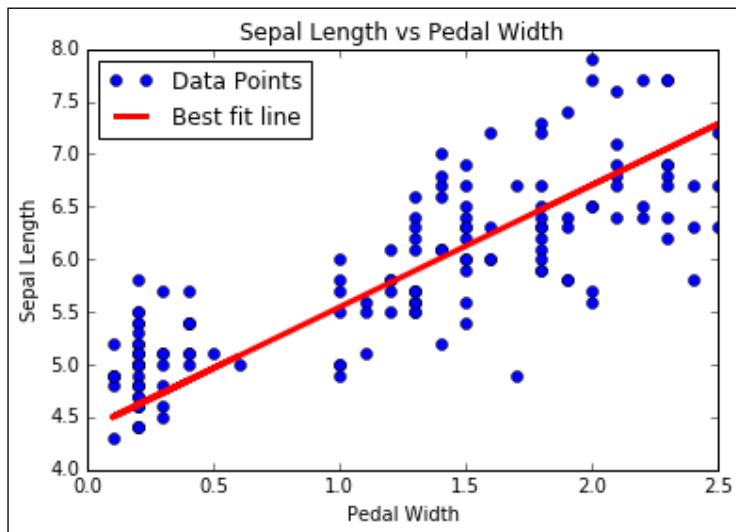


Figure 3: These are the data points from the iris dataset (sepal length versus pedal width) overlaid with the optimal line fit found in TensorFlow with the specified algorithm.

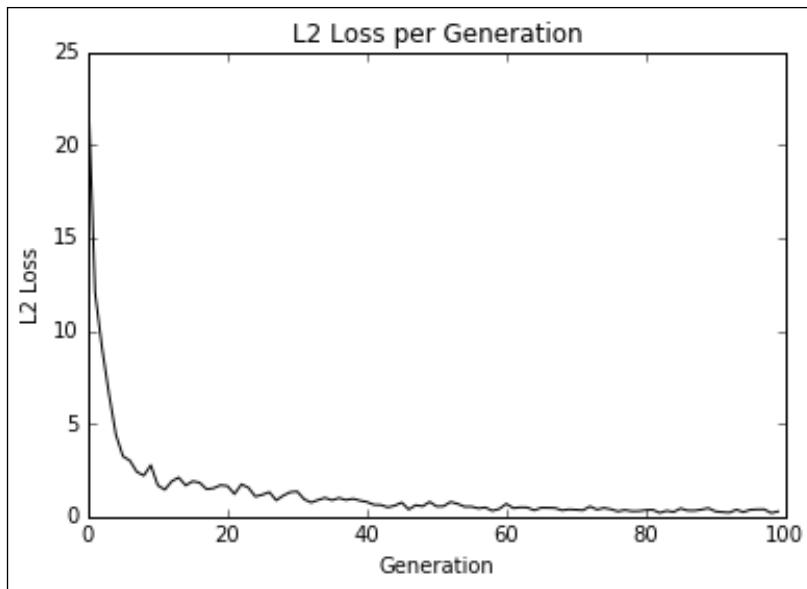


Figure 4: Here is the L2 loss of fitting the data with our algorithm. Note the jitter in the loss function; this can be decreased with a larger batch size or increased with a smaller batch size.

 Here is a good place to note how to see if the model is over-or underfitting the data. If our data is broken into a `test` and `train` set, and the accuracy is greater on the `train` set and going down on the `test` set, then we are overfitting the data. If the accuracy is still increasing on both the `test` and `train` set, then the model is underfitting and we should continue training.

## How it works...

The optimal line found is not guaranteed to be the best-fit line. Convergence to the best-fit line depends on the number of iterations, batch size, learning rate, and the loss function. It is always good practice to observe the loss function over time as it can help us troubleshoot problems or hyperparameter changes.

## Understanding Loss Functions in Linear Regression

It is important to know the effect of loss functions in algorithm convergence. Here we will illustrate how the L1 and L2 loss functions affect convergence in linear regression.

## Getting ready

We will use the same iris dataset as in the prior recipe, but we will change our loss functions and learning rates to see how convergence changes.

## How to do it...

1. The start of the program is unchanged from before until we get to our loss function. We load the necessary libraries, start a session, load the data, create placeholders, and define our variables and model. One thing to note is that we are pulling out our learning rate and model iterations. We are doing this because we want to show the effect of quickly changing these parameters. Use the following code:

```
import matplotlib.pyplot as plt
import numpy as np
import tensorflow as tf
from sklearn import datasets
sess = tf.Session()
iris = datasets.load_iris()
x_vals = np.array([x[3] for x in iris.data])
y_vals = np.array([y[0] for y in iris.data])
batch_size = 25
learning_rate = 0.1 # Will not converge with learning rate at 0.4
iterations = 50
x_data = tf.placeholder(shape=[None, 1], dtype=tf.float32)
y_target = tf.placeholder(shape=[None, 1], dtype=tf.float32)
A = tf.Variable(tf.random_normal(shape=[1,1]))
b = tf.Variable(tf.random_normal(shape=[1,1]))
model_output = tf.add(tf.matmul(x_data, A), b)
```

2. Our loss function will change to the L1 loss, as follows:

```
loss_l1 = tf.reduce_mean(tf.abs(y_target - model_output))
```



Note that we can change this back to the L2 loss by substituting in the following formula: `tf.reduce_mean(tf.square(y_target - model_output))`.

3. Now we resume by initializing the variables declaring our optimizer, and looping them through the training part. Note that we are also saving our loss at every generation to measure the convergence. Use the following code:

```
init = tf.global_variables_initializer()
sess.run(init)
my_opt_l1 = tf.train.GradientDescentOptimizer(learning_rate)
train_step_l1 = my_opt_l1.minimize(loss_l1)
loss_vec_l1 = []
for i in range(iterations):
 rand_index = np.random.choice(len(x_vals), size=batch_size)
 rand_x = np.transpose([x_vals[rand_index]])
 rand_y = np.transpose([y_vals[rand_index]])
 sess.run(train_step_l1, feed_dict={x_data: rand_x, y_target:
rand_y})
 temp_loss_l1 = sess.run(loss_l1, feed_dict={x_data: rand_x,
y_target: rand_y})
 loss_vec_l1.append(temp_loss_l1)
 if (i+1)%25==0:
 print('Step #' + str(i+1) + ' A = ' + str(sess.run(A)) + ' '
b = ' + str(sess.run(b)))
plt.plot(loss_vec_l1, 'k-', label='L1 Loss')
plt.plot(loss_vec_l2, 'r--', label='L2 Loss')
plt.title('L1 and L2 Loss per Generation')
plt.xlabel('Generation')
plt.ylabel('Loss')
plt.legend(loc='upper right')
plt.show()
```

## How it works...

When choosing a loss function, we must also choose a corresponding learning rate that will work with our problem. Here, we will illustrate two situations, one in which L2 is preferred and one in which L1 is preferred.

If our learning rate is small, our convergence will take more time. But if our learning rate is too large, we will have issues with our algorithm never converging. Here is a plot of the loss function of the L1 and L2 loss for the iris linear regression problem when the learning rate is 0.05:

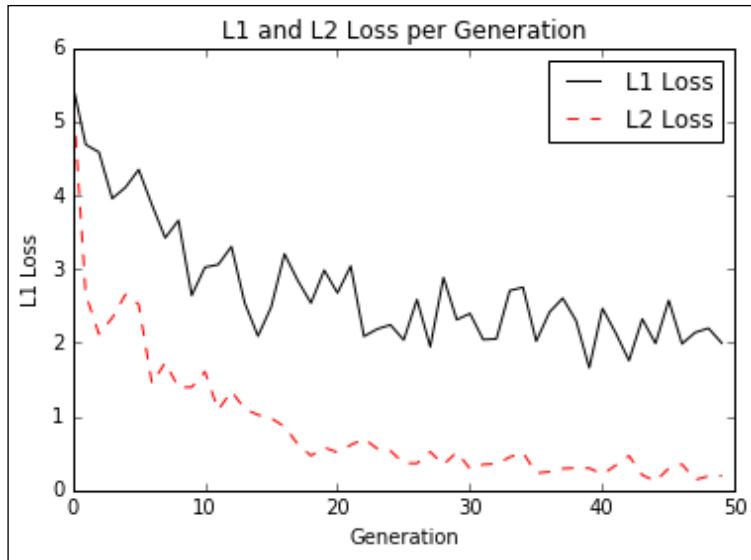


Figure 5: Here is the L1 and L2 loss with a learning rate of 0.05 for the iris linear regression problem.

With a learning rate of 0.05, it would appear that L2 loss is preferred, as it converges to a lower loss on the data. Here is a graph of the loss functions when we increase the learning rate to 0.4:

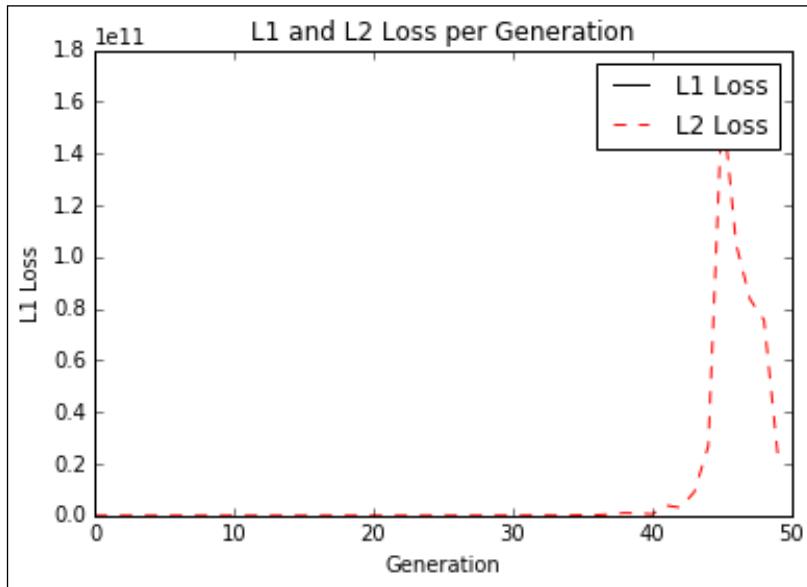


Figure 6: Shows the L1 and L2 loss on the iris linear regression problem with a learning rate of 0.4.  
Note that the L1 loss is not visible because of the high scale of the y-axis.

Here, we can see that the large learning rate can overshoot in the L2 norm, whereas the L1 norm converges.

### There's more...

To understand what is happening, we should look at how a large learning rate and small learning rate act on L1 and L2 norms. To visualize this, we look at a one-dimensional representation of learning steps on both norms, as follows:

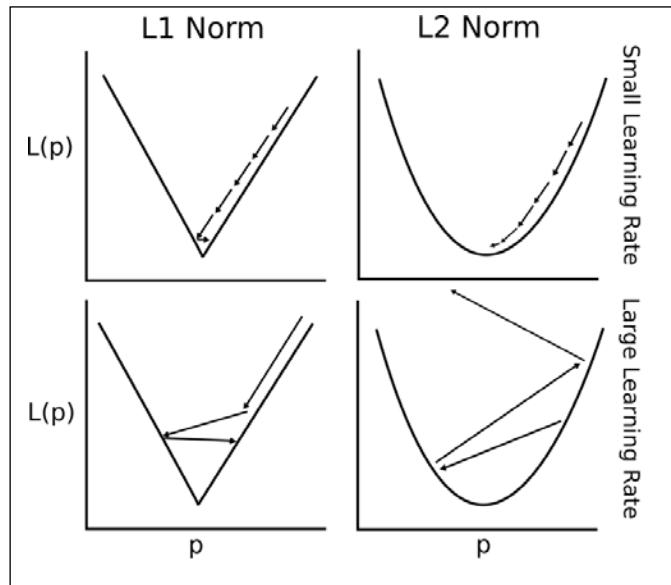


Figure 7: Illustrates what can happen with the L1 and L2 norm with larger and smaller learning rates.

## Implementing Deming regression

In this recipe, we will implement Deming regression (total regression), which means we will need a different way to measure the distance between the model line and data points.

## Getting ready

If least squares linear regression minimizes the vertical distance to the line, Deming regression minimizes the total distance to the line. This type of regression minimizes the error in the y values and the x values. See the following figure for a comparison:

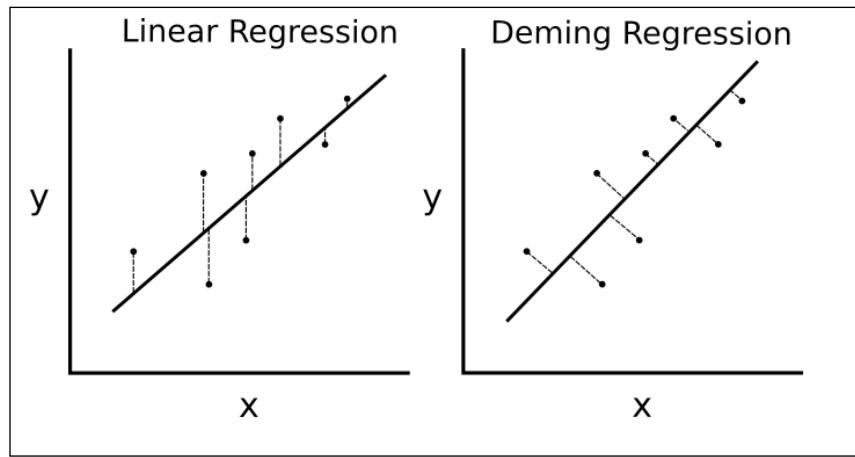


Figure 8: Here we illustrate the difference between regular linear regression and Deming regression. Linear regression on the left minimizes the vertical distance to the line, and Deming regression minimizes the total distance to the line.

To implement Deming regression, we have to modify the `loss` function. The `loss` function in regular linear regression minimizes the vertical distance. Here, we want to minimize the total distance. Given a slope and intercept of a line, the perpendicular distance to a point is a known geometric formula. We just have to substitute this formula in and tell TensorFlow to minimize it.

## How to do it...

1. Everything stays the same except when we get to the `loss` function. We begin by loading the libraries, starting a session, loading the data, declaring the batch size, creating the placeholders, variables, and model output, as follows:

```
import matplotlib.pyplot as plt
import numpy as np
import tensorflow as tf
from sklearn import datasets
sess = tf.Session()
iris = datasets.load_iris()
x_vals = np.array([x[3] for x in iris.data])
```

```
y_vals = np.array([y[0] for y in iris.data])
batch_size = 50
x_data = tf.placeholder(shape=[None, 1], dtype=tf.float32)
y_target = tf.placeholder(shape=[None, 1], dtype=tf.float32)
A = tf.Variable(tf.random_normal(shape=[1,1]))
b = tf.Variable(tf.random_normal(shape=[1,1]))
model_output = tf.add(tf.matmul(x_data, A), b)
```

2. The loss function is a geometric formula that comprises of a numerator and denominator. For clarity we will write these out separately. Given a line,  $y=mx+b$  and a point,  $(x_0, y_0)$ , the perpendicular distance between the two can be written as follows:

$$d = \frac{|y_0 - (mx_0 + b)|}{\sqrt{m^2 + 1}}$$

```
demming_numerator = tf.abs(tf.sub(y_target, tf.add(tf.matmul(x_data, A), b)))
demming_denominator = tf.sqrt(tf.add(tf.square(A), 1))
loss = tf.reduce_mean(tf.truediv(demming_numerator, demming_denominator))
```

3. We now initialize our variables, declare our optimizer, and loop through the training set to arrive at our parameters, as follows:

```
init = tf.global_variables_initializer()
sess.run(init)
my_opt = tf.train.GradientDescentOptimizer(0.1)
train_step = my_opt.minimize(loss)
loss_vec = []
for i in range(250):
 rand_index = np.random.choice(len(x_vals), size=batch_size)
 rand_x = np.transpose([x_vals[rand_index]])
 rand_y = np.transpose([y_vals[rand_index]])
 sess.run(train_step, feed_dict={x_data: rand_x, y_target: rand_y})
 temp_loss = sess.run(loss, feed_dict={x_data: rand_x, y_target: rand_y})
 loss_vec.append(temp_loss)
 if (i+1)%50==0:
 print('Step #' + str(i+1) + ' A = ' + str(sess.run(A)) +
 ' b = ' + str(sess.run(b)))
 print('Loss = ' + str(temp_loss))
```

4. We can plot the output with the following code:

```
[slope] = sess.run(A)
[y_intercept] = sess.run(b)
best_fit = []
for i in x_vals:
 best_fit.append(slope*i+y_intercept)
plt.plot(x_vals, y_vals, 'o', label='Data Points')
plt.plot(x_vals, best_fit, 'r-', label='Best fit line',
linewidth=3)
plt.legend(loc='upper left')
plt.title('Sepal Length vs Pedal Width')
plt.xlabel('Pedal Width')
plt.ylabel('Sepal Length')
plt.show()
```

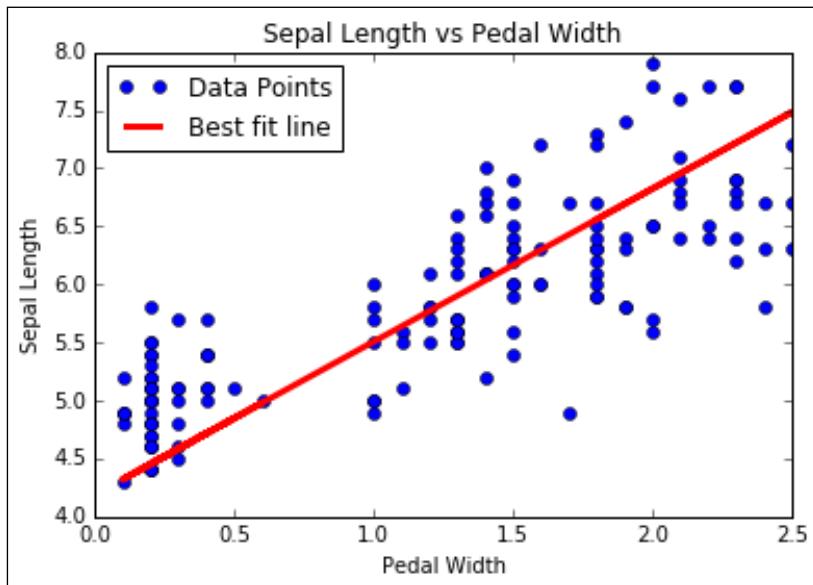


Figure 9: The graph depicting the solution to Deming regression on the iris dataset.

## How it works...

The recipe here for Deming regression is almost identical to regular linear regression. The key difference here is how we measure the loss between the predictions and the data points. Instead of a vertical loss, we have a perpendicular loss (or total loss) with the  $y$  values and  $x$  values.



Note that the type of Deming regression implemented here is called total regression. Total regression is when we assume the error in the x and y values are similar. We can also scale the x and y axes in the distance calculation by the difference in the errors according to our beliefs.

## Implementing Lasso and Ridge Regression

There are also ways to limit the influence of coefficients on the regression output. These methods are called regularization methods and two of the most common regularization methods are lasso and ridge regression. We cover how to implement both of these in this recipe.

### Getting ready

Lasso and ridge regression are very similar to regular linear regression, except we adding regularization terms to limit the slopes (or partial slopes) in the formula. There may be multiple reasons for this, but a common one is that we wish to restrict the features that have an impact on the dependent variable. This can be accomplished by adding a term to the loss function that depends on the value of our slope, A.

For lasso regression, we must add a term that greatly increases our loss function if the slope, A, gets above a certain value. We could use TensorFlow's logical operations, but they do not have a gradient associated with them. Instead, we will use a continuous approximation to a step function, called the continuous heavy step function, that is scaled up and over to the regularization cut off we choose. We will show how to do lasso regression shortly.

For ridge regression, we just add a term to the L2 norm, which is the scaled L2 norm of the slope coefficient. This modification is simple and is shown in the *There's more...* section at the end of this recipe.

### How to do it...

1. We will use the iris dataset again and set up our script the same way as before. We first load the libraries, start a session, load the data, declare the batch size, create the placeholders, variables, and model output as follows:

```
import matplotlib.pyplot as plt
import numpy as np
import tensorflow as tf
from sklearn import datasets
from tensorflow.python.framework import ops
ops.reset_default_graph()
sess = tf.Session()
```

```
iris = datasets.load_iris()
x_vals = np.array([x[3] for x in iris.data])
y_vals = np.array([y[0] for y in iris.data])
batch_size = 50
learning_rate = 0.001
x_data = tf.placeholder(shape=[None, 1], dtype=tf.float32)
y_target = tf.placeholder(shape=[None, 1], dtype=tf.float32)
A = tf.Variable(tf.random_normal(shape=[1,1]))
b = tf.Variable(tf.random_normal(shape=[1,1]))
model_output = tf.add(tf.matmul(x_data, A), b)
```

2. We add the loss function, which is a modified continuous heavyside step function. We also set the cutoff for lasso regression at 0.9. This means that we want to restrict the slope coefficient to be less than 0.9. Use the following code:

```
lasso_param = tf.constant(0.9)
heavyside_step = tf.truediv(1., tf.add(1., tf.exp(tf.mul(-100.,
tf.sub(A, lasso_param)))))
regularization_param = tf.mul(heavyside_step, 99.)
loss = tf.add(tf.reduce_mean(tf.square(y_target - model_output)), regularization_param)
```

3. We now initialize our variables and declare our optimizer, as follows:

```
init = tf.global_variables_initializer()
sess.run(init)
my_opt = tf.train.GradientDescentOptimizer(learning_rate)
train_step = my_opt.minimize(loss)
```

4. We will run the training loop a fair bit longer because it can take a while to converge. We can see that the slope coefficient is less than 0.9. Use the following code:

```
loss_vec = []
for i in range(1500):
 rand_index = np.random.choice(len(x_vals), size=batch_size)
 rand_x = np.transpose([x_vals[rand_index]])
 rand_y = np.transpose([y_vals[rand_index]])
 sess.run(train_step, feed_dict={x_data: rand_x, y_target: rand_y})
 temp_loss = sess.run(loss, feed_dict={x_data: rand_x, y_target: rand_y})
 loss_vec.append(temp_loss[0])
 if (i+1)%300==0:
 print('Step #' + str(i+1) + ' A = ' + str(sess.run(A)) +
 ' b = ' + str(sess.run(b)))
 print('Loss = ' + str(temp_loss))
Step #300 A = [[0.82512331]] b = [[2.30319238]]
Loss = [[6.84168959]]
```

## *Linear Regression*

---

```
Step #600 A = [[0.8200165]] b = [[3.45292258]]
Loss = [[2.02759886]]
Step #900 A = [[0.81428504]] b = [[4.08901262]]
Loss = [[0.49081498]]
Step #1200 A = [[0.80919558]] b = [[4.43668795]]
Loss = [[0.40478843]]
Step #1500 A = [[0.80433637]] b = [[4.6360755]]
Loss = [[0.23839757]]
```

### **How it works...**

We implement lasso regression by adding a continuous heavyside step function to the loss function of linear regression. Because of the steepness of the step function, we have to be careful with the step size. Too big of a step size and it will not converge. For ridge regression, see the necessary change in the next section.

### **There's' more...**

For ridge regression, we change the loss function to look like the following code:

```
ridge_param = tf.constant(1.)
ridge_loss = tf.reduce_mean(tf.square(A))
loss = tf.expand_dims(tf.add(tf.reduce_mean(tf.square(y_target -
model_output)), tf.mul(ridge_param, ridge_loss)), 0)
```

## **Implementing Elastic Net Regression**

Elastic net regression is a type of regression that combines lasso regression with ridge regression by adding a L1 and L2 regularization term to the loss function.

### **Getting ready**

Implementing elastic net regression should be straightforward after the previous two recipes, so we will implement this in multiple linear regression on the iris dataset, instead of sticking to the two-dimensional data as before. We will use pedal length, pedal width, and sepal width to predict sepal length.

## How to do it...

1. First we load the necessary libraries and initialize a graph, as follows:

```
import matplotlib.pyplot as plt
import numpy as np
import tensorflow as tf
from sklearn import datasets
sess = tf.Session()
```

2. Now we will load the data. This time, each element of x data will be a list of three values instead of one. Use the following code:

```
iris = datasets.load_iris()
x_vals = np.array([[x[1], x[2], x[3]] for x in iris.data])
y_vals = np.array([y[0] for y in iris.data])
```

3. Next we declare the batch size, placeholders, variables, and model output. The only difference here is that we change the size specifications of the x data placeholder to take three values instead of one, as follows:

```
batch_size = 50
learning_rate = 0.001
x_data = tf.placeholder(shape=[None, 3], dtype=tf.float32)
y_target = tf.placeholder(shape=[None, 1], dtype=tf.float32)
A = tf.Variable(tf.random_normal(shape=[3,1]))
b = tf.Variable(tf.random_normal(shape=[1,1]))
model_output = tf.add(tf.matmul(x_data, A), b)
```

4. For elastic net, the loss function has the L1 and L2 norms of the partial slopes. We create these terms and then add them into the loss function, as follows:

```
elastic_param1 = tf.constant(1.)
elastic_param2 = tf.constant(1.)
l1_a_loss = tf.reduce_mean(tf.abs(A))
l2_a_loss = tf.reduce_mean(tf.square(A))
e1_term = tf.mul(elastic_param1, l1_a_loss)
e2_term = tf.mul(elastic_param2, l2_a_loss)
loss = tf.expand_dims(tf.add(tf.add(tf.reduce_mean(tf.square(y_
target - model_output)), e1_term), e2_term), 0)
```

5. Now we can initialize the variables, declare our optimizer, and run the training loop and fit our coefficients, as follows:

```
init = tf.global_variables_initializer()
sess.run(init)
my_opt = tf.train.GradientDescentOptimizer(learning_rate)
train_step = my_opt.minimize(loss)
loss_vec = []
```

## Linear Regression

---

```
for i in range(1000):
 rand_index = np.random.choice(len(x_vals), size=batch_size)
 rand_x = x_vals[rand_index]
 rand_y = np.transpose([y_vals[rand_index]])
 sess.run(train_step, feed_dict={x_data: rand_x, y_target:
rand_y})
 temp_loss = sess.run(loss, feed_dict={x_data: rand_x, y_
target: rand_y})
 loss_vec.append(temp_loss[0])
 if (i+1)%250==0:
 print('Step #' + str(i+1) + ' A = ' + str(sess.run(A)) + ' '
b = ' + str(sess.run(b)))
 print('Loss = ' + str(temp_loss))
```

6. Here is the output of the code:

```
Step #250 A = [[0.42095602]
 [0.1055888]
 [1.77064979]] b = [[1.76164341]]
Loss = [2.87764359]
Step #500 A = [[0.62762028]
 [0.06065864]
 [1.36294949]] b = [[1.87629771]]
Loss = [1.8032167]
Step #750 A = [[0.67953539]
 [0.102514]
 [1.06914485]] b = [[1.95604002]]
Loss = [1.33256555]
Step #1000 A = [[0.6777274]
 [0.16535147]
 [0.8403284]] b = [[2.02246833]]
Loss = [1.21458709]
```

7. Now we can observe the loss over the training iterations to be sure that it converged, as follows:

```
plt.plot(loss_vec, 'k-')
plt.title('Loss' per Generation')
plt.xlabel('Generation')
plt.ylabel('Loss')
plt.show()
```

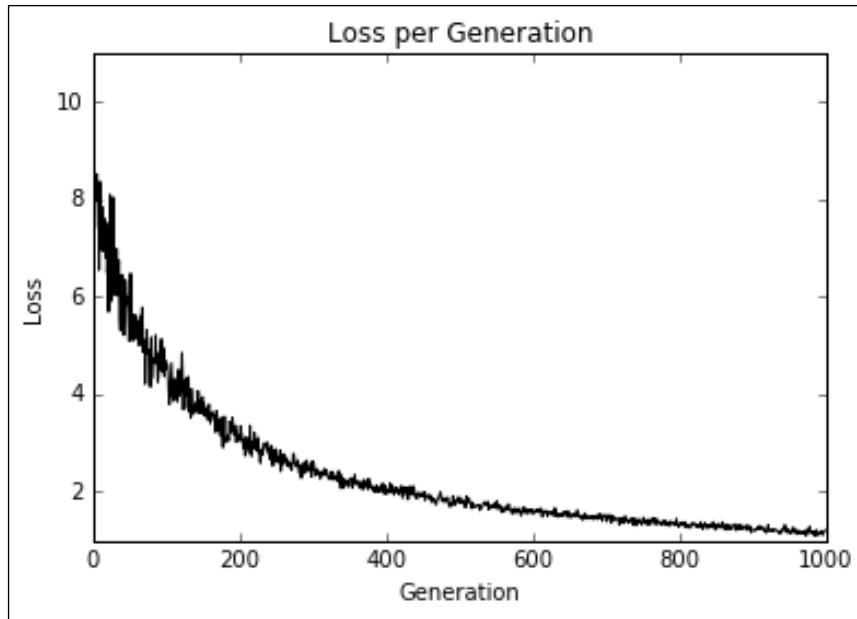


Figure 10: Elastic net regression loss plotted over the 1,000 training iterations

## How it works...

Elastic net regression is implemented here as well as multiple linear regression. We can see that with these regularization terms in the loss function the convergence is slower than in prior sections. Regularization is as simple as adding in the appropriate terms in the loss functions.

## Implementing Logistic Regression

For this recipe, we will implement logistic regression to predict the probability of low birthweight.

### Getting ready

Logistic regression is a way to turn linear regression into a binary classification. This is accomplished by transforming the linear output in a sigmoid function that scales the output between zero and 1. The target is a zero or 1, which indicates whether or not a data point is in one class or another. Since we are predicting a number between zero or 1, the prediction is classified into class value 1" if the prediction is above a specified cut off value and class 0 otherwise. For the purpose of this example, we will specify that cut off to be 0 . 5, which will make the classification as simple as rounding the output.

The data we will use for this example will be the low birthweight data that is obtained through the University of Massachusetts Amherst statistical dataset repository (<https://www.umass.edu/statdata/statdata/>). We will be predicting low birthweight from several other factors.

## How to do it...

1. We start by loading the libraries, including the request library, because we will access the low birth weight data through a hyperlink. We will also initiate a session:

```
import matplotlib.pyplot as plt
import numpy as np
import tensorflow as tf
import requests
from sklearn import datasets
from sklearn.preprocessing import normalize
from tensorflow.python.framework import ops
ops.reset_default_graph()
sess = tf.Session()
```

2. Next we will load the data through the request module and specify which features we want to use. We have to be specific because one feature is the actual birth weight and we don't want to use this to predict if the birthweight is greater or less than a specific amount. We also do not want to use the ID column as a predictor either:

```
birthdata_url = 'https://www.umass.edu/statdata/statdata/data/
lowbwt.dat'
birth_file = requests.get(birthdata_url)
birth_data = birth_file.text.split('\r\n')[5:]
birth_header = [x for x in birth_data[0].split(' ') if len(x)>=1]
birth_data = [[float(x) for x in y.split(' ') if len(x)>=1] for y
in birth_data[1:] if len(y)>=1]
y_vals = np.array([x[1] for x in birth_data])
x_vals = np.array([x[2:9] for x in birth_data])
```

3. First we split the dataset into test and train sets:

```
train_indices = np.random.choice(len(x_vals), round(len(x_
vals)*0.8), replace=False)
test_indices = np.array(list(set(range(len(x_vals))) - set(train_
indices)))
x_vals_train = x_vals[train_indices]
x_vals_test = x_vals[test_indices]
y_vals_train = y_vals[train_indices]
y_vals_test = y_vals[test_indices]
```

4. Logistic regression convergence works better when the features are scaled between 0 and 1 (min-max scaling). So next we will scale each feature:

```
def normalize_cols(m):
 col_max = m.max(axis=0)
 col_min = m.min(axis=0)
 return (m-col_min) / (col_max - col_min)

x_vals_train = np.nan_to_num(normalize_cols(x_vals_train))
x_vals_test = np.nan_to_num(normalize_cols(x_vals_test))
```

 Note that we split the dataset into `train` and `test` before we scaled the dataset. This is an important distinction to make. We want to make sure that the training set does not influence the `test` set at all. If we scaled the whole set before splitting, then we cannot guarantee that they don't influence each other.

5. Next we declare the batch size, placeholders, variables, and the logistic model. We do not wrap the output in a sigmoid because that operation is built into the `loss` function:

```
batch_size = 25
x_data = tf.placeholder(shape=[None, 7], dtype=tf.float32)
y_target = tf.placeholder(shape=[None, 1], dtype=tf.float32)
A = tf.Variable(tf.random_normal(shape=[7,1]))
b = tf.Variable(tf.random_normal(shape=[1,1]))
model_output = tf.add(tf.matmul(x_data, A), b)
```

6. Now we declare our `loss` function, which has the `sigmoid` function, initialize our variables, and declare our `optimizer` function:

```
loss = tf.reduce_mean(tf.nn.sigmoid_cross_entropy_with_
logits(model_output, y_target))
init = tf.global_variables_initializer()
sess.run(init)
my_opt = tf.train.GradientDescentOptimizer(0.01)
train_step = my_opt.minimize(loss)
```

7. Along with recording the `loss` function, we will also want to record the classification accuracy on the training and `test` set. So we will create a prediction function that returns the accuracy for any size batch:

```
prediction = tf.round(tf.sigmoid(model_output))
predictions_correct = tf.cast(tf.equal(prediction, y_target),
tf.float32)
accuracy = tf.reduce_mean(predictions_correct)
```

8. Now we can start our training loop and recording the loss and accuracies:

```
loss_vec = []
train_acc = []
test_acc = []
for i in range(1500):
 rand_index = np.random.choice(len(x_vals_train), size=batch_size)
 rand_x = x_vals_train[rand_index]
 rand_y = np.transpose([y_vals_train[rand_index]])
 sess.run(train_step, feed_dict={x_data: rand_x, y_target: rand_y})
 temp_loss = sess.run(loss, feed_dict={x_data: rand_x, y_target: rand_y})
 loss_vec.append(temp_loss)
 temp_acc_train = sess.run(accuracy, feed_dict={x_data: x_vals_train, y_target: np.transpose([y_vals_train])})
 train_acc.append(temp_acc_train)
 temp_acc_test = sess.run(accuracy, feed_dict={x_data: x_vals_test, y_target: np.transpose([y_vals_test])})
 test_acc.append(temp_acc_test)
```

9. Here is the code to look at the plots of the loss and accuracies:

```
plt.plot(loss_vec, 'k-')
plt.title('Cross Entropy Loss per Generation')
plt.xlabel('Generation')
plt.ylabel('Cross Entropy Loss')
plt.show()
plt.plot(train_acc, 'k-', label='Train Set Accuracy')
plt.plot(test_acc, 'r--', label='Test Set Accuracy')
plt.title('Train' and Test Accuracy')
plt.xlabel('Generation')
plt.ylabel('Accuracy')
plt.legend(loc='lower right')
plt.show()
```

## How it works...

Here is the loss over the iterations and train and test set accuracies. Since the dataset is only 189 observations, the train and test accuracy plots will change owing to the random splitting of the dataset:

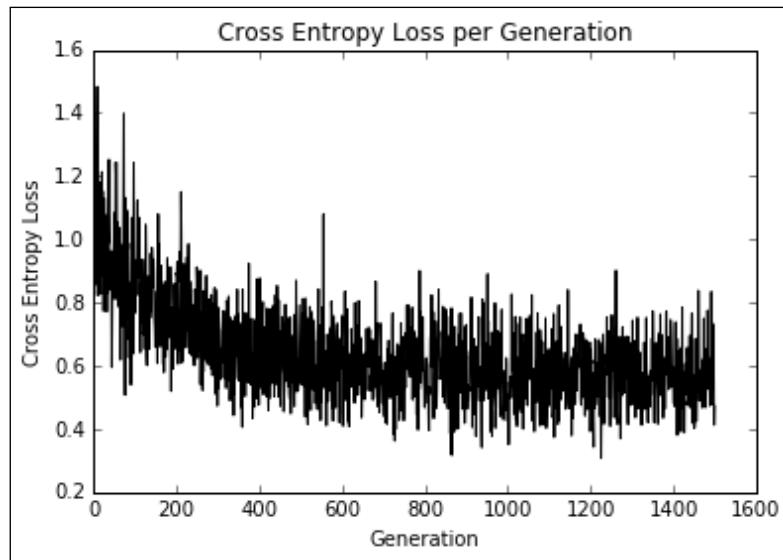


Figure 11: Cross-entropy loss plotted over the course of 1,500 iterations

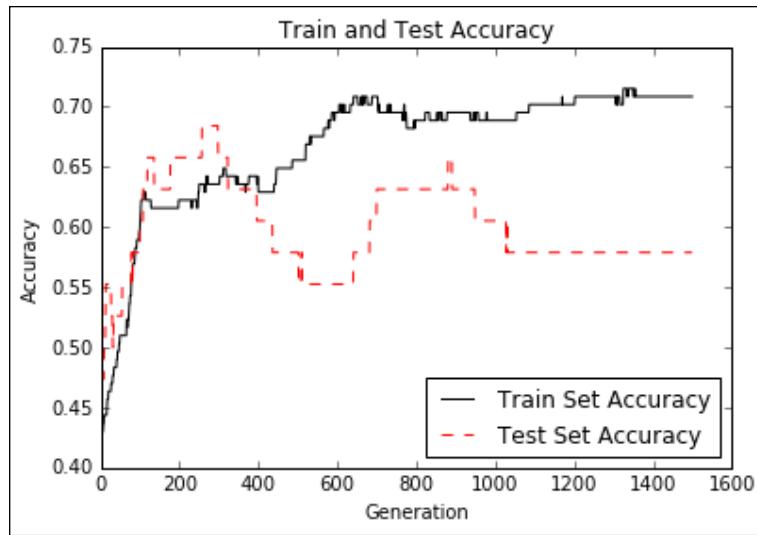


Figure 12: Test and train set accuracy plotted over 1,500 generations.



# 4

## Support Vector Machines

This chapter will cover some important recipes regarding how to use, implement, and evaluate **support vector machines (SVM)** in TensorFlow. The following areas will be covered:

- ▶ Working with a Linear SVM
- ▶ Reduction to Linear Regression
- ▶ Working with Kernels in TensorFlow
- ▶ Implementing a Non-Linear SVM
- ▶ Implementing a Multi-Class SVM

 Note that both the prior covered logistic regression and most of the SVMs in this chapter are binary predictors. While logistic regression tries to find any separating line that maximizes the distance (probabilistically), SVMs also try to minimize the error while maximizing the margin between classes. In general, if the problem has a large number of features compared to training examples, try logistic regression or a linear SVM. If the number of training examples is larger, or the data is not linearly separable, a SVM with a Gaussian kernel may be used.

Also remember that all the code for this chapter is available online at [https://github.com/nfmccclure/tensorflow\\_cookbook](https://github.com/nfmccclure/tensorflow_cookbook).

## Introduction

Support vector machines are a method of binary classification. The basic idea is to find a linear separating line (or hyperplane) between the two classes. We first assume that the binary class targets are -1 or 1, instead of the prior 0 or 1 targets. Since there may be many lines that separate two classes, we define the best linear separator that maximizes the distance between both classes.

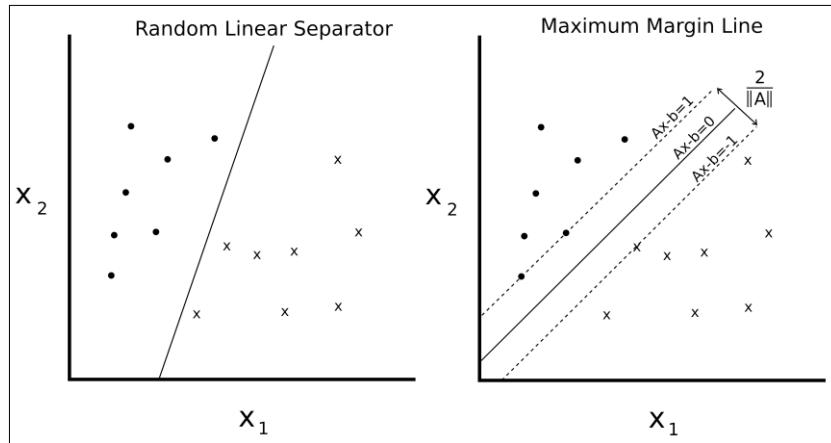


Figure 1: Given two separable classes, 'o' and 'x', we wish to find the equation for the linear separator between the two. The left shows that there are many lines that separate the two classes. The right shows the unique maximum margin line. The margin width is given by  $2/||A||$ . This line is found by minimizing the L2 norm of A.

We can write such a hyperplane as follows:

$$Ax - b = 0$$

Here, A is a vector of our partial slopes and x is a vector of inputs. The width of the maximum margin can be shown to be two divided by the L2 norm of A. There are many proofs out there of this fact, but for a geometric idea, solving the perpendicular distance from a 2D point to a line may provide motivation for moving forward.

For linearly separable binary class data, to maximize the margin, we minimize the L2 norm of A,  $||A||$ . We must also subject this minimum to the constraint:

$$y_i(Ax_i - b) \geq 1 \forall i$$

The preceding constraint assures us that all the points from the corresponding classes are on the same side of the separating line.

Since not all datasets are linearly separable, we can introduce a loss function for points that cross the margin lines. For  $n$  data points, we introduce what is called the *soft margin* loss function, as follows:

$$\frac{1}{n} \sum_{i=1}^n \max(0, 1 - y_i(Ax_i - b)) + \alpha \|A\|^2$$

Note that the product  $y_i(Ax_i - b)$  is always greater than 1 if the point is on the correct side of the margin. This makes the left term of the loss function equal to zero, and the only influence on the loss function is the size of the margin.

The preceding loss function will seek a linearly separable line, but will allow for points crossing the margin line. This can be a hard or soft allowance, depending on the value of  $\alpha$ . Larger values of  $\alpha$  result in more emphasis on widening the margin, and smaller values of  $\alpha$  result in the model acting more like a hard margin, while allowing data points to cross the margin, if need be.

In this chapter, we will set up a soft margin SVM and show how to extend it to nonlinear cases and multiple classes.

## Working with a Linear SVM

For this example, we will create a linear separator from the `iris` data set. We know from prior chapters that the sepal length and petal width create a linear separable binary data set for predicting if a flower is *I. setosa* or not.

### Getting ready

To implement a soft separable SVM in TensorFlow, we will implement the specific loss function, as follows:

$$\frac{1}{n} \sum_{i=1}^n \max(0, 1 - y_i(Ax_i - b)) + \alpha \|A\|^2$$

Here,  $A$  is the vector of partial slopes,  $b$  is the intercept,  $x_i$  is a vector of inputs,  $y_i$  is the actual class, (-1 or 1) and  $\alpha$  is the soft separability regularization parameter.

## How to do it...

1. We start by loading the necessary libraries. This will include the scikit learn dataset library for access to the iris data set. Use the following code:

```
import matplotlib.pyplot as plt
import numpy as np
import tensorflow as tf
from sklearn import datasets
```



To set up Scikit-learn for this exercise, we just need to type  
\$pip install -U scikit-learn. Note that it also  
comes installed with Anaconda as well.

2. Next we start a graph session and load the data as we need it. Remember that we are loading the first and fourth variables in the `iris` dataset as they are the sepal length and sepal width. We are loading the target variable, which will take on the value 1 for *I. setosa* and -1 otherwise. Use the following code:

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

```
iris = datasets.load_iris()
x_vals = np.array([[x[0], x[3]] for x in iris.data])
y_vals = np.array([1 if y==0 else -1 for y in iris.target])
```

3. We should now split the dataset into train and test sets. We will evaluate the accuracy on both the training and test sets. Since we know this data set is linearly separable, we should expect to get one hundred percent accuracy on both sets. Use the following code:

```
train_indices = np.random.choice(len(x_vals), round(len(x_vals)*0.8), replace=False)
test_indices = np.array(list(set(range(len(x_vals))) - set(train_indices)))
x_vals_train = x_vals[train_indices]
x_vals_test = x_vals[test_indices]
y_vals_train = y_vals[train_indices]
y_vals_test = y_vals[test_indices]
```

4. Next we set our batch size, placeholders, and model variables. It is important to mention that with this SVM algorithm, we want very large batch sizes to help with convergence. We can imagine that with very small batch sizes, the maximum margin line would jump around slightly. Ideally, we would also slowly decrease the learning rate as well, but this will suffice for now. Also, the  $A$  variable will take on the shape  $2 \times 1$  because we have two predictor variables, sepal length and petal width. Use the following code:

```
batch_size = 100

x_data = tf.placeholder(shape=[None, 2], dtype=tf.float32)
y_target = tf.placeholder(shape=[None, 1], dtype=tf.float32)

A = tf.Variable(tf.random_normal(shape=[2,1]))
b = tf.Variable(tf.random_normal(shape=[1,1]))
```

5. We now declare our model output. For correctly classified points, this will return numbers that are greater than or equal to 1 if the target is *I. setosa* and less than or equal to -1 otherwise. Use the following code:

```
model_output = tf.sub(tf.matmul(x_data, A), b)
```

6. Next we will put together and declare the necessary components for the maximum margin loss. First we will declare a function that will calculate the L2 norm of a vector. Then we add the margin parameter,  $\alpha$ . We then declare our classification loss and add together the two terms. Use the following code:

```
l2_norm = tf.reduce_sum(tf.square(A))

alpha = tf.constant([0.1])

classification_term = tf.reduce_mean(tf.maximum(0., tf.sub(1.,
tf.mul(model_output, y_target))))
```

```
loss = tf.add(classification_term, tf.mul(alpha, l2_norm))
```

7. Now we declare our prediction and accuracy functions so that we can evaluate the accuracy on both the training and test sets, as follows;

```
prediction = tf.sign(model_output)
accuracy = tf.reduce_mean(tf.cast(tf.equal(prediction, y_target),
tf.float32))
```

8. Here we will declare our `optimizer` function and initialize our model variables, as follows:

```
my_opt = tf.train.GradientDescentOptimizer(0.01)
train_step = my_opt.minimize(loss)

init = tf.initialize_all_variables()
sess.run(init)
```

9. We now can start our training loop, keeping in mind that we want to record our loss and training accuracy on both the `training` and `test` set, as follows:

```
loss_vec = []
train_accuracy = []
test_accuracy = []
for i in range(500):
 rand_index = np.random.choice(len(x_vals_train), size=batch_size)
 rand_x = x_vals_train[rand_index]
 rand_y = np.transpose([y_vals_train[rand_index]])
 sess.run(train_step, feed_dict={x_data: rand_x, y_target: rand_y})

 temp_loss = sess.run(loss, feed_dict={x_data: rand_x, y_target: rand_y})
 loss_vec.append(temp_loss)

 train_acc_temp = sess.run(accuracy, feed_dict={x_data: x_vals_train, y_target: np.transpose([y_vals_train])})
 train_accuracy.append(train_acc_temp)

 test_acc_temp = sess.run(accuracy, feed_dict={x_data: x_vals_test, y_target: np.transpose([y_vals_test])})
 test_accuracy.append(test_acc_temp)

 if (i+1)%100==0:
 print('Step #' + str(i+1) + ' A = ' + str(sess.run(A)) + ' b = ' + str(sess.run(b)))
 print('Loss = ' + str(temp_loss))
```

10. The output of the script during training should look like the following.

```
Step #100 A = [[-0.10763293]
[-0.65735245]] b = [[-0.68752676]]
Loss = [0.48756418]
Step #200 A = [[-0.0650763]
[-0.89443302]] b = [[-0.73912662]]
Loss = [0.38910741]
```

```
Step #300 A = [[-0.02090022]
[-1.12334013]] b = [[-0.79332656]]
Loss = [0.28621092]
Step #400 A = [[0.03189624]
[-1.34912157]] b = [[-0.8507266]]
Loss = [0.22397576]
Step #500 A = [[0.05958777]
[-1.55989814]] b = [[-0.9000265]]
Loss = [0.20492229]
```

11. In order to plot the outputs, we have to extract the coefficients and separate the  $x$  values into  $I.$  setosa and non-  $I.$  setosa, as follows:

```
[[a1], [a2]] = sess.run(A)
[[b]] = sess.run(b)
slope = -a2/a1
y_intercept = b/a1

x1_vals = [d[1] for d in x_vals]

best_fit = []
for i in x1_vals:
 best_fit.append(slope*i+y_intercept)

setosa_x = [d[1] for i,d in enumerate(x_vals) if y_vals[i]==1]
setosa_y = [d[0] for i,d in enumerate(x_vals) if y_vals[i]==1]
not_setosa_x = [d[1] for i,d in enumerate(x_vals) if y_
vals[i]==-1]
not_setosa_y = [d[0] for i,d in enumerate(x_vals) if y_
vals[i]==-1]
```

12. The following is the code to plot the data with the linear separator, accuracies, and loss:

```
plt.plot(setosa_x, setosa_y, 'o', label='I. setosa')
plt.plot(not_setosa_x, not_setosa_y, 'x', label='Non-setosa')
plt.plot(x1_vals, best_fit, 'r-', label='Linear Separator',
linewidth=3)
plt.ylim([0, 10])
plt.legend(loc='lower right')
plt.title('Sepal Length vs Pedal Width')
plt.xlabel('Pedal Width')
plt.ylabel('Sepal Length')
plt.show()

plt.plot(train_accuracy, 'k-', label='Training Accuracy')
```

```

plt.plot(test_accuracy, 'r--', label='Test Accuracy')
plt.title('Train and Test Set Accuracies')
plt.xlabel('Generation')
plt.ylabel('Accuracy')
plt.legend(loc='lower right')
plt.show()

plt.plot(loss_vec, 'k-')
plt.title('Loss per Generation')
plt.xlabel('Generation')
plt.ylabel('Loss')
plt.show()

```

[  Using TensorFlow in this manner to implement the SVD algorithm may result in slightly different outcomes each run. The reasons for this include the random train/test set splitting and the selection of different batches of points on each training batch. Also it would be ideal to also slowly lower the learning rate after each generation. ]

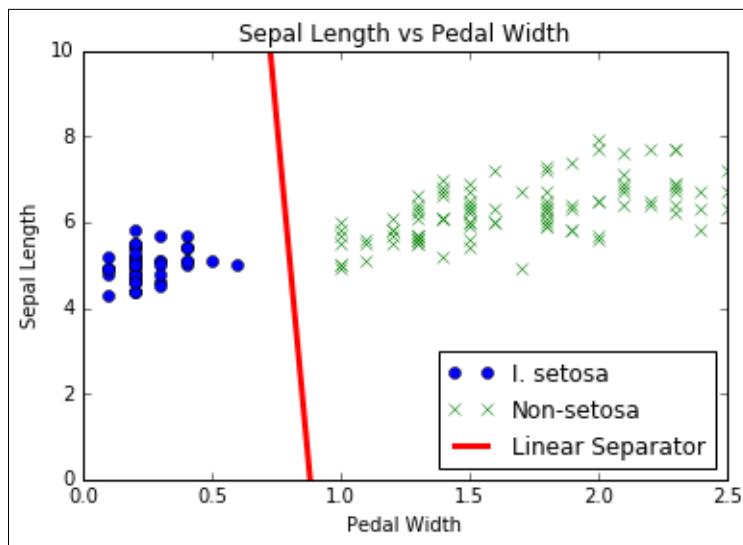


Figure 2: Final linear SVM fit with the two classes plotted.

Final linear SVM fit with the two classes plotted:

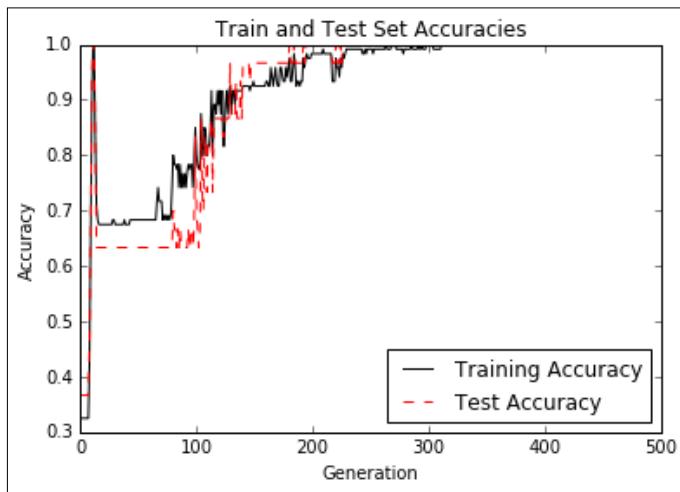


Figure 3: Test and train set accuracy over iterations. We do get 100% accuracy because the two classes are linearly separable.

Test and train set accuracy over iterations. We do get 100% accuracy because the two classes are linearly separable:

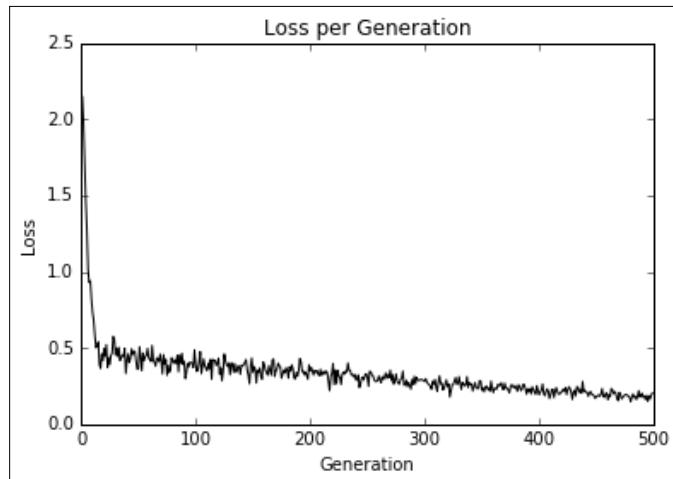


Figure 4: Plot of the maximum margin loss over 500 iterations.

## How it works...

In this recipe, we have shown that implementing a linear SVD model is possible by using the maximum margin loss function.

## Reduction to Linear Regression

Support vector machines can be used to fit linear regression. In this chapter, we will explore how to do this with TensorFlow.

### Getting ready

The same *maximum margin* concept can be applied toward fitting linear regression. Instead of maximizing the margin that separates the classes, we can think about maximizing the margin that contains the most  $(x, y)$  points. To illustrate this, we will use the same `iris` data set, and show that we can use this concept to fit a line between sepal length and petal width.

The corresponding loss function will be similar to  $\max(0, |y_i - (Ax_i + b)| - \varepsilon)$ . Here,  $\varepsilon$  is half of the width of the margin, which makes the loss equal to zero if a point lies in this region.

### How to do it...

- First we load the necessary libraries, start a graph, and load the `iris` dataset. After that, we will split the dataset into `train` and `test` sets to visualize the loss on both. Use the following code:

```
import matplotlib.pyplot as plt
import numpy as np
import tensorflow as tf
from sklearn import datasets
sess = tf.Session()
iris = datasets.load_iris()
x_vals = np.array([x[3] for x in iris.data])
y_vals = np.array([y[0] for y in iris.data])
train_indices = np.random.choice(len(x_vals), round(len(x_vals)*0.8), replace=False)
test_indices = np.array(list(set(range(len(x_vals))) - set(train_indices)))
x_vals_train = x_vals[train_indices]
x_vals_test = x_vals[test_indices]
y_vals_train = y_vals[train_indices]
y_vals_test = y_vals[test_indices]
```

 For this example, we have split the data into train and test. It is also common to split the data into three datasets, which includes the validation set. We can use this validation set to verify that we are not overfitting models as we train them.

2. Let's declare our batch size, placeholders, and variables, and create our linear model, as follows:

```
batch_size = 50

x_data = tf.placeholder(shape=[None, 1], dtype=tf.float32)
y_target = tf.placeholder(shape=[None, 1], dtype=tf.float32)

A = tf.Variable(tf.random_normal(shape=[1,1]))
b = tf.Variable(tf.random_normal(shape=[1,1]))

model_output = tf.add(tf.matmul(x_data, A), b)
```

3. Now we declare our loss function. The loss function, as described in the preceding text, is implemented to follow with  $\varepsilon = 0.5$ . Remember that the epsilon is part of our loss function, which allows for a soft margin instead of a hard margin.

```
epsilon = tf.constant([0.5])
loss = tf.reduce_mean(tf.maximum(0., tf.sub(tf.abs(tf.sub(model_
output, y_target)), epsilon)))
```

4. We create an optimizer and initialize our variables next, as follows:

```
my_opt = tf.train.GradientDescentOptimizer(0.075)
train_step = my_opt.minimize(loss)

init = tf.initialize_all_variables()
sess.run(init)
```

5. Now we iterate through 200 training iterations and save the training and test loss for plotting later:

```
train_loss = []
test_loss = []
for i in range(200):
 rand_index = np.random.choice(len(x_vals_train), size=batch_
size)
 rand_x = np.transpose([x_vals_train[rand_index]])
 rand_y = np.transpose([y_vals_train[rand_index]])
 sess.run(train_step, feed_dict={x_data: rand_x, y_target:
rand_y})

 temp_train_loss = sess.run(loss, feed_dict={x_data:
np.transpose([x_vals_train]), y_target: np.transpose([y_vals_
train])})
 train_loss.append(temp_train_loss)
```

```
temp_test_loss = sess.run(loss, feed_dict={x_data:
np.transpose([x_vals_test]), y_target: np.transpose([y_vals_
test])})
test_loss.append(temp_test_loss)
if (i+1)%50==0:
 print('-----')
 print('Generation: ' + str(i))
 print('A = ' + str(sess.run(A)) + ' b = ' + str(sess.
run(b)))
 print('Train Loss = ' + str(temp_train_loss))
 print('Test Loss = ' + str(temp_test_loss))
```

6. This results in the following output:

```
Generation: 50
A = [[2.20651722]] b = [[2.71290684]]
Train Loss = 0.609453
Test Loss = 0.460152

Generation: 100
A = [[1.6440177]] b = [[3.75240564]]
Train Loss = 0.242519
Test Loss = 0.208901

Generation: 150
A = [[1.27711761]] b = [[4.3149066]]
Train Loss = 0.108192
Test Loss = 0.119284

Generation: 200
A = [[1.05271816]] b = [[4.53690529]]
Train Loss = 0.0799957
Test Loss = 0.107551
```

7. We can now extract the coefficients we found, and get values for the best-fit line. For plotting purposes, we will also get values for the margins as well. Use the following code:

```
[[slope]] = sess.run(A)
[[y_intercept]] = sess.run(b)
[width] = sess.run(epsilon)

best_fit = []
best_fit_upper = []
best_fit_lower = []
for i in x_vals:
```

```
best_fit.append(slope*i+y_intercept)
best_fit_upper.append(slope*i+y_intercept+width)
best_fit_lower.append(slope*i+y_intercept-width)
```

8. Finally, here is the code to plot the data with the fitted line and the train-test loss:

```
plt.plot(x_vals, y_vals, 'o', label='Data Points')
plt.plot(x_vals, best_fit, 'r-', label='SVM Regression Line',
linewidth=3)
plt.plot(x_vals, best_fit_upper, 'r--', linewidth=2)
plt.plot(x_vals, best_fit_lower, 'r--', linewidth=2)
plt.ylim([0, 10])
plt.legend(loc='lower right')
plt.title('Sepal Length vs Pedal Width')
plt.xlabel('Pedal Width')
plt.ylabel('Sepal Length')
plt.show()

plt.plot(train_loss, 'k-', label='Train Set Loss')
plt.plot(test_loss, 'r--', label='Test Set Loss')
plt.title('L2 Loss per Generation')
plt.xlabel('Generation')
plt.ylabel('L2 Loss')
plt.legend(loc='upper right')
plt.show()
```

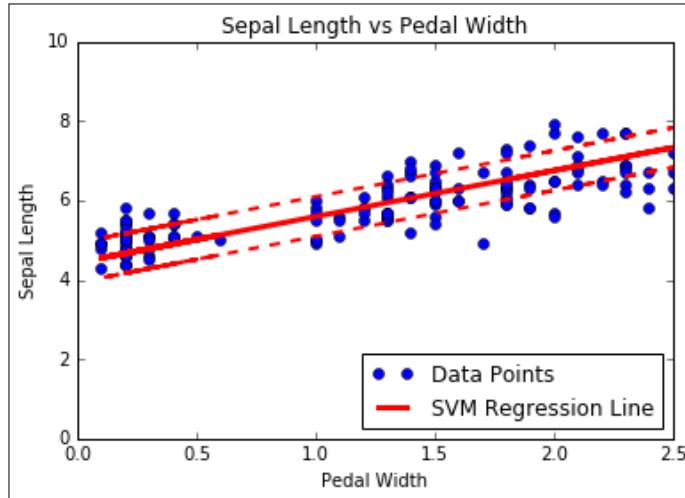


Figure 5: SVM regression with a 0.5 margin on the iris data (sepal length versus petal width).

Here is the train and test loss over the training iterations:

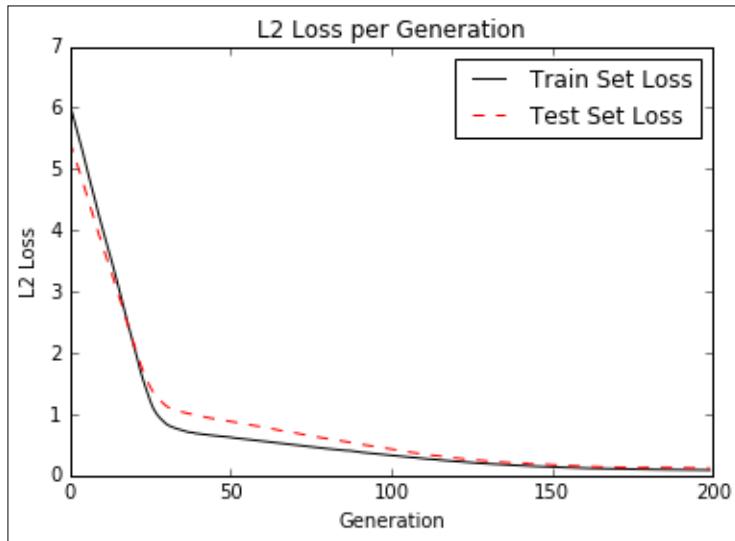


Figure 6: SVM regression loss per generation on both the train and test sets.

## How it works...

Intuitively, we can think of SVM regression as a function that is trying to fit as many points in the  $2\epsilon$  width margin from the line as possible. The fitting of this line is somewhat sensitive to this parameter. If we choose too small an epsilon, the algorithm will not be able to fit many points in the margin. If we choose too large of an epsilon, there will be many lines that are able to fit all the data points in the margin. We prefer a smaller epsilon, since nearer points to the margin contribute less loss than further away points.

## Working with Kernels in TensorFlow

The prior SVMs worked with linear separable data. If we would like to separate non-linear data, we can change how we project the linear separator onto the data. This is done by changing the kernel in the SVM loss function. In this chapter, we introduce how to change kernels and separate non-linear separable data.

## Getting ready

In this recipe, we will motivate the usage of kernels in support vector machines. In the linear SVM section, we solved the soft margin with a specific loss function. A different approach to this method is to solve what is called the dual of the optimization problem. It can be shown that the dual for the linear SVM problem is given by the following formula:

$$\max \sum_{i=1}^n b_i - \frac{1}{2} \sum_{i=1}^n \sum_{j=1}^n y_i b_i (x_i \cdot x_j) y_j b_j$$

Where:

$$\sum_{i=1}^n b_i y_i = 0 \text{ and } 0 \leq b_i \leq \frac{1}{2ny}$$

Here, the variable in the model will be the  $b$  vector. Ideally, this vector will be quite sparse, only taking on values near 1 and -1 for the corresponding support vectors of our dataset. Our data point vectors are indicated by  $x_i$  and our targets (1 or -1) are represented by  $y_i$ .

The kernel in the preceding equations is the dot product,  $x_i \cdot x_j$ , which gives us the linear kernel. This kernel is a square matrix filled with the  $i, j$  dot products of the data points.

Instead of just doing the dot product between data points, we can expand them with more complicated functions into higher dimensions, in which the classes may be linear separable. This may seem needlessly complicated, but if we select a function,  $k$ , that has the property where:

$$k(x_i, x_j) = \varphi(x_i) \cdot \varphi(x_j)$$

then  $k$  is called a kernel function. This is one of the more common kernels if the Gaussian kernel (also known as the radial basis function kernel or the RBF kernel) is used. This kernel is described with the following equation:

$$k(x_i, x_j) = e^{-y} \|x_i - x_j\|^2$$

In order to make predictions on this kernel, say at a point  $p_i$ , we just substitute in the prediction point in the appropriate equation in the kernel as follows:

$$k(x_i, p_j) = e^{-y} \|x_i - p_j\|^2$$

In this section, we will discuss how to implement the Gaussian kernel. We will also make a note of where to make the substitution for implementing the linear kernel where appropriate. The dataset we will use will be manually created to show where the Gaussian kernel would be more appropriate to use over the linear kernel.

## How to do it...

- First we load the necessary libraries and start a graph session, as follows:

```
import matplotlib.pyplot as plt
import numpy as np
import tensorflow as tf
from sklearn import datasets
sess = tf.Session()
```

- Now we generate the data. The data we will generate will be two concentric rings of data, each ring will belong to a different class. We have to make sure that the classes are -1 or 1 only. Then we will split the data into x and y values for each class for plotting purposes. Use the following code:

```
(x_vals, y_vals) = datasets.make_circles(n_samples=500, factor=.5,
noise=.1)
y_vals = np.array([1 if y==1 else -1 for y in y_vals])
class1_x = [x[0] for i,x in enumerate(x_vals) if y_vals[i]==1]
class1_y = [x[1] for i,x in enumerate(x_vals) if y_vals[i]==1]
class2_x = [x[0] for i,x in enumerate(x_vals) if y_vals[i]==-1]
class2_y = [x[1] for i,x in enumerate(x_vals) if y_vals[i]==-1]
```

- Next we declare our batch size, placeholders, and create our model variable,  $b$ . For SVMs we tend to want larger batch sizes because we want a very stable model that won't fluctuate much with each training generation. Also note that we have an extra placeholder for the prediction points. To visualize the results, we will create a color grid to see which areas belong to which class at the end. Use the following code:

```
batch_size = 250
x_data = tf.placeholder(shape=[None, 2], dtype=tf.float32)
y_target = tf.placeholder(shape=[None, 1], dtype=tf.float32)
prediction_grid = tf.placeholder(shape=[None, 2], dtype=tf.
float32)
b = tf.Variable(tf.random_normal(shape=[1,batch_size]))
```

- We will now create the Gaussian kernel. This kernel can be expressed as matrix operations as follows:

```
gamma = tf.constant(-50.0)
dist = tf.reduce_sum(tf.square(x_data), 1)
dist = tf.reshape(dist, [-1,1])
```

```

sq_dists = tf.add(tf.sub(dist, tf.mul(2., tf.matmul(x_data,
tf.transpose(x_data)))), tf.transpose(dist))
my_kernel = tf.exp(tf.mul(gamma, tf.abs(sq_dists)))

```



Note the usage of broadcasting in the `sq_dists` line of the add and subtract operations.

Note that the linear kernel can be expressed as `my_kernel = tf.matmul(x_data, tf.transpose(x_data))`.

- Now we declare the dual problem as previously stated in this recipe. At the end, instead of maximizing, we will be minimizing the negative of the loss function with a `tf.neg()` function. Use the following code:

```

model_output = tf.matmul(b, my_kernel)
first_term = tf.reduce_sum(b)
b_vec_cross = tf.matmul(tf.transpose(b), b)
y_target_cross = tf.matmul(y_target, tf.transpose(y_target))
second_term = tf.reduce_sum(tf.mul(my_kernel, tf.mul(b_vec_cross,
y_target_cross)))
loss = tf.neg(tf.sub(first_term, second_term))

```

- We now create the `prediction` and `accuracy` functions. First, we must create a prediction kernel, similar to step 4, but instead of a kernel of the points with itself, we have the kernel of the points with the prediction data. The prediction is then the sign of the output of the model. Use the following code:

```

rA = tf.reshape(tf.reduce_sum(tf.square(x_data), 1), [-1,1])
rB = tf.reshape(tf.reduce_sum(tf.square(prediction_grid), 1), [-1,1])
pred_sq_dist = tf.add(tf.sub(rA, tf.mul(2., tf.matmul(x_data,
tf.transpose(prediction_grid)))), tf.transpose(rB))
pred_kernel = tf.exp(tf.mul(gamma, tf.abs(pred_sq_dist)))

prediction_output = tf.matmul(tf.mul(tf.transpose(y_target), b),
pred_kernel)
prediction = tf.sign(prediction_output - tf.reduce_mean(prediction_output))
accuracy = tf.reduce_mean(tf.cast(tf.equal(tf.squeeze(prediction),
tf.squeeze(y_target)), tf.float32))

```



To implement the linear prediction kernel, we can write `pred_kernel = tf.matmul(x_data, tf.transpose(prediction_grid))`.

7. Now we can create an `optimizer` function and initialize all the variables, as follows:

```
my_opt = tf.train.GradientDescentOptimizer(0.001)
train_step = my_opt.minimize(loss)
init = tf.initialize_all_variables()
sess.run(init)
```

8. Next we start the training loop. We will record the loss vector and the batch accuracy for each generation. When we run the accuracy, we have to put in all three placeholders, but we feed in the `x` data twice to get the prediction on the points. Use the following code:

```
loss_vec = []
batch_accuracy = []
for i in range(500):
 rand_index = np.random.choice(len(x_vals), size=batch_size)
 rand_x = x_vals[rand_index]
 rand_y = np.transpose([y_vals[rand_index]])
 sess.run(train_step, feed_dict={x_data: rand_x, y_target:
rand_y})

 temp_loss = sess.run(loss, feed_dict={x_data: rand_x, y_
target: rand_y})
 loss_vec.append(temp_loss)

 acc_temp = sess.run(accuracy, feed_dict={x_data: rand_x,
y_target: rand_y,
prediction_
grid:rand_x})
 batch_accuracy.append(acc_temp)

if (i+1)%100==0:
 print('Step #' + str(i+1))
 print('Loss = ' + str(temp_loss))
```

9. This results in the following output:

```
Step #100
Loss = -28.0772
Step #200
Loss = -3.3628
Step #300
Loss = -58.862
Step #400
Loss = -75.1121
Step #500
Loss = -84.8905
```

10. In order to see the output class on the whole space, we will create a mesh of prediction points in our system and run the prediction on all of them, as follows:

```
x_min, x_max = x_vals[:, 0].min() - 1, x_vals[:, 0].max() + 1
y_min, y_max = x_vals[:, 1].min() - 1, x_vals[:, 1].max() + 1
xx, yy = np.meshgrid(np.arange(x_min, x_max, 0.02),
 np.arange(y_min, y_max, 0.02))
grid_points = np.c_[xx.ravel(), yy.ravel()]
[grid_predictions] = sess.run(prediction, feed_dict={x_data:
rand_x,
 y_target:
rand_y,
 prediction_
grid: grid_points})
grid_predictions = grid_predictions.reshape(xx.shape)
```

11. The following is the code to plot the result, batch accuracy, and loss:

```
plt.contourf(xx, yy, grid_predictions, cmap=plt.cm.Paired,
alpha=0.8)
plt.plot(class1_x, class1_y, 'ro', label='Class 1')
plt.plot(class2_x, class2_y, 'kx', label='Class -1')
plt.legend(loc='lower right')
plt.ylim([-1.5, 1.5])
plt.xlim([-1.5, 1.5])
plt.show()

plt.plot(batch_accuracy, 'k-', label='Accuracy')
plt.title('Batch Accuracy')
plt.xlabel('Generation')
plt.ylabel('Accuracy')
plt.legend(loc='lower right')
plt.show()

plt.plot(loss_vec, 'k-')
plt.title('Loss per Generation')
plt.xlabel('Generation')
plt.ylabel('Loss')
plt.show()
```

12. For succinctness, we will show only the results graph, but we can also separately run the plotting code and see all three if we so choose:

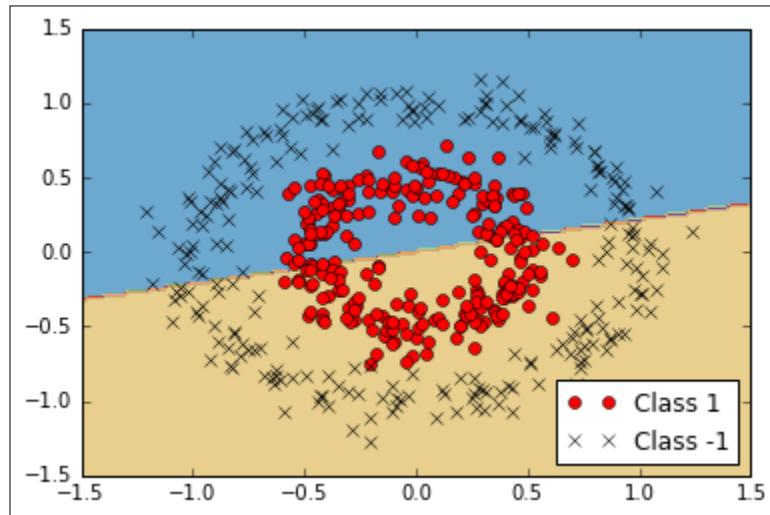


Figure 7: Linear SVM on non-linear separable data.

Linear SVM on non-linear separable data.

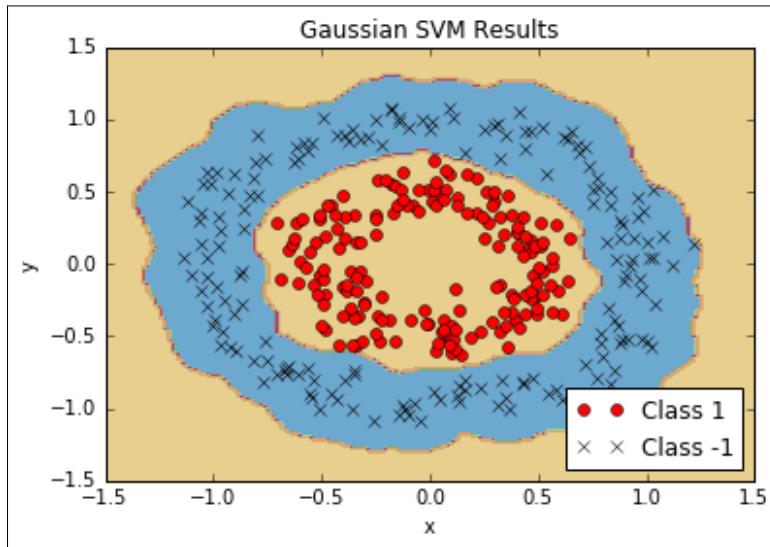


Figure 8: Non-linear SVM with Gaussian kernel results on nonlinear ring data.

Non-linear SVM with Gaussian kernel results on nonlinear ring data.

## How it works...

There are two important pieces of the code to know about: how we implemented the kernel and how we implemented the loss function for the SVM dual optimization problem. We have shown how to implement the linear and Gaussian kernel and that the Gaussian kernel can separate nonlinear datasets.

We should also mention that there is another parameter, the gamma value in the Gaussian kernel. This parameter controls how much influence points have on the curvature of the separation. Small values are commonly chosen, but it depends heavily on the dataset. Ideally this parameter is chosen with statistical techniques such as cross-validation.

## There's more...

There are many more kernels that we could implement if we so choose. Here is a list of a few more common nonlinear kernels:

- ▶ Polynomial homogeneous kernel:

$$k(x_i, x_j) = (x_i \cdot x_j)^d$$

- ▶ Polynomial inhomogeneous kernel:

$$k(x_i, x_j) = (x_i \cdot x_j + 1)^d$$

- ▶ Hyperbolic tangent kernel:

$$k(x_i, x_j) = \tanh(ax_i \cdot x_j + k)$$

## Implementing a Non-Linear SVM

For this recipe, we will apply a non-linear kernel to split a dataset.

### Getting ready

In this section, we will implement the preceding Gaussian kernel SVM on real data. We will load the iris data set and create a classifier for *I. setosa* (versus non-setosa). We will see the effect of various gamma values on the classification.

## How to do it...

1. We first load the necessary libraries, which includes the scikit learn datasets so that we can load the iris data. Then we will start a graph session. Use the following code:

```
import matplotlib.pyplot as plt
import numpy as np
import tensorflow as tf
from sklearn import datasets
sess = tf.Session()
```

2. Next we will load the iris data, extract the sepal length and petal width, and separated the x and y values for each class (for plotting purposes later) , as follows:

```
iris = datasets.load_iris()
x_vals = np.array([[x[0], x[3]] for x in iris.data])
y_vals = np.array([1 if y==0 else -1 for y in iris.target])
class1_x = [x[0] for i,x in enumerate(x_vals) if y_vals[i]==1]
class1_y = [x[1] for i,x in enumerate(x_vals) if y_vals[i]==1]
class2_x = [x[0] for i,x in enumerate(x_vals) if y_vals[i]==-1]
class2_y = [x[1] for i,x in enumerate(x_vals) if y_vals[i]==-1]
```

3. Now we declare our batch size (larger batches are preferred), placeholders, and the model variable, b, as follows:

```
batch_size = 100

x_data = tf.placeholder(shape=[None, 2], dtype=tf.float32)
y_target = tf.placeholder(shape=[None, 1], dtype=tf.float32)
prediction_grid = tf.placeholder(shape=[None, 2], dtype=tf.
float32)

b = tf.Variable(tf.random_normal(shape=[1,batch_size]))
```

4. Next we declare our Gaussian kernel. This kernel is dependent on the gamma value, and we will illustrate the effects of various gamma values on the classification later in this recipe. Use the following code:

```
gamma = tf.constant(-10.0)
dist = tf.reduce_sum(tf.square(x_data), 1)
dist = tf.reshape(dist, [-1,1])
sq_dists = tf.add(tf.sub(dist, tf.mul(2., tf.matmul(x_data,
tf.transpose(x_data)))), tf.transpose(dist)))
my_kernel = tf.exp(tf.mul(gamma, tf.abs(sq_dists)))

We now compute the loss for the dual optimization problem, as
follows:
```

```
model_output = tf.matmul(b, my_kernel)
first_term = tf.reduce_sum(b)
b_vec_cross = tf.matmul(tf.transpose(b), b)
y_target_cross = tf.matmul(y_target, tf.transpose(y_target))
second_term = tf.reduce_sum(tf.mul(my_kernel, tf.mul(b_vec_cross,
y_target_cross)))
loss = tf.neg(tf.sub(first_term, second_term))
```

5. In order to perform predictions using an SVM, we must create a prediction kernel function. After that we also declare an accuracy calculation, which will just be a percentage of points correctly classified. Use the following code:

```
rA = tf.reshape(tf.reduce_sum(tf.square(x_data), 1), [-1,1])
rB = tf.reshape(tf.reduce_sum(tf.square(prediction_grid), 1), [-1,1])
pred_sq_dist = tf.add(tf.sub(rA, tf.mul(2., tf.matmul(x_data,
tf.transpose(prediction_grid)))), tf.transpose(rB))
pred_kernel = tf.exp(tf.mul(gamma, tf.abs(pred_sq_dist)))

prediction_output = tf.matmul(tf.mul(tf.transpose(y_target), b),
pred_kernel)
prediction = tf.sign(prediction_output-tf.reduce_mean(prediction_output))
accuracy = tf.reduce_mean(tf.cast(tf.equal(tf.squeeze(prediction),
tf.squeeze(y_target)), tf.float32))
```

6. Next we declare our optimizer function and initialize the variables, as follows:

```
my_opt = tf.train.GradientDescentOptimizer(0.01)
train_step = my_opt.minimize(loss)
init = tf.initialize_all_variables()
sess.run(init)
```

7. Now we can start the training loop. We run the loop for 300 iterations and will store the loss value and the batch accuracy. Use the following code:

```
loss_vec = []
batch_accuracy = []
for i in range(300):
 rand_index = np.random.choice(len(x_vals), size=batch_size)
 rand_x = x_vals[rand_index]
 rand_y = np.transpose([y_vals[rand_index]])
 sess.run(train_step, feed_dict={x_data: rand_x, y_target:
rand_y})

 temp_loss = sess.run(loss, feed_dict={x_data: rand_x, y_
target: rand_y})
```

```
loss_vec.append(temp_loss)
```

```
acc_temp = sess.run(accuracy, feed_dict={x_data: rand_x,
 y_target: rand_y,
 prediction_
 grid:rand_x})
batch_accuracy.append(acc_temp)
```

8. In order to plot the decision boundary, we will create a mesh of x, y points and evaluate the prediction function we created on all of these points, as follows:

```
x_min, x_max = x_vals[:, 0].min() - 1, x_vals[:, 0].max() + 1
y_min, y_max = x_vals[:, 1].min() - 1, x_vals[:, 1].max() + 1
xx, yy = np.meshgrid(np.arange(x_min, x_max, 0.02),
 np.arange(y_min, y_max, 0.02))
grid_points = np.c_[xx.ravel(), yy.ravel()]
[grid_predictions] = sess.run(prediction, feed_dict={x_data:
rand_x,
 y_target:
rand_y,
 prediction_
 grid: grid_points})
grid_predictions = grid_predictions.reshape(xx.shape)
```

9. For succinctness, we will only show how to plot the points with the decision boundaries. For the plot and effect of gamma, see the next section in this recipe. Use the following code:

```
plt.contourf(xx, yy, grid_predictions, cmap=plt.cm.Paired,
alpha=0.8)
plt.plot(class1_x, class1_y, 'ro', label='I. setosa')
plt.plot(class2_x, class2_y, 'kx', label='Non setosa')
plt.title('Gaussian SVM Results on Iris Data')
plt.xlabel('Pedal Length')
plt.ylabel('Sepal Width')
plt.legend(loc='lower right')
plt.ylim([-0.5, 3.0])
plt.xlim([3.5, 8.5])
plt.show()
```

## How it works...

Here is the classification of *I. setosa* results for four different gamma values (1, 10, 25, 100). Notice how the higher the gamma value, the more of an effect each individual point has on the classification boundary.

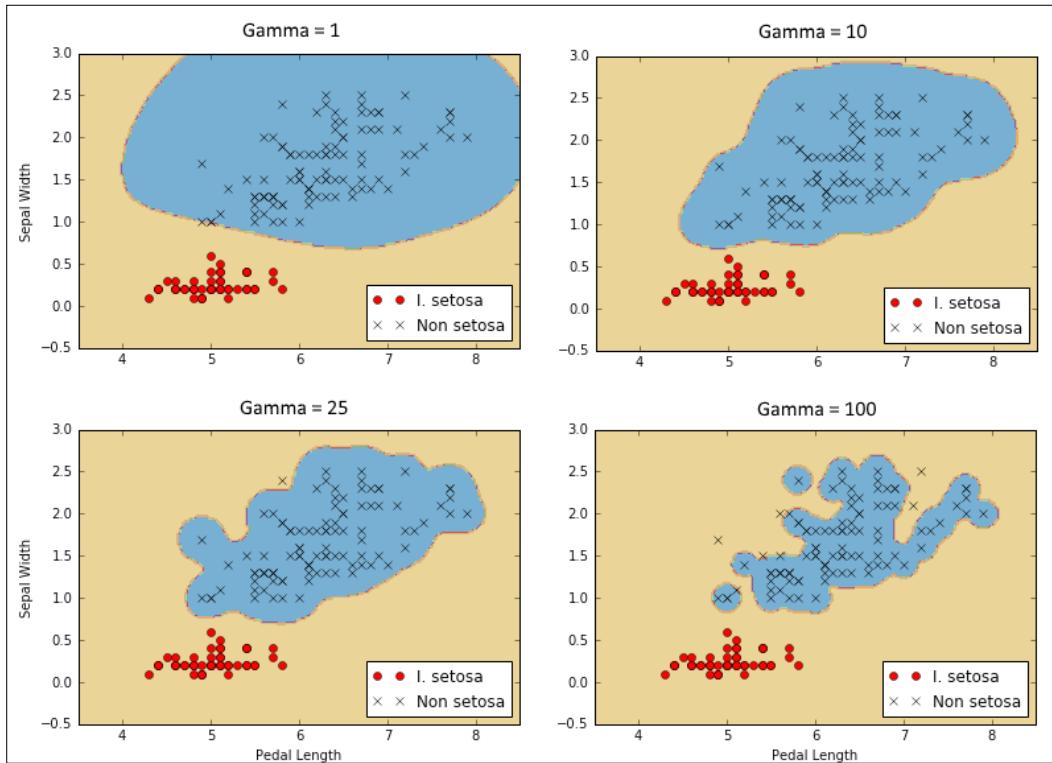


Figure 9: Classification results of *I. setosa* using a Gaussian kernel SVM with four different values of gamma.

## Implementing a Multi-Class SVM

We can also use SVMs to categorize multiple classes instead of just two. In this recipe, we will use a multi-class SVM to categorize the three types of flowers in the iris dataset.

### Getting ready

By design, SVM algorithms are binary classifiers. However, there are a few strategies employed to get them to work on multiple classes. The two main strategies are called one versus all, and one versus one.

One versus one is a strategy where a binary classifier is created for each possible pair of classes. Then a prediction is made for a point for the class that has the most votes. This can be computationally hard as we must create  $k!/(k-2)!2!$  classifiers for  $k$  classes.

Another way to implement multi-class classifiers is to do a one versus all strategy where we create a classifier for each of the classes. The predicted class of a point will be the class that creates the largest SVM margin. This is the strategy we will implement in this section.

Here, we will load the iris dataset and perform multiclass nonlinear SVM with a Gaussian kernel. The iris dataset is ideal because there are three classes (*I. setosa*, *I. virginica*, and *I. versicolor*). We will create three Gaussian kernel SVMs for each class and make the prediction of points where the highest margin exists.

## How to do it...

1. First we load the libraries we need and start a graph, as follows:

```
import matplotlib.pyplot as plt
import numpy as np
import tensorflow as tf
from sklearn import datasets
sess = tf.Session()
```

2. Next, we will load the iris dataset and split apart the targets for each class. We will only be using the sepal length and petal width to illustrate because we want to be able to plot the outputs. We also separate the x and y values for each class for plotting purposes at the end. Use the following code:

```
iris = datasets.load_iris()
x_vals = np.array([[x[0], x[3]] for x in iris.data])
y_vals1 = np.array([1 if y==0 else -1 for y in iris.target])
y_vals2 = np.array([1 if y==1 else -1 for y in iris.target])
y_vals3 = np.array([1 if y==2 else -1 for y in iris.target])
y_vals = np.array([y_vals1, y_vals2, y_vals3])
class1_x = [x[0] for i,x in enumerate(x_vals) if iris.
target[i]==0]
class1_y = [x[1] for i,x in enumerate(x_vals) if iris.
target[i]==0]
class2_x = [x[0] for i,x in enumerate(x_vals) if iris.
target[i]==1]
class2_y = [x[1] for i,x in enumerate(x_vals) if iris.
target[i]==1]
class3_x = [x[0] for i,x in enumerate(x_vals) if iris.
target[i]==2]
class3_y = [x[1] for i,x in enumerate(x_vals) if iris.
target[i]==2]
```

3. The biggest change we have in this example, as compared to the *Implementing a Non-Linear SVM* recipe, is that a lot of the dimensions will change (we have three classifiers now instead of one). We will also make use of matrix broadcasting and reshaping techniques to calculate all three SVMs at once. Since we are doing this all at once, our `y_target` placeholder now has the dimensions `[3, None]` and our model variable, `b`, will be initialized to be size `[3, batch_size]`. Use the following code:

```
batch_size = 50

x_data = tf.placeholder(shape=[None, 2], dtype=tf.float32)
y_target = tf.placeholder(shape=[3, None], dtype=tf.float32)
prediction_grid = tf.placeholder(shape=[None, 2], dtype=tf.
float32)

b = tf.Variable(tf.random_normal(shape=[3,batch_size]))
```

4. Next we calculate the Gaussian kernel. Since this is only dependent on the `x` data, this code doesn't change from the prior recipe. Use the following code:

```
gamma = tf.constant(-10.0)
dist = tf.reduce_sum(tf.square(x_data), 1)
dist = tf.reshape(dist, [-1,1])
sq_dists = tf.add(tf.sub(dist, tf.mul(2., tf.matmul(x_data,
tf.transpose(x_data)))), tf.transpose(dist))
my_kernel = tf.exp(tf.mul(gamma, tf.abs(sq_dists)))
```

5. One big change is that we will do batch matrix multiplication. We will end up with three-dimensional matrices and we will want to broadcast matrix multiplication across the third index. Our data and target matrices are not set up for this. In order for an operation such as  $x^T \cdot x$  to work across an extra dimension, we create a function to expand such matrices, reshape the matrix into a transpose, and then call TensorFlow's `batch_matmul` across the extra dimension. Use the following code:

```
def reshape_matmul(mat):
 v1 = tf.expand_dims(mat, 1)
 v2 = tf.reshape(v1, [3, batch_size, 1])
 return(tf.batch_matmul(v2, v1))
```

6. With this function created, we can now compute the dual loss function, as follows:

```
model_output = tf.matmul(b, my_kernel)
first_term = tf.reduce_sum(b)
b_vec_cross = tf.matmul(tf.transpose(b), b)
y_target_cross = reshape_matmul(y_target)

second_term = tf.reduce_sum(tf.mul(my_kernel, tf.mul(b_vec_cross,
y_target_cross)), [1,2])
loss = tf.reduce_sum(tf.neg(tf.sub(first_term, second_term)))
```

7. Now we can create the prediction kernel. Notice that we have to be careful with the `reduce_sum` function and not reduce across all three SVM predictions, so we have to tell TensorFlow not to sum everything up with a second index argument. Use the following code:

```
rA = tf.reshape(tf.reduce_sum(tf.square(x_data), 1), [-1,1])
rB = tf.reshape(tf.reduce_sum(tf.square(prediction_grid), 1), [-1,1])
pred_sq_dist = tf.add(tf.sub(rA, tf.mul(2., tf.matmul(x_data,
tf.transpose(prediction_grid)))), tf.transpose(rB))
pred_kernel = tf.exp(tf.mul(gamma, tf.abs(pred_sq_dist)))
```

8. When we are done with the prediction kernel, we can create predictions. A big change here is that the predictions are not the `sign()` of the output. Since we are implementing a one versus all strategy, the prediction is the classifier that has the largest output. To accomplish this, we use TensorFlow's built in `argmax()` function, as follows:

```
prediction_output = tf.matmul(tf.mul(y_target,b), pred_kernel)
prediction = tf.argmax(prediction_output-tf.expand_dims(tf.
reduce_mean(prediction_output,1), 1), 0)
accuracy = tf.reduce_mean(tf.cast(tf.equal(prediction,
tf.argmax(y_target,0)), tf.float32))
```

9. Now that we have the kernel, loss, and prediction capabilities set up, we just have to declare our `optimizer` function and initialize our variables, as follows:

```
my_opt = tf.train.GradientDescentOptimizer(0.01)
train_step = my_opt.minimize(loss)
init = tf.initialize_all_variables()
sess.run(init)
```

10. This algorithm converges relatively quickly, so we won't have run the training loop for more than 100 iterations. We do so with the following code:

```
loss_vec = []
batch_accuracy = []
for i in range(100):
 rand_index = np.random.choice(len(x_vals), size=batch_size)
 rand_x = x_vals[rand_index]
 rand_y = y_vals[:,rand_index]
 sess.run(train_step, feed_dict={x_data: rand_x, y_target:
rand_y})

 temp_loss = sess.run(loss, feed_dict={x_data: rand_x, y_
target: rand_y})
 loss_vec.append(temp_loss)

 acc_temp = sess.run(accuracy, feed_dict={x_data: rand_x, y_
```

```
target: rand_y, prediction_grid:rand_x})
batch_accuracy.append(acc_temp)

if (i+1)%25==0:
 print('Step #' + str(i+1))
 print('Loss = ' + str(temp_loss))

Step #25
Loss = -2.8951
Step #50
Loss = -27.9612
Step #75
Loss = -26.896
Step #100
Loss = -30.2325
```

11. We can now create the prediction grid of points and run the prediction function on all of them, as follows:

```
x_min, x_max = x_vals[:, 0].min() - 1, x_vals[:, 0].max() + 1
y_min, y_max = x_vals[:, 1].min() - 1, x_vals[:, 1].max() + 1
xx, yy = np.meshgrid(np.arange(x_min, x_max, 0.02),
 np.arange(y_min, y_max, 0.02))
grid_points = np.c_[xx.ravel(), yy.ravel()]
grid_predictions = sess.run(prediction, feed_dict={x_data: rand_x,
 y_target:
rand_y,
 prediction_
grid: grid_points})
grid_predictions = grid_predictions.reshape(xx.shape)
```

12. The following is code to plot the results, batch accuracy, and loss function. For succinctness we will only display the end result:

```
plt.contourf(xx, yy, grid_predictions, cmap=plt.cm.Paired,
alpha=0.8)
plt.plot(class1_x, class1_y, 'ro', label='I. setosa')
plt.plot(class2_x, class2_y, 'kx', label='I. versicolor')
plt.plot(class3_x, class3_y, 'gv', label='I. virginica')
plt.title('Gaussian SVM Results on Iris Data')
plt.xlabel('Pedal Length')
plt.ylabel('Sepal Width')
plt.legend(loc='lower right')
plt.ylim([-0.5, 3.0])
plt.xlim([3.5, 8.5])
plt.show()

plt.plot(batch_accuracy, 'k-', label='Accuracy')
```

```
plt.title('Batch Accuracy')
plt.xlabel('Generation')
plt.ylabel('Accuracy')
plt.legend(loc='lower right')
plt.show()

plt.plot(loss_vec, 'k-')
plt.title('Loss per Generation')
plt.xlabel('Generation')
plt.ylabel('Loss')
plt.show()
```

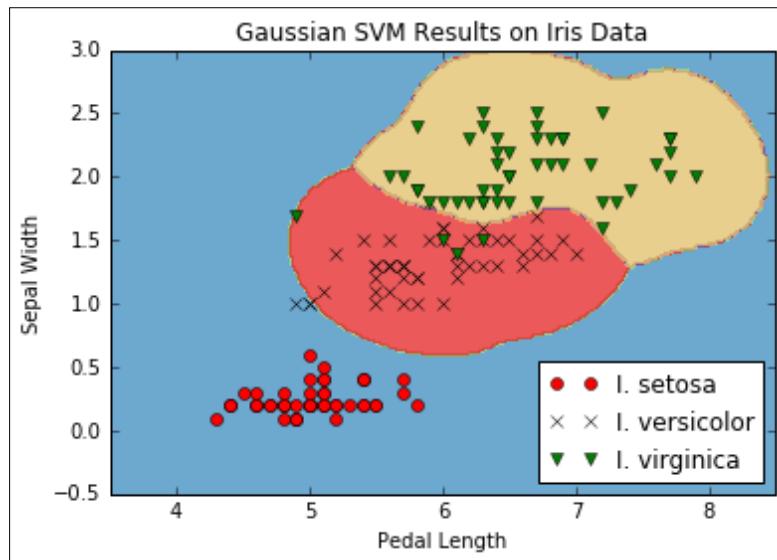


Figure 10: Multi-class (three classes) nonlinear Gaussian SVM results on the iris dataset with gamma = 10.

## How it works...

The important point to notice in this recipe is how we changed our algorithm to optimize over three SVM models at once. Our model parameter,  $b$ , has an extra dimension to take into account all three models. Here we can see that the extension of an algorithm to multiple similar algorithms was made relatively easy owing to TensorFlow's built-in capabilities to deal with extra dimensions.

# 5

## Nearest Neighbor Methods

This chapter will focus on nearest neighbor methods and how to implement them in TensorFlow. We will start with an introduction to the method and show how to implement various forms, and the chapter will end with examples of address matching and image recognition. This is what we will cover:

- ▶ Working with Nearest Neighbors
- ▶ Working with Text-Based Distances
- ▶ Computing Mixed Distance Functions
- ▶ Using an Address Matching Example
- ▶ Using Nearest Neighbors for Image Recognition

Note that all the code is available online at [https://github.com/nfmccclure/tensorflow\\_cookbook](https://github.com/nfmccclure/tensorflow_cookbook).

### Introduction

Nearest neighbor methods are based on a simple idea. We consider our training set as the model and make predictions on new points based on how close they are to points in the training set. The most naïve way is to make the prediction as the closest training data point class. But since most datasets contain a degree of noise, a more common method would be to take a weighted average of a set of  $k$  nearest neighbors. This method is called  **$k$ -nearest neighbors ( $k$ -NN)**.

Given a training dataset  $(x_1, x_2, \dots, x_n)$ , with corresponding targets  $(y_1, y_2, \dots, y_n)$ , we can make a prediction on a point,  $z$ , by looking at a set of nearest neighbors. The actual method of prediction depends on whether or not we are doing regression (continuous  $y_i$ ) or classification (discrete  $y_i$ ).

For discrete classification targets, the prediction may be given by a maximum voting scheme weighted by the distance to the prediction point:

$$f(z) = \max_j \sum_{i=1}^k \varphi(d_{ij}) I_{ij}$$

Here, our prediction,  $f(z)$  is the maximum weighted value over all classes,  $j$ , where the weighted distance from the prediction point to the training point,  $i$ , is given by  $\varphi(d_{ij})$ . And  $I_{ij}$  is just an indicator function if point  $i$  is in class  $j$ .

For continuous regression targets, the prediction is given by a weighted average of all  $k$  points nearest to the prediction:

- $f(z) = \frac{1}{k} \sum_{i=1}^k \varphi(d_i)$

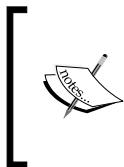
It is obvious that the prediction is heavily dependent on the choice of the distance metric,  $d$ .

Common specifications of the distance metric are L1 and L2 distances:

- $d_{L1}(x_i, x_j) = |x_i - x_j| = |x_{i1} - x_{j1}| + |x_{i2} - x_{j2}| + \dots$
- $d_{L2}(x_i, x_j) = \|x_i - x_j\| = \sqrt{(x_{i1} - x_{j1})^2 + (x_{i2} - x_{j2})^2 + \dots}$

There are many different specifications of distance metrics that we can choose. In this chapter, we will explore the L1 and L2 metrics as well as edit and textual distances.

We also have to choose how to weight the distances. A straightforward way to weight the distances is by the distance itself. Points that are further away from our prediction should have less impact than nearer points. The most common way to weight is by the normalized inverse of the distance. We will implement this method in the next recipe.



Note that k-NN is an aggregating method. For regression, we are performing a weighted average of neighbors. Because of this, predictions will be less extreme and less varied than the actual targets. The magnitude of this effect will be determined by  $k$ , the number of neighbors in the algorithm.

## Working with Nearest Neighbors

We start this chapter by implementing nearest neighbors to predict housing values. This is a great way to start with nearest neighbors because we will be dealing with numerical features and continuous targets.

### Getting ready

To illustrate how making predictions with nearest neighbors works in TensorFlow, we will use the Boston housing dataset. Here we will be predicting the median neighborhood housing value as a function of several features.

Since we consider the training set the trained model, we will find the k-NNs to the prediction points and do a weighted average of the target value.

### How to do it...

1. First, we will start by loading the required libraries and starting a graph session. We will use the requests module to load the necessary Boston housing data from the UCI machine learning repository:

```
import matplotlib.pyplot as plt
import numpy as np
import tensorflow as tf
import requests

sess = tf.Session()
```

2. Next, we will load the data using the requests module:

```
housing_url = 'https://archive.ics.uci.edu/ml/machine-learning-
databases/housing/housing.data'
housing_header = ['CRIM', 'ZN', 'INDUS', 'CHAS', 'NOX', 'RM',
'AGE', 'DIS', 'RAD', 'TAX', 'PTRATIO', 'B', 'LSTAT', 'MEDV']
cols_used = ['CRIM', 'INDUS', 'NOX', 'RM', 'AGE', 'DIS', 'TAX',
'PTRATIO', 'B', 'LSTAT']
num_features = len(cols_used)
Request data
housing_file = requests.get(housing_url)
Parse Data
housing_data = [[float(x) for x in y.split(' ') if len(x)>=1] for
y in housing_file.text.split('\n') if len(y)>=1]
```

3. Next, we separate the data into our dependent and independent features. We will be predicting the last variable, MEDV, which is the median value for the group of houses. We will also not use the features ZN, CHAS, and RAD because of their uninformative or binary nature:

```
y_vals = np.transpose([np.array([y[13] for y in housing_data])])
x_vals = np.array([[x for i,x in enumerate(y) if housing_header[i]
in cols_used] for y in housing_data])

x_vals = (x_vals - x_vals.min(0)) / x_vals.ptp(0)
```

4. Now we split the x and y values into the train and test sets. We will create the training set by selecting about 80% of the rows at random, and leave the remaining 20% for the test set:

```
train_indices = np.random.choice(len(x_vals), round(len(x_
vals)*0.8), replace=False)
test_indices = np.array(list(set(range(len(x_vals))) - set(train_
indices)))
x_vals_train = x_vals[train_indices]
x_vals_test = x_vals[test_indices]
y_vals_train = y_vals[train_indices]
y_vals_test = y_vals[test_indices]
```

5. Next, we declare our  $k$  value and batch size:

```
k = 4
batch_size=len(x_vals_test)
```

6. We will declare our placeholders next. Remember that there are no model variables to train, as the model is determined exactly by our training set:

```
x_data_train = tf.placeholder(shape=[None, num_features],
dtype=tf.float32)
x_data_test = tf.placeholder(shape=[None, num_features], dtype=tf.
float32)
y_target_train = tf.placeholder(shape=[None, 1], dtype=tf.float32)
y_target_test = tf.placeholder(shape=[None, 1], dtype=tf.float32)
```

7. Next, we create our distance function for a batch of test points. Here, we illustrate the use of the L1 distance:

```
distance = tf.reduce_sum(tf.abs(tf.sub(x_data_train, tf.expand_.
dims(x_data_test,1))), reduction_indices=2)
```



Note that the L2 distance function can be used as well. We would change the distance formula to the following:

```
distance = tf.sqrt(tf.reduce_sum(tf.square(tf.
 sub(x_data_train, tf.expand_dims(x_data_test, 1))), ,
 reduction_indices=1))
```

8. Now we create our prediction function. To do this, we will use the `top_k()`, function, which returns the values and indices of the largest values in a tensor. Since we want the indices of the smallest distances, we will instead find the k-biggest negative distances. We also declare the predictions and the **mean squared error (MSE)** of the target values:

```
top_k_xvals, top_k_indices = tf.nn.top_k(tf.neg(distance), k=k)
x_sums = tf.expand_dims(tf.reduce_sum(top_k_xvals, 1), 1)
x_sums_repeated = tf.matmul(x_sums, tf.ones([1, k], tf.float32))
x_val_weights = tf.expand_dims(tf.div(top_k_xvals, x_sums_
repeated), 1)

top_k_yvals = tf.gather(y_target_train, top_k_indices)
prediction = tf.squeeze(tf.batch_matmul(x_val_weights, top_k_
yvals), squeeze_dims=[1])
mse = tf.div(tf.reduce_sum(tf.square(tf.sub(prediction, y_target_
test))), batch_size)
```

9. Test:

```
num_loops = int(np.ceil(len(x_vals_test)/batch_size))

for i in range(num_loops):
 min_index = i*batch_size
 max_index = min((i+1)*batch_size, len(x_vals_train))
 x_batch = x_vals_test[min_index:max_index]
 y_batch = y_vals_test[min_index:max_index]
 predictions = sess.run(prediction, feed_dict={x_data_train: x_vals_train,
 x_data_test: x_batch, y_target_train: y_vals_train,
 y_target_test: y_batch})

 batch_mse = sess.run(mse, feed_dict={x_data_train: x_vals_
train, x_data_test: x_batch, y_target_train: y_vals_train, y_
target_test: y_batch})

 print('Batch #' + str(i+1) + ' MSE: ' + str(np.round(batch_
mse, 3)))
```

Batch #1 MSE: 23.153

10. Additionally, we can also look at a histogram of the actual target values compared with the predicted values. One reason to look at this is to notice the fact that with an averaging method, we have trouble predicting the extreme ends of the targets:

```
bins = np.linspace(5, 50, 45)

plt.hist(predictions, bins, alpha=0.5, label='Prediction')
plt.hist(y_batch, bins, alpha=0.5, label='Actual')
plt.title('Histogram of Predicted and Actual Values')
plt.xlabel('Med Home Value in $1,000s')
plt.ylabel('Frequency')
plt.legend(loc='upper right')
plt.show()
```

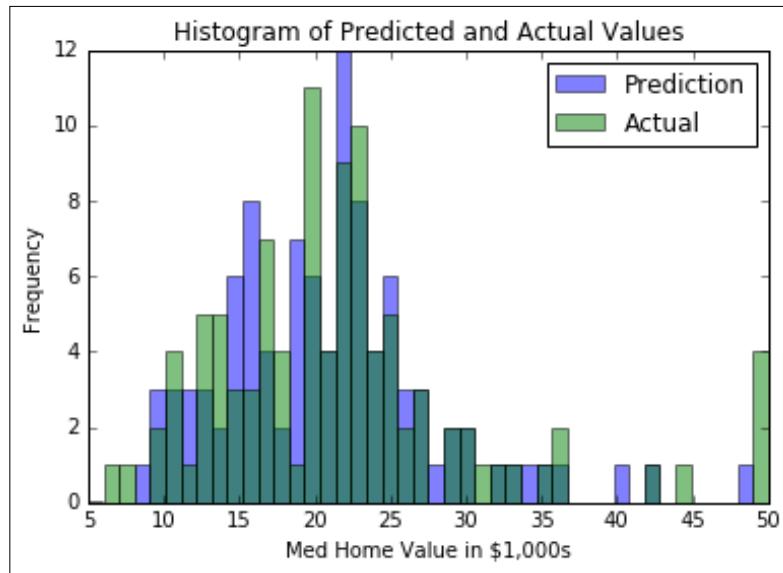


Figure 1: A histogram of the predicted values and actual target values for k-NN (k=4).

11. One hard thing to determine is the best value of  $k$ . For the preceding figure and predictions, we used  $k=4$  for our model. We chose this specifically because it gives us the lowest MSE. This is verified by cross validation. If we use cross validation across multiple values of  $k$ , we will see that  $k=4$  gives us a minimum MSE. We show this in the following figure. It is also worthwhile to plotting the variance in the predicted values to show that it will decrease the more neighbors we average over:

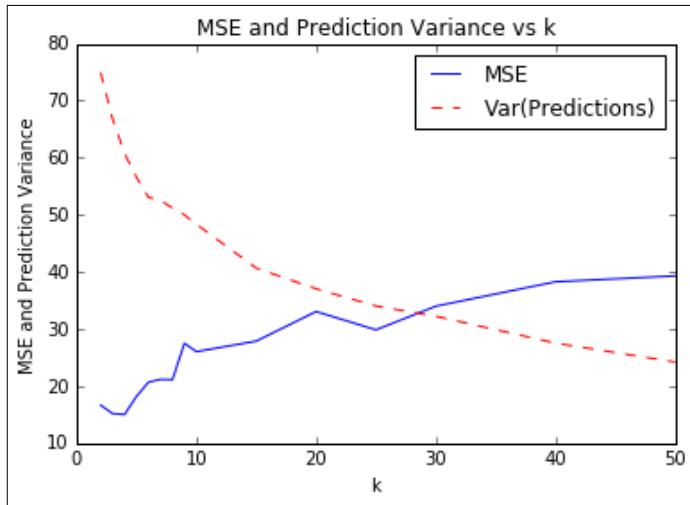


Figure 2: The MSE for k-NN predictions for various values of k. We also plot the variance of the predicted values on the test set. Note that the variance decreases as k increases.

## How it works...

With the nearest neighbors algorithm, the model is the training set. Because of this, we do not have to train any variables in our model. The only parameter, k, we determined via cross-validation to minimize our MSE.

## There's more...

For the weighting of the k-NN, we chose to weight directly by the distance. There are other options that we could consider as well. Another common method is to weight by the inverse squared distance.

## Working with Text-Based Distances

Nearest neighbors is more versatile than just dealing with numbers. As long as we have a way to measure distances between features, we can apply the nearest neighbors algorithm. In this recipe, we will introduce how to measure text distances with TensorFlow.

## Getting ready

In this recipe, we will illustrate how to use TensorFlow's text distance metric, the Levenshtein distance (the edit distance), between strings. This will be important later in this chapter as we expand the nearest neighbor methods to include features with text.

The Levenshtein distance is the minimal number of edits to get from one string to another string. The allowed edits are inserting a character, deleting a character, or substituting a character with a different one. For this recipe, we will use TensorFlow's Levenshtein distance function, `edit_distance()`. It is worthwhile to illustrate the use of this function because the usage of this function will be applicable to later chapters.



Note that TensorFlow's `edit_distance()` function only accepts sparse tensors. We will have to create our strings as sparse tensors of individual characters.

## How to do it...

- First, we load TensorFlow and initialize a graph:

```
import tensorflow as tf
sess = tf.Session()
```

- Then we will show how to calculate the edit distance between two words, 'bear' and 'beer'. First, we will create a list of characters from our strings with Python's `'list()'` function. Next, we create a sparse 3D matrix from that list. We have to tell TensorFlow the character indices, the shape of the matrix, and which characters we want in the tensor. After this we can decide if we would like to go with the total edit distance (`normalize=False`) or the normalized edit distance (`normalize=True`), where we divide the edit distance by the length of the second word:



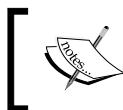
TensorFlow's documentation treats the two strings as a proposed (hypothesis) string and a ground truth string. We will continue this notation here with `h` and `t` tensors.

```
hypothesis = list('bear')
truth = list('beers')
h1 = tf.SparseTensor([[0,0,0], [0,0,1], [0,0,2], [0,0,3]],
 hypothesis, [1,1,1])
t1 = tf.SparseTensor([[0,0,0], [0,0,1], [0,0,2], [0,0,3], [0,0,4]],
 truth, [1,1,1])

print(sess.run(tf.edit_distance(h1, t1, normalize=False)))
```

- This results in the following output:

```
[[2.]]
```



The function, `SparseTensorValue()`, is a way to create a sparse tensor in TensorFlow. It accepts the indices, values, and shape of a sparse tensor we wish to create.

4. Next, we will illustrate how to compare two words, bear and beer, both with another word, beers. In order to achieve this, we must replicate the beers in order to have the same amount of comparable words:

```
hypothesis2 = list('bearbeer')
truth2 = list('beersbeers')
h2 = tf.SparseTensor([[0,0,0], [0,0,1], [0,0,2], [0,0,3], [0,1,0],
[0,1,1], [0,1,2], [0,1,3]], hypothesis2, [1,2,4])
t2 = tf.SparseTensor([[0,0,0], [0,0,1], [0,0,2], [0,0,3], [0,0,4],
[0,1,0], [0,1,1], [0,1,2], [0,1,3], [0,1,4]], truth2, [1,2,5])

print(sess.run(tf.edit_distance(h2, t2, normalize=True)))
```

5. This results in the following output:

```
[[0.40000001 0.2]]
```

6. A more efficient way to compare a set of words against another word is shown in this example. We create the indices and list of characters beforehand for both the hypothesis and ground truth string:

```
hypothesis_words = ['bear','bar','tensor','flow']
truth_word = ['beers''']
num_h_words = len(hypothesis_words)
h_indices = [[xi, 0, yi] for xi,x in enumerate(hypothesis_words)
for yi,y in enumerate(x)]
h_chars = list(''.join(hypothesis_words))
h3 = tf.SparseTensor(h_indices, h_chars, [num_h_words,1,1])
truth_word_vec = truth_word*num_h_words
t_indices = [[xi, 0, yi] for xi,x in enumerate(truth_word_vec) for
yi,y in enumerate(x)]
t_chars = list(''.join(truth_word_vec))
t3 = tf.SparseTensor(t_indices, t_chars, [num_h_words,1,1])

print(sess.run(tf.edit_distance(h3, t3, normalize=True)))
```

7. This results in the following output:

```
[[0.40000001]
 [0.60000002]
 [0.80000001]
 [1.]]
```

- 
8. Now we will illustrate how to calculate the edit distance between two word lists using placeholders. The concept is the same, except we will be feeding in `SparseTensorValue()` instead of sparse tensors. First, we will create a function that creates the sparse tensors from a word list:

```
def create_sparse_vec(word_list):
 num_words = len(word_list)
 indices = [[xi, 0, yi] for xi,x in enumerate(word_list) for
 yi,y in enumerate(x)]
 chars = list(''.join(word_list))
 return(tf.SparseTensorValue(indices, chars, [num_words,1,1]))

hyp_string_sparse = create_sparse_vec(hypothesis_words)
truth_string_sparse = create_sparse_vec(truth_word*len(hypothesis_
words))

hyp_input = tf.sparse_placeholder(dtype=tf.string)
truth_input = tf.sparse_placeholder(dtype=tf.string)

edit_distances = tf.edit_distance(hyp_input, truth_input,
normalize=True)

feed_dict = {hyp_input: hyp_string_sparse,
 truth_input: truth_string_sparse}

print(sess.run(edit_distances, feed_dict=feed_dict))
```

9. This results in the following output:

```
[[0.40000001]
 [0.60000002]
 [0.80000001]
 [1.]]
```

## How it works...

For this recipe, we have shown that we can measure text distances several ways using TensorFlow. This will be extremely useful for performing nearest neighbors on data that has text features. We will see more of this later in the chapter when we perform address matching.

## There's more...

Other text distance metrics exist that we should discuss. Here is a definition table describing other various text distances between two strings,  $s_1$  and  $s_2$ :

| Name             | Description                                                                                 | Formula                                                                              |
|------------------|---------------------------------------------------------------------------------------------|--------------------------------------------------------------------------------------|
| Hamming distance | Number of equal character positions. Only valid if the strings are equal length.            | $D(s_1, s_2) = \sum_i I_i$ , where $I$ is an indicator function of equal characters. |
| Cosine distance  | The dot product of the k-gram differences divided by the L2 norm of the k-gram differences. | $D(s_1, s_2) = 1 - \frac{k(s_1) \cdot k(s_2)}{\ k(s_1)\  \ k(s_2)\ }$                |
| Jaccard distance | Number of characters in common divided by the total union of characters in both strings.    | $D(s_1, s_2) = \frac{ s_1 \cap s_2 }{ s_1 \cup s_2 }$                                |

## Computing with Mixed Distance Functions

When dealing with data observations that have multiple features, we should be aware that features can be scaled differently on different scales. In this recipe, we account for that to improve our housing value predictions.

### Getting ready

It is important to extend the nearest neighbor algorithm to take into account variables that are scaled differently. In this example, we will show how to scale the distance function for different variables. Specifically, we will scale the distance function as a function of the feature variance.

The key to weighting the distance function is to use a weight matrix. The distance function written with matrix operations becomes the following formula:

$$D(x, y) = \sqrt{(x - y)^T A (x - y)}$$

Here,  $A$  is a diagonal weight matrix that we use to scale the distance metric for each feature.

For this recipe, we will try to improve our MSE on the Boston housing value dataset. This dataset is a great example of features that are on different scales, and the nearest neighbor algorithm would benefit from scaling the distance function.

## How to do it...

- First, we will load the necessary libraries and start a graph session:

```
import matplotlib.pyplot as plt
import numpy as np
import tensorflow as tf
import requests
sess = tf.Session()
```

- Next, we load the data and store it in a numpy array. Again, note that we will only use certain columns for prediction. We do not use id variables nor variables that have very low variance:

```
housing_url = 'https://archive.ics.uci.edu/ml/machine-learning-databases/housing/housing.data'
housing_header = ['CRIM', 'ZN', 'INDUS', 'CHAS', 'NOX', 'RM', 'AGE', 'DIS', 'RAD', 'TAX', 'PTRATIO', 'B', 'LSTAT', 'MEDV']
cols_used = ['CRIM', 'INDUS', 'NOX', 'RM', 'AGE', 'DIS', 'TAX', 'PTRATIO', 'B', 'LSTAT']
num_features = len(cols_used)
housing_file = requests.get(housing_url)
housing_data = [[float(x) for x in y.split(' ') if len(x)>=1] for y in housing_file.text.split('\n') if len(y)>=1]
y_vals = np.transpose([np.array([y[13] for y in housing_data])])
x_vals = np.array([[x for i,x in enumerate(y) if housing_header[i] in cols_used] for y in housing_data])
```

- Now we scale the x values to be between zero and 1 with min-max scaling:

```
x_vals = (x_vals - x_vals.min(0)) / x_vals.ptp(0)
```

- We now create the diagonal weight matrix that will provide the scaling of the distance metric by the standard deviation of the features:

```
weight_diagonal = x_vals.std(0)
weight_matrix = tf.cast(tf.diag(weight_diagonal), dtype=tf.float32)
```

- Now we split the data into a training and test set. We also declare k, the amount of nearest neighbors, and make the batch size equal to the test set size:

```
train_indices = np.random.choice(len(x_vals), round(len(x_vals)*0.8), replace=False)
test_indices = np.array(list(set(range(len(x_vals))) - set(train_indices)))
x_vals_train = x_vals[train_indices]
x_vals_test = x_vals[test_indices]
y_vals_train = y_vals[train_indices]
y_vals_test = y_vals[test_indices]
```

```
k = 4
batch_size=len(x_vals_test)
```

6. We declare our placeholders that we need next. We have four placeholders, the x-inputs and y-targets for both the training and test set:

```
x_data_train = tf.placeholder(shape=[None, num_features],
 dtype=tf.float32)
x_data_test = tf.placeholder(shape=[None, num_features], dtype=tf.
 float32)
y_target_train = tf.placeholder(shape=[None, 1], dtype=tf.float32)
y_target_test = tf.placeholder(shape=[None, 1], dtype=tf.float32)
```

7. Now we can declare our distance function. For readability, we break up the distance function into its components. Note that we will have to tile the weight matrix by the batch size and use the `batch_matmul()` function to perform batch matrix multiplication across the batch size:

```
subtraction_term = tf.sub(x_data_train, tf.expand_dims(x_data_
test,1))
first_product = tf.batch_matmul(subtraction_term, tf.tile(tf.
expand_dims(weight_matrix,0), [batch_size,1,1]))
second_product = tf.batch_matmul(first_product,
tf.transpose(subtraction_term, perm=[0,2,1]))
distance = tf.sqrt(tf.batch_matrix_diag_part(second_product))
```

8. After we calculate all the training distances for each test point, we need to return the top k-NNs. We do this with the `top_k()` function. Since this function returns the largest values, and we want the smallest distances, we return the largest of the negative distance values. We then want to make predictions as the weighted average of the distances of the top k neighbors:

```
top_k_xvals, top_k_indices = tf.nn.top_k(tf.neg(distance), k=k)
x_sums = tf.expand_dims(tf.reduce_sum(top_k_xvals, 1),1)
x_sums_repeated = tf.matmul(x_sums, tf.ones([1, k], tf.float32))
x_val_weights = tf.expand_dims(tf.div(top_k_xvals,x_sums_
repeated), 1)
top_k_yvals = tf.gather(y_target_train, top_k_indices)
prediction = tf.squeeze(tf.batch_matmul(x_val_weights,top_k_
yvals), squeeze_dims=[1])
```

9. To evaluate our model, we calculate the MSE of our predictions:

```
mse = tf.div(tf.reduce_sum(tf.square(tf.sub(prediction, y_target_
test))), batch_size)
```

10. Now we can loop through our test batches and calculate the MSE for each:

```
num_loops = int(np.ceil(len(x_vals_test)/batch_size))
for i in range(num_loops):
 min_index = i*batch_size
```

```

max_index = min((i+1)*batch_size,len(x_vals_train))
x_batch = x_vals_test[min_index:max_index]
y_batch = y_vals_test[min_index:max_index]
predictions = sess.run(prediction, feed_dict={x_data_train:
x_vals_train, x_data_test: x_batch, y_target_train: y_vals_train,
y_target_test: y_batch})
batch_mse = sess.run(mse, feed_dict={x_data_train: x_vals_
train, x_data_test: x_batch, y_target_train: y_vals_train, y_
target_test: y_batch})
print('Batch #' + str(i+1) + ' MSE: ' + str(np.round(batch_
mse,3)))

```

11. This results in the following output:

Batch #1 MSE: 21.322

12. As a final comparison, we can plot the distribution of housing values for the actual test set and the predictions on the test set with the following code:

```

bins = np.linspace(5, 50, 45)
plt.hist(predictions, bins, alpha=0.5, label='Prediction')
plt.hist(y_batch, bins, alpha=0.5, label='Actual')
plt.title('Histogram of Predicted and Actual Values')
plt.xlabel('Med Home Value in $1,000s')
plt.ylabel('Frequency')
plt.legend(loc='upper right')
plt.show()

```

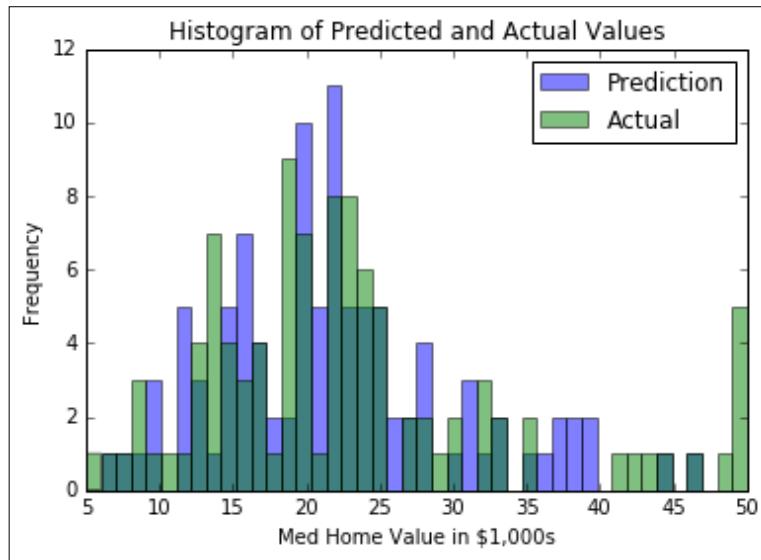


Figure 3: The two histograms of the predicted and actual housing values on the Boston dataset.  
This time we have scaled the distance function differently for each feature.

## How it works...

We decreased our MSE on the test set here by introducing a method of scaling the distance functions for each feature. Here, we scaled the distance functions by a factor of the feature's standard deviation. This provides a more accurate view of measuring which points are the closest neighbors or not. From this we also took the weighted average of the top k neighbors as a function of distance to get the housing value prediction.

## There's more...

This scaling factor can also be used to down-weight or up-weight features in the nearest neighbor distance calculation. This can be useful in situations where we trust features more or less than others.

## Using an Address Matching Example

Now that we have measured numerical and text distances, we will spend time learning how to combine them to measure distances between observations that have both text and numerical features.

### Getting ready

Nearest neighbor is a great algorithm to use for address matching. Address matching is a type of record matching in which we have addresses in multiple datasets and we would like to match them up. In address matching, we may have typos in the address, different cities, or different zip codes, but they may all refer to the same address. Using the nearest neighbor algorithm across the numerical and character components of an address may help us identify addresses that are actually the same.

In this example, we will generate two datasets. Each dataset will comprise a street address and a zip code. But one dataset has a high number of typos in the street address. We will take the non-typo dataset as our gold standard and return one address from it for each typo address that is the closest as a function of the string distance (for the street) and numerical distance (for the zip code).

The first part of the code will focus on generating the two datasets. Then the second part of the code will run through the test set and return the closest address from the training set.

## How to do it...

1. We first start by loading the necessary libraries:

```
import random
import string
import numpy as np
import tensorflow as tf
```

2. We will now create the reference dataset. To show succinct output, we will only make each dataset comprise of 10 addresses (but it can be run with many more):

```
n = 10
street_names = ['abbey', 'baker', 'canal', 'donner', 'elm']
street_types = ['rd', 'st', 'ln', 'pass', 'ave']
rand_zips = [random.randint(65000,65999) for i in range(5)]
numbers = [random.randint(1, 9999) for i in range(n)]
streets = [random.choice(street_names) for i in range(n)]
street_suffs = [random.choice(street_types) for i in range(n)]
zips = [random.choice(rand_zips) for i in range(n)]
full_streets = [str(x) + ' ' + y + ' ' + z for x,y,z in
zip(numbers, streets, street_suffs)]
reference_data = [list(x) for x in zip(full_streets,zips)]
```

3. To create the test set, we need a function that will randomly create a typo in a string and return the resulting string:

```
def create_typos(s, prob=0.75):
 if random.uniform(0,1) < prob:
 rand_ind = random.choice(range(len(s)))
 s_list = list(s)
 s_list[rand_ind]=random.choice(string.ascii_lowercase)
 s = ''.join(s_list)
 return(s)
typo_streets = [create_typos(x) for x in streets]
typo_full_streets = [str(x) + ' ' + y + ' ' + z for x,y,z in
zip(numbers, typo_streets, street_suffs)]
test_data = [list(x) for x in zip(typo_full_streets,zips)]
```

4. Now we can initialize a graph session and declare the placeholders we need. We will need four placeholders in each test and reference set, and we will need an address and zip code placeholder:

```
sess = tf.Session()
test_address = tf.sparse_placeholder(dtype=tf.string)
test_zip = tf.placeholder(shape=[None, 1], dtype=tf.float32)
ref_address = tf.sparse_placeholder(dtype=tf.string)
ref_zip = tf.placeholder(shape=[None, n], dtype=tf.float32)
```

5. Now we declare the numerical zip distance and the edit distance for the address string:

```
zip_dist = tf.square(tf.sub(ref_zip, test_zip))
address_dist = tf.edit_distance(test_address, ref_address,
normalize=True)
```

6. We now convert the zip distance and the address distance into similarities. For the similarities, we want a similarity of 1 when the two inputs are exactly the same and near 0 when they are very different. For the zip distance, we can do this by taking the distances, subtracting from the max, and then dividing by the range of the distances. For the address similarity, since the distance is already scaled between 0 and 1, we just subtract it from 1 to get the similarity:

```
zip_max = tf.gather(tf.squeeze(zip_dist), tf.argmax(zip_dist, 1))
zip_min = tf.gather(tf.squeeze(zip_dist), tf.argmin(zip_dist, 1))
zip_sim = tf.div(tf.sub(zip_max, zip_dist), tf.sub(zip_max, zip_min))
address_sim = tf.sub(1., address_dist)
```

7. To combine the two similarity functions, we take a weighted average of the two. For this recipe, we put equal weight on the address and the zip code. We can also change this depending on how much we trust each feature. We then return the index of the highest similarity of the reference set:

```
address_weight = 0.5
zip_weight = 1. - address_weight
weighted_sim = tf.add(tf.transpose(tf.mul(address_weight, address_sim)),
tf.mul(zip_weight, zip_sim))
top_match_index = tf.argmax(weighted_sim, 1)
```

8. In order to use the edit distance in TensorFlow, we have to convert the address strings to a sparse vector. In a prior recipe in this chapter, *Working with Text-Based Distances* recipe, we created the following function and will use it in this recipe as well:

```
def sparse_from_word_vec(word_vec):
 num_words = len(word_vec)
 indices = [[xi, 0, yi] for xi,x in enumerate(word_vec) for
yi,y in enumerate(x)]
 chars = list(''.join(word_vec))
 # Now we return our sparse vector
 return(tf.SparseTensorValue(indices, chars, [num_words,1,1]))
```

9. We need to separate the addresses and zip codes in the reference dataset, so we can feed them into the placeholders when we loop through the test set:

```
reference_addresses = [x[0] for x in reference_data]
reference_zips = np.array([[x[1] for x in reference_data]])
```

10. We need to create the sparse tensor set of reference addresses using the function we created in step 8:

```
sparse_ref_set = sparse_from_word_vec(reference_addresses)
```

11. Now we can loop though each entry of the test set and return the index of the reference set that it is the closest to. We print off both the test and reference for each entry. As you can see, we have great results on this generated dataset:

```
for i in range(n):
 test_address_entry = test_data[i][0]
 test_zip_entry = [[test_data[i][1]]]

 # Create sparse address vectors
 test_address_repeated = [test_address_entry] * n
 sparse_test_set = sparse_from_word_vec(test_address_repeated)

 feeddict={test_address: sparse_test_set,
 test_zip: test_zip_entry,
 ref_address: sparse_ref_set,
 ref_zip: reference_zips}
 best_match = sess.run(top_match_index, feed_dict=feeddict)
 best_street = reference_addresses[best_match]
 [best_zip] = reference_zips[0][best_match]
 [[test_zip_]] = test_zip_entry
 print('Address: ' + str(test_address_entry) + ', ' +
 str(test_zip_))
 print('Match : ' + str(best_street) + ', ' + str(best_
zip))
```

12. This results in the following output:

```
Address: 8659 beker ln, 65463
Match : 8659 baker ln, 65463
Address: 1048 eanal ln, 65681
Match : 1048 canal ln, 65681
Address: 1756 vaker st, 65983
Match : 1756 baker st, 65983
Address: 900 abbjy pass, 65983
Match : 900 abbey pass, 65983
Address: 5025 canal rd, 65463
Match : 5025 canal rd, 65463
Address: 6814 elh st, 65154
Match : 6814 elm st, 65154
Address: 3057 cagal ave, 65463
Match : 3057 canal ave, 65463
Address: 7776 iaker ln, 65681
```

```
Match : 7776 baker ln, 65681
Address: 5167 caker rd, 65154
Match : 5167 baker rd, 65154
Address: 8765 donnor st, 65154
Match : 8765 donner st, 65154
```

## How it works...

One of the hard things to figure out in address matching problems like this is the value of the weights and how to scale the distances. This may take some exploration and insight into the data itself. Also, when dealing with addresses we may consider different components than we did here. We may consider the street number a separate component from the street address, or even have other components, such as city and state. When dealing with numerical address components, note that they can be treated as numbers (with a numerical distance) or as characters (with an edit distance). It is up to you to choose how. Also note that we might consider using an edit distance with the zip code if we think that typos in the zip code come from human entry and not, say, computer mapping errors.

To get a feel for how typos affect the results, we encourage the reader to change the typo function to make more typos or more frequent typos and increase the dataset's size to see how well this algorithm works.

## Using Nearest Neighbors for Image Recognition

### Getting ready

Nearest neighbors can also be used for image recognition. The **Hello World** of image recognition datasets is the MNIST handwritten digit dataset. Since we will be using this dataset for various neural network image recognition algorithms in later chapters, it will be great to compare the results to a non-neural network algorithm.

The MNIST digit dataset is composed of thousands of labeled images that are 28x28 pixels in size. Although this is considered to be a small image, it has a total of 784 pixels (or features) for the nearest neighbor algorithm. We will compute the nearest neighbor prediction for this categorical problem by considering the mode prediction of the nearest k neighbors ( $k=4$  in this example).

## How to do it...

1. We start by loading the necessary libraries. Note that we will also import the **Python Image Library (PIL)** to be able to plot a sample of the predicted outputs. And TensorFlow has a built-in method to load the MNIST dataset that we will use:

```
import random
import numpy as np
import tensorflow as tf
import matplotlib.pyplot as plt
from PIL import Image
from tensorflow.examples.tutorials.mnist import input_data
```

2. Now we start a graph session and load the MNIST data in a one hot encoded form:

```
sess = tf.Session()
mnist = input_data.read_data_sets("MNIST_data/", one_hot=True)
```



One hot encoding is a numerical representation of categorical values that are better suited for numerical computations. Here we have 10 categories (numbers 0-9), and represent them as a 0-1 vector of length 10. For example, the '0' category is denoted by the vector 1,0,0,0,0,0,0,0,0,0, the 1 vector is denoted by 0,1,0,0,0,0,0,0,0,0, and so on.

3. Because the MNIST dataset is large and computing the distances between 784 features on tens of thousands of inputs would be computationally hard, we will sample a smaller set of images to train on. Also, we choose a test set number that is divisible by six only for plotting purposes, as we will plot the last batch of six images to see a sample of the results:

```
train_size = 1000
test_size = 102
rand_train_indices = np.random.choice(len(mnist.train.images),
train_size, replace=False)
rand_test_indices = np.random.choice(len(mnist.test.images), test_
size, replace=False)
x_vals_train = mnist.train.images[rand_train_indices]
x_vals_test = mnist.test.images[rand_test_indices]
y_vals_train = mnist.train.labels[rand_train_indices]
y_vals_test = mnist.test.labels[rand_test_indices]
```

4. We declare our  $k$  value and batch size:

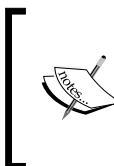
```
k = 4
batch_size=6
```

5. Now we initialize our placeholders that we will feed in the graph:

```
x_data_train = tf.placeholder(shape=[None, 784], dtype=tf.float32)
x_data_test = tf.placeholder(shape=[None, 784], dtype=tf.float32)
y_target_train = tf.placeholder(shape=[None, 10], dtype=tf.
float32)
y_target_test = tf.placeholder(shape=[None, 10], dtype=tf.float32)
```

6. We declare our distance metric. Here we will use the L1 metric (absolute value):

```
distance = tf.reduce_sum(tf.abs(tf.sub(x_data_train, tf.expand_
dims(x_data_test,1))), reduction_indices=2)
```



Note that we can also make our distance function use the L2 distance by using the following code instead: `distance = tf.sqrt(tf.reduce_sum(tf.square(tf.sub(x_data_train, tf.expand_dims(x_data_test,1))), reduction_indices=1))`

7. Now we find the top k images that are the closest and predict the mode. The mode will be performed on one hot encoded indices and counting which occurs the most:

```
top_k_xvals, top_k_indices = tf.nn.top_k(tf.neg(distance), k=k)
prediction_indices = tf.gather(y_target_train, top_k_indices)
count_of_predictions = tf.reduce_sum(prediction_indices,
reduction_indices=1)
prediction = tf.argmax(count_of_predictions, dimension=1)
```

8. We can now loop through our test set, compute the predictions, and store them:

```
num_loops = int(np.ceil(len(x_vals_test)/batch_size))
test_output = []
actual_vals = []
for i in range(num_loops):
 min_index = i*batch_size
 max_index = min((i+1)*batch_size, len(x_vals_train))
 x_batch = x_vals_test[min_index:max_index]
 y_batch = y_vals_test[min_index:max_index]
 predictions = sess.run(prediction, feed_dict={x_data_train: x_
 vals_train, x_data_test: x_batch,
 y_target_train: y_vals_
 train, y_target_test: y_batch})
 test_output.extend(predictions)
 actual_vals.extend(np.argmax(y_batch, axis=1))
```

9. Now that we have saved the actual and predicted output, we can calculate the accuracy. This will change due to our random sampling of the test/training datasets, but we should end up with accuracies of around 80% to 90%:

```
accuracy = sum([1./test_size for i in range(test_size) if test_output[i]==actual_vals[i]])
print('Accuracy on test set: ' + str(accuracy))
Accuracy on test set: 0.833333333333325
```

10. Here is the code to plot the last batch results:

```
actuals = np.argmax(y_batch, axis=1)
Nrows = 2
Ncols = 3
for i in range(len(actuals)):
 plt.subplot(Nrows, Ncols, i+1)
 plt.imshow(np.reshape(x_batch[i], [28,28]), cmap='Greys_r')
 plt.title('Actual: ' + str(actuals[i]) + ' Pred: ' +
 str(predictions[i]), fontsize=10)
 frame = plt.gca()
 frame.axes.get_xaxis().set_visible(False)
 frame.axes.get_yaxis().set_visible(False)
```

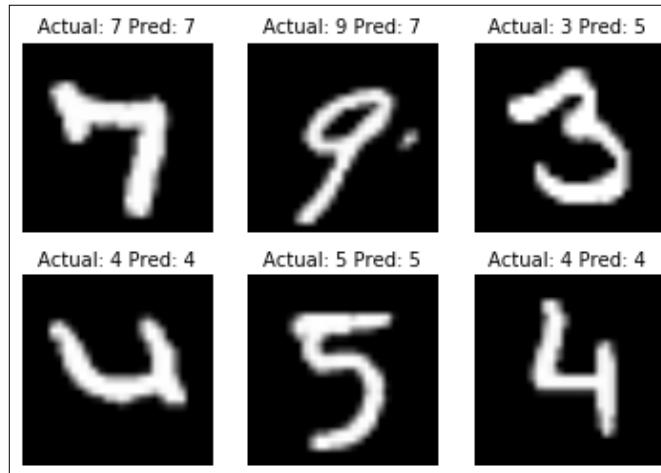


Figure 4: The last batch of six images we ran our nearest neighbor prediction on.  
We can see that we do not get all of the images exactly correct

## How it works...

Given enough computation time and computational resources, we could have made the test and training sets bigger. This probably would have increased our accuracy, and also is a common way to prevent overfitting. Also, this algorithm warrants further exploration on the ideal  $k$  value to choose. The  $k$  value would be chosen after a set of cross-validation experiments on the dataset.

## There's more...

We can also use the nearest neighbor algorithm here for evaluating unseen numbers from the user as well. Please see the online repository for a way to use this model to evaluate user input digits here: [https://github.com/nfmccclure/tensorflow\\_cookbook](https://github.com/nfmccclure/tensorflow_cookbook).

In this chapter, we've explored how to use kNN algorithms for regression and classification. We've talked about the different usage of distance functions and how to mix them together. We encourage the reader to explore different distance metrics, weights, and  $k$  values to optimize the accuracy of these methods.



# 6

## Neural Networks

In this chapter, we will introduce neural networks and how to implement them in TensorFlow. Most of the subsequent chapters will be based on neural networks, so learning how to use them in TensorFlow is very important. We will start by introducing basic concepts of neural networking and work up to multilayer networks. In the last section, we will create a neural network that learns to play Tic Tac Toe.

In this chapter, we'll cover the following recipes:

- ▶ Implementing Operational Gates
- ▶ Working with Gates and Activation Functions
- ▶ Implementing a One-Layer Neural Network
- ▶ Implementing Different Layers
- ▶ Using Multilayer Networks
- ▶ Improving Predictions of Linear Models
- ▶ Learning to Play Tic Tac Toe

The reader can find all the code from this chapter online, at [https://github.com/nfmccleure/tensorflow\\_cookbook](https://github.com/nfmccleure/tensorflow_cookbook).

### Introduction

Neural networks are currently breaking records in tasks such as image and speech recognition, reading handwriting, understanding text, image segmentation, dialog systems, autonomous car driving, and so much more. While some of these aforementioned tasks will be covered in later chapters, it is important to introduce neural networks as an easy-to-implement machine learning algorithm, so that we can expand on it later.

The concept of a neural network has been around for decades. However, it only recently gained traction computationally because we now have the computational power to train large networks because of advances in processing power, algorithm efficiency, and data sizes.

A neural network is basically a sequence of operations applied to a matrix of input data. These operations are usually collections of additions and multiplications followed by applications of non-linear functions. One example that we have already seen is logistic regression, the last section in *Chapter 3, Linear Regression*. Logistic regression is the sum of the partial slope-feature products followed by the application of the sigmoid function, which is non-linear. Neural networks generalize this a bit more by allowing any combination of operations and non-linear functions, which includes the applications of absolute value, maximum, minimum, and so on.

The important trick with neural networks is called 'backpropagation'. Back propagation is a procedure that allows us to update the model variables based on the learning rate and the output of the loss function. We used back propagation to update our model variables in the *Chapter 3, Linear Regression* and *Chapter 4*, and the *Support Vector Machine*.

Another important feature to take note of in neural networks is the non-linear activation function. Since most neural networks are just combinations of addition and multiplication operations, they will not be able to model non-linear datasets. To address this issue, we have used the non-linear activation functions in the neural networks. This will allow the neural network to adapt to most non-linear situations.

It is important to remember that, like most of the algorithms we have seen so far, neural networks are sensitive to the hyper-parameters that we choose. In this chapter, we will see the impact of different learning rates, loss functions, and optimization procedures.

There are more resources for learning about neural networks that are more in-depth and detailed.

The seminal paper describing back propagation is *Efficient BackProp* by Yann LeCun and others. The PDF is located here: <http://yann.lecun.com/exdb/publis/pdf/lecun-98b.pdf>.

CS231, *Convolutional Neural Networks for Visual Recognition*, by Stanford University, class resources available here: <http://cs231n.stanford.edu/>.

CS224d, *Deep Learning for Natural Language Processing*, by Stanford University, class resources available here: <http://cs224d.stanford.edu/>.

 *Deep Learning*, a book by the MIT Press. Goodfellow and others, 2016. Located here: <http://www.deeplearningbook.org>.

There is an online book called *Neural Networks and Deep Learning* by Michael Nielsen, located here: <http://neuralnetworksanddeeplearning.com/>.

For a more pragmatic approach and introduction to neural networks, Andrej Karpathy has written a great summary and JavaScript examples called *A Hacker's Guide to Neural Networks*. The write-up is located here: <http://karpathy.github.io/neuralsnets/>.

Another site that summarizes some good notes on deep learning is called *Deep Learning for Beginners* by Ian Goodfellow, Yoshua Bengio, and Aaron Courville. This web page can be found here: <http://randomekek.github.io/deep/deeplearning.html>.

## Implementing Operational Gates

One of the most fundamental concepts of neural networks is an operation known as an operational gate. In this section, we will start with a multiplication operation as a gate and then we will consider nested gate operations.

### Getting ready

The first operational gate we will implement looks like  $f(x)=a \cdot x$ . To optimize this gate, we declare the  $a$  input as a variable and the  $x$  input as a placeholder. This means that TensorFlow will try to change the  $a$  value and not the  $x$  value. We will create the loss function as the difference between the output and the target value, which is 50.

The second, nested operational gate will be  $f(x)=a \cdot x + b$ . Again, we will declare  $a$  and  $b$  as variables and  $x$  as a placeholder. We optimize the output toward the target value of 50 again. The interesting thing to note is that the solution for this second example is not unique. There are many combinations of model variables that will allow the output to be 50. With neural networks, we do not care as much for the values of the intermediate model variables, but place more emphasis on the desired output.

Think of the operations as operational gates on our computational graph. Here is a figure depicting the two examples:

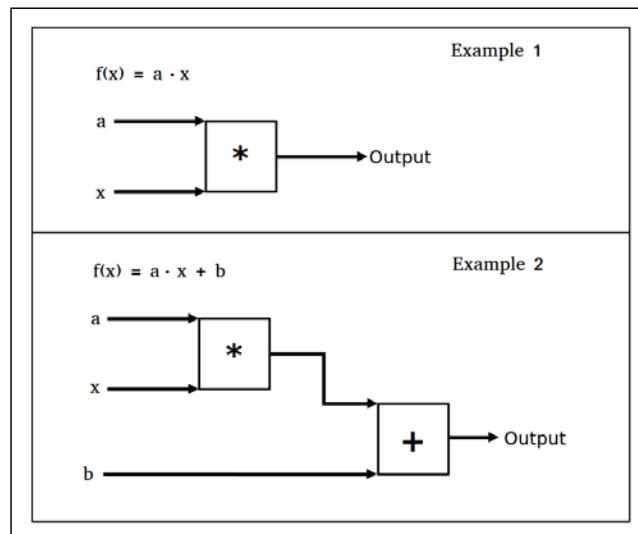


Figure 1: Two operational gate examples in this section.

## How to do it...

To implement the first operational  $f(x)=a \cdot x$  in TensorFlow and train the output toward the value of 50, follow these steps:

1. We start off by loading TensorFlow and creating a graph session:

```
import tensorflow as tf
sess = tf.Session()
```

2. Now, we declare our model variable, input data, and placeholder. We make our input data equal to the value 5, so that the multiplication factor to get 50 will be 10 (that is,  $5 \times 10 = 50$ ):

```
a = tf.Variable(tf.constant(4.))
x_val = 5.
x_data = tf.placeholder(dtype=tf.float32)
```

3. Next we add the operation to our computational graph:

```
multiplication = tf.mul(a, x_data)
```

4. We will declare the loss function as the L2 distance between the output and the desired target value of 50:

```
loss = tf.square(tf.sub(multiplication, 50.))
```

5. Now we initialize our model variable and declare our optimizing algorithm as the standard gradient descent:

```
init = tf.initialize_all_variables()
sess.run(init)
my_opt = tf.train.GradientDescentOptimizer(0.01)
train_step = my_opt.minimize(loss)
```

6. We can now optimize our model output towards the desired value of 50. We do this by continually feeding in the input value of 5 and back propagating the loss to update the model variable towards the value of 10:

```
print('Optimizing a Multiplication Gate Output to 50.')
for i in range(10):
 sess.run(train_step, feed_dict={x_data: x_val})
 a_val = sess.run(a)
 mult_output = sess.run(multiplication, feed_dict={x_data: x_val})
 print(str(a_val) + ' * ' + str(x_val) + ' = ' + str(mult_output))
```

7. This results in the following output:

```
Optimizing a Multiplication Gate Output to 50.
7.0 * 5.0 = 35.0
8.5 * 5.0 = 42.5
9.25 * 5.0 = 46.25
9.625 * 5.0 = 48.125
9.8125 * 5.0 = 49.0625
9.90625 * 5.0 = 49.5312
9.95312 * 5.0 = 49.7656
9.97656 * 5.0 = 49.8828
9.98828 * 5.0 = 49.9414
9.99414 * 5.0 = 49.9707
```

8. Next, we will do the same with a two-nested operations,  $f(x)=a.x+b$ .

9. We will start in exactly same way as the preceding example, except now we'll initialize two model variables, a and b:

```
from tensorflow.python.framework import ops
ops.reset_default_graph()
sess = tf.Session()

a = tf.Variable(tf.constant(1.))
b = tf.Variable(tf.constant(1.))
x_val = 5.
x_data = tf.placeholder(dtype=tf.float32)

two_gate = tf.add(tf.mul(a, x_data), b)

loss = tf.square(tf.sub(two_gate, 50.))

my_opt = tf.train.GradientDescentOptimizer(0.01)
train_step = my_opt.minimize(loss)

init = tf.initialize_all_variables()
sess.run(init)
```

10. We now optimize the model variables to train the output towards the target value of 50:

```
print('\nOptimizing Two Gate Output to 50.')
for i in range(10):
 # Run the train step
 sess.run(train_step, feed_dict={x_data: x_val})
 # Get the a and b values
 a_val, b_val = (sess.run(a), sess.run(b))
 # Run the two-gate graph output
 two_gate_output = sess.run(two_gate, feed_dict={x_data: x_val})
 print(str(a_val) + ' * ' + str(x_val) + ' + ' + str(b_val) + ' =
= ' + str(two_gate_output))
```

11. This results in the following output:

```
Optimizing Two Gate Output to 50.
5.4 * 5.0 + 1.88 = 28.88
7.512 * 5.0 + 2.3024 = 39.8624
8.52576 * 5.0 + 2.50515 = 45.134
9.01236 * 5.0 + 2.60247 = 47.6643
9.24593 * 5.0 + 2.64919 = 48.8789
9.35805 * 5.0 + 2.67161 = 49.4619
9.41186 * 5.0 + 2.68237 = 49.7417
```

```

9.43769 * 5.0 + 2.68754 = 49.876
9.45009 * 5.0 + 2.69002 = 49.9405
9.45605 * 5.0 + 2.69121 = 49.9714

```

[ It is important to note here that the solution to the second example is not unique. This does not matter as much in neural networks, as all parameters are adjusted towards reducing the loss. The final solution here will depend on the initial values of  $a$  and  $b$ . If these were randomly initialized, instead of to the value of 1, we would see different ending values for the model variables for each iteration. ]



## How it works...

We achieved the optimization of a computational gate via TensorFlow's implicit back propagation. TensorFlow keeps track of our model's operations and variable values and makes adjustments in respect of our optimization algorithm specification and the output of the loss function.

We can keep expanding the operational gates, while keeping track of which inputs are variables and which inputs are data. This is important to keep track of, because TensorFlow will change all variables to minimize the loss, but not the data, which is declared as placeholders.

The implicit ability to keep track of the computational graph and update the model variables automatically with every training step is one of the great features of TensorFlow and what makes it so powerful.

## Working with Gates and Activation Functions

Now that we can link together operational gates, we will want to run the computational graph output through an activation function. Here we introduce common activation functions.

### Getting ready

In this section, we will compare and contrast two different activation functions, the **sigmoid** and the **rectified linear unit (ReLU)**. Recall that the two functions are given by the following equations:

$$\text{sigmoid}(x) = \frac{1}{1 + e^{-x}}$$

$$\text{ReLU}(x) = \max(0, x)$$

In this example, we will create two one-layer neural networks with the same structure except one will feed through the sigmoid activation and one will feed through the ReLU activation. The loss function will be governed by the L2 distance from the value 0.75. We will randomly pull batch data from a normal distribution (*Normal(mean=2, sd=0.1)*), and optimize the output towards 0.75.

## How to do it...

1. We'll start by loading the necessary libraries and initializing a graph. This is also a good point to bring up how to set a random seed with TensorFlow. Since we will be using a random number generator from NumPy and TensorFlow, we need to set a random seed for both. With the same random seeds set, we should be able to replicate:

```
import tensorflow as tf
import numpy as np
import matplotlib.pyplot as plt
sess = tf.Session()
tf.set_random_seed(5)
np.random.seed(42)
```

2. Now we'll declare our batch size, model variables, data, and a placeholder for feeding the data in. Our computational graph will consist of feeding in our normally distributed data into two similar neural networks that differ only by the activation function at the end:

```
batch_size = 50
a1 = tf.Variable(tf.random_normal(shape=[1,1]))
b1 = tf.Variable(tf.random_uniform(shape=[1,1]))
a2 = tf.Variable(tf.random_normal(shape=[1,1]))
b2 = tf.Variable(tf.random_uniform(shape=[1,1]))
x = np.random.normal(2, 0.1, 500)
x_data = tf.placeholder(shape=[None, 1], dtype=tf.float32)
```

3. Next, we'll declare our two models, the sigmoid activation model and the ReLU activation model:

```
sigmoid_activation = tf.sigmoid(tf.add(tf.matmul(x_data, a1), b1))
relu_activation = tf.nn.relu(tf.add(tf.matmul(x_data, a2), b2))
```

4. The loss functions will be the average L2 norm between the model output and the value of 0.75:

```
loss1 = tf.reduce_mean(tf.square(tf.sub(sigmoid_activation,
0.75)))
loss2 = tf.reduce_mean(tf.square(tf.sub(relu_activation, 0.75)))
```

5. Now we declare our optimization algorithm and initialize our variables:

```
my_opt = tf.train.GradientDescentOptimizer(0.01)
train_step_sigmoid = my_opt.minimize(loss1)
train_step_relu = my_opt.minimize(loss2)
init = tf.initialize_all_variables()
sess.run(init)
```

6. Now we'll loop through our training for 750 iterations for both models. We will also save the loss output and the activation output values for plotting after:

```
loss_vec_sigmoid = []
loss_vec_relu = []
activation_sigmoid = []
activation_relu = []
for i in range(750):
 rand_indices = np.random.choice(len(x), size=batch_size)
 x_vals = np.transpose([x[rand_indices]])
 sess.run(train_step_sigmoid, feed_dict={x_data: x_vals})
 sess.run(train_step_relu, feed_dict={x_data: x_vals})

 loss_vec_sigmoid.append(sess.run(loss1, feed_dict={x_data: x_vals}))
 loss_vec_relu.append(sess.run(loss2, feed_dict={x_data: x_vals}))

 activation_sigmoid.append(np.mean(sess.run(sigmoid_activation,
 feed_dict={x_data: x_vals})))
 activation_relu.append(np.mean(sess.run(rectilinear_activation,
 feed_dict={x_data: x_vals})))
```

7. The following is the code to plot the loss and the activation outputs:

```
plt.plot(activation_sigmoid, 'k-', label='Sigmoid Activation')
plt.plot(activation_relu, 'r--', label='Rectilinear Activation')
plt.ylim([0, 1.0])
plt.title('Activation Outputs')
plt.xlabel('Generation')
plt.ylabel('Outputs')
plt.legend(loc='upper right')
plt.show()

plt.plot(loss_vec_sigmoid, 'k-', label='Sigmoid Loss')
plt.plot(loss_vec_relu, 'r--', label='Rectilinear Loss')
plt.ylim([0, 1.0])
plt.title('Loss per Generation')
```

```

plt.xlabel('Generation')
plt.ylabel('Loss')
plt.legend(loc='upper right')
plt.show()

```

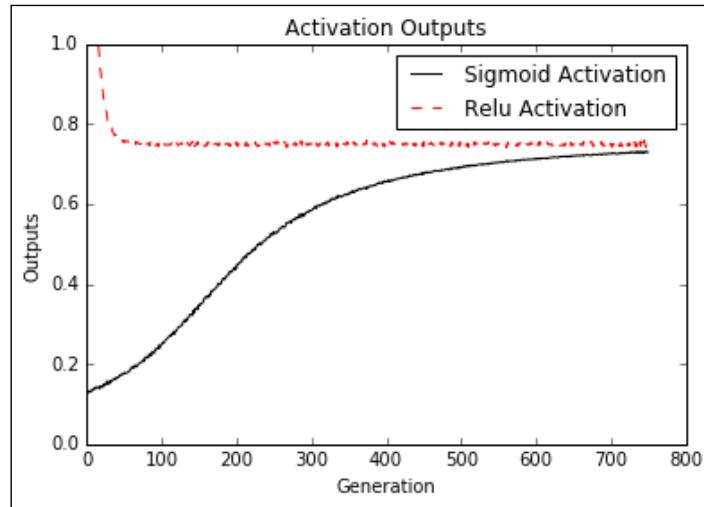


Figure 2: Computational graph outputs from the network with the sigmoid activation and a network with the ReLU activation.

The two neural networks work with similar architecture and target (0.75) with two different activation functions, sigmoid and ReLU. It is important to notice how much quicker the ReLU activation network converges to the desired target of 0.75 than sigmoid:

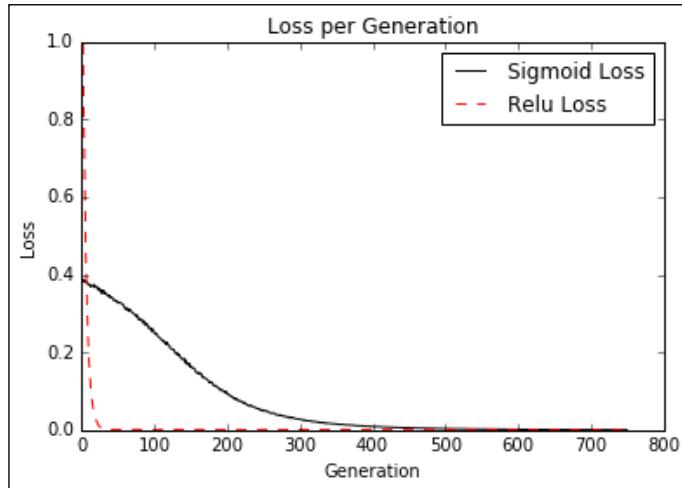


Figure 3: This figure depicts the loss value of the sigmoid and the ReLU activation networks. Notice how extreme the ReLU loss is at the beginning of the iterations.

## How it works...

Because of the form of the ReLU activation function, it returns the value of zero much more often than the sigmoid function. We consider this behavior as a type of sparsity. This sparsity results in a speed up of convergence, but a loss of controlled gradients. On the other hand, the sigmoid function has very well-controlled gradients and does not risk the extreme values that the ReLU activation does:

| Activation function | Advantages           | Disadvantages                  |
|---------------------|----------------------|--------------------------------|
| Sigmoid             | Less extreme outputs | Slower convergence             |
| ReLU                | Converges quicker    | Extreme output values possible |

## There's more...

In this section, we compared the ReLU activation function and the sigmoid activation for neural networks. There are many other activation functions that are commonly used for neural networks, but most fall into one of two categories: the first category contains functions that are shaped like the sigmoid function (arctan, hypertangent, heavyside step, and so on) and the second category contains functions that are shaped like the ReLU function (softplus, leaky ReLU, and so on). Most of what was discussed in this section about comparing the two functions will hold true for activations in either category. However, it is important to note that the choice of the activation function has a big impact on the convergence and output of the neural networks.

## Implementing a One-Layer Neural Network

We have all the tools to implement a neural network that operates on real data. We will create a neural network with one layer that operates on the Iris dataset.

### Getting ready

In this section, we will implement a neural network with one hidden layer. It will be important to understand that a fully connected neural network is based mostly on matrix multiplication. As such, the dimensions of the data and matrix are very important to get lined up correctly.

Since this is a regression problem, we will use the mean squared error as the loss function.

## How to do it...

1. To create the computational graph, we'll start by loading the necessary libraries:

```
import matplotlib.pyplot as plt
import numpy as np
import tensorflow as tf
from sklearn import datasets
```

2. Now we'll load the Iris data and store the pedal length as the target value. Then we'll start a graph session:

```
iris = datasets.load_iris()
x_vals = np.array([x[0:3] for x in iris.data])
y_vals = np.array([x[3] for x in iris.data])
sess = tf.Session()
```

3. Since the dataset is of a smaller size, we want to set a seed to make the results reproducible:

```
seed = 2
tf.set_random_seed(seed)
np.random.seed(seed)
```

4. To prepare the data, we'll create a 80-20 train-test split and normalize the x features to be between 0 and 1 via min-max scaling:

```
train_indices = np.random.choice(len(x_vals), round(len(x_vals)*0.8), replace=False)
test_indices = np.array(list(set(range(len(x_vals))) - set(train_indices)))
x_vals_train = x_vals[train_indices]
x_vals_test = x_vals[test_indices]
y_vals_train = y_vals[train_indices]
y_vals_test = y_vals[test_indices]
def normalize_cols(m):
 col_max = m.max(axis=0)
 col_min = m.min(axis=0)
 return (m-col_min) / (col_max - col_min)

x_vals_train = np.nan_to_num(normalize_cols(x_vals_train))
x_vals_test = np.nan_to_num(normalize_cols(x_vals_test))
```

5. Now we will declare the batch size and placeholders for the data and target:

```
batch_size = 50
x_data = tf.placeholder(shape=[None, 3], dtype=tf.float32)
y_target = tf.placeholder(shape=[None, 1], dtype=tf.float32)
```

6. The important part is to declare our model variables with the appropriate shape. We can declare the size of our hidden layer to be any size we wish; here we set it to have five hidden nodes:

```
hidden_layer_nodes = 5
A1 = tf.Variable(tf.random_normal(shape=[3,hidden_layer_nodes]))
b1 = tf.Variable(tf.random_normal(shape=[hidden_layer_nodes]))
A2 = tf.Variable(tf.random_normal(shape=[hidden_layer_nodes,1]))
b2 = tf.Variable(tf.random_normal(shape=[1]))
```

7. We'll now declare our model in two steps. The first step will be creating the hidden layer output and the second will be creating the final output of the model:

 As a note, our model goes from (three features) (five hidden nodes) (one output value).

```
hidden_output = tf.nn.relu(tf.add(tf.matmul(x_data, A1), b1))
final_output = tf.nn.relu(tf.add(tf.matmul(hidden_output, A2),
b2))
```

8. Here is our mean squared error as a loss function:

```
loss = tf.reduce_mean(tf.square(y_target - final_output))
```

9. Now we'll declare our optimizing algorithm and initialize our variables:

```
my_opt = tf.train.GradientDescentOptimizer(0.005)
train_step = my_opt.minimize(loss)
init = tf.initialize_all_variables()
sess.run(init)
```

10. Next we loop through our training iterations. We'll also initialize two lists that we can store our train and test loss. In every loop we also want to randomly select a batch from the training data for fitting to the model:

```
First we initialize the loss vectors for storage.
loss_vec = []
test_loss = []
for i in range(500):
 # First we select a random set of indices for the batch.
 rand_index = np.random.choice(len(x_vals_train), size=batch_size)
 # We then select the training values
 rand_x = x_vals_train[rand_index]
 rand_y = np.transpose([y_vals_train[rand_index]])
 # Now we run the training step
 sess.run(train_step, feed_dict={x_data: rand_x, y_target:
```

```
rand_y})
 # We save the training loss
 temp_loss = sess.run(loss, feed_dict={x_data: rand_x, y_
target: rand_y})
 loss_vec.append(np.sqrt(temp_loss))

 # Finally, we run the test-set loss and save it.
 test_temp_loss = sess.run(loss, feed_dict={x_data: x_vals_
test, y_target: np.transpose([y_vals_test])})
 test_loss.append(np.sqrt(test_temp_loss))
 if (i+1)%50==0:
 print('Generation: ' + str(i+1) + '. Loss = ' + str(temp_
loss))
```

11. And here is how we can plot the losses with matplotlib:

```
plt.plot(loss_vec, 'k-', label='Train Loss')
plt.plot(test_loss, 'r--', label='Test Loss')
plt.title('Loss (MSE) per Generation')
plt.xlabel('Generation')
plt.ylabel('Loss')
plt.legend(loc='upper right')
plt.show()
```

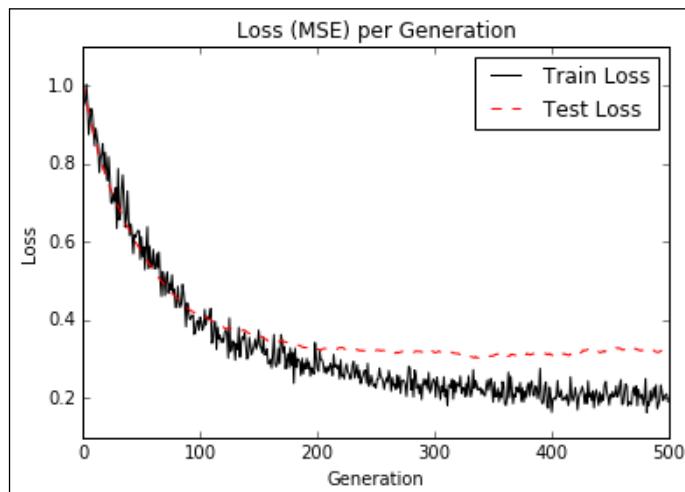


Figure 4: We plot the loss (MSE) of the train and test sets. Notice that we are slightly overfitting the model after 200 generations, as the test MSE does not drop any further, but the training MSE does continue to drop.

## How it works...

To visualize our model as a neural network diagram, refer to the following figure:

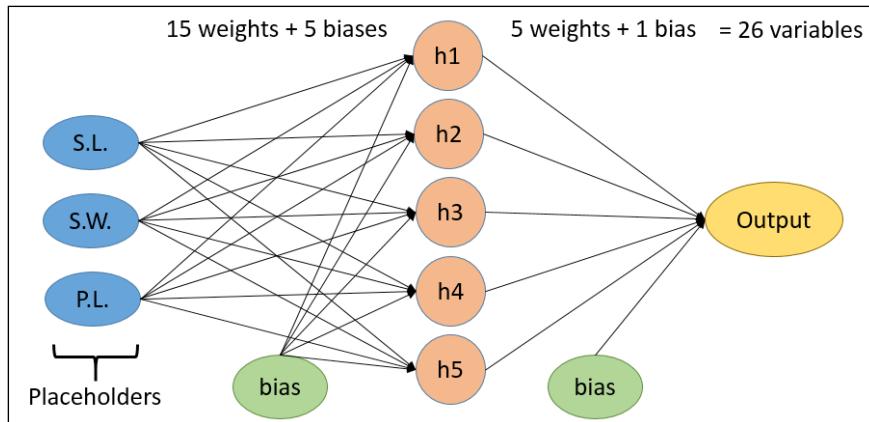


Figure 5: Here is a visualization of our neural network that has five nodes in the hidden layer. We are feeding in three values, the sepal length (S.L.), the sepal width (S.W.), and the pedal length (P.L.). The target will be the petal width. In total, there will be 26 total variables in the model.

## There's more...

Note that we can identify when the model starts overfitting on the training data from viewing the `loss` function on the `test` and `train` sets. We can also see that the `train` set loss is much less smooth than the `test` set. This is because of two reasons: the first is that we are using a smaller batch size than the test set, although not by much, and the second is that we are training on the `train` set and the `test` set does not impact the variables of the model.

## Implementing Different Layers

It is important to know how to implement different layers. In the prior recipe, we implemented fully connected layers. We will expand our knowledge of various layers in this recipe.

## Getting ready

We have explored how to connect between data inputs and a fully connected hidden layer. There are more types of layers that are built-in functions inside TensorFlow. The most popular layers that are used are convolutional layers and maxpool layers. We will show you how to create and use such layers with input data and with fully connected data. First we will look at how to use these layers on one-dimensional data, and then on two-dimensional data.

While neural networks can be layered in any fashion, one of the most common uses is to use convolutional layers and fully connected layers to first create features. If we have too many features, it is common to have a maxpool layer. After these layers, non-linear layers are commonly introduced as activation functions. Convolutional neural networks (CNNs), which we will consider in *Chapter 8, Convolutional Neural Networks*, usually have the form Convolutional, maxpool, activation, convolutional, maxpool, activation, and so on.

## How to do it...

We will first look at one-dimensional data. We generate a random array of data for this task:

1. We'll start by loading the libraries we need and starting a graph session:

```
import tensorflow as tf
import numpy as np
sess = tf.Session()
```

2. Now we can initialize our data (NumPy array of length 25) and create the placeholder that we will feed it through:

```
data_size = 25
data_1d = np.random.normal(size=data_size)
x_input_1d = tf.placeholder(dtype=tf.float32, shape=[data_size])
```

3. We will now define a function that will make a convolutional layer. Then we will declare a random filter and create the convolutional layer:

Note that many of TensorFlow's layer functions are designed to deal with 4D data (4D = [batch size, width, height, channels]). We will need to modify our input data and the output data to extend or collapse the extra dimensions needed. For our example data, we have a batch size of 1, a width of 1, a height of 25, and a channel size of 1. To expand dimensions, we use the `expand_dims()` function, and to collapse dimensions, we use the `squeeze()` function. Also note that we can calculate the output dimensions of convolutional layers from the formula `output_size = (W - F + 2P) / S + 1`, where `W` is the input size, `F` is the filter size, `P` is the padding size, and `S` is the stride size.



```

def conv_layer_1d(input_1d, my_filter):
 # Make 1d input into 4d
 input_2d = tf.expand_dims(input_1d, 0)
 input_3d = tf.expand_dims(input_2d, 0)
 input_4d = tf.expand_dims(input_3d, 3)
 # Perform convolution
 convolution_output = tf.nn.conv2d(input_4d, filter=my_filter,
 strides=[1,1,1,1], padding="VALID")
 # Now drop extra dimensions
 conv_output_1d = tf.squeeze(convolution_output)
 return(conv_output_1d)

my_filter = tf.Variable(tf.random_normal(shape=[1,5,1,1]))
my_convolution_output = conv_layer_1d(x_input_1d, my_filter)

```

4. TensorFlow's activation functions will act element-wise by default. This means we just have to call our activation function on the layer of interest. We do this by creating an activation function and then initializing it on the graph:

```

def activation(input_1d):
 return(tf.nn.relu(input_1d))
my_activation_output = activation(my_convolution_output)

```

5. Now we'll declare a maxpool layer function. This function will create a maxpool on a moving window across our one-dimensional vector. For this example, we will initialize it to have a width of 5:

 TensorFlow's maxpool arguments are very similar to the convolutional layer. While it does not have a filter, it does have a size, stride, and padding option. Since we have a window of 5 with valid padding (no zero padding), then our output array will have 4 or  $2 \cdot \text{floor}(5/2)$  less entries.

```

def max_pool(input_1d, width):
 # First we make the 1d input into 4d.
 input_2d = tf.expand_dims(input_1d, 0)
 input_3d = tf.expand_dims(input_2d, 0)
 input_4d = tf.expand_dims(input_3d, 3)
 # Perform the max pool operation
 pool_output = tf.nn.max_pool(input_4d, ksize=[1, 1, width, 1],
 strides=[1, 1, 1, 1], padding='VALID')
 pool_output_1d = tf.squeeze(pool_output)
 return(pool_output_1d)
my_maxpool_output = max_pool(my_activation_output, width=5)

```

- 
6. The final layer that we will connect is the fully connected layer. We want to create a versatile function that inputs a 1D array and outputs the number of values indicated. Also remember that to do matrix multiplication with a 1D array, we must expand the dimensions into 2D:

```
def fully_connected(input_layer, num_outputs):
 # Create weights
 weight_shape = tf.squeeze(tf.pack([tf.shape(input_layer),
 [num_outputs]]))
 weight = tf.random_normal(weight_shape, stddev=0.1)
 bias = tf.random_normal(shape=[num_outputs])
 # Make input into 2d
 input_layer_2d = tf.expand_dims(input_layer, 0)
 # Perform fully connected operations
 full_output = tf.add(tf.matmul(input_layer_2d, weight), bias)
 # Drop extra dimensions
 full_output_1d = tf.squeeze(full_output)
 return(full_output_1d)

my_full_output = fully_connected(my_maxpool_output, 5)
```

7. Now we'll initialize all the variables and run the graph and print the output of each of the layers:

```
init = tf.initialize_all_variables()
sess.run(init)
feed_dict = {x_input_1d: data_1d}
Convolution Output
print('Input = array of length 25')
print('Convolution w/filter, length = 5, stride size = 1, results
in an array of length 21')
print(sess.run(my_convolution_output, feed_dict=feed_dict))
Activation Output
print('\nInput = the above array of length 21')
print('ReLU element wise returns the array of length 21')
print(sess.run(my_activation_output, feed_dict=feed_dict))
Maxpool Output
print('\nInput = the above array of length 21')
print('MaxPool, window length = 5, stride size = 1, results in the
array of length 17')
print(sess.run(my_maxpool_output, feed_dict=feed_dict))
Fully Connected Output
print('\nInput = the above array of length 17')
print('Fully connected layer on all four rows with five
outputs')
print(sess.run(my_full_output, feed_dict=feed_dict))
```

8. This results in the following output:

```
Input = array of length 25
Convolution w/filter, length = 5, stride size = 1, results in an
array of length 21:
[-0.91608119 1.53731811 -0.7954089 0.5041104 1.88933098
 -1.81099761 0.56695032 1.17945457 -0.66252393 -1.90287709
 0.87184119 0.84611893 -5.25024986 -0.05473572 2.19293165
 -4.47577858 -1.71364677 3.96857905 -2.0452652 -1.86647367
 -0.12697852]
Input = the above array of length 21
ReLU element wise returns the array of length 21:
[0. 1.53731811 0. 0.5041104 1.88933098
 0. 0. 1.17945457 0. 0.
 0.87184119 0.84611893 0. 0. 2.19293165
 0. 0. 3.96857905 0. 0.
 0.]
Input = the above array of length 21
MaxPool, window length = 5, stride size = 1, results in the array
of length 17:
[1.88933098 1.88933098 1.88933098 1.88933098 1.88933098
 1.17945457 1.17945457 1.17945457 0.87184119 0.87184119
 2.19293165 2.19293165 2.19293165 3.96857905 3.96857905
 3.96857905 3.96857905]
Input = the above array of length 17
Fully connected layer on all four rows with five outputs:
[1.23588216 -0.42116445 1.44521213 1.40348077 -0.79607368]
```



One-dimensional data is very important to consider for neural networks. Time series, signal processing, and some text embeddings are considered to be one-dimensional and are frequently used in neural networks.

We will now consider the same types of layers in an equivalent order but for two-dimensional data:

1. We will start by clearing and resetting the computational graph:

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

2. First of all, we will initialize our input array to be a 10x10 matrix, and then we will initialize a placeholder for the graph with the same shape:

```
data_size = [10,10]
```

- ```
data_2d = np.random.normal(size=data_size)
x_input_2d = tf.placeholder(dtype=tf.float32, shape=data_size)
```
3. Just as in the one-dimensional example, we declare a convolutional layer function. Since our data has a height and width already, we just need to expand it in two dimensions (a batch size of 1, and a channel size of 1) so that we can operate on it with the `conv2d()` function. For the filter, we will use a random 2x2 filter, stride two in both directions, and use valid padding (no zero padding). Because our input matrix is 10x10, our convolutional output will be 5x5:
- ```
def conv_layer_2d(input_2d, my_filter):
 # First, change 2d input to 4d
 input_3d = tf.expand_dims(input_2d, 0)
 input_4d = tf.expand_dims(input_3d, 3)
 # Perform convolution
 convolution_output = tf.nn.conv2d(input_4d, filter=my_filter,
 strides=[1,2,2,1], padding="VALID")
 # Drop extra dimensions
 conv_output_2d = tf.squeeze(convolution_output)
 return(conv_output_2d)

my_filter = tf.Variable(tf.random_normal(shape=[2,2,1,1]))
my_convolution_output = conv_layer_2d(x_input_2d, my_filter)
```
4. The activation function works on an element-wise basis, so now we can create an activation operation and initialize it on the graph:
- ```
def activation(input_2d):
    return(tf.nn.relu(input_2d))
my_activation_output = activation(my_convolution_output)
```
5. Our maxpool layer is very similar to the one-dimensional case except we have to declare a width and height for the maxpool window. Just like our convolutional 2D layer, we only have to expand our into in two dimensions this time:
- ```
def max_pool(input_2d, width, height):
 # Make 2d input into 4d
 input_3d = tf.expand_dims(input_2d, 0)
 input_4d = tf.expand_dims(input_3d, 3)
 # Perform max pool
 pool_output = tf.nn.max_pool(input_4d, ksize=[1, height,
 width, 1], strides=[1, 1, 1, 1], padding='VALID')
 # Drop extra dimensions
 pool_output_2d = tf.squeeze(pool_output)
 return(pool_output_2d)

my_maxpool_output = max_pool(my_activation_output, width=2,
 height=2)
```

6. Our fully connected layer is very similar to the one-dimensional output. We should also note here that the 2D input to this layer is considered as one object, so we want each of the entries connected to each of the outputs. In order to accomplish this, we fully flatten out the two-dimensional matrix and then expand it for matrix multiplication:

```
def fully_connected(input_layer, num_outputs):
 # Flatten into 1d
 flat_input = tf.reshape(input_layer, [-1])
 # Create weights
 weight_shape = tf.squeeze(tf.pack([tf.shape(flat_input), [num_outputs]]))
 weight = tf.random_normal(weight_shape, stddev=0.1)
 bias = tf.random_normal(shape=[num_outputs])
 # Change into 2d
 input_2d = tf.expand_dims(flat_input, 0)
 # Perform fully connected operations
 full_output = tf.add(tf.matmul(input_2d, weight), bias)
 # Drop extra dimensions
 full_output_2d = tf.squeeze(full_output)
 return(full_output_2d)

my_full_output = fully_connected(my_maxpool_output, 5)
```

7. We'll now initialize our variables and create a feed dictionary for our operations:

```
init = tf.initialize_all_variables()
sess.run(init)
```

```
feed_dict = {x_input_2d: data_2d}
```

8. And here is how we can see the outputs for each of the layers:

```
Convolution Output
print('Input = [10 X 10] array')
print('2x2 Convolution, stride size = [2x2], results in the [5x5]
array:')
print(sess.run(my_convolution_output, feed_dict=feed_dict))
Activation Output
print('\nInput = the above [5x5] array')
print('ReLU element wise returns the [5x5] array:')
print(sess.run(my_activation_output, feed_dict=feed_dict))
Max Pool Output
print('\nInput = the above [5x5] array')
print('MaxPool, stride size = [1x1], results in the [4x4]
array:')
print(sess.run(my_maxpool_output, feed_dict=feed_dict))
```

```
Fully Connected Output
print('\nInput = the above [4x4] array')
print('Fully connected layer on all four rows with five
outputs:')
print(sess.run(my_full_output, feed_dict=feed_dict))
```

9. This results in the following output:

```
Input = [10 X 10] array
2x2 Convolution, stride size = [2x2], results in the [5x5] array:
[[0.37630892 -1.41018617 -2.58821273 -0.32302785 1.18970704]
 [-4.33685207 1.97415686 1.0844903 -1.18965471 0.84643292]
 [5.23706436 2.46556497 -0.95119286 1.17715418 4.1117816]
 [5.86972761 1.2213701 1.59536231 2.66231227 2.28650784]
 [-0.88964868 -2.75502229 4.3449688 2.67776585 -2.23714781]]

Input = the above [5x5] array
ReLU element wise returns the [5x5] array:
[[0.37630892 0. 0. 0. 1.18970704]
 [0. 1.97415686 1.0844903 0. 0.84643292]
 [5.23706436 2.46556497 0. 1.17715418 4.1117816]
 [5.86972761 1.2213701 1.59536231 2.66231227 2.28650784]
 [0. 0. 4.3449688 2.67776585 0.]]

Input = the above [5x5] array
MaxPool, stride size = [1x1], results in the [4x4] array:
[[1.97415686 1.97415686 1.0844903 1.18970704]
 [5.23706436 2.46556497 1.17715418 4.1117816]
 [5.86972761 2.46556497 2.66231227 4.1117816]
 [5.86972761 4.3449688 4.3449688 2.67776585]]

Input = the above [4x4] array
Fully connected layer on all four rows with five outputs:
[-0.6154139 -1.96987963 -1.88811922 0.20010889 0.32519674]
```

## How it works...

We can now see how to use the convolutional and maxpool layers in TensorFlow with one-dimensional and two-dimensional data. Regardless of the shape of the input, we ended up with the same size output. This is important to illustrate the flexibility of neural network layers. This section should also impress upon us again the importance of shapes and sizes in neural network operations.

## Using a Multilayer Neural Network

We will now apply our knowledge of different layers to real data with using a multilayer neural network on the Low Birthweight dataset.

## Getting ready

Now that we know how to create neural networks and work with layers, we will apply this methodology towards predicting the birthweight in the low birthweight dataset. We'll create a neural network with three hidden layers. The low- birthweight dataset includes the actual birthweight and an indicator variable if the birthweight is above or below 2,500 grams. In this example, we'll make the target the actual birthweight (regression) and then see what the accuracy is on the classification at the end, and let's see if our model can identify if the birthweight will be <2,500 grams.

## How to do it...

1. First we'll start by loading the libraries and initializing our computational graph:

```
import tensorflow as tf
import matplotlib.pyplot as plt
import requests
import numpy as np
sess = tf.Session()
```

2. Now we'll load the data from the website using the `requests` module. After this, we will split the data into the features of interest and the target value:

```
birthdata_url = 'https://www.umass.edu/statdata/statdata/data/
lowbwt.dat'
birth_file = requests.get(birthdata_url)
birth_data = birth_file.text.split('\r\n')[5:]
birth_header = [x for x in birth_data[0].split(' ') if len(x)>=1]
birth_data = [[float(x) for x in y.split(' ') if len(x)>=1] for y
in birth_data[1:] if len(y)>=1]
y_vals = np.array([x[10] for x in birth_data])
cols_of_interest = ['AGE', 'LWT', 'RACE', 'SMOKE', 'PTL', 'HT',
'UI', 'FTV']
x_vals = np.array([[x[ix] for ix, feature in enumerate(birth_
header) if feature in cols_of_interest] for x in birth_data])
```

3. To help with repeatability, we set the random seed for both NumPy and TensorFlow. Then we declare our batch size:

```
seed = 3
tf.set_random_seed(seed)
np.random.seed(seed)
batch_size = 100
```

4. Next we'll split the data into an 80-20 train-test split. After this, we will normalize our input features to be between zero and one with a min-max scaling:

```
train_indices = np.random.choice(len(x_vals), round(len(x_
```

```

 vals)*0.8), replace=False)
test_indices = np.array(list(set(range(len(x_vals))) - set(train_
indices)))
x_vals_train = x_vals[train_indices]
x_vals_test = x_vals[test_indices]
y_vals_train = y_vals[train_indices]
y_vals_test = y_vals[test_indices]

def normalize_cols(m):
 col_max = m.max(axis=0)
 col_min = m.min(axis=0)
 return (m-col_min) / (col_max - col_min)

x_vals_train = np.nan_to_num(normalize_cols(x_vals_train))
x_vals_test = np.nan_to_num(normalize_cols(x_vals_test))

```

 Normalizing input features is a common feature transformation, and especially useful for neural networks. It will help convergence if our data is centered near zero to one for the activation functions to operate on.

5. Since we will have multiple layers that have similar initialized variables, we will create a function to initialize both the weights and the bias:

```
def init_weight(shape, st_dev):
 weight = tf.Variable(tf.random_normal(shape, stddev=st_dev))
 return(weight)
```

```
def init_bias(shape, st_dev):
 bias = tf.Variable(tf.random_normal(shape, stddev=st_dev))
 return(bias)
```

6. We'll initialize our placeholders next. There will be eight input features and one output, the birthweight in grams:

```
x_data = tf.placeholder(shape=[None, 8], dtype=tf.float32)
y_target = tf.placeholder(shape=[None, 1], dtype=tf.float32)
```

7. The fully connected layer will be used three times for all three hidden layers. To prevent repeated code, we will create a layer function to use when we initialize our model:

```
def fully_connected(input_layer, weights, biases):
 layer = tf.add(tf.matmul(input_layer, weights), biases)
 return(tf.nn.relu(layer))
```

8. We'll now create our model. For each layer (and output layer), we will initialize a weight matrix, bias matrix, and the fully connected layer. For this example, we will use hidden layers of sizes 25, 10, and 3:

 The model that we are using will have 522 variables to fit. To arrive at this number, we can see that between the data and the first hidden layer we have  $8 \times 25 + 25 = 225$  variables. If we continue in this way and add them up, we'll have  $225 + 260 + 33 + 4 = 522$  variables. This is significantly larger than the nine variables that we used in the logistic regression model on this data.

```
Create second layer (25 hidden nodes)
weight_1 = init_weight(shape=[8, 25], st_dev=10.0)
bias_1 = init_bias(shape=[25], st_dev=10.0)
layer_1 = fully_connected(x_data, weight_1, bias_1)

Create second layer (10 hidden nodes)
weight_2 = init_weight(shape=[25, 10], st_dev=10.0)
bias_2 = init_bias(shape=[10], st_dev=10.0)
layer_2 = fully_connected(layer_1, weight_2, bias_2)

Create third layer (3 hidden nodes)
weight_3 = init_weight(shape=[10, 3], st_dev=10.0)
bias_3 = init_bias(shape=[3], st_dev=10.0)
layer_3 = fully_connected(layer_2, weight_3, bias_3)
Create output layer (1 output value)

weight_4 = init_weight(shape=[3, 1], st_dev=10.0)
bias_4 = init_bias(shape=[1], st_dev=10.0)
final_output = fully_connected(layer_3, weight_4, bias_4)
```

9. We'll now use the L1 loss function (absolute value), declare our optimizer (Adam optimization), and initialize our variables:

```
loss = tf.reduce_mean(tf.abs(y_target - final_output))
my_opt = tf.train.AdamOptimizer(0.05)
train_step = my_opt.minimize(loss)
init = tf.initialize_all_variables()
sess.run(init)
```

 While the learning rate we use here for the Adam optimization function is 0.05, there is research that suggests a lower learning rate consistently produces better results. For this recipe, we use a larger learning rate because of the consistency of the data and the need for quick convergence.

10. Next we will train our model for 200 iterations. We'll also include code that will store the train and test loss, select a random batch size, and print the status every 25 generations:

```
Initialize the loss vectors
loss_vec = []
test_loss = []
for i in range(200):
 # Choose random indices for batch selection
 rand_index = np.random.choice(len(x_vals_train), size=batch_size)
 # Get random batch
 rand_x = x_vals_train[rand_index]
 rand_y = np.transpose([y_vals_train[rand_index]])
 # Run the training step
 sess.run(train_step, feed_dict={x_data: rand_x, y_target:
rand_y})
 # Get and store the train loss
 temp_loss = sess.run(loss, feed_dict={x_data: rand_x, y_
target: rand_y})
 loss_vec.append(temp_loss)
 # Get and store the test loss
 test_temp_loss = sess.run(loss, feed_dict={x_data: x_vals_
test, y_target: np.transpose([y_vals_test])})
 test_loss.append(test_temp_loss)
 if (i+1)%25==0:
 print('Generation: ' + str(i+1) + '. Loss = ' + str(temp_
loss))
```

11. This results in the following output:

```
Generation: 25. Loss = 5922.52
Generation: 50. Loss = 2861.66
Generation: 75. Loss = 2342.01
Generation: 100. Loss = 1880.59
Generation: 125. Loss = 1394.39
Generation: 150. Loss = 1062.43
Generation: 175. Loss = 834.641
Generation: 200. Loss = 848.54
```

12. Here is a snippet of code that plots the train and test loss with matplotlib:

```
plt.plot(loss_vec, 'k-', label='Train Loss')
plt.plot(test_loss, 'r--', label='Test Loss')
plt.title('Loss per Generation')
```

```

plt.xlabel('Generation')
plt.ylabel('Loss')
plt.legend(loc='upper right')
plt.show()

```

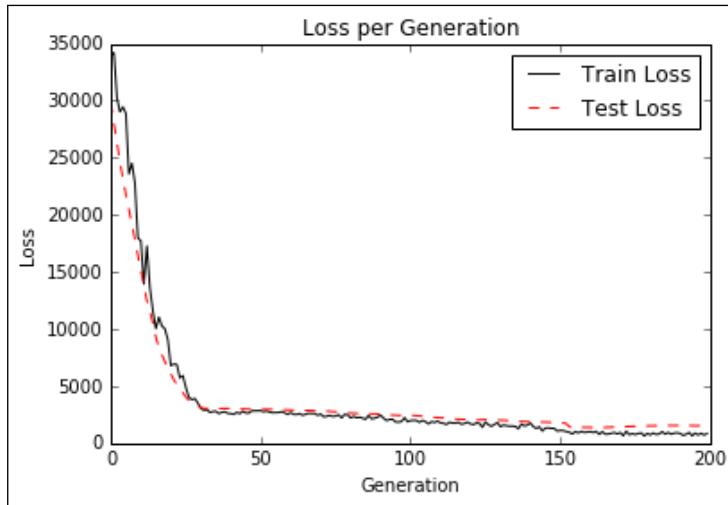


Figure 6: Here we plot the train and test loss for our neural network that we trained to predict the birthweight in grams. Notice that only after about 30 generations we have arrived at a good model.

13. Now we want to compare our birthweight results to our prior logistic results. In logistic linear regression (see the *Implementing Logistic Regression* recipe in *Chapter 3, Linear Regression*), we achieved around 60% accuracy after thousands of iterations. To compare this with what we have done here, we will output the train/test regression results and turn them into classification results by creating an indicator if they are above or below 2,500 grams. Here is the code to arrive find out what this model's accuracy is likely to be:

```

actuals = np.array([x[1] for x in birth_data])
test_actuals = actuals[test_indices]
train_actuals = actuals[train_indices]
test_preds = [x[0] for x in sess.run(final_output, feed_dict={x_
data: x_vals_test})]
train_preds = [x[0] for x in sess.run(final_output, feed_dict={x_
data: x_vals_train})]
test_preds = np.array([1.0 if x<2500.0 else 0.0 for x in test_
preds])

```

```
train_preds = np.array([1.0 if x<2500.0 else 0.0 for x in train_
preds])
Print out accuracies
test_acc = np.mean([x==y for x,y in zip(test_preds, test_
actuals)])
train_acc = np.mean([x==y for x,y in zip(train_preds, train_
actuals)])
print('On predicting the category of low birthweight from
regression output (<2500g):')
print('Test Accuracy: {}'.format(test_acc))
print('Train Accuracy: {}'.format(train_acc))
```

14. This results in the following output:

```
Test Accuracy: 0.5526315789473685
Train Accuracy: 0.6688741721854304
```

## How it works...

In this recipe, we created a regression neural network with three fully connected hidden layers to predict the birthweight of the low-birthweight data set. When comparing this to a logistic output to predict above or below 2,500 grams, we achieved similar results and achieved them in fewer generations. In the next recipe, we will try to improve our logistic regression by making it a multiple-layer logistic-type neural network.

# Improving the Predictions of Linear Models

In the prior recipes, we have noted that the number of parameters we are fitting far exceeds the equivalent linear models. In this recipe, we will attempt to improve our logistic model of low birthweight with using a neural network.

## Getting ready

For this recipe, we will load the low birth-weight data and use a neural network with two hidden fully connected layers with sigmoid activations to fit the probability of a low birth-weight.

## How to do it

1. We start by loading the libraries and initializing our computational graph:

```
import matplotlib.pyplot as plt
import numpy as np
```

```
import tensorflow as tf
import requests
sess = tf.Session()
```

2. Now we will load, extract, and normalize our data just like as in the prior recipe, except that we are going to using the low birthweight indicator variable as our target instead of the actual birthweight:

```
birthdata_url = 'https://www.umass.edu/statdata/statdata/data/
lowbwt.dat'
birth_file = requests.get(birthdata_url)
birth_data = birth_file.text.split('\r\n')[5:]
birth_header = [x for x in birth_data[0].split(' ') if len(x)>=1]
birth_data = [[float(x) for x in y.split(' ') if len(x)>=1] for y
in birth_data[1:] if len(y)>=1]
y_vals = np.array([x[1] for x in birth_data])
x_vals = np.array([x[2:9] for x in birth_data])
train_indices = np.random.choice(len(x_vals), round(len(x_
vals)*0.8), replace=False)
test_indices = np.array(list(set(range(len(x_vals))) - set(train_-
indices)))
x_vals_train = x_vals[train_indices]
x_vals_test = x_vals[test_indices]
y_vals_train = y_vals[train_indices]
y_vals_test = y_vals[test_indices]

def normalize_cols(m):
 col_max = m.max(axis=0)
 col_min = m.min(axis=0)
 return (m-col_min) / (col_max - col_min)

x_vals_train = np.nan_to_num(normalize_cols(x_vals_train))
x_vals_test = np.nan_to_num(normalize_cols(x_vals_test))
```

3. Next we'll declare our batch size and our placeholders for the data:

```
batch_size = 90
x_data = tf.placeholder(shape=[None, 7], dtype=tf.float32)
y_target = tf.placeholder(shape=[None, 1], dtype=tf.float32)
```

- 
4. Just as before, we will declare functions that initialize a variable and a layer in our model. To create a better logistic function, we need to create a function that returns a logistic layer on an input layer. In other words, we will just use a fully connected layer and return a sigmoid element-wise for each layer. It is important to remember that our loss function will have the final sigmoid included, so we want to specify on our last layer that we will not return the sigmoid of the output:

```
def init_variable(shape):
 return(tf.Variable(tf.random_normal(shape=shape)))
Create a logistic layer definition
def logistic(input_layer, multiplication_weight, bias_weight,
activation = True):
 linear_layer = tf.add(tf.matmul(input_layer, multiplication_
weight), bias_weight)

 if activation:
 return(tf.nn.sigmoid(linear_layer))
 else:
 return(linear_layer)
```

5. Now we will declare three layers (two hidden layers and an output layer). We will start by initializing a weight and bias matrix for each layer and defining the layer operations:

```
First logistic layer (7 inputs to 14 hidden nodes)
A1 = init_variable(shape=[7,14])
b1 = init_variable(shape=[14])
logistic_layer1 = logistic(x_data, A1, b1)
Second logistic layer (14 hidden inputs to 5 hidden nodes)
A2 = init_variable(shape=[14,5])
b2 = init_variable(shape=[5])
logistic_layer2 = logistic(logistic_layer1, A2, b2)
Final output layer (5 hidden nodes to 1 output)
A3 = init_variable(shape=[5,1])
b3 = init_variable(shape=[1])
final_output = logistic(logistic_layer2, A3, b3, activation=False)
```

6. Next we declare our loss function (cross-entropy) and optimization algorithm, and initialize the variables:

```
Create loss function
loss = tf.reduce_mean(tf.nn.sigmoid_cross_entropy_with_logits(
final_output, y_target))
Declare optimizer
my_opt = tf.train.AdamOptimizer(learning_rate = 0.002)
train_step = my_opt.minimize(loss)
```

```
Initialize variables
init = tf.initialize_all_variables()
sess.run(init)
```

 Cross-entropy is a way to measure distances between probabilities. Here we want to measure the difference between certainty (0 or 1) and our model probability ( $0 < x < 1$ ). TensorFlow implements cross entropy with the sigmoid function built in. Also, it is important as part of the hyperparameter tuning to find the best loss function, learning rate, and optimization algorithm for the problem at hand. For brevity in this recipe, we do not include hyperparameter tuning.

7. In order to evaluate and compare our model to prior models, we want to create a prediction and accuracy operation on the graph. This will allow us to feed in the whole test set and determine the accuracy:

```
prediction = tf.round(tf.nn.sigmoid(final_output))
predictions_correct = tf.cast(tf.equal(prediction, y_target),
tf.float32)
accuracy = tf.reduce_mean(predictions_correct)
```

8. Now we are ready to start our training loop. We will train for 1500 generations and save the model loss and train/test accuracies for plotting later:

```
Initialize loss and accuracy vectors
loss_vec = []
train_acc = []
test_acc = []
for i in range(1500):
 # Select random indicies for batch selection
 rand_index = np.random.choice(len(x_vals_train), size=batch_size)
 # Select batch
 rand_x = x_vals_train[rand_index]
 rand_y = np.transpose([y_vals_train[rand_index]])
 # Run training step
 sess.run(train_step, feed_dict={x_data: rand_x, y_target:
rand_y})
 # Get training loss
 temp_loss = sess.run(loss, feed_dict={x_data: rand_x, y_
target: rand_y})
 loss_vec.append(temp_loss)
 # Get training accuracy
```

```
temp_acc_train = sess.run(accuracy, feed_dict={x_data: x_vals_
train, y_target: np.transpose([y_vals_train])})
train_acc.append(temp_acc_train)
Get test accuracy
temp_acc_test = sess.run(accuracy, feed_dict={x_data: x_vals_
test, y_target: np.transpose([y_vals_test])})
test_acc.append(temp_acc_test)
if (i+1)%150==0:
 print('Loss = ' + str(temp_loss))
```

9. This results in the following output:

```
Loss = 0.696393
Loss = 0.591708
Loss = 0.59214
Loss = 0.505553
Loss = 0.541974
Loss = 0.512707
Loss = 0.590149
Loss = 0.502641
Loss = 0.518047
Loss = 0.502616
```

10. The following code blocks illustrate how to plot the cross entropy loss and the train and test set accuracies with matplotlib:

```
Plot loss over time
plt.plot(loss_vec, 'k-')
plt.title('Cross Entropy Loss per Generation')
plt.xlabel('Generation')
plt.ylabel('Cross Entropy Loss')
plt.show()

Plot train and test accuracy
plt.plot(train_acc, 'k-', label='Train Set Accuracy')
plt.plot(test_acc, 'r--', label='Test Set Accuracy')
plt.title('Train and Test Accuracy')
plt.xlabel('Generation')
plt.ylabel('Accuracy')
plt.legend(loc='lower right')
plt.show()
```

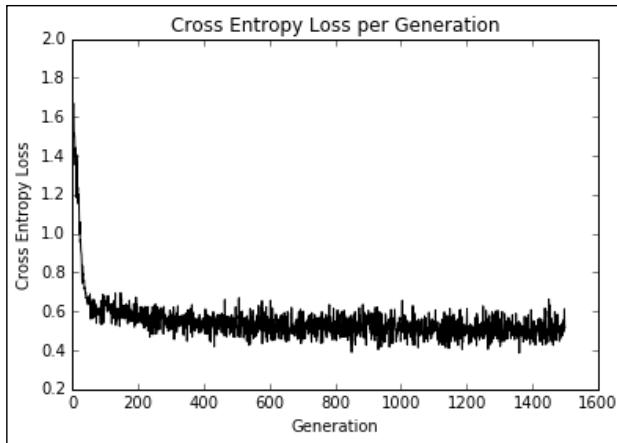


Figure 7: Training loss over 1,500 iterations.

Within approximately 50 generations, we have reached a good model. As we continue to train, we can see that very little is gained over the remaining iterations:

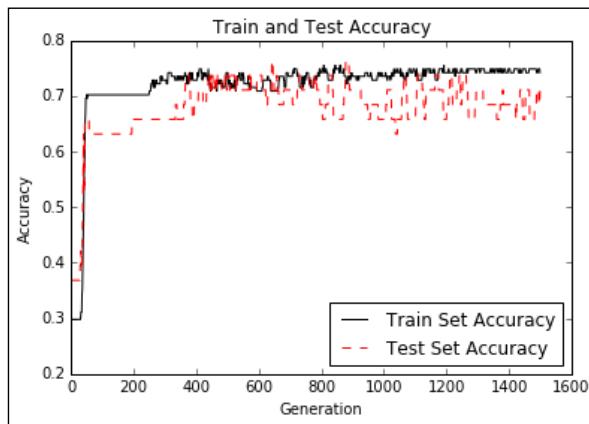


Figure 8: Accuracy for the train set and test set.

Here we can see that we arrived at a good model very quickly.

## How it works...

When considering using neural networks to model data, we have to consider the advantages and disadvantages. While our model has converged faster than prior models and is maybe a bit more accurate in some cases, this comes with a price: we are training many more model variables and have a greater chance of overfitting. To see overfitting occurring, we look at the accuracy of the test and train sets and see the accuracy of the training set continue to increase slightly, while the accuracy on the test set stays the same or even decreases slightly.

To combat underfitting, we can increase our model depth or train the model for more iterations. To address overfitting, we can add more data or add regularization techniques to our model.

It is also important to note that our model variables are not as interpretable as a linear model. Neural network models have coefficients that are harder to interpret than linear models as it pertains to explaining the significance of features in the model.

## Learning to Play Tic Tac Toe

To show how adaptable neural networks can be, we will attempt to use a neural network to learn the optimal moves of Tic Tac Toe. We will approach this knowing that Tic Tac Toe is a deterministic game and that the optimal moves are already known.

### Getting ready

To train our model, we will have a list of board positions followed by the best optimal response for a number of different boards. We can reduce the amount of boards to train on by considering only board positions that are different with respect to symmetries. The non-identity transformations of a Tic Tac Toe board are a rotation (either direction) by 90 degrees, 180 degrees, 270 degrees, a horizontal reflection, and a vertical reflection. Given this idea, we will use a shortlist of boards with the optimal move, apply two random transformations, and feed that into our neural network to learn.



Since tic-tac-toe is a deterministic game, it is worth noting that whoever goes first should either win or draw. We will hope for a model that can respond to our moves optimally and result in a draw.

If we annotate Xs by 1, Os by -1, and empty spaces by zero, then the following shows us how we can consider a board position and optimal move as a row of data:

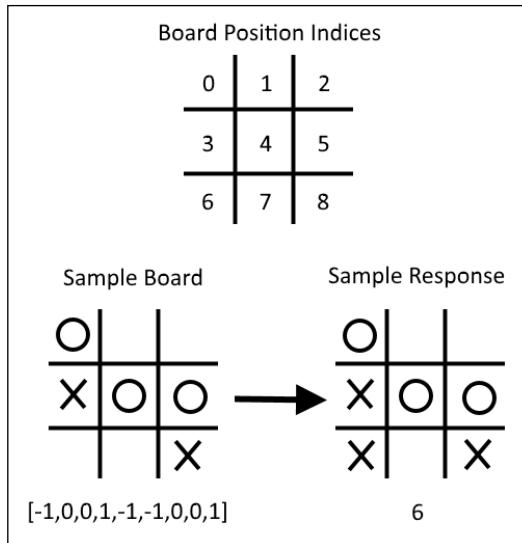


Figure 9: Here we illustrate how to consider a board and optimal move as a row of data.  
Note that X = 1, O = -1, and empty spaces are 0, and we start indexing at 0.

In addition to the model loss, to check how our model is performing, we will do two things. The first check we will perform is to remove a position and optimal move row from our training set. This will allow us to see whether the neural network model can generalize out to a move it hasn't seen before. The second method we will take to evaluate our model is to actually play a game against it at the end.

The list of possible boards and optimal moves can be found on the GitHub directory for this recipe here: [https://github.com/nfmccclure/tensorflow\\_cookbook/tree/master/06\\_Neural\\_Networks/08\\_Learning\\_Tic\\_Tac\\_Toe](https://github.com/nfmccclure/tensorflow_cookbook/tree/master/06_Neural_Networks/08_Learning_Tic_Tac_Toe).

## How to do it...

1. We will start by loading the necessary libraries for this script:

```
import tensorflow as tf
import matplotlib.pyplot as plt
import csv
import random
import numpy as np
import random
```

2. Next we declare our batch size for training our model:

```
batch_size = 50
```

- 
3. To make visualizing the boards a bit easier, we will create a function that outputs the Tic Tac Toe boards with Xs and Os:

```
def print_board(board):
 symbols = ['O', ' ', 'X']
 board_plus1 = [int(x) + 1 for x in board]
 print(' ' + symbols[board_plus1[0]] + ' | ' + symbols[board_
plus1[1]] + ' | ' + symbols[board_plus1[2]])
 print(' _____')
 print(' ' + symbols[board_plus1[3]] + ' | ' + symbols[board_
plus1[4]] + ' | ' + symbols[board_plus1[5]])
 print(' _____')
 print(' ' + symbols[board_plus1[6]] + ' | ' + symbols[board_
plus1[7]] + ' | ' + symbols[board_plus1[8]])
```

4. Now we have to create a function that will return a new board and optimal response position under a transformation:

```
def get_symmetry(board, response, transformation):
 '''
 :param board: list of integers 9 long:
 opposing mark = -1
 friendly mark = 1
 empty space = 0
 :param transformation: one of five transformations on a board:
 rotate180, rotate90, rotate270, flip_v, flip_h
 :return: tuple: (new_board, new_response)
 '''

 if transformation == 'rotate180':
 new_response = 8 - response
 return(board[::-1], new_response)

 elif transformation == 'rotate90':
 new_response = [6, 3, 0, 7, 4, 1, 8, 5, 2].index(response)
 tuple_board = list(zip(*[board[6:9], board[3:6],
 board[0:3]]))
 return([value for item in tuple_board for value in item],
 new_response)

 elif transformation == 'rotate270':
 new_response = [2, 5, 8, 1, 4, 7, 0, 3, 6].index(response)
 tuple_board = list(zip(*[board[0:3], board[3:6],
 board[6:9]]))[:-1]
```

```
 return([value for item in tuple_board for value in item],
new_response)

 elif transformation == 'flip_v':
 new_response = [6, 7, 8, 3, 4, 5, 0, 1, 2].index(response)
 return(board[6:9] + board[3:6] + board[0:3], new_
response)

 elif transformation == 'flip_h':
 # flip_h = rotate180, then flip_v
 new_response = [2, 1, 0, 5, 4, 3, 8, 7, 6].index(response)
 new_board = board[::-1]
 return(new_board[6:9] + new_board[3:6] + new_board[0:3],
new_response)

 else:
 raise ValueError('Method not implemented.')
```

5. The list of boards and their optimal response is in a .csv file in the directory. We will create a function that will load the file with the f boards and responses and store it as a list of tuples:

```
def get_moves_from_csv(csv_file):
 '''
 :param csv_file: csv file location containing the boards w/
 responses
 :return: moves: list of moves with index of best response
 '''
 moves = []
 with open(csv_file, 'rt') as csvfile:
 reader = csv.reader(csvfile, delimiter=',')
 for row in reader:
 moves.append(([int(x) for x in row[0:9]], int(row[9])))
 return(moves)
```

6. Now we'll tie everything together to create a function that will return a randomly transformed board and response:

```
def get_rand_move(moves, rand_transforms=2):
 # This function performs random transformations on a board.
 (board, response) = random.choice(moves)
 possible_transforms = ['rotate90', 'rotate180', 'rotate270',
 'flip_v', 'flip_h']
 for i in range(rand_transforms):
 random_transform = random.choice(possible_transforms)
```

```
(board, response) = get_symmetry(board, response, random_
transform)
return(board, response)
```

7. Next we'll initialize our graph session, load our data, and create a training set:

```
sess = tf.Session()
moves = get_moves_from_csv('base_tic_tac_toe_moves.csv')
Create a train set:
train_length = 500
train_set = []
for t in range(train_length):
 train_set.append(get_rand_move(moves))
```

8. Remember that we want to remove one board and optimal response from our training set to see whether the model can generalize out to make the best move. The best move for the following board will be to play at index number six:

```
test_board = [-1, 0, 0, 1, -1, -1, 0, 0, 1]
train_set = [x for x in train_set if x[0] != test_board]
```

9. We can now create functions to create our model variables and our model operations. Note that we do not include the softmax() activation function in the model because it is included in the loss function:

```
def init_weights(shape):
 return(tf.Variable(tf.random_normal(shape)))

def model(X, A1, A2, bias1, bias2):
 layer1 = tf.nn.sigmoid(tf.add(tf.matmul(X, A1), bias1))
 layer2 = tf.add(tf.matmul(layer1, A2), bias2)
 return(layer2)
```

10. Now we will declare our placeholders, variables, and model:

```
X = tf.placeholder(dtype=tf.float32, shape=[None, 9])
Y = tf.placeholder(dtype=tf.int32, shape=[None])
A1 = init_weights([9, 81])
bias1 = init_weights([81])
A2 = init_weights([81, 9])
bias2 = init_weights([9])
model_output = model(X, A1, A2, bias1, bias2)
```

11. Next we'll declare our loss function, which will be the average softmax of the final output logits. Then we will declare our training step and optimizer. We also need to create a prediction operation if we want to be able to play against our model in the future:

```
loss = tf.reduce_mean(tf.nn.sparse_softmax_cross_entropy_with_
logits(model_output, Y))
train_step = tf.train.GradientDescentOptimizer(0.025).
minimize(loss)
prediction = tf.argmax(model_output, 1)
```

12. We can now initialize our variables and loop through the training of our neural network:

```
Initialize variables
init = tf.initialize_all_variables()
sess.run(init)
loss_vec = []
for i in range(10000):
 # Select random indices for batch
 rand_indices = np.random.choice(range(len(train_set)), batch_
size, replace=False)
 # Get batch
 batch_data = [train_set[i] for i in rand_indices]
 x_input = [x[0] for x in batch_data]
 y_target = np.array([y[1] for y in batch_data])
 # Run training step
 sess.run(train_step, feed_dict={X: x_input, Y: y_target})
 # Get training loss
 temp_loss = sess.run(loss, feed_dict={X: x_input, Y: y_
target})
 loss_vec.append(temp_loss)
 if i%500==0:
 print('iteration ' + str(i) + ' Loss: ' + str(temp_loss))
```

13. Here is code to plot the loss over the model training:

```
plt.plot(loss_vec, 'k-', label='Loss')
plt.title('Loss (MSE) per Generation')
```

```

plt.xlabel('Generation')
plt.ylabel('Loss')
plt.show()

```

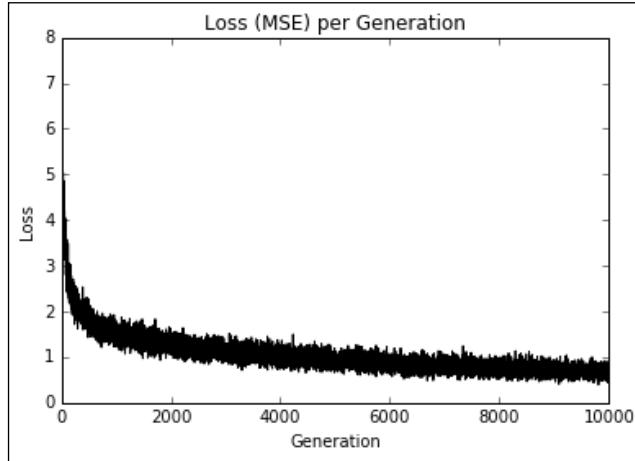


Figure 10: Tic-Tac-Toe train set loss over 10,000 iterations.

Here we plot the loss over the training steps:

1. To test the model, we see how it performs on the test board that we removed from the training set. We are hoping that the model can generalize and predict the optimal index for moving, which will be the index six. Most of the time, the model will succeed here:

```

test_boards = [test_board]
feed_dict = {X: test_boards}
logits = sess.run(model_output, feed_dict=feed_dict)
predictions = sess.run(prediction, feed_dict=feed_dict)
print(predictions)

```

2. This results in the following output:

[6]

3. In order to evaluate our model, we planned to play against our trained model. To do this, we have to create a function that will check for a win. This way, our program will know when to stop asking for more moves:

```

def check(board):
 wins = [[0,1,2], [3,4,5], [6,7,8], [0,3,6], [1,4,7], [2,5,8],
 [0,4,8], [2,4,6]]
 for i in range(len(wins)):
 if board[wins[i][0]]==board[wins[i][1]]==board[wins[i][2]]==1.:
 return(1)

```

```
 elif board[wins[i][0]]==board[wins[i][1]]==board[wins[i][2]]==-1.:
 return(1)
 return(0)
```

4. Now we can loop through and play a game with our model. We start with a blank board (all zeros), and then we ask the user to input an index (0-8) of where to play and then feed that into the model for a prediction. For the model's move, we take the largest available prediction that is also an open space. A sample game is shown at the end. From this game, we can see that our model is not perfect:

```
game_tracker = [0., 0., 0., 0., 0., 0., 0., 0., 0.]
win_logical = False
num_moves = 0
while not win_logical:
 player_index = input('Input index of your move (0-8): ')
 num_moves += 1
 # Add player move to game
 game_tracker[int(player_index)] = 1.

 # Get model's move by first getting all the logits for each
 # index
 [potential_moves] = sess.run(model_output, feed_dict={X:
 [game_tracker]})

 # Now find allowed moves (where game tracker values = 0.0)
 allowed_moves = [ix for ix,x in enumerate(game_tracker) if
 x==0.0]

 # Find best move by taking argmax of logits if they are in
 # allowed moves
 model_move = np.argmax([x if ix in allowed_moves else -999.0
 for ix,x in enumerate(potential_moves)])

 # Add model move to game
 game_tracker[int(model_move)] = -1.
 print('Model has moved')
 print_board(game_tracker)
 # Now check for win or too many moves
 if check(game_tracker)==1 or num_moves>=5:
 print('Game Over!')
 win_logical = True
```

5. This results in the following interactive output:

```
Input index of your move (0-8) : 4
```

```
Model has moved
```

|       |   |  |
|-------|---|--|
| o     |   |  |
| _____ |   |  |
|       | x |  |
| _____ |   |  |
|       |   |  |

```
Input index of your move (0-8) : 6
```

```
Model has moved
```

|       |   |   |
|-------|---|---|
| o     |   |   |
| _____ |   |   |
|       | x |   |
| _____ |   |   |
| x     |   | o |

```
Input index of your move (0-8) : 2
```

```
Model has moved
```

|       |   |   |
|-------|---|---|
| o     |   | x |
| _____ |   |   |
| o     | x |   |
| _____ |   |   |
| x     |   | o |

```
Game Over!
```

## How it works...

We trained a neural network to play tic-tac-toe by feeding in board positions, a nine-dimensional vector, and predicted the optimal response. We only had to feed in a few possible Tic Tac Toe boards and apply random transformations to each board to increase the training set size.

To test our algorithm, we removed all instances of one specific board and saw whether our model could generalize to predict the optimal response. Finally, we also played a sample game against our model. While it is not perfect yet, we could still try different architectures and training procedures to improve it.

# 7

## Natural Language Processing

Here we will cover an introduction to working with text in TensorFlow. We start by introducing how word embeddings work and using the bag of words method, then we move on to implementing more advanced embeddings such as Word2vec and Doc2vec:

- ▶ Working with bag of words
- ▶ Implementing TF-IDF
- ▶ Working with Skip-gram Embeddings
- ▶ Working with CBOW Embeddings
- ▶ Making Predictions with Word2vec
- ▶ Using Doc2vec for Sentiment Analysis

As a note, the reader may find all the code for this chapter online at [https://github.com/nfmccclure/tensorflow\\_cookbook](https://github.com/nfmccclure/tensorflow_cookbook).

### Introduction

Up to this point, we have only considered machine learning algorithms that mostly operate on numerical inputs. If we want to use text, we must find a way to convert the text into numbers. There are many ways to do this and we will explore a few common ways this is achieved.

If we consider the sentence *TensorFlow makes machine learning easy*, we could convert the words to numbers in the order that we observe them. This would make the sentence become **1 2 3 4 5**. Then when we see a new sentence, *machine learning is easy*, we can translate this as **3 4 0 5**, denoting words we haven't seen with an index of zero. With these two examples, we have limited our vocabulary to six numbers. With large texts, we can choose how many words we want to keep, and usually keep the most frequent words, labeling everything else with the index of zero.

If the word **learning** has a numerical value of 4, and the word **makes** has a numerical value of 2, then it would be natural to assume that **learning** is twice **makes**. Since we do not want this type of numerical relationship between words, we assume these numbers represent categories and not relational numbers.

Another problem is that these two sentences are of different sizes. Each observation we make (sentences in this case) needs to have the same size input to the model we wish to create. To get around this, we create each sentence into a sparse vector that has the value of one in a specific index if that word occurs in that index:

| TensorFlow | makes | machine | learning | easy |
|------------|-------|---------|----------|------|
| 1          | 2     | 3       | 4        | 5    |

```
first_sentence = [0,1,1,1,1,1]
```

| machine | learning | is | easy |
|---------|----------|----|------|
| 3       | 4        | 0  | 5    |

```
second_sentence = [1,0,0,1,1,1]
```

A disadvantage to this method is that we lose any indication of word order. The two sentences *TensorFlow makes machine learning easy* and *machine learning makes TensorFlow easy* would result in the same sentence vector.

It is also worthwhile to note that the length of these vectors is equal to the size of our vocabulary that we pick. It is common to pick a very large vocabulary, so these sentence vectors can be very sparse. This type of embedding that we have covered in this introduction is called *bag of words*. We will implement this in the next section.

Another drawback is that the words *is* and *TensorFlow* have the same numerical index value of one. We can imagine that the word *is* might be less important than the occurrence of the word *TensorFlow*.

We will explore different types of embeddings in this chapter that attempt to address these ideas, but first we start with an implementation of bag of words.

## Working with bag of words

We start by showing how to work with a bag of words embedding in TensorFlow. This mapping is what we introduced in the introduction. Here we show how to use this type of embedding to do spam prediction.

### Getting ready

To illustrate how to use bag of words with a text dataset, we will use a spam-ham phone text database from the UCI machine learning data repository (<https://archive.ics.uci.edu/ml/datasets/SMS+Spam+Collection>). This is a collection of phone text messages that are spam or not-spam (ham). We will download this data, store it for future use, and then proceed with the bag of words method to predict whether a text is spam or not. The model that will operate on the bag of words will be a logistic model with no hidden layers. We will use stochastic training, with batch size of one, and compute the accuracy on a held-out test set at the end.

### How to do it...

For this example, we will start by getting the data, normalizing and splitting the text, running it through an embedding function, and training the logistic function to predict spam:

1. The first task will be to import the necessary libraries for this task. Among the usual libraries, we will need a .zip file library to unzip the data from the UCI machine learning website we retrieve it from:

```
import tensorflow as tf
import matplotlib.pyplot as plt
import os
import numpy as np
import csv
import string
import requests
import io
from zipfile import ZipFile
from tensorflow.contrib import learn
sess = tf.Session()
```

2. Instead of downloading the text data every time the script is run, we will save it and check whether the file has been saved before. This prevents us from repeatedly downloading the data over and over if we want to change the script parameters. After downloading, we will extract the input and target data and change the target to be 1 for spam and 0 for ham:

```
save_file_name = os.path.join('temp','temp_spam_data.csv')
```

```
if os.path.isfile(save_file_name):
 text_data = []
 with open(save_file_name, 'r') as temp_output_file:
 reader = csv.reader(temp_output_file)
 for row in reader:
 text_data.append(row)
else:
 zip_url = 'http://archive.ics.uci.edu/ml/machine-learning-
databases/00228/smsspamcollection.zip'
 r = requests.get(zip_url)
 z = ZipFile(io.BytesIO(r.content))
 file = z.read('SMSSpamCollection')
 # Format Data
 text_data = file.decode()
 text_data = text_data.encode('ascii', errors='ignore')
 text_data = text_data.decode().split('\n')
 text_data = [x.split('\t') for x in text_data if len(x)>=1]

 # And write to csv
 with open(save_file_name, 'w') as temp_output_file:
 writer = csv.writer(temp_output_file)
 writer.writerows(text_data)
texts = [x[1] for x in text_data]
target = [x[0] for x in text_data]
Relabel 'spam' as 1, 'ham' as 0
target = [1 if x=='spam' else 0 for x in target]
```

3. To reduce the potential vocabulary size, we normalize the text. To do this, we remove the influence of capitalization and numbers in the text. Use the following code:

```
Convert to lower case
texts = [x.lower() for x in texts]
Remove punctuation
texts = [''.join(c for c in x if c not in string.punctuation) for
x in texts]
Remove numbers
texts = [''.join(c for c in x if c not in '0123456789') for x in
texts]
Trim extra whitespace
texts = [' '.join(x.split()) for x in texts]
```

4. We must also determine the maximum sentence size. To do this, we look at a histogram of text lengths in the data set. We see that a good cut-off might be around 25 words. Use the following code:

```
Plot histogram of text lengths
text_lengths = [len(x.split()) for x in texts]
```

```

text_lengths = [x for x in text_lengths if x < 50]
plt.hist(text_lengths, bins=25)
plt.title('Histogram of # of Words in Texts')
sentence_size = 25
min_word_freq = 3

```

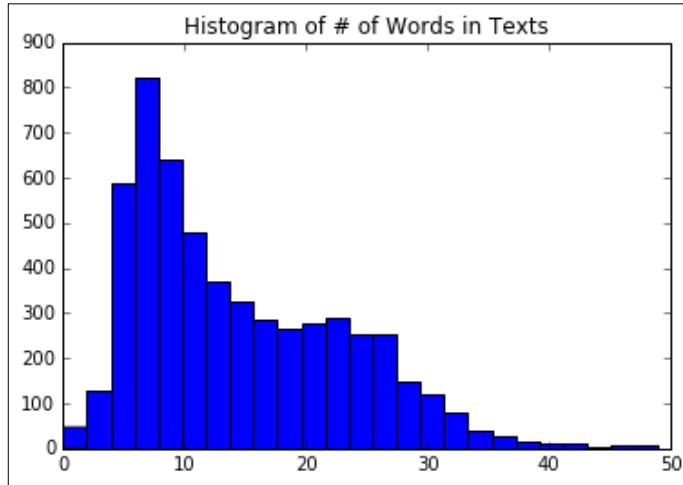


Figure 1: A histogram of the number of words in each text in our data. We use this to establish a maximum length of words to consider in each text. We set this as 25 words, but it can easily be set as 30 or 40 as well.

5. TensorFlow has a built-in processing tool for determining vocabulary embedding, called `VocabularyProcessor()`, under the `learn.preprocessing` library:

```

vocab_processor = learn.preprocessing.VocabularyProcessor(sentence_size, min_frequency=min_word_freq)
vocab_processor.fit_transform(texts)
embedding_size = len(vocab_processor.vocabulary_)

```

6. Now we will split the data into a `train` and `test` set:

```

train_indices = np.random.choice(len(texts),
round(len(texts)*0.8), replace=False)
test_indices = np.array(list(set(range(len(texts))) - set(train_indices)))
texts_train = [x for ix, x in enumerate(texts) if ix in train_indices]
texts_test = [x for ix, x in enumerate(texts) if ix in test_indices]
target_train = [x for ix, x in enumerate(target) if ix in train_indices]
target_test = [x for ix, x in enumerate(target) if ix in test_indices]

```

- 
7. Next we declare the embedding matrix for the words. Sentence words will be translated into indices. These indices will be translated into one-hot-encoded vectors that we can create with an identity matrix, which will be the size of our word embeddings. We will use this matrix to look up the sparse vector for each word and add them together for the sparse sentence vector. Use the following code:

```
identity_mat = tf.diag(tf.ones(shape=[embedding_size]))
```

8. Since we will end up doing logistic regression to predict the probability of spam, we need to declare our logistic regression variables. Then we declare our data placeholders as well. It is important to note that the `x_data` input placeholder should be of integer type because it will be used to look up the row index of our identity matrix and TensorFlow requires that lookup to be an integer:

```
A = tf.Variable(tf.random_normal(shape=[embedding_size, 1]))
b = tf.Variable(tf.random_normal(shape=[1, 1]))
Initialize placeholders
x_data = tf.placeholder(shape=[sentence_size], dtype=tf.int32)
y_target = tf.placeholder(shape=[1, 1], dtype=tf.float32)
```

9. Now we use TensorFlow's embedding lookup function that will map the indices of the words in the sentence to the one-hot-encoded vectors of our identity matrix. When we have that matrix, we create the sentence vector by summing up the aforementioned word vectors. Use the following code:

```
x_embed = tf.nn.embedding_lookup(identity_mat, x_data)
x_col_sums = tf.reduce_sum(x_embed, 0)
```

10. Now that we have our fixed-length sentence vectors for each sentence, we want to perform logistic regression. To do this, we will need to declare the actual model operations. Since we are doing this one data point at a time (stochastic training), we will expand the dimensions of our input and perform linear regression operations on it. Remember that TensorFlow has a loss function that includes the sigmoid function, so we do not need to include it in our output here:

```
x_col_sums_2D = tf.expand_dims(x_col_sums, 0)
model_output = tf.add(tf.matmul(x_col_sums_2D, A), b)
```

11. We now declare the loss function, prediction operation, and optimization function for training the model. Use the following code:

```
loss = tf.reduce_mean(tf.nn.sigmoid_cross_entropy_with_
logits(model_output, y_target))
Prediction operation
prediction = tf.sigmoid(model_output)
Declare optimizer
my_opt = tf.train.GradientDescentOptimizer(0.001)
train_step = my_opt.minimize(loss)
```

12. Next we initialize our graph variables before we start the training generations:

```
init = tf.initialize_all_variables()
sess.run(init)
```

13. Now we start the iteration over the sentences. TensorFlow's `vocab_processor`.

`fit()` function is a generator that operates one sentence at a time. We will use this to our advantage to do stochastic training on our logistic model. To get a better idea of the accuracy trend, we keep a trailing average of the past 50 training steps. If we just plotted the current one, we would either see 1 or 0 depending on whether we predicted that training data point correctly or not. Use the following code:

```
loss_vec = []
train_acc_all = []
train_acc_avg = []
for ix, t in enumerate(vocab_processor.fit_transform(texts_train)):
 y_data = [[target_train[ix]]]

 sess.run(train_step, feed_dict={x_data: t, y_target: y_data})

 temp_loss = sess.run(loss, feed_dict={x_data: t, y_target: y_data})
 loss_vec.append(temp_loss)

 if (ix+1)%10==0:
 print('Training Observation #' + str(ix+1) + ': Loss = ' +
str(temp_loss))

 # Keep trailing average of past 50 observations accuracy
 # Get prediction of single observation
 [[temp_pred]] = sess.run(prediction, feed_dict={x_data:t, y_target:y_data})
 # Get True/False if prediction is accurate
 train_acc_temp = target_train[ix]==np.round(temp_pred)
 train_acc_all.append(train_acc_temp)
 if len(train_acc_all) >= 50:
 train_acc_avg.append(np.mean(train_acc_all[-50:]))
```

14. This results in the following output:

```
Starting Training Over 4459 Sentences.
Training Observation #10: Loss = 5.45322
Training Observation #20: Loss = 3.58226
Training Observation #30: Loss = 0.0
Training Observation #4430: Loss = 1.84636
Training Observation #4440: Loss = 1.46626e-05
Training Observation #4450: Loss = 0.045941
```

15. To get the test set accuracy, we repeat the preceding process, but only on the prediction operation, not the training operation with the test texts:

```
print('Getting Test Set Accuracy')
test_acc_all = []
for ix, t in enumerate(vocab_processor.fit_transform(texts_test)):
 y_data = [[target_test[ix]]]

 if (ix+1)%50==0:
 print('Test Observation #' + str(ix+1))

 # Keep trailing average of past 50 observations accuracy
 # Get prediction of single observation
 [[temp_pred]] = sess.run(prediction, feed_dict={x_data:t, y_
target:y_data})
 # Get True/False if prediction is accurate
 test_acc_temp = target_test[ix]==np.round(temp_pred)
 test_acc_all.append(test_acc_temp)
print('\nOverall Test Accuracy: {}'.format(np.mean(test_acc_all)))
Getting Test Set Accuracy For 1115 Sentences.

Test Observation #10
Test Observation #20
Test Observation #30
Test Observation #1000
Test Observation #1050
Test Observation #1100
Overall Test Accuracy: 0.8035874439461883
```

## How it works...

For this example, we worked with the spam-ham text data from the UCI machine learning repository. We used TensorFlow's vocabulary processing functions to create a standardized vocabulary to work with and created sentence vectors which were the sum of each text's word vectors. We used this sentence vector in logistic regression and obtained about an 80% accuracy model to predict a text being spam.

## There's more...

It is worthwhile to mention the motivation of limiting the sentence (or text) size. In this example, we limited the text size to 25 words. This is a common practice with bag of words because it limits the effect of text length on the prediction. You can imagine that if we find a word, meeting for example, that is predictive of a text being ham (not spam), then a spam message might get through by putting in many occurrences of that word at the end.

In fact, this is a common problem with imbalanced target data. Imbalanced data might occur in this situation, since spam may be hard to find and ham may be easy to find. Because of this fact, our vocabulary that we create might be heavily skewed toward words represented in the ham part of our data (more ham means more words are represented in ham than spam). If we allow unlimited lengths of texts, then spammers might take advantage of this and create very long texts, which have a higher probability of triggering non-spam word factors in our logistic model.

In the next section, we attempt to tackle this problem in a better way by using the frequency of word occurrence to determine the values of the word embeddings.

## Implementing TF-IDF

Since we can choose the embedding for each word, we might decide to change the weighting on certain words. One such strategy is to upweight useful words and downweight overly common or too rare words. The embedding we will explore in this recipe is an attempt to achieve this.

### Getting ready

**TF-IDF** is an acronym that stands for **Text Frequency – Inverse Document Frequency**. This term is essentially the product of text frequency and inverse document frequency for each word.

In the prior recipe, we introduced the bag of words methodology, which assigned a value of one for every occurrence of a word in a sentence. This is probably not ideal as each category of sentence (spam and ham for the prior recipe example) most likely has the same frequency of *the*, *and*, and other words, whereas words such as *viagra* and *sale* probably should have increased importance in figuring out whether or not the text is spam.

We first want to take into consideration the word frequency. Here we consider the frequency with which a word occurs in an individual entry. The purpose of this part (TF) is to find terms that appear to be important in each entry:

$$w_{tf-idf} = w_{tf} \cdot \log \left( \frac{1}{w_{df}} \right)$$

But words such as *the* and *and* may appear very frequently in every entry. We want to down weight the importance of these words, so we can imagine that multiplying the above text frequency (TF) by the inverse of the whole document frequency might help find important words. But since a collection of texts (a corpus) may be quite large, it is common to take the logarithm of the inverse document frequency. This leaves us with the following formula for TF-IDF for each word in each document entry:

$$w_{tf-idf} = w_{tf} \cdot \log \left( \frac{1}{w_{df}} \right)$$

Here  $w_{tf}$  is the word frequency by document, and  $w_{df}$  is the total frequency of such words across all documents. We can imagine that high values of TF-IDF might indicate words that are very important to determining what a document is about.

Creating the TF-IDF vectors requires us to load all the text into memory and count the occurrences of each word before we can start training our model. Because of this, it is not implemented fully in TensorFlow, so we will use scikit-learn for creating our TF-IDF embedding, but use TensorFlow to fit the logistic model.

## How to do it...

1. We start by loading the necessary libraries, and this time we are loading the Scikit-learn TF-IDF preprocessing library for our texts. Use the following code:

```
import tensorflow as tf
import matplotlib.pyplot as plt
import csv
import numpy as np
import os
import string
import requests
import io
import nltk
from zipfile import ZipFile
from sklearn.feature_extraction.text import TfidfVectorizer
```

2. We start a graph session and declare our batch size and maximum feature size for our vocabulary:

```
sess = tf.Session()
batch_size= 200
max_features = 1000
```

3. Next we load the data, either from the Web or from our `temp` data folder if we have saved it before. Use the following code:

```
save_file_name = os.path.join('temp', 'temp_spam_data.csv')
if os.path.isfile(save_file_name):
 text_data = []
 with open(save_file_name, 'r') as temp_output_file:
 reader = csv.reader(temp_output_file)
 for row in reader:
 text_data.append(row)
else:
 zip_url = 'http://archive.ics.uci.edu/ml/machine-learning-databases/00228/smsspamcollection.zip'
 r = requests.get(zip_url)
 z = ZipFile(io.BytesIO(r.content))
 file = z.read('SMSSpamCollection')
 # Format Data
 text_data = file.decode()
 text_data = text_data.encode('ascii', errors='ignore')
 text_data = text_data.decode().split('\n')
 text_data = [x.split('\t') for x in text_data if len(x)>=1]

 # And write to csv
 with open(save_file_name, 'w') as temp_output_file:
 writer = csv.writer(temp_output_file)
 writer.writerows(text_data)
texts = [x[1] for x in text_data]
target = [x[0] for x in text_data]
Relabel 'spam' as 1, 'ham' as 0
target = [1. if x=='spam' else 0. for x in target]
```

4. Just like in the prior recipe, we will decrease our vocabulary size by converting everything to lowercase, removing punctuation, and getting rid of numbers:

```
Lower case
texts = [x.lower() for x in texts]
Remove punctuation
texts = [''.join(c for c in x if c not in string.punctuation) for x in texts]
Remove numbers
texts = [''.join(c for c in x if c not in '0123456789') for x in texts]
Trim extra whitespace
texts = [' '.join(x.split()) for x in texts]
```

5. In order to use scikit-learn's TF-IDF processing functions, we have to tell it how to tokenize our sentences. By this, we just mean how to break up a sentence into the corresponding words. A great tokenizer is already built for us in the `nltk` package that does a great job of breaking up sentences into the corresponding words:

```
def tokenizer(text):
 words = nltk.word_tokenize(text)
 return words

Create TF-IDF of texts
tfidf = TfidfVectorizer(tokenizer=tokenizer, stop_words='english',
max_features=max_features)
sparse_tfidf_texts = tfidf.fit_transform(texts)
```

6. Next we break up our data set into a `train` and `test` set. Use the following code:

```
train_indices = np.random.choice(sparse_tfidf_texts.shape[0],
round(0.8*sparse_tfidf_texts.shape[0]), replace=False)
test_indices = np.array(list(set(range(sparse_tfidf_texts.shape[0])) -
set(train_indices)))
texts_train = sparse_tfidf_texts[train_indices]
texts_test = sparse_tfidf_texts[test_indices]
target_train = np.array([x for ix, x in enumerate(target) if ix in
train_indices])
target_test = np.array([x for ix, x in enumerate(target) if ix in
test_indices])
```

7. Now we can declare our model variables for logistic regression and our data placeholders:

```
A = tf.Variable(tf.random_normal(shape=[max_features, 1]))
b = tf.Variable(tf.random_normal(shape=[1, 1]))
Initialize placeholders
x_data = tf.placeholder(shape=[None, max_features], dtype=tf.
float32)
y_target = tf.placeholder(shape=[None, 1], dtype=tf.float32)
```

8. We can now declare the model operations and the loss function. Remember that the sigmoid part of the logistic regression is in our loss function. Use the following code:

```
model_output = tf.add(tf.matmul(x_data, A), b)
loss = tf.reduce_mean(tf.nn.sigmoid_cross_entropy_with_
logits(model_output, y_target))
```

9. We add a prediction and accuracy function to the graph so that we can see the accuracy of the train and test set as our model is training:

```
prediction = tf.round(tf.sigmoid(model_output))
predictions_correct = tf.cast(tf.equal(prediction, y_target),
tf.float32)
accuracy = tf.reduce_mean(predictions_correct)
```

10. We declare an optimizer and initialize our graph variables next:

```
my_opt = tf.train.GradientDescentOptimizer(0.0025)
train_step = my_opt.minimize(loss)
Initialize Variables
init = tf.initialize_all_variables()
sess.run(init)
```

11. We now train our model over 10,000 generations and record the test/train loss and accuracy every 100 generations and print out the status every 500 generations. Use the following code:

```
train_loss = []
test_loss = []
train_acc = []
test_acc = []
i_data = []
for i in range(10000):
 rand_index = np.random.choice(texts_train.shape[0],
size=batch_size)
 rand_x = texts_train[rand_index].todense()
 rand_y = np.transpose([target_train[rand_index]])
 sess.run(train_step, feed_dict={x_data: rand_x, y_target:
rand_y})

 # Only record loss and accuracy every 100 generations
 if (i+1)%100==0:
 i_data.append(i+1)
 train_loss_temp = sess.run(loss, feed_dict={x_data:
rand_x, y_target: rand_y})
 train_loss.append(train_loss_temp)

 test_loss_temp = sess.run(loss, feed_dict={x_data: texts_
test.todense(), y_target: np.transpose([target_test])})
 test_loss.append(test_loss_temp)

 train_acc_temp = sess.run(accuracy, feed_dict={x_data:
rand_x, y_target: rand_y})
```

```

 train_acc.append(train_acc_temp)

 test_acc_temp = sess.run(accuracy, feed_dict={x_data:
textts_test.todense(), y_target: np.transpose([target_test])})
 test_acc.append(test_acc_temp)
if (i+1)%500==0:
 acc_and_loss = [i+1, train_loss_temp, test_loss_temp,
train_acc_temp, test_acc_temp]
 acc_and_loss = [np.round(x,2) for x in acc_and_loss]
 print('Generation # {}. Train Loss (Test Loss): {:.2f} ({:.2f}). Train Acc (Test Acc): {:.2f} ({:.2f})'.format(*acc_and_
loss))

```

12. This results in the following output:

```

Generation # 500. Train Loss (Test Loss): 0.69 (0.73). Train Acc
(Test Acc): 0.62 (0.57)
Generation # 1000. Train Loss (Test Loss): 0.62 (0.63). Train Acc
(Test Acc): 0.68 (0.66)
...
Generation # 9500. Train Loss (Test Loss): 0.39 (0.45). Train Acc
(Test Acc): 0.89 (0.85)
Generation # 10000. Train Loss (Test Loss): 0.48 (0.45). Train Acc
(Test Acc): 0.84 (0.85)

```

13. And here is the code to plot the accuracy and loss for both the `train` and `test` set:

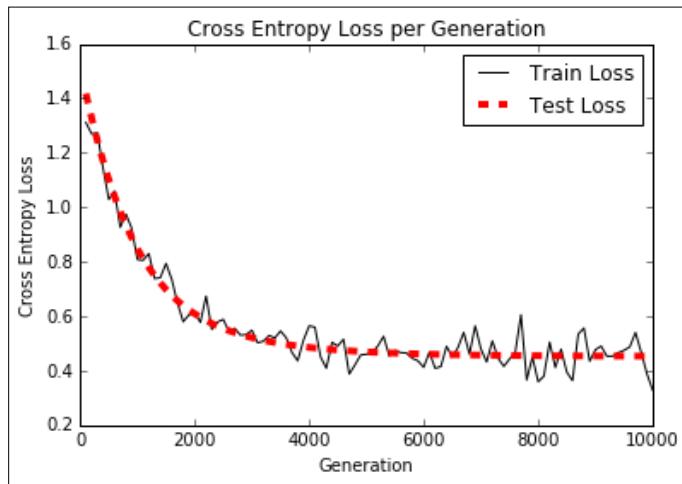


Figure 2: Cross entropy loss for our logistic spam model built off of TF-IDF values.

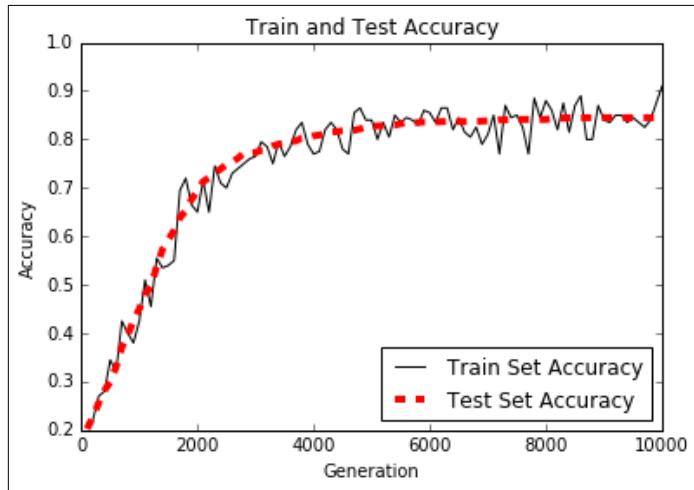


Figure 3: Train and test set accuracy for the logistic spam model built off TF-IDF values.

## How it works...

Using TF-IDF values for the model has increased our prediction over the prior bag of words model from 80% accuracy to almost 90% accuracy. We achieved this by using scikit-learn's TF-IDF vocabulary processing functions and using those TF-IDF values for the logistic regression.

## There's more...

While we might have addressed the issue of word importance, we have not addressed the issue of word ordering. Both bag of words and TF-IDF have no features that take into account word ordering in a sentence. We will attempt to address this in the next few sections, which will introduce us to Word2vec techniques.

## Working with Skip-gram Embeddings

In the prior recipes, we dictated our textual embeddings before training the model. With neural networks, we can make the embedding values part of the training procedure. The first such method we will explore is called **skip-gram embedding**.

## Getting ready

Prior to this recipe, we have not considered the order of words to be relevant in creating word embeddings. In early 2013, Tomas Mikolov and other researchers at Google authored a paper about creating word embeddings that addresses this issue (<https://arxiv.org/abs/1301.3781>), and they named their method **Word2vec**.

The basic idea is to create word embeddings that capture the relational aspect of words. We seek to understand how various words are related to each other. Some examples of how these embeddings might behave are as follows:

*king - man + woman = queen*

*India pale ale – hops + malt = stout*

We might achieve such numerical representation of words if we only consider their positional relationship to each other. If we could analyze a large enough source of coherent documents, we might find that the words *king*, *man*, and *queen* are mentioned closely to each other in our texts. If we also know that *man* and *woman* are related in a different way, then we might conclude that *man* is to *king* as *woman* is to *queen*, and so on.

To go about finding such an embedding, we will use a neural network that predicts surrounding words giving an input word. We could, just as easily, switch that and try to predict a target word given a set of surrounding words, but we will start with the prior method. Both are variations of the Word2vec procedure. But the prior method of predicting the surrounding words (the context) from a target word is called the skip-gram model. In the next recipe, we will implement the other method, predicting the target word from the context, which is called the **continuous bag of words (CBOW)** method:

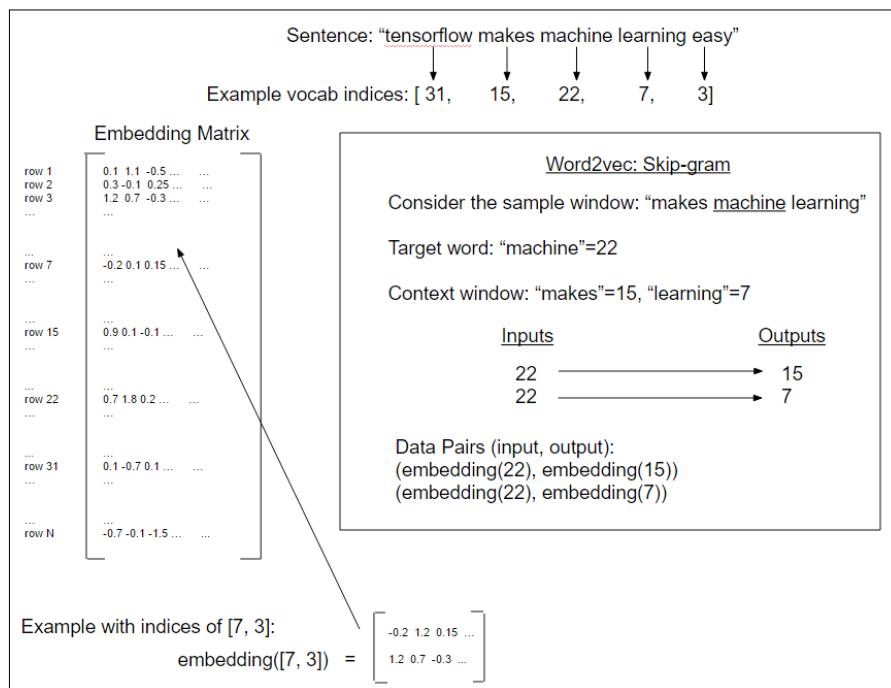


Figure 4: An illustration of the skip-gram implementations of Word2vec. The skip-gram predicts a window of context from the target word (window size of 1 on each side).

For this recipe, we will implement the skip-gram model on a set of movie review data from Cornell University (<http://www.cs.cornell.edu/people/pabo/movie-review-data/>). The CBOW method will be implemented in the next recipe.

## How to do it...

For this recipe, we will create several helper functions: functions that will load the data, normalize the text, generate the vocabulary, and generate data batches. Only after all this will we then start training our word embeddings. To be clear, we are not predicting any target variables, but we will be fitting the word embeddings instead:

1. We load the necessary libraries and start a graph session:

```
import tensorflow as tf
import matplotlib.pyplot as plt
import numpy as np
import random
import os
import string
import requests
import collections
import io
import tarfile
import urllib.request
from nltk.corpus import stopwords
sess = tf.Session()
```

2. We declare some model parameters. We will look at 50 pairs of word embeddings at a time (batch size). The embedding size of each word will be a vector of length 200, and we will only consider the 10,000 most frequent words (every other word will be classified as unknown). We will train for 50,000 generations and print out the loss every 500. Then we declare a num\_sampled variable that we will use in the loss function (explained later), and we also declare our skip-gram window size. Here we set our window size to two, so we will look at the surrounding two words on each side of the target. We set our stopwords from the Python package nltk. We also want a way to check how our word embeddings are performing, so we choose some common movie review words and we will print out the nearest neighbor words from these every 2,000 iterations:

```
batch_size = 50
embedding_size = 200
vocabulary_size = 10000
generations = 50000
print_loss_every = 500
num_sampled = int(batch_size/2)
window_size = 2
```

```
stops = stopwords.words('english')
print_valid_every = 2000
valid_words = ['cliche', 'love', 'hate', 'silly', 'sad']
```

3. Next we declare our data loading function, which checks to make sure we have not downloaded the data before it downloads, or it will load the data from the disk if we have it saved before. Use the following code:

```
def load_movie_data():
 save_folder_name = 'temp'
 pos_file = os.path.join(save_folder_name, 'rt-polarity.pos')
 neg_file = os.path.join(save_folder_name, 'rt-polarity.neg')
 # Check if files are already downloaded
 if os.path.exists(save_folder_name):
 pos_data = []
 with open(pos_file, 'r') as temp_pos_file:
 for row in temp_pos_file:
 pos_data.append(row)
 neg_data = []
 with open(neg_file, 'r') as temp_neg_file:
 for row in temp_neg_file:
 neg_data.append(row)
 else: # If not downloaded, download and save
 movie_data_url = 'http://www.cs.cornell.edu/people/pabo/movie-review-data/rt-polaritydata.tar.gz'
 stream_data = urllib.request.urlopen(movie_data_url)
 tmp = io.BytesIO()
 while True:
 s = stream_data.read(16384)
 if not s:
 break
 tmp.write(s)
 stream_data.close()
 tmp.seek(0)
 tar_file = tarfile.open(fileobj=tmp, mode="r:gz")
 pos = tar_file.extractfile('rt-polaritydata/rt-polarity.
pos')
 neg = tar_file.extractfile('rt-polaritydata/rt-polarity.
neg')
 # Save pos/neg reviews
 pos_data = []
 for line in pos:
 pos_data.append(line.decode('ISO-8859-1').
encode('ascii', errors='ignore').decode())
 neg_data = []
 for line in neg:
```

```
 neg_data.append(line.decode('ISO-8859-1').
 encode('ascii', errors='ignore').decode())
 tar_file.close()
 # Write to file
 if not os.path.exists(save_folder_name):
 os.makedirs(save_folder_name)
 # Save files
 with open(pos_file, "w") as pos_file_handler:
 pos_file_handler.write(''.join(pos_data))
 with open(neg_file, "w") as neg_file_handler:
 neg_file_handler.write(''.join(neg_data))
 texts = pos_data + neg_data
 target = [1]*len(pos_data) + [0]*len(neg_data)
 return(texts, target)
texts, target = load_movie_data()
```

4. Next we create a normalization function for text. This function will input a list of strings and apply lowercasing, remove punctuation, remove numbers, trim extra whitespace, and remove stop words. Use the following code:

```
def normalize_text(texts, stops):
 # Lower case
 texts = [x.lower() for x in texts]
 # Remove punctuation
 texts = ['''.join(c for c in x if c not in string.punctuation)
for x in texts]
 # Remove numbers
 texts = ['''.join(c for c in x if c not in '0123456789') for x
in texts]
 # Remove stopwords
 texts = [' '.join([word for word in x.split() if word not in
(stops)]) for x in texts]
 # Trim extra whitespace
 texts = [' '.join(x.split()) for x in texts]

 return(texts)
texts = normalize_text(texts, stops)
```

5. To make sure that all our movie reviews are informative, we should make sure they are long enough to contain important word relationships. We arbitrarily set this to three or more words:

```
target = [target[ix] for ix, x in enumerate(texts) if len(x.
split()) > 2]
texts = [x for x in texts if len(x.split()) > 2]
```

6. To build our vocabulary, we create a function that creates a dictionary of words with their count, and any word that is uncommon enough to not make our vocabulary size cut-off, we label as 'RARE'. Use the following code:

```
def build_dictionary(sentences, vocabulary_size):
 # Turn sentences (list of strings) into lists of words
 split_sentences = [s.split() for s in sentences]
 words = [x for sublist in split_sentences for x in sublist]
 # Initialize list of [word, word_count] for each word,
 starting with unknown
 count = [['RARE', -1]]
 # Now add most frequent words, limited to the N-most frequent
(N=vocabulary size)
 count.extend(collections.Counter(words).most_common(vocabulary_
size-1))
 # Now create the dictionary
 word_dict = {}
 # For each word, that we want in the dictionary, add it, then
 make it the value of the prior dictionary length
 for word, word_count in count:
 word_dict[word] = len(word_dict)
 return(word_dict)
```

7. We need a function that will convert a list of sentences into lists of word indices that we can pass into our embedding lookup function. Use the following code:

```
def text_to_numbers(sentences, word_dict):
 # Initialize the returned data
 data = []
 for sentence in sentences:
 sentence_data = []
 # For each word, either use selected index or rare word
index
 for word in sentence:
 if word in word_dict:
 word_ix = word_dict[word]
 else:
 word_ix = 0
 sentence_data.append(word_ix)
 data.append(sentence_data)
 return(data)
```

8. Now we can actually create our dictionary and transform our list of sentences into lists of word indices:

```
word_dictionary = build_dictionary(texts, vocabulary_size)
word_dictionary_rev = dict(zip(word_dictionary.values(), word_dictionary.keys()))
text_data = text_to_numbers(texts, word_dictionary)
```

9. From the preceding word dictionary, we can look up the index for the validation words we choose in step 2. Use the following code:

```
valid_examples = [word_dictionary[x] for x in valid_words]
```

10. We now create a function that will return our skip-gram batches. We want to train on pairs of words where one word is the training input (from the target word at the center of our window) and the other word is selected from the window. For example, the sentence *the cat in the hat* may result in (input, output) pairs such as the following: (*the, in*), (*cat, in*), (*the, in*), (*hat, in*), if *in* was the target word, and we had a window size of two in each direction:

```
def generate_batch_data(sentences, batch_size, window_size,
method='skip_gram'):
 # Fill up data batch
 batch_data = []
 label_data = []
 while len(batch_data) < batch_size:
 # select random sentence to start
 rand_sentence = np.random.choice(sentences)
 # Generate consecutive windows to look at
 window_sequences = [rand_sentence[max((ix-window_size),0):(ix+window_size+1)] for ix, x in enumerate(rand_sentence)]
 # Denote which element of each window is the center word
 # of interest
 label_indices = [ix if ix<window_size else window_size for ix,x in enumerate(window_sequences)]

 # Pull out center word of interest for each window and
 # create a tuple for each window
 if method=='skip_gram':
 batch_and_labels = [(x[y], x[:y] + x[(y+1):]) for x,y
in zip(window_sequences, label_indices)]
 # Make it into a big list of tuples (target word,
 surrounding word)
 tuple_data = [(x, y_) for x,y in batch_and_labels for
y_ in y]
 else:
```

```
 raise ValueError('Method {} not implemented
yet.'.format(method))

 # extract batch and labels
 batch, labels = [list(x) for x in zip(*tuple_data)]
 batch_data.extend(batch[:batch_size])
 label_data.extend(labels[:batch_size])
 # Trim batch and label at the end
 batch_data = batch_data[:batch_size]
 label_data = label_data[:batch_size]

 # Convert to numpy array
 batch_data = np.array(batch_data)
 label_data = np.transpose(np.array([label_data]))

 return(batch_data, label_data)
```

11. We can now initialize our embedding matrix, and declare our placeholders and our embedding lookup function. Use the following code:

```
embeddings = tf.Variable(tf.random_uniform([vocabulary_size,
 embedding_size], -1.0, 1.0))
Create data/target placeholders
x_inputs = tf.placeholder(tf.int32, shape=[batch_size])
y_target = tf.placeholder(tf.int32, shape=[batch_size, 1])
valid_dataset = tf.constant(valid_examples, dtype=tf.int32)

Lookup the word embedding:
embed = tf.nn.embedding_lookup(embeddings, x_inputs)
```

12. The loss function should be something such as a softmax, which calculates the loss on predicting the wrong word category. But since our target has 10,000 different categories, it is very sparse. This sparsity causes problems fitting or converging for a model. To tackle this, we use a loss function called noise-contrastive error (NCE). This NCE loss function turns our problem into a binary prediction, by predicting the word class versus random noise predictions. The num\_sampled parameter is how much of the batch to turn into random noise:

```
nce_weights = tf.Variable(tf.truncated_normal([vocabulary_size,
 embedding_size], stddev=1.0 / np.sqrt(embedding_size)))
nce_biases = tf.Variable(tf.zeros([vocabulary_size]))
loss = tf.reduce_mean(tf.nn.nce_loss(nce_weights, nce_biases,
 embed,
 y_target, num_sampled, vocabulary_size))
```

13. Now we need to create a way to find nearby words to our validation words. We will do this by computing the cosine similarity between the validation set and all of our word embeddings, then we can print out the closest set of words for each validation word. Use the following code:

```
norm = tf.sqrt(tf.reduce_sum(tf.square(embeddings), 1, keep_
dims=True))
normalized_embeddings = embeddings / norm
valid_embeddings = tf.nn.embedding_lookup(normalized_embeddings,
valid_dataset)
similarity = tf.matmul(valid_embeddings, normalized_embeddings,
transpose_b=True)
```

14. We now declare our optimizer function, and initialize our model variables:

```
optimizer = tf.train.GradientDescentOptimizer(learning_rate=1.0).
minimize(loss)
init = tf.initialize_all_variables()
sess.run(init)
```

15. Now we can train our embeddings and print off the loss and the closest words to our validation set during training. Use the following code:

```
loss_vec = []
loss_x_vec = []
for i in range(generations):
 batch_inputs, batch_labels = generate_batch_data(text_data,
batch_size, window_size)
 feed_dict = {x_inputs : batch_inputs, y_target : batch_labels}
 # Run the train step
 sess.run(optimizer, feed_dict=feed_dict)
 # Return the loss
 if (i+1) % print_loss_every == 0:
 loss_val = sess.run(loss, feed_dict=feed_dict)
 loss_vec.append(loss_val)
 loss_x_vec.append(i+1)
 print("Loss at step {} : {}".format(i+1, loss_val))

 # Validation: Print some random words and top 5 related words
 if (i+1) % print_valid_every == 0:
 sim = sess.run(similarity, feed_dict=feed_dict)
 for j in range(len(valid_words)):
 valid_word = word_dictionary_rev[valid_examples[j]]
 top_k = 5 # number of nearest neighbors
 nearest = (-sim[j, :]).argsort()[1:top_k+1]
 log_str = "Nearest to {}:".format(valid_word)
 for k in range(top_k):
 close_word = word_dictionary_rev[nearest[k]]
```

```
log_str = "%s %s," % (log_str, close_word)
print(log_str)
```

16. This results in the following output:

```
Loss at step 500 : 13.387781143188477
Loss at step 1000 : 7.240757465362549
Loss at step 49500 : 0.9395825862884521
Loss at step 50000 : 0.30323168635368347
Nearest to cliche: walk, intrigue, brim, eileen, dumber,
Nearest to love: plight, fiction, complete, lady, bartleby,
Nearest to hate: style, throws, players, fearlessness, astringent,
Nearest to silly: delivers, meow, regain, nicely, anger,
Nearest to sad: dizzying, variety, existing, environment, tunney,
```

## How it works...

We have trained a Word2vec model, via the skip-gram method, on a corpus of movie review data. We downloaded the data, converted the words to an index with a dictionary, and used those index numbers as an embedding lookup, which we trained so that nearby words could be predictive of each other.

## There's more...

At first glance, we might expect the set of nearby words to the validation set to be synonyms. This is not quite the case because very rarely do synonyms actually appear next to each other in sentences. What we are really getting at is predicting which words are in proximity to each other in our data set. We hope that using an embedding like this would make prediction easier.

In order to use these embeddings, we must make them reusable and save them. We do this in the next recipe by implementing the CBOW embeddings.

## Working with CBOW Embeddings

In this recipe we will implement the CBOW method of word2vec. It is very similar to the skip-gram method, except we are predicting a single target word from a surrounding window of context words.

## Getting ready

In this recipe, we will implement the CBOW method of Word2vec. It is very similar to the skip-gram method, except we are predicting a single target word from a surrounding window of context words.

In the prior example, we treated each combination of window and target as a group of paired inputs and outputs, but with CBOW we will add the surrounding window embeddings together to get one embedding to predict the target word embedding:

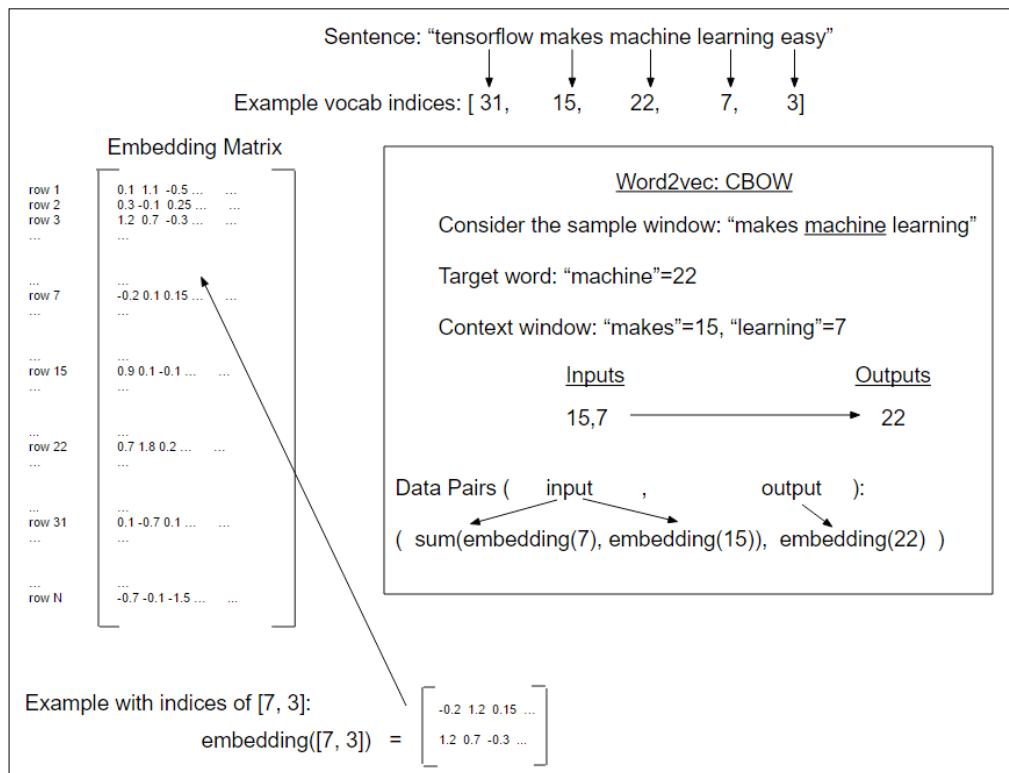


Figure 5: A depiction of how the CBOW embedding data is created out of a window on an example sentence (window size = 1 on each side).

Most of the code will stay the same, except we will need to change how we create the embeddings and how we generate the data from the sentences.

To make the code easier to read, we have moved all the major functions to a separate file, called `text_helpers.py`, in the same directory. This function holds the data loading, text normalization, dictionary creation, and batch generation functions. These functions are exactly as they appear in the *Working with Skip-gram Embeddings* recipe, except where noted.

## How to do it...

1. We start by loading the necessary libraries, including the aforementioned `text_helpers.py` script, where we put our functions for text loading and manipulation. We then start a graph session:

```
import tensorflow as tf
import matplotlib.pyplot as plt
import numpy as np
import random
import os
import pickle
import string
import requests
import collections
import io
import tarfile
import urllib.request
import text_helpers
from nltk.corpus import stopwords
sess = tf.Session()
```

2. We want to make sure that our temporary data and parameter saving folder exists before we start saving to it. Use the following code:

```
Make a saving directory if it doesn't exist
data_folder_name = 'temp'
if not os.path.exists(data_folder_name):
 os.makedirs(data_folder_name)
```

3. We declare the parameters of our model, which will be similar to the skip-gram method in the prior recipe:

```
Declare model parameters
batch_size = 500
embedding_size = 200
vocabulary_size = 2000
generations = 50000
model_learning_rate = 0.001
num_sampled = int(batch_size/2)
window_size = 3
Add checkpoints to training
save_embeddings_every = 5000
print_valid_every = 5000
print_loss_every = 100
```

```
Declare stop words
stops = stopwords.words('english')
We pick some test words. We are expecting synonyms to appear
valid_words = ['love', 'hate', 'happy', 'sad', 'man', 'woman']
```

4. We have moved over the data loading and text normalization functions to a separate file that we imported at the start, so we can call them now. We also want only reviews that have three or more words in them. Use the following code:

```
texts, target = text_helpers.load_movie_data(data_folder_name)
texts = text_helpers.normalize_text(texts, stops)
Texts must contain at least 3 words
target = [target[ix] for ix, x in enumerate(texts) if len(x.
split()) > 2]
texts = [x for x in texts if len(x.split()) > 2]
```

5. Now we create our vocabulary dictionary that will help us to look up words. We also need a reverse dictionary that looks up words from indices when we want to print out the nearest words to our validation set:

```
word_dictionary = text_helpers.build_dictionary(texts,
vocabulary_size)
word_dictionary_rev = dict(zip(word_dictionary.values(), word_
dictionary.keys()))
text_data = text_helpers.text_to_numbers(texts, word_dictionary)
Get validation word keys
valid_examples = [word_dictionary[x] for x in valid_words]
```

6. Next we initialize the word embeddings that we want to fit and declare the model data placeholders. Use the following code:

```
embeddings = tf.Variable(tf.random_uniform([vocabulary_size,
embedding_size], -1.0, 1.0))
Create data/target placeholders
x_inputs = tf.placeholder(tf.int32, shape=[batch_size,
2*window_size])
y_target = tf.placeholder(tf.int32, shape=[batch_size, 1])
valid_dataset = tf.constant(valid_examples, dtype=tf.int32)
```

7. We can now create how we want to deal with the word embeddings. Since the CBOW model adds up the embeddings of the context window, we create a loop and add up all of the embeddings in the window:

```
Lookup the word embeddings and
Add together window embeddings:
embed = tf.zeros([batch_size, embedding_size])
for element in range(2*window_size):
 embed += tf.nn.embedding_lookup(embeddings, x_inputs[:, element])
```

8. We use the NCE loss function that TensorFlow has built in because our categorical output is too sparse for the softmax to converge, as follows:

```
NCE loss parameters
nce_weights = tf.Variable(tf.truncated_normal([vocabulary_size,
embedding_size], stddev=1.0 / np.sqrt(embedding_size)))
nce_biases = tf.Variable(tf.zeros([vocabulary_size]))
Declare loss function (NCE)
loss = tf.reduce_mean(tf.nn.nce_loss(nce_weights, nce_biases,
embed,
y_target, num_sampled, vocabulary_size))
```

9. Just like in the skip-gram recipe, we will use cosine similarity to print off the nearest words to our validation word data set to get an idea of how our embeddings are working. Use the following code:

```
norm = tf.sqrt(tf.reduce_sum(tf.square(embeddings), 1, keep_
dims=True))
normalized_embeddings = embeddings / norm
valid_embeddings = tf.nn.embedding_lookup(normalized_embeddings,
valid_dataset)
similarity = tf.matmul(valid_embeddings, normalized_embeddings,
transpose_b=True)
```

10. To save our embeddings, we must load the TensorFlow `train.Saver` method. This method defaults to saving the whole graph, but we can give it an argument just to save the embedding variable, and we can also give it a specific name. Here we give it the same name as the variable name in our graph:

```
saver = tf.train.Saver({"embeddings": embeddings})
```

11. We now declare an `optimizer` function and initialize our model variables. Use the following code:

```
optimizer = tf.train.GradientDescentOptimizer(learning_rate=model_
learning_rate).minimize(loss)
init = tf.initialize_all_variables()
sess.run(init)
```

12. Finally, we can loop across our training step and print out the loss, and save the embeddings and dictionary when we specify:

```
loss_vec = []
loss_x_vec = []
for i in range(generations):
 batch_inputs, batch_labels = text_helpers.generate_batch_
 data(text_data, batch_size, window_size, method='cbow')
 feed_dict = {x_inputs : batch_inputs, y_target : batch_labels}
 # Run the train step
 sess.run(optimizer, feed_dict=feed_dict)
```

```
Return the loss
if (i+1) % print_loss_every == 0:
 loss_val = sess.run(loss, feed_dict=feed_dict)
 loss_vec.append(loss_val)
 loss_x_vec.append(i+1)
 print('Loss at step {} : {}'.format(i+1, loss_val))

Validation: Print some random words and top 5 related words
if (i+1) % print_valid_every == 0:
 sim = sess.run(similarity, feed_dict=feed_dict)
 for j in range(len(valid_words)):
 valid_word = word_dictionary_rev[valid_examples[j]]
 top_k = 5 # number of nearest neighbors
 nearest = (-sim[j, :]).argsort()[1:top_k+1]
 log_str = "Nearest to {}".format(valid_word)
 for k in range(top_k):
 close_word = word_dictionary_rev[nearest[k]]
 print_str = '{} {}'.format(log_str, close_word)
 print(print_str)

Save dictionary + embeddings
if (i+1) % save_embeddings_every == 0:
 # Save vocabulary dictionary
 with open(os.path.join(data_folder_name, 'movie_vocab.pkl'), 'wb') as f:
 pickle.dump(word_dictionary, f)

 # Save embeddings
 model_checkpoint_path = os.path.join(os.getcwd(), data_folder_name, 'cbow_movie_embeddings.ckpt')
 save_path = saver.save(sess, model_checkpoint_path)
 print('Model saved in file: {}'.format(save_path))
```

13. This results in the following output:

```
Loss at step 100 : 62.04829025268555
Loss at step 200 : 33.182334899902344
Loss at step 49900 : 1.6794960498809814
Loss at step 50000 : 1.5071022510528564
Nearest to love: clarity, cult, cliched, literary, memory,
Nearest to hate: bringing, gifted, almost, next, wish,
Nearest to happy: ensemble, fall, courage, uneven, girls,
Nearest to sad: santa, devoid, biopic, genuinely, becomes,
Nearest to man: project, stands, none, soul, away,
Nearest to woman: crush, even, x, team, ensemble,
Model saved in file: .../temp/cbow_movie_embeddings.ckpt
```

14. All but one of the functions in the `text_helpers.py` file have functions that come directly from the prior recipe. We make a slight addition to the `generate_batch_data()` function by adding a 'cbow' method as follows:

```
elif method=='cbow':
 batch_and_labels = [(x[:y] + x[(y+1):], x[y]) for x,y in
 zip(window_sequences, label_indices)]
 # Only keep windows with consistent 2*window_size
 batch_and_labels = [(x,y) for x,y in batch_and_labels if
 len(x)==2*window_size]
 batch, labels = [list(x) for x in zip(*batch_and_labels)]
```

## How it works...

This recipe, Word2vec embeddings via CBOW, works very similarly to creating the embeddings like we did with skip-gram. The main difference is how we generate the data and combine the embeddings.

For this recipe, we loaded the data, normalized the text, created a vocabulary dictionary, used the dictionary to look up embeddings, combined the embeddings, and trained a neural network to predict the target word.

## There's more...

It is worthwhile to note that the CBOW method trains on a summed-up embedding of the surrounding window to predict the target word. One effect of this is that the CBOW method of word2vec has a smoothing effect that the skip-gram method does not and it is reasonable to think that this might be preferred for smaller textual data sets.

## Making Predictions with Word2vec

In this recipe, we use the previously learned embedding strategies to perform classification.

## Getting ready

Now that we have created and saved CBOW word embeddings, we need to use them to make sentiment predictions on the movie data set. In this recipe, we will learn how to load and use prior-trained embeddings and use these embeddings to perform sentiment analysis by training a logistic linear model to predict a good or bad review.

Sentiment analysis is a really hard task to do because human language makes it very hard to grasp the subtleties and nuances of the true meaning. Sarcasm, jokes, and ambiguous references all make the task exponentially harder. We will create a simple logistic regression on the movie review data set to see whether we can get any information out of the CBOW embeddings we created and saved in the prior recipe. Since the focus of this recipe is in the loading and usage of saved embeddings, we will not pursue more complicated models.

## How to do it...

1. We begin by loading the necessary libraries and starting a graph session:

```
import tensorflow as tf
import matplotlib.pyplot as plt
import numpy as np
import random
import os
import pickle
import string
import requests
import collections
import io
import tarfile
import urllib.request
import text_helpers
from nltk.corpus import stopwords
sess = tf.Session()
```

2. Now we declare the model parameters. We should note that the embedding size should be the same as the embedding size we used to create the prior CBOW embeddings. Use the following code:

```
embedding_size = 200
vocabulary_size = 2000
batch_size = 100
max_words = 100
stops = stopwords.words('english')
```

3. We load and transform the text data from our `text_helpers.py` file we have created. Use the following code:

```
data_folder_name = 'temp'
texts, target = text_helpers.load_movie_data(data_folder_name)
Normalize text
print('Normalizing Text Data')
texts = text_helpers.normalize_text(texts, stops)
Texts must contain at least 3 words
```

```
target = [target[ix] for ix, x in enumerate(texts) if len(x.split()) > 2]
texts = [x for x in texts if len(x.split()) > 2]

train_indices = np.random.choice(len(target),
round(0.8*len(target)), replace=False)
test_indices = np.array(list(set(range(len(target))) - set(train_indices)))
texts_train = [x for ix, x in enumerate(texts) if ix in train_indices]
texts_test = [x for ix, x in enumerate(texts) if ix in test_indices]
target_train = np.array([x for ix, x in enumerate(target) if ix in train_indices])
target_test = np.array([x for ix, x in enumerate(target) if ix in test_indices])
```

4. We now load our word dictionary we created while fitting the CBOW embeddings. This is important to load so that we have the same exact mapping from word to embedding index, as follows:

```
dict_file = os.path.join(data_folder_name, 'movie_vocab.pkl')
word_dictionary = pickle.load(open(dict_file, 'rb'))
```

5. We can now convert our loaded sentence data to a numerical numpy array with our word dictionary:

```
text_data_train = np.array(text_helpers.text_to_numbers(texts_train,
word_dictionary))
text_data_test = np.array(text_helpers.text_to_numbers(texts_test,
word_dictionary))
```

6. Since movie reviews are of different lengths, we standardize them to be all the same length, and in our case we set it to 100 words. If a review has less than 100 words, we will pad it with zeros. Use the following code:

```
text_data_train = np.array([x[0:max_words] for x in [y+[0]*max_
words for y in text_data_train]])
text_data_test = np.array([x[0:max_words] for x in [y+[0]*max_
words for y in text_data_test]])
```

7. Now we declare our model variables and placeholders for the logistic regression. Use the following code:

```
A = tf.Variable(tf.random_normal(shape=[embedding_size,1]))
b = tf.Variable(tf.random_normal(shape=[1,1]))
Initialize placeholders
x_data = tf.placeholder(shape=[None, max_words], dtype=tf.int32)
y_target = tf.placeholder(shape=[None, 1], dtype=tf.float32)
```

8. In order for TensorFlow to restore our prior-trained embeddings, we must first give the saver method a variable to restore into, so we create a embedding variable that is of the same shape as the embeddings we will load:

```
embeddings = tf.Variable(tf.random_uniform([vocabulary_size,
 embedding_size], -1.0, 1.0))
```

9. Now we put our embedding lookup function on the graph and take the average embeddings of all the words in the sentence. Use the following code:

```
embed = tf.nn.embedding_lookup(embeddings, x_data)
Take average of all word embeddings in documents
embed_avg = tf.reduce_mean(embed, 1)
```

10. Next, we declare our model operations and our loss function, remembering that our loss function has the sigmoid operation built in already, as follows:

```
model_output = tf.add(tf.matmul(embed_avg, A), b)
Declare loss function (Cross Entropy loss)
loss = tf.reduce_mean(tf.nn.sigmoid_cross_entropy_with_
logits(model_output, y_target))
```

11. Now we add prediction and accuracy functions to the graph so that we can evaluate the accuracy as the model is training. Use the following code:

```
prediction = tf.round(tf.sigmoid(model_output))
predictions_correct = tf.cast(tf.equal(prediction, y_target),
tf.float32)
accuracy = tf.reduce_mean(predictions_correct)
```

12. We declare an optimizer function and initialize the following model variables:

```
my_opt = tf.train.AdagradOptimizer(0.005)
train_step = my_opt.minimize(loss)
init = tf.initialize_all_variables()
sess.run(init)
```

13. Now that we have a random initialized embedding, we can tell the Saver method to load our prior CBOW embeddings into our embedding variable. Use the following code:

```
model_checkpoint_path = os.path.join(data_folder_name, 'cbow_movie_
embeddings.ckpt')
saver = tf.train.Saver({'embeddings': embeddings})
saver.restore(sess, model_checkpoint_path)
```

14. Now we can start the training generations. Note that every 100 generations, we save the training and test loss and accuracy. We will only print out the model status every 500 generations. Use the following code:

```
train_loss = []
test_loss = []
```

```
train_acc = []
test_acc = []
i_data = []
for i in range(10000):
 rand_index = np.random.choice(text_data_train.shape[0],
size=batch_size)
 rand_x = text_data_train[rand_index]
 rand_y = np.transpose([target_train[rand_index]])
 sess.run(train_step, feed_dict={x_data: rand_x, y_target:
rand_y})

 # Only record loss and accuracy every 100 generations
 if (i+1)%100==0:
 i_data.append(i+1)
 train_loss_temp = sess.run(loss, feed_dict={x_data:
rand_x, y_target: rand_y})
 train_loss.append(train_loss_temp)

 test_loss_temp = sess.run(loss, feed_dict={x_data: text_
data_test, y_target: np.transpose([target_test])})
 test_loss.append(test_loss_temp)

 train_acc_temp = sess.run(accuracy, feed_dict={x_data:
rand_x, y_target: rand_y})
 train_acc.append(train_acc_temp)
 test_acc_temp = sess.run(accuracy, feed_dict={x_data:
text_data_test, y_target: np.transpose([target_test])})
 test_acc.append(test_acc_temp)
 if (i+1)%500==0:
 acc_and_loss = [i+1, train_loss_temp, test_loss_temp,
train_acc_temp, test_acc_temp]
 acc_and_loss = [np.round(x,2) for x in acc_and_loss]
 print('Generation # {}. Train Loss (Test Loss): {:.2f} ({:.2f}) . Train Acc (Test Acc): {:.2f} ({:.2f})'.format(*acc_and_
loss))
```

15. This results in the following output:

```
Generation # 500. Train Loss (Test Loss): 0.70 (0.71). Train Acc
(Test Acc): 0.52 (0.48)
Generation # 1000. Train Loss (Test Loss): 0.69 (0.72). Train Acc
(Test Acc): 0.56 (0.47)
...
Generation # 9500. Train Loss (Test Loss): 0.69 (0.70). Train Acc
(Test Acc): 0.57 (0.55)
Generation # 10000. Train Loss (Test Loss): 0.70 (0.70). Train Acc
(Test Acc): 0.59 (0.55)
```

16. Here is the code to plot the training and test loss and accuracy that we saved every 100 generations. Use the following code:

```
Plot loss over time
plt.plot(i_data, train_loss, 'k-', label='Train Loss')
plt.plot(i_data, test_loss, 'r--', label='Test Loss', linewidth=4)
plt.title('Cross Entropy Loss per Generation')
plt.xlabel('Generation')
plt.ylabel('Cross Entropy Loss')
plt.legend(loc='upper right')
plt.show()

Plot train and test accuracy
plt.plot(i_data, train_acc, 'k-', label='Train Set Accuracy')
plt.plot(i_data, test_acc, 'r--', label='Test Set Accuracy',
 linewidth=4)
plt.title('Train and Test Accuracy')
plt.xlabel('Generation')
plt.ylabel('Accuracy')
plt.legend(loc='lower right')
plt.show()
```

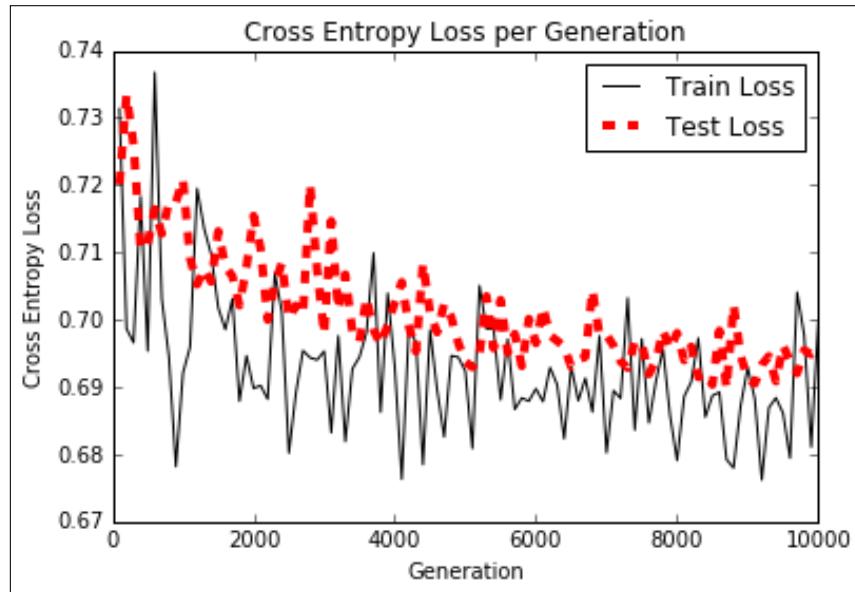


Figure 6: Here we observe the train and test loss over 10,000 generations.

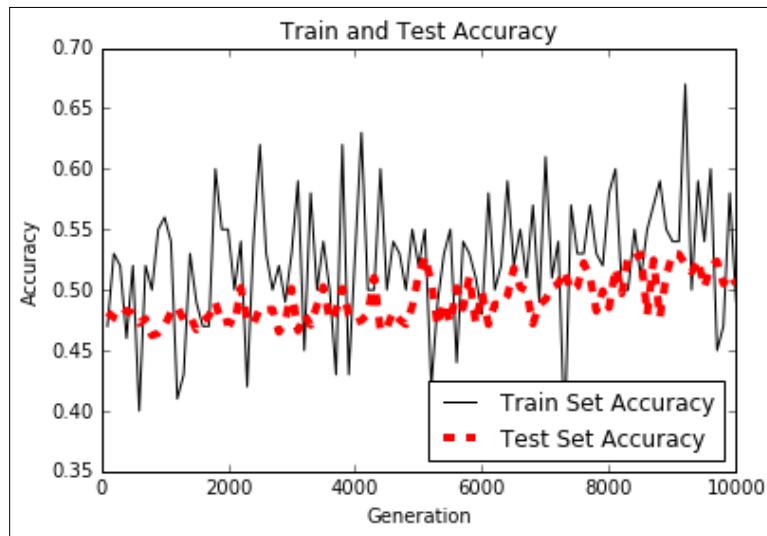


Figure 7: We can observe that the train and test set accuracy is slowly improving over 10,000 generations. It is worthwhile to note that this model performs very poorly and is only slightly better than a random predictor.

## How it works...

We loaded our prior CBOW embeddings, and performed logistic regression on the average embedding of a review. The important methods to note here are how we load model variables from the disk onto already initialized variables in our current model. We also have to remember to store and load our vocabulary dictionary that was created prior to training the embeddings. It is very important to have the same mapping from words to embedding indices when using the same embedding.

## There's more...

We can see we almost achieve a 60% accuracy on predicting the sentiment. For example, it is a hard task to know the meaning behind the word *great*; it could be used in a negative or positive context within the review.

To tackle this problem, we want to somehow create embeddings for the documents themselves that can address the sentiment issue. Usually, a whole review is positive or a whole review is negative. We can use this to our advantage in the *Using Doc2vec for sentiment analysis* recipe.

## Using Doc2vec for Sentiment Analysis

Now that we know how to train word embeddings, we can also extend those methodologies to have a document embedding. We explore how to do this in this recipe with TensorFlow.

### Getting ready

In the prior sections about Word2vec methods, we have managed to capture positional relationships between words. What we have not done is capture the relationship of words to the document (or movie review) that they come from. One extension of Word2vec that captures a document effect is called Doc2vec.

The basic idea of Doc2vec is to introduce document embedding, along with the word embeddings that may help to capture the tone of the document. For example, just knowing that the words *movie* and *love* are nearby to each other may not help us determine the sentiment of the review. The review may be talking about how they love the movie or how they do not love the movie. But if the review is long enough and more negative words are found in the document, maybe we can pick up on an overall tone that may help us predict the next words.

Doc2vec simply adds an additional embedding matrix for the documents and uses a window of words plus the document index to predict the next word. All word windows in a document have the same document index. It is worthwhile to mention that it is important to think about how we will combine the document embedding and the word embeddings. We combine the word embeddings in the word window by taking the sum and there are two main ways to combine these embeddings with the document embedding. Commonly, the document embedding is either added to the word embeddings, or concatenated to the end of the word embeddings. If we add the two embeddings, we limit the document embedding size to be the same size as the word embedding size. If we concatenate, we lift that restriction, but increase the number of variables that the logistic regression must deal with. For illustrative purposes, we show how to deal with concatenation in this recipe. But in general, for smaller datasets, addition is the better choice.

The first step will be to fit both the document and word embeddings on the whole corpus of movie reviews, then we perform a train-test split, train a logistic model, and see whether we can improve upon the accuracy of predicting the review sentiment.

## How to do it...

1. We start by loading the necessary libraries and starting a graph session, as follows:

```
import tensorflow as tf
import matplotlib.pyplot as plt
import numpy as np
import random
import os
import pickle
import string
import requests
import collections
import io
import tarfile
import urllib.request
import text_helpers
from nltk.corpus import stopwords
sess = tf.Session()
```

2. We load the movie review corpus, just as we have done in the prior two recipes. Use the following code:

```
data_folder_name = 'temp'
if not os.path.exists(data_folder_name):
 os.makedirs(data_folder_name)
texts, target = text_helpers.load_movie_data(data_folder_name)
```

3. We declare the model parameters. See the following:

```
batch_size = 500
vocabulary_size = 7500
generations = 100000
model_learning_rate = 0.001
embedding_size = 200 # Word embedding size
doc_embedding_size = 100 # Document embedding size
concatenated_size = embedding_size + doc_embedding_size
num_sampled = int(batch_size/2)
window_size = 3 # How many words to consider to the left.
Add checkpoints to training
save_embeddings_every = 5000
print_valid_every = 5000
print_loss_every = 100
Declare stop words
stops = stopwords.words('english')
We pick a few test words.
valid_words = ['love', 'hate', 'happy', 'sad', 'man', 'woman']
```

4. We normalize the movie reviews and make sure that each movie review is larger than the desired window size. Use the following code:

```
texts = text_helpers.normalize_text(texts, stops)
Texts must contain at least as much as the prior window size
target = [target[ix] for ix, x in enumerate(texts) if len(x.
split()) > window_size]
texts = [x for x in texts if len(x.split()) > window_size]
assert(len(target)==len(texts))
```

5. Now we create our word dictionary. It is important to note that we do not have to create a document dictionary. The document indices will be just the index of the document; each document will have a unique index. See the following code:

```
word_dictionary = text_helpers.build_dictionary(texts, vocabulary_
size)
word_dictionary_rev = dict(zip(word_dictionary.values(), word_
dictionary.keys()))
text_data = text_helpers.text_to_numbers(texts, word_dictionary)
Get validation word keys
valid_examples = [word_dictionary[x] for x in valid_words]
```

6. Next we define our word embeddings and document embeddings. Then we declare our noise-contrastive loss parameters. Use the following code:

```
embeddings = tf.Variable(tf.random_uniform([vocabulary_size,
embedding_size], -1.0, 1.0))
doc_embeddings = tf.Variable(tf.random_uniform([len(texts)], doc_
embedding_size], -1.0, 1.0))
NCE loss parameters
nce_weights = tf.Variable(tf.truncated_normal([vocabulary_size,
concatenated_size],
stddev=1.0 /
np.sqrt(concatenated_size)))
nce_biases = tf.Variable(tf.zeros([vocabulary_size]))
```

7. We now declare our placeholders for the Doc2vec indices and target word index. Note that the size of the input indices is the window size plus one. This is because every data window we generate will have an additional document index with it, as follows:

```
x_inputs = tf.placeholder(tf.int32, shape=[None, window_size + 1])
y_target = tf.placeholder(tf.int32, shape=[None, 1])
valid_dataset = tf.constant(valid_examples, dtype=tf.int32)
```

8. Now we have to create our embedding function that adds together the word embeddings and then concatenates the document embedding at the end. Use the following code:

```
embed = tf.zeros([batch_size, embedding_size])
for element in range(window_size):
 embed += tf.nn.embedding_lookup(embeddings, x_inputs[:, element])
doc_indices = tf.slice(x_inputs, [0,window_size], [batch_size,1])
doc_embed = tf.nn.embedding_lookup(doc_embeddings, doc_indices)
concatenate embeddings
final_embed = tf.concat(1, [embed, tf.squeeze(doc_embed)])
```

9. We also need to declare the cosine distance from a set of validation words that we can print out every so often to observe the progress of our Doc2vec model. See the following code:

```
loss = tf.reduce_mean(tf.nn.nce_loss(nce_weights, nce_biases,
final_embed, y_target, num_sampled, vocabulary_size))

Create optimizer
optimizer =
tf.train.GradientDescentOptimizer(learning_rate=model_learning_
rate)
train_step = optimizer.minimize(loss)
```

10. We also need to declare the cosine distance from a set of validation words that we can print out every so often to observe the progress of our Doc2vec model. Use the following code:

```
norm = tf.sqrt(tf.reduce_sum(tf.square(embeddings), 1,
keep_dims=True))
normalized_embeddings = embeddings / norm
valid_embeddings = tf.nn.embedding_lookup(normalized_embeddings,
valid_dataset)
similarity = tf.matmul(valid_embeddings, normalized_embeddings,
transpose_b=True)
```

11. To save our embeddings for later, we create a model saver function. Then we can initialize the variables, the last step before we commence training on the word embeddings:

```
saver = tf.train.Saver({"embeddings": embeddings, "doc_"
embeddings":
doc_embeddings})
init = tf.initialize_all_variables()
sess.run(init)

Test
```

```
loss_vec = []
loss_x_vec = []
for i in range(generations):
 batch_inputs, batch_labels = text_helpers.generate_batch_
data(text_data, batch_size,
 window_size, method='doc2vec')
 feed_dict = {x_inputs : batch_inputs, y_target : batch_labels}

 # Run the train step
 sess.run(train_step, feed_dict=feed_dict)

 # Return the loss
 if (i+1) % print_loss_every == 0:
 loss_val = sess.run(loss, feed_dict=feed_dict)
 loss_vec.append(loss_val)
 loss_x_vec.append(i+1)
 print('Loss at step {} : {}'.format(i+1, loss_val))

 # Validation: Print some random words and top 5 related words
 if (i+1) % print_valid_every == 0:
 sim = sess.run(similarity, feed_dict=feed_dict)
 for j in range(len(valid_words)):
 valid_word = word_dictionary_rev[valid_examples[j]]
 top_k = 5 # number of nearest neighbors
 nearest = (-sim[j, :]).argsort()[1:top_k+1]
 log_str = "Nearest to {}".format(valid_word)
 for k in range(top_k):
 close_word = word_dictionary_rev[nearest[k]]
 log_str = '{} {}'.format(log_str, close_word)
 print(log_str)

 # Save dictionary + embeddings
 if (i+1) % save_embeddings_every == 0:
 # Save vocabulary dictionary
 with open(os.path.join(data_folder_name, 'movie_vocab.
pkl'), 'wb') as f:
 pickle.dump(word_dictionary, f)

 # Save embeddings
 model_checkpoint_path = os.path.join(os.getcwd(), data_
folder_name, 'doc2vec_movie_embeddings.ckpt')
 save_path = saver.save(sess, model_checkpoint_path)
 print('Model saved in file: {}'.format(save_path))
```

12. This results in the following output:

```
Loss at step 100 : 126.176816940307617
Loss at step 200 : 89.608322143554688
Loss at step 99900 : 17.733346939086914
Loss at step 100000 : 17.384489059448242
Nearest to love: ride, with, by, its, start,
Nearest to hate: redundant, snapshot, from, performances,
extravagant,
Nearest to happy: queen, chaos, them, succumb, elegance,
Nearest to sad: terms, pity, chord, wallet, morality,
Nearest to man: of, teen, an, our, physical,
Nearest to woman: innocuous, scenes, prove, except, lady,
Model saved in file: /.../temp/doc2vec_movie_embeddings.ckpt
```

13. Now that we have trained the Doc2vec embeddings, we can use these embeddings in a logistic regression to predict the review sentiment. First we set some parameters for the logistic regression. Use the following code:

```
max_words = 20 # maximum review word length
logistic_batch_size = 500 # training batch size
```

14. We now split the data set into a train and test set:

```
train_indices = np.sort(np.random.choice(len(target),
round(0.8*len(target)), replace=False))
test_indices = np.sort(np.array(list(set(range(len(target))) -
set(train_indices))))
texts_train = [x for ix, x in enumerate(texts) if ix in train_
indices]
texts_test = [x for ix, x in enumerate(texts) if ix in test_
indices]
target_train = np.array([x for ix, x in enumerate(target) if ix in
train_indices])
target_test = np.array([x for ix, x in enumerate(target) if ix in
test_indices])
```

15. Next we convert the reviews to numerical word indices and pad or crop each review to be 20 words, as follows:

```
text_data_train = np.array(text_helpers.text_to_numbers(texts_
train,
word_dictionary))
text_data_test = np.array(text_helpers.text_to_numbers(texts_test,
word_dictionary))
Pad/crop movie reviews to specific length
text_data_train = np.array([x[0:max_words] for x in [y+[0]*max_
words
for y in text_data_train]])
```

```
text_data_test = np.array([x[0:max_words] for x in [y+[0]*max_
words
for y in text_data_test]])
```

16. Now we declare the parts of the graph that pertain to the logistic regression model. We add the data placeholders, the variables, model operations, and the loss function as follows:

```
Define Logistic placeholders
log_x_inputs = tf.placeholder(tf.int32, shape=[None, max_words +
1])
log_y_target = tf.placeholder(tf.int32, shape=[None, 1])
A = tf.Variable(tf.random_normal(shape=[concatenated_size,1]))
b = tf.Variable(tf.random_normal(shape=[1,1]))

Declare logistic model (sigmoid in loss function)
model_output = tf.add(tf.matmul(log_final_embed, A), b)

Declare loss function (Cross Entropy loss)
logistic_loss = tf.reduce_mean(tf.nn.sigmoid_cross_entropy_with_
logits(model_output,
tf.cast(log_y_target, tf.float32)))
```

17. We need to create another embedding function. The embedding function in the first half is trained on a smaller window of three words (and a document index) to predict the next word. Here we will do the same but with the 20-word review. Use the following code:

```
Add together element embeddings in window:
log_embed = tf.zeros([logistic_batch_size, embedding_size])
for element in range(max_words):
 log_embed += tf.nn.embedding_lookup(embeddings, log_x_
inputs[:, element])
log_doc_indices = tf.slice(log_x_inputs, [0,max_words], [logistic_
batch_size,1])
log_doc_embed = tf.nn.embedding_lookup(doc_embeddings, log_doc_
indices)
concatenate embeddings
log_final_embed = tf.concat(1, [log_embed, tf.squeeze(log_doc_
embed)])
```

18. Next we create a prediction function and accuracy method on the graph so that we can evaluate the performance of the model as we run through the training generations. Then we declare an optimizing function and initialize all the variables:

```
prediction = tf.round(tf.sigmoid(model_output))
predictions_correct = tf.cast(tf.equal(prediction, tf.cast(log_y_
target, tf.float32)), tf.float32)
```

```
accuracy = tf.reduce_mean(predictions_correct)
Declare optimizer
logistic_opt = tf.train.GradientDescentOptimizer(learning_
rate=0.01)
logistic_train_step = logistic_opt.minimize(logistic_loss, var_
list=[A, b])
Initialize Variables
init = tf.initialize_all_variables()
sess.run(init)
```

19. Now we can start the logistic model training:

```
train_loss = []
test_loss = []
train_acc = []
test_acc = []
i_data = []
for i in range(10000):
 rand_index = np.random.choice(text_data_train.shape[0],
size=logistic_batch_size)
 rand_x = text_data_train[rand_index]
 # Append review index at the end of text data
 rand_x_doc_indices = train_indices[rand_index]
 rand_x = np.hstack((rand_x, np.transpose([rand_x_doc_
indices])))
 rand_y = np.transpose([target_train[rand_index]])

 feed_dict = {log_x_inputs : rand_x, log_y_target : rand_y}
 sess.run(logistic_train_step, feed_dict=feed_dict)

 # Only record loss and accuracy every 100 generations
 if (i+1)%100==0:
 rand_index_test = np.random.choice(text_data_test.
shape[0], size=logistic_batch_size)
 rand_x_test = text_data_test[rand_index_test]
 # Append review index at the end of text data
 rand_x_doc_indices_test = test_indices[rand_index_test]
 rand_x_test = np.hstack((rand_x_test,
np.transpose([rand_x_doc_indices_test])))
 rand_y_test = np.transpose([target_test[rand_index_test]])

 test_feed_dict = {log_x_inputs: rand_x_test, log_y_target:
rand_y_test}

 i_data.append(i+1)
 train_loss_temp = sess.run(logistic_loss, feed_dict=feed_
dict)
 train_loss.append(train_loss_temp)
```

```
 test_loss_temp = sess.run(logistic_loss, feed_dict=test_feed_dict)
 test_loss.append(test_loss_temp)

 train_acc_temp = sess.run(accuracy, feed_dict=feed_dict)
 train_acc.append(train_acc_temp)

 test_acc_temp = sess.run(accuracy, feed_dict=test_feed_dict)
 test_acc.append(test_acc_temp)
 if (i+1)%500==0:
 acc_and_loss = [i+1, train_loss_temp, test_loss_temp,
train_acc_temp, test_acc_temp]
 acc_and_loss = [np.round(x,2) for x in acc_and_loss]
 print('Generation # {}. Train Loss (Test Loss): {:.2f} ({:.2f}). Train Acc (Test Acc): {:.2f} ({:.2f})'.format(*acc_and_loss))
```

20. This results in the following output:

```
Generation # 500. Train Loss (Test Loss): 5.62 (7.45). Train Acc
(Test Acc): 0.52 (0.48)
Generation # 10000. Train Loss (Test Loss): 2.35 (2.51). Train Acc
(Test Acc): 0.59 (0.58)
```

21. We should also note that we have created a separate data batch generating method in the `text_helpers.generate_batch_data()` function called Doc2vec, which we used in the first part of this recipe to train the Doc2vec embeddings. Here is the excerpt from that function that pertains to this method:

```
def generate_batch_data(sentences, batch_size, window_size,
method='skip_gram'):
 # Fill up data batch
 batch_data = []
 label_data = []
 while len(batch_data) < batch_size:
 # select random sentence to start
 rand_sentence_ix = int(np.random.choice(len(sentences),
size=1))
 rand_sentence = sentences[rand_sentence_ix]
 # Generate consecutive windows to look at
 window_sequences = [rand_sentence[max((ix-window_size),0):(ix+window_size+1)] for ix, x in enumerate(rand_sentence)]
```

# Denote which element of each window is the center word  
if interest

```
label_indices = [ix if ix<window_size else window_size for ix,x in enumerate(window_sequences)]
```

```
Pull out center word of interest for each window and
create a tuple for each window
if method=='skip_gram':
 ...
elif method=='cbow':
 ...
elif method=='doc2vec':
 # For doc2vec we keep LHS window only to predict
 target word
 batch_and_labels = [(rand_sentence[i:i+window_size],
 rand_sentence[i+window_size]) for i in range(0, len(rand_
 sentence)-window_size)]
 batch, labels = [list(x) for x in zip(*batch_and_
 labels)]
 # Add document index to batch!! Remember that we must
 extract the last index in batch for the doc-index
 batch = [x + [rand_sentence_ix] for x in batch]
else:
 raise ValueError('Method {} not implemented
yet.'.format(method))

extract batch and labels
batch_data.extend(batch[:batch_size])
label_data.extend(labels[:batch_size])
Trim batch and label at the end
batch_data = batch_data[:batch_size]
label_data = label_data[:batch_size]

Convert to numpy array
batch_data = np.array(batch_data)
label_data = np.transpose(np.array([label_data]))

return(batch_data, label_data)
```

## How it works...

In this recipe, we performed two training loops. The first was to fit the Doc2vec embeddings, and the second loop was to fit the logistic regression on the movie sentiment.

While we did not increase the sentiment prediction accuracy by much (still slightly under 60%), we have successfully implemented the concatenation version of Doc2vec on the movie corpus. To increase our accuracy, we should try different parameters for the Doc2vec embeddings and possibly a more complicated model, as logistic regression may not be able to capture all the non-linear behavior in natural language.

# 8

## Convolutional Neural Networks

**Convolutional Neural Networks (CNNs)** are responsible for the major breakthroughs in image recognition made in the past few years. In this chapter we will cover:

- ▶ Implementing a Simpler CNN
- ▶ Implementing an Advanced CNN
- ▶ Retraining Existing CNN models
- ▶ Applying StyleNet/Neural-Style
- ▶ Implementing DeepDream

As a reminder, the reader may find all of the code for this chapter available online here:  
[https://github.com/nfmccclure/tensorflow\\_cookbook](https://github.com/nfmccclure/tensorflow_cookbook).

## Introduction

In mathematics, a convolution is a function which is applied over the output of another function. In our case, we will consider applying a matrix multiplication (filter) across an image. See the following diagram for a conceptual understanding of how image convolution can work:

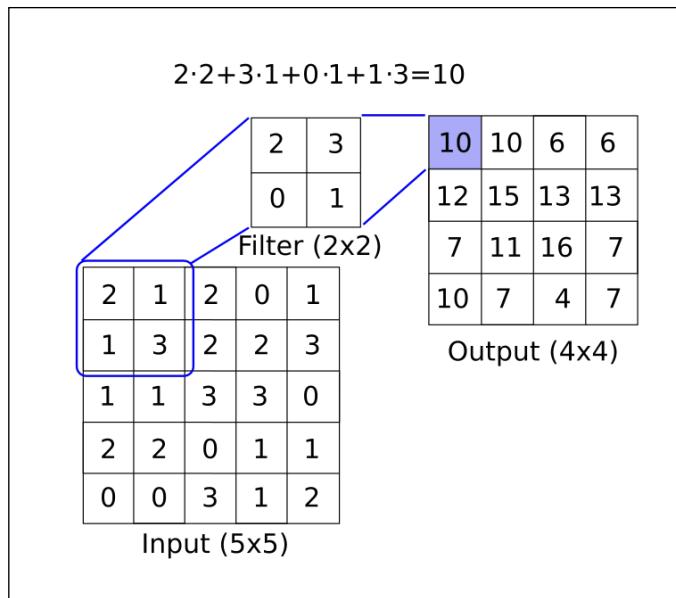


Figure 1: How a convolutional filter applied across an image (length by width by depth) operates to create a new feature layer. Here we have a 2x2 convolutional filter, operating in the valid spaces of the 5x5 input with stride 1 in both directions. The result is a 4x4 matrix.

Convolutional neural networks also have other operations that fulfill other necessities, such as introducing non-linearities (ReLU), or aggregating parameters (maxpool), and other similar operations. The preceding image is an example of applying a convolution operation on a 5x5 array with the convolutional filter being a 2x2 matrix. The step size is 1 and we only consider valid placements. The trainable variables in this operation would be the 2x2 filter weights. After a convolution, it is common to follow up with an aggregation operation, like maxpool. The following diagram provides an example of how maxpool operates:

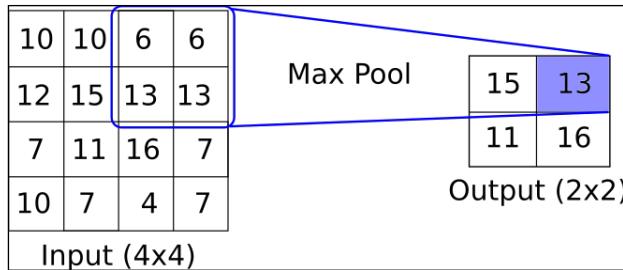
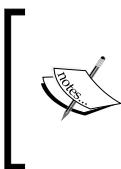


Figure 2: An example of how a max-pool operation could operate. Here we have a 2x2 window, operating on the valid spaces of a 4x4 input with stride 2 in both directions. The result is a 2x2 matrix.

Although we will start by creating our own CNN for image recognition, it is highly recommended to use existing architectures, as we will do in the remainder of the chapter.



It is common to take a pre-trained network and retrain it with a new dataset with a new fully connected layer at the end. This method is very useful and we will illustrate it in, the *Retraining existing CNN models* recipe, where we will retrain an existing architecture to improve on our CIFAR-10 predictions.



## Implementing a Simpler CNN

In this recipe, we will develop a four-layer convolutional neural network to improve upon our accuracy in predicting the MNIST digits. The first two convolution layers will each be compromised of Convolution-ReLU-maxpool operations and the final two layers will be fully connected layers.

### Getting ready

To access the MNIST data, TensorFlow has a contrib package that has great dataset loading functionalities. After we load the data, we will setup our model variables, create the model, train the model in batches, and then visualize loss, accuracy, and some sample digits.

### How to do it...

- First, we'll load the necessary libraries and start a graph session:

```
import matplotlib.pyplot as plt
import numpy as np
import tensorflow as tf
from tensorflow.contrib.learn.python.learn.datasets.mnist import
read_data_sets
sess = tf.Session()
```

- 
2. Next, we will load the data and transform the images into 28x28 arrays:

```
data_dir = 'temp'
mnist = read_data_sets(data_dir)
train_xdata = np.array([np.reshape(x, (28,28)) for x in mnist.train.images])
test_xdata = np.array([np.reshape(x, (28,28)) for x in mnist.test.images])
train_labels = mnist.train.labels
test_labels = mnist.test.labels
```



Note that the MNIST data set downloaded here also includes a validation set. This validation set is the same size as the test set. If we do any hyperparameter tuning or model selection, it would be wise to load this in as well for additional testing.

3. Now we'll set the model parameters. Remember that the depth of the image (number of channels) is 1 because these images are grayscale:

```
batch_size = 100
learning_rate = 0.005
evaluation_size = 500
image_width = train_xdata[0].shape[0]
image_height = train_xdata[0].shape[1]
target_size = max(train_labels) + 1
num_channels = 1
generations = 500
eval_every = 5
conv1_features = 25
conv2_features = 50
max_pool_size1 = 2
max_pool_size2 = 2
fully_connected_size1 = 100
```

4. We can now declare our placeholders for the data. We'll declare our training data variables and our test data variables. We will have different batch sizes for training and evaluation sizes. You may change these depending on the physical memory you have available for training and evaluating:

```
x_input_shape = (batch_size, image_width, image_height, num_channels)
x_input = tf.placeholder(tf.float32, shape=x_input_shape)
y_target = tf.placeholder(tf.int32, shape=(batch_size))
eval_input_shape = (evaluation_size, image_width, image_height,
num_channels)
eval_input = tf.placeholder(tf.float32, shape=eval_input_shape)
eval_target = tf.placeholder(tf.int32, shape=(evaluation_size))
```

5. We'll declare our convolution weights and biases with the parameters we set up in the previous steps:

```
conv1_weight = tf.Variable(tf.truncated_normal([4, 4, num_
channels, conv1_features], stddev=0.1, dtype=tf.float32))
conv1_bias = tf.Variable(tf.zeros([conv1_features], dtype=tf.
float32))

conv2_weight = tf.Variable(tf.truncated_normal([4, 4, conv1_
features, conv2_features], stddev=0.1, dtype=tf.float32))
conv2_bias = tf.Variable(tf.zeros([conv2_features], dtype=tf.
float32))
```

6. Next, we are going to declare our fully connected weights and biases for the last two layers of the model:

```
resulting_width = image_width // (max_pool_size1 * max_pool_size2)
resulting_height = image_height // (max_pool_size1 * max_pool_
size2)
full1_input_size = resulting_width * resulting_height*conv2_
features
full1_weight = tf.Variable(tf.truncated_normal([full1_input_size,
fully_connected_size1], stddev=0.1, dtype=tf.float32))
full1_bias = tf.Variable(tf.truncated_normal([fully_connected_-
size1], stddev=0.1, dtype=tf.float32))
full2_weight = tf.Variable(tf.truncated_normal([fully_connected_-
size1, target_size], stddev=0.1, dtype=tf.float32))
full2_bias = tf.Variable(tf.truncated_normal([target_size],
stddev=0.1, dtype=tf.float32))
```

7. Now we'll declare our model. We do this, first, by creating a `model` function. Note that the function will look in the global scope for the layer weights and biases necessary. Also, to get the fully connected layer to work, we transform the output of the second convolutional layer to be flat, so we can use it in the fully connected layer:

```
def my_conv_net(input_data):
 # First Conv-ReLU-MaxPool Layer
 conv1 = tf.nn.conv2d(input_data, conv1_weight, strides=[1, 1,
1, 1], padding='SAME')
 relu1 = tf.nn.relu(tf.nn.bias_add(conv1, conv1_bias))
 max_pool1 = tf.nn.max_pool(relu1, ksize=[1, max_pool_size1,
max_pool_size1, 1], strides=[1, max_pool_size1, max_pool_size1,
1], padding='SAME')
 # Second Conv-ReLU-MaxPool Layer
 conv2 = tf.nn.conv2d(max_pool1, conv2_weight, strides=[1, 1,
1, 1], padding='SAME')
 relu2 = tf.nn.relu(tf.nn.bias_add(conv2, conv2_bias))
 max_pool2 = tf.nn.max_pool(relu2, ksize=[1, max_pool_size2,
max_pool_size2, 1], strides=[1, max_pool_size2, max_pool_size2,
1], padding='SAME')
```

```
Transform Output into a 1xN layer for next fully connected
layer
final_conv_shape = max_pool2.get_shape().as_list()
final_shape = final_conv_shape[1] * final_conv_shape[2] *
final_conv_shape[3]
flat_output = tf.reshape(max_pool2, [final_conv_shape[0], final_shape])
First Fully Connected Layer
fully_connected1 = tf.nn.relu(tf.add(tf.matmul(flat_output, full1_weight), full1_bias))
Second Fully Connected Layer
final_model_output = tf.add(tf.matmul(fully_connected1, full2_weight), full2_bias)
return(final_model_output)
```

8. Next, we can declare the model on the training and test data:

```
model_output = my_conv_net(x_input)
test_model_output = my_conv_net(eval_input)
```

9. The loss function we will use is the softmax function. We use a sparse softmax because our predictions will be only one category and not multiple categories. We are also going to use a loss function that operates on logits and not the scaled probabilities:

```
loss = tf.reduce_mean(tf.nn.sparse_softmax_cross_entropy_with_
logits(model_output, y_target))
```

10. Next, we'll create a training and test\_prediction function. Then, we will also create an accuracy function to determine how accurate the model is on each batch:

```
prediction = tf.nn.softmax(model_output)
test_prediction = tf.nn.softmax(test_model_output)
Create accuracy function
def get_accuracy(logits, targets):
 batch_predictions = np.argmax(logits, axis=1)
 num_correct = np.sum(np.equal(batch_predictions, targets))
 return(100. * num_correct/batch_predictions.shape[0])
```

11. Now we can create the optimizer function, declare the training step and initialize all the model variables:

```
my_optimizer = tf.train.MomentumOptimizer(learning_rate, 0.9)
train_step = my_optimizer.minimize(loss)
Initialize Variables
init = tf.initialize_all_variables()
sess.run(init)
```

12. We can now start training our model. We loop through the data in randomly chosen batches. Every so often, we choose to evaluate the model on the train and test batches and record the accuracy and loss. We can see that, after 500 generations, we quickly achieve 96%-97% accuracy on the test data:

```
train_loss = []
train_acc = []
test_acc = []
for i in range(generations):
 rand_index = np.random.choice(len(train_xdata), size=batch_size)
 rand_x = train_xdata[rand_index]
 rand_x = np.expand_dims(rand_x, 3)
 rand_y = train_labels[rand_index]
 train_dict = {x_input: rand_x, y_target: rand_y}
 sess.run(train_step, feed_dict=train_dict)
 temp_train_loss, temp_train_preds = sess.run([loss, prediction], feed_dict=train_dict)
 temp_train_acc = get_accuracy(temp_train_preds, rand_y)
 if (i+1) % eval_every == 0:
 eval_index = np.random.choice(len(test_xdata), size=evaluation_size)
 eval_x = test_xdata[eval_index]
 eval_x = np.expand_dims(eval_x, 3)
 eval_y = test_labels[eval_index]
 test_dict = {eval_input: eval_x, eval_target: eval_y}
 test_preds = sess.run(test_prediction, feed_dict=test_dict)
 temp_test_acc = get_accuracy(test_preds, eval_y)
 # Record and print results
 train_loss.append(temp_train_loss)
 train_acc.append(temp_train_acc)
 test_acc.append(temp_test_acc)
 acc_and_loss = [(i+1), temp_train_loss, temp_train_acc, temp_test_acc]
 acc_and_loss = [np.round(x, 2) for x in acc_and_loss]
```

13. This results in the following output:

```
print('Generation # {}. Train Loss: {:.2f}. Train Acc (Test Acc): {:.2f} ({:.2f})'.format(*acc_and_loss))
Generation # 5. Train Loss: 2.37. Train Acc (Test Acc): 7.00 (9.80)
Generation # 10. Train Loss: 2.16. Train Acc (Test Acc): 31.00 (22.00)
Generation # 15. Train Loss: 2.11. Train Acc (Test Acc): 36.00 (35.20)
```

```
Generation # 490. Train Loss: 0.06. Train Acc (Test Acc): 98.00
(97.40)
Generation # 495. Train Loss: 0.10. Train Acc (Test Acc): 98.00
(95.40)
Generation # 500. Train Loss: 0.14. Train Acc (Test Acc): 98.00
(96.00)
```

14. Here is the code to plot the loss and accuracies using Matplotlib:

```
eval_indices = range(0, generations, eval_every)
Plot loss over time
plt.plot(eval_indices, train_loss, 'k-')
plt.title('Softmax Loss per Generation')
plt.xlabel('Generation')
plt.ylabel('Softmax Loss')
plt.show()

Plot train and test accuracy
plt.plot(eval_indices, train_acc, 'k-', label='Train Set
Accuracy')
plt.plot(eval_indices, test_acc, 'r--', label='Test Set Accuracy')
plt.title('Train and Test Accuracy')
plt.xlabel('Generation')
plt.ylabel('Accuracy')

plt.legend(loc='lower right')
plt.show()
```

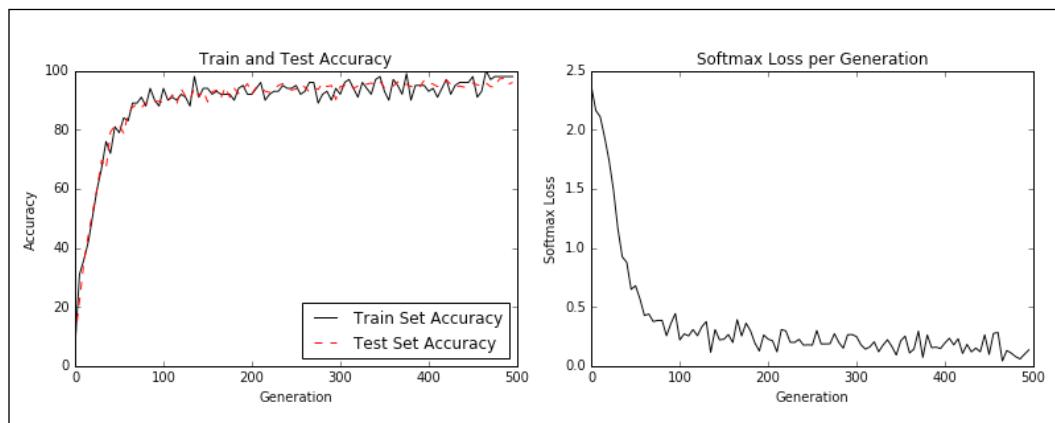


Figure 3: The left plot is the train and test set accuracy across our 500 training generations. The right plot is the softmax loss value over 500 generations.

15. If we want to plot a sample of the latest batch results, here is the code to plot a sample of six of the latest results:

```
Plot the 6 of the last batch results:
actuals = rand_y[0:6]
predictions = np.argmax(temp_train_preds, axis=1) [0:6]
images = np.squeeze(rand_x[0:6])
Nrows = 2
Ncols = 3
for i in range(6):
 plt.subplot(Nrows, Ncols, i+1)
 plt.imshow(np.reshape(images[i], [28,28]), cmap='Greys_r')
 plt.title('Actual: ' + str(actuals[i]) + ' Pred: ' + str(predictions[i]), fontsize=10)
 frame = plt.gca()
 frame.axes.get_xaxis().set_visible(False)
 frame.axes.get_yaxis().set_visible(False)
```

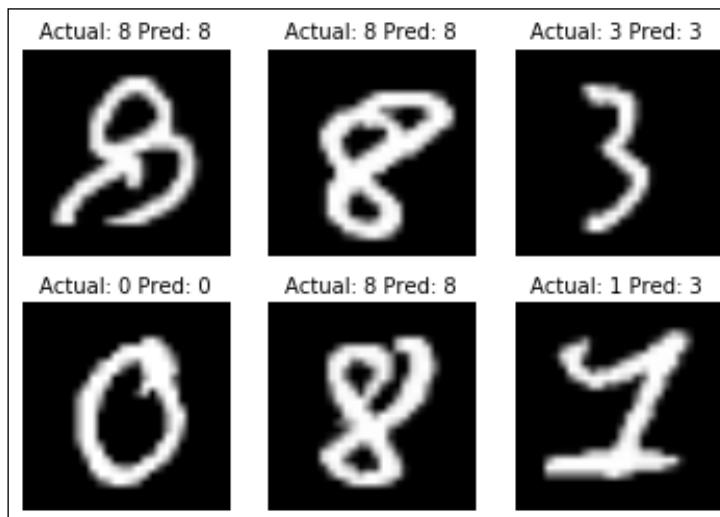


Figure 4: A plot of six random images with the actual and predicted values in the title. The lower right picture was predicted to be a '3', when in fact it is a '1'.

## How it works...

We increased our performance on the MNIST dataset and built a model that quickly achieves about 97% accuracy while training from scratch. Our first two layers are a combination of convolutions, ReLU, and maxpooling. The second two layers are fully connected layers. We trained in batches of size 100 and looked at the accuracy and loss across the generations we trained. Finally, we also plotted six random digits and the predictions/actuals for each.

A convolutional neural network does very well with image recognition. Part of the reason for this is that the convolutional layer creates its own low-level features that are activated when they come across part of the image that is important. This type of model creates features on its own and uses them for prediction.

### There's more...

CNN models have made vast strides in the past few years in image recognition. There are many novel ideas being explored and new architectures are discovered very frequently. A great repository of papers in this field is a repository website called Arxiv.org (<https://arxiv.org/>), which is created and maintained by Cornell University. Arxiv.org includes some very recent papers in many fields, including computer science and computer science subfields like *Computer Vision and Image Recognition* (<https://arxiv.org/list/cs.CV/recent>).

### See also

There are other great resources for learning about convolutional neural networks. Here is a list of some great resources:

- ▶ Stanford University has a great wiki at: [http://scarlet.stanford.edu/teach/index.php/An\\_Introduction\\_to\\_Convolutional\\_Neural\\_Networks](http://scarlet.stanford.edu/teach/index.php/An_Introduction_to_Convolutional_Neural_Networks)
- ▶ *Deep Learning* by Michael Nielsen, at: <http://neuralnetworksanddeeplearning.com/chap6.html>
- ▶ *An Introduction to Convolutional Neural Networks* by Jianxin Wu at: <http://cs.nju.edu.cn/wujx/paper/CNN.pdf>

## Implementing an Advanced CNN

It is important to be able to extend CNN models for image recognition so that we understand how to increase the depth of the network. This may increase the accuracy of our predictions if we have enough data. Extending the depth of CNN networks is done in a standard fashion: we just repeat the convolution, maxpool, ReLU series until we are satisfied with the depth. Many of the more accurate image recognition networks operate in this fashion.

### Getting ready

In this recipe, we will implement a more advanced method of reading image data and use a larger CNN to do image recognition on the CIFAR10 dataset (<https://www.cs.toronto.edu/~kriz/cifar.html>). This dataset has 60,000 32x32 images that fall into exactly one of ten possible classes. The potential classes for the images are airplane, automobile, bird, cat, deer, dog, frog, horse, ship, and truck. You can also refer to the first bullet point of the See also section.

Most image datasets will be too large to fit into memory. What we can do with TensorFlow is set up an image pipeline to read in a batch at a time from a file. We do this by essentially setting up an image reader and then creating a batch queue that operates on the image reader.

Also, with image recognition data, it is common to randomly perturb the image before sending it through for training. Here, we will randomly crop, flip, and change the brightness.

This recipe is an adapted version of the official TensorFlow CIFAR-10 tutorial, which is available under the *See also* section at the end of this chapter. We have condensed the tutorial into one script and will go through it line-by-line and explain all the code that is necessary. We also revert some constants and parameters to the original cited paper values, which we will point out in the following appropriated steps.

## How to do it...

1. To start with, we load the necessary libraries and start a graph session:

```
import os
import sys
import tarfile
import matplotlib.pyplot as plt
import numpy as np
import tensorflow as tf
from six.moves import urllib
sess = tf.Session()
```

2. Now we'll declare some of the model parameters. Our batch size will be 128 (for train and test). We will output a status every 50 generations and run for a total of 20,000 generations. Every 500 generations, we'll evaluate on a batch of the test data. We'll then declare some image parameters, height and width, and what size the random cropped images will take. There are three channels (red, green, and blue), and we have ten different targets. Then, we'll declare where we will store the data and image batches from the queue:

```
batch_size = 128
output_every = 50
generations = 20000
eval_every = 500
image_height = 32
image_width = 32
crop_height = 24
crop_width = 24
num_channels = 3
num_targets = 10
data_dir = 'temp'
extract_folder = 'cifar-10-batches-bin'
```

- 
3. It is recommended to lower the learning rate as we progress towards a good model, so we will exponentially decrease the learning rate: the initial learning rate will be set at 0.1, and we will exponentially decrease it by a factor of 10% every 250 generations. The exact formula will be given by  $0.1 \cdot 0.9^{\frac{x}{250}}$  where x is the current generation number. The default is for this to continually decrease, but TensorFlow does accept a `staircase` argument which only updates the learning rate:

```
learning_rate = 0.1
lr_decay = 0.9
num_gens_to_wait = 250.
```

4. Now we'll set up parameters so that we can read in the binary CIFAR-10 images:

```
image_vec_length = image_height * image_width * num_channels
record_length = 1 + image_vec_length
```

5. Next, we'll set up the data directory and the URL to download the CIFAR-10 images, if we don't have them already:

```
data_dir = 'temp'
if not os.path.exists(data_dir):
 os.makedirs(data_dir)
cifar10_url = 'http://www.cs.toronto.edu/~kriz/cifar-10-binary.tar.gz'
data_file = os.path.join(data_dir, 'cifar-10-binary.tar.gz')
if not os.path.isfile(data_file):
 # Download file
 filepath, _ = urllib.request.urlretrieve(cifar10_url, data_file, progress)
 # Extract file
 tarfile.open(filepath, 'r:gz').extractall(data_dir)
```

6. We'll set up the record reader and return a randomly distorted image with the following `read_cifar_files()` function. First, we need to declare a record reader object that will read in a fixed length of bytes. After we read the image queue, we'll split apart the image and label. Finally, we will randomly distort the image with TensorFlow's built in image modification functions:

```
def read_cifar_files(filename_queue, distort_images = True):
 reader = tf.FixedLengthRecordReader(record_bytes=record_length)
 key, record_string = reader.read(filename_queue)
 record_bytes = tf.decode_raw(record_string, tf.uint8)
 # Extract label
 image_label = tf.cast(tf.slice(record_bytes, [0], [1]), tf.int32)
 # Extract image
```

```
 image_extracted = tf.reshape(tf.slice(record_bytes, [1],
[image_vec_length]), [num_channels, image_height, image_width])
 # Reshape image
 image_uint8image = tf.transpose(image_extracted, [1, 2, 0])
 reshaped_image = tf.cast(image_uint8image, tf.float32)
 # Randomly Crop image
 final_image = tf.image.resize_image_with_crop_or_pad(reshaped_
image, crop_width, crop_height)
 if distort_images:
 # Randomly flip the image horizontally, change the
 brightness and contrast
 final_image = tf.image.random_flip_left_right(final_image)
 final_image = tf.image.random_brightness(final_image,max_
delta=63)
 final_image = tf.image.random_contrast(final_
image,lower=0.2, upper=1.8)
 # Normalize whitening
 final_image = tf.image.per_image_whitening(final_image)
 return(final_image, image_label)
```

7. Now we'll declare a function that will populate our image pipeline for the batch processor to use. We first need to set up the file list of images we want to read through, and to define how to read them with an input producer object, created through prebuilt TensorFlow functions. The input producer can be passed into the reading function that we created in the preceding step, `read_cifar_files()`. We'll then set a batch reader on the queue, `shuffle_batch()`:

```
def input_pipeline(batch_size, train_logical=True):
 if train_logical:
 files = [os.path.join(data_dir, extract_folder, 'data_'
batch_{}.bin'.format(i)) for i in range(1,6)]
 else:
 files = [os.path.join(data_dir, extract_folder, 'test_'
batch.bin')]
 filename_queue = tf.train.string_input_producer(files)
 image, label = read_cifar_files(filename_queue)

 min_after_dequeue = 1000
 capacity = min_after_dequeue + 3 * batch_size
 example_batch, label_batch = tf.train.shuffle_batch([image,
label], batch_size, capacity, min_after_dequeue)
 return(example_batch, label_batch)
```

 It is important to set the `min_after_dequeue` properly. This parameter is responsible for setting the minimum size of an image buffer for sampling. The official TensorFlow documentation recommends setting it to `(#threads + error margin) *batch_size`. Note that setting it to a larger size results in more uniform shuffling, as it is shuffling from a larger set of data in the queue, but that more memory will also be used in the process.

8. Next, we can declare our `model` function. The model we will use has two convolutional layers, followed by three fully connected layers. To make variable declaration easier, we'll start by declaring two variable functions. The two convolutional layers will create 64 features each. The first fully connected layer will connect the 2nd convolutional layer with 384 hidden nodes. The second fully connected operation will connect those 384 hidden nodes to 192 hidden nodes. The final hidden layer operation will then connect the 192 nodes to the 10 output classes we are trying to predict. See the following inline comments marked with #:

```
def cifar_cnn_model(input_images, batch_size, train_logical=True):
 def truncated_normal_var(name, shape, dtype):
 return(tf.get_variable(name=name, shape=shape,
 dtype=dtype, initializer=tf.truncated_normal_
 initializer(stddev=0.05)))
 def zero_var(name, shape, dtype):
 return(tf.get_variable(name=name, shape=shape,
 dtype=dtype, initializer=tf.constant_initializer(0.0)))
 # First Convolutional Layer
 with tf.variable_scope('conv1') as scope:
 # Conv_kernel is 5x5 for all 3 colors and we will create
 64 features
 conv1_kernel = truncated_normal_var(name='conv_kernel1',
 shape=[5, 5, 3, 64], dtype=tf.float32)
 # We convolve across the image with a stride size of 1
 conv1 = tf.nn.conv2d(input_images, conv1_kernel, [1, 1, 1,
 1], padding='SAME')
 # Initialize and add the bias term
 conv1_bias = zero_var(name='conv_bias1', shape=[64],
 dtype=tf.float32)
 conv1_add_bias = tf.nn.bias_add(conv1, conv1_bias)
 # ReLU element wise
 relu_conv1 = tf.nn.relu(conv1_add_bias)
 # Max Pooling
 pool1 = tf.nn.max_pool(relu_conv1, ksize=[1, 3, 3, 1],
 strides=[1, 2, 2, 1], padding='SAME', name='pool_layer1')

 # Local Response Normalization
```

```
norm1 = tf.nn.lrn(pool1, depth_radius=5, bias=2.0, alpha=1e-3,
beta=0.75, name='norm1')
Second Convolutional Layer
with tf.variable_scope('conv2') as scope:
 # Conv kernel is 5x5, across all prior 64 features and we
 # create 64 more features
 conv2_kernel = truncated_normal_var(name='conv_kernel2',
shape=[5, 5, 64, 64], dtype=tf.float32)
 # Convolve filter across prior output with stride size of
 1
 conv2 = tf.nn.conv2d(norm1, conv2_kernel, [1, 1, 1, 1],
padding='SAME')
 # Initialize and add the bias
 conv2_bias = zero_var(name='conv_bias2', shape=[64],
dtype=tf.float32)
 conv2_add_bias = tf.nn.bias_add(conv2, conv2_bias)
 # ReLU element wise
 relu_conv2 = tf.nn.relu(conv2_add_bias)
 # Max Pooling
 pool2 = tf.nn.max_pool(relu_conv2, ksize=[1, 3, 3, 1],
strides=[1, 2, 2, 1], padding='SAME', name='pool_layer2')
 # Local Response Normalization (parameters from paper)
 norm2 = tf.nn.lrn(pool2, depth_radius=5, bias=2.0, alpha=1e-3,
beta=0.75, name='norm2')
 # Reshape output into a single matrix for multiplication for
 # the fully connected layers
 reshaped_output = tf.reshape(norm2, [batch_size, -1])
 reshaped_dim = reshaped_output.get_shape()[1].value

 # First Fully Connected Layer
 with tf.variable_scope('full1') as scope:
 # Fully connected layer will have 384 outputs.
 full_weight1 = truncated_normal_var(name='full_mult1',
shape=[reshaped_dim, 384], dtype=tf.float32)
 full_bias1 = zero_var(name='full_bias1', shape=[384],
dtype=tf.float32)
 full_layer1 = tf.nn.relu(tf.add(tf.matmul(reshaped_output,
full_weight1), full_bias1))
 # Second Fully Connected Layer
 with tf.variable_scope('full2') as scope:
 # Second fully connected layer has 192 outputs.
 full_weight2 = truncated_normal_var(name='full_mult2',
shape=[384, 192], dtype=tf.float32)
 full_bias2 = zero_var(name='full_bias2', shape=[192],
dtype=tf.float32)
```

```

 full_layer2 = tf.nn.relu(tf.add(tf.matmul(full_layer1,
full_weight2), full_bias2))
 # Final Fully Connected Layer -> 10 categories for output
(num_targets)
 with tf.variable_scope('full3') as scope:
 # Final fully connected layer has 10 (num_targets)
outputs.
 full_weight3 = truncated_normal_var(name='full_mult3',
shape=[192, num_targets], dtype=tf.float32)
 full_bias3 = zero_var(name='full_bias3', shape=[num_
targets], dtype=tf.float32)
 final_output = tf.add(tf.matmul(full_layer2, full_
weight3), full_bias3)

 return(final_output)

```



Our local response normalization parameters are taken from the paper and are referenced in See also (3).

- Now we'll create the `loss` function. We will use the `softmax` function because a picture can only take on exactly one category, so the output should be a probability distribution over the ten targets:

```

def cifar_loss(logits, targets):
 # Get rid of extra dimensions and cast targets into integers
 targets = tf.squeeze(tf.cast(targets, tf.int32))
 # Calculate cross entropy from logits and targets
 cross_entropy = tf.nn.sparse_softmax_cross_entropy_with_
logits(logits, targets)
 # Take the average loss across batch size
 cross_entropy_mean = tf.reduce_mean(cross_entropy)
 return(cross_entropy_mean)

```

- Next, we declare our training step. The learning rate will decrease in an exponential step function:

```

def train_step(loss_value, generation_num):
 # Our learning rate is an exponential decay (stepped down)
 model_learning_rate = tf.train.exponential_decay(learning_
rate, generation_num, num_gens_to_wait, lr_decay, staircase=True)
 # Create optimizer
 my_optimizer = tf.train.GradientDescentOptimizer(model_-
learning_rate)
 # Initialize train step
 train_step = my_optimizer.minimize(loss_value)
 return(train_step)

```

11. We must also have an accuracy function that calculates the accuracy across a batch of images. We'll input the logits and target vectors, and output an averaged accuracy. We can then use this for both the train and test batches:

```
def accuracy_of_batch(logits, targets):
 # Make sure targets are integers and drop extra dimensions
 targets = tf.squeeze(tf.cast(targets, tf.int32))
 # Get predicted values by finding which logit is the greatest
 batch_predictions = tf.cast(tf.argmax(logits, 1), tf.int32)
 # Check if they are equal across the batch
 predicted_correctly = tf.equal(batch_predictions, targets)
 # Average the 1's and 0's (True's and False's) across the
 batch size
 accuracy = tf.reduce_mean(tf.cast(predicted_correctly,
 tf.float32))
 return(accuracy)
```

12. Now that we have an `imagepipeline` function, we can initialize both the training image pipeline and the test image pipeline:

```
images, targets = input_pipeline(batch_size, train_logical=True)
test_images, test_targets = input_pipeline(batch_size, train_
logical=False)
```

13. Next, we'll initialize the model for the training output and the test output. It is important to note that we must declare `scope.reuse_variables()` after we create the training model so that, when we declare the model for the test network, it will use the same model parameters:

```
with tf.variable_scope('model_definition') as scope:
 # Declare the training network model
 model_output = cifar_cnn_model(images, batch_size)
 # Use same variables within scope
 scope.reuse_variables()
 # Declare test model output
 test_output = cifar_cnn_model(test_images, batch_size)
```

14. We can now initialize our loss and test accuracy functions. Then we'll declare the generation variable. This variable needs to be declared as non-trainable, and passed to our training function that uses it in the learning rate exponential decay calculation:

```
loss = cifar_loss(model_output, targets)
accuracy = accuracy_of_batch(test_output, test_targets)
generation_num = tf.Variable(0, trainable=False)
train_op = train_step(loss, generation_num)
```

15. We'll now initialize all of the model's variables and then start the image pipeline by running the TensorFlow function, `start_queue_runners()`. When we start the train or test model output, the pipeline will feed in a batch of images in place of a feed dictionary:

```
init = tf.initialize_all_variables()
sess.run(init)
tf.train.start_queue_runners(sess=sess)
```

16. We now loop through our training generations and save the training loss and the test accuracy:

```
train_loss = []
test_accuracy = []
for i in range(generations):
 _, loss_value = sess.run([train_op, loss])
 if (i+1) % output_every == 0:
 train_loss.append(loss_value)
 output = 'Generation {}: Loss = {:.5f}'.format((i+1),
loss_value)
 print(output)
 if (i+1) % eval_every == 0:
 [temp_accuracy] = sess.run([accuracy])
 test_accuracy.append(temp_accuracy)
 acc_output = ' --- Test Accuracy= {:.2f}%.'.format(100.*temp_accuracy)
 print(acc_output)
```

17. This results in the following output:

```
Generation 19500: Loss = 0.04461
--- Test Accuracy = 80.47%.
Generation 19550: Loss = 0.01171
Generation 19600: Loss = 0.06911
Generation 19650: Loss = 0.08629
Generation 19700: Loss = 0.05296
Generation 19750: Loss = 0.03462
Generation 19800: Loss = 0.03182
Generation 19850: Loss = 0.07092
Generation 19900: Loss = 0.11342
Generation 19950: Loss = 0.08751
Generation 20000: Loss = 0.02228
--- Test Accuracy = 83.59%.
```

18. Finally, here is some `matplotlib` code that will plot the loss and test accuracy over the course of the training:

```
eval_indices = range(0, generations, eval_every)
output_indices = range(0, generations, output_every)
Plot loss over time
plt.plot(output_indices, train_loss, 'k-')
plt.title('Softmax Loss per Generation')
plt.xlabel('Generation')
plt.ylabel('Softmax Loss')
plt.show()
Plot accuracy over time
plt.plot(eval_indices, test_accuracy, 'k-')
plt.title('Test Accuracy')
plt.xlabel('Generation')
plt.ylabel('Accuracy')
plt.show()
```

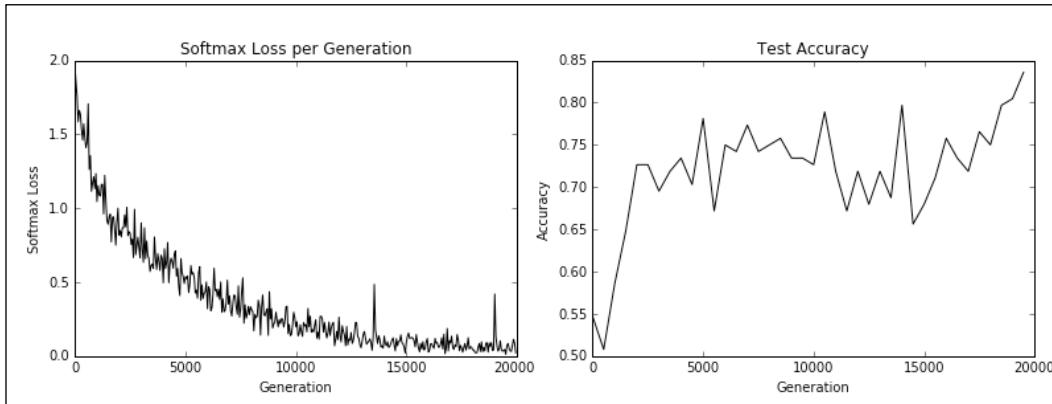


Figure 5: The training loss is on the left and the test accuracy is on the right. For the CIFAR-10 image recognition CNN, we were able to achieve a model that reaches around 75% accuracy on the test set.

## How it works...

After we downloaded the CIFAR-10 data, we established an image pipeline instead of using a feed dictionary. For more information on the image pipeline, please see the official TensorFlow CIFAR-10 tutorials. We used this train and test pipeline to try to predict the correct category of the images. By the end, the model had achieved around 75% accuracy on the test set.

## See also

- ▶ For more information about the CIFAR-10 dataset, please see *Learning Multiple Layers of Features from Tiny Images*, Alex Krizhevsky, 2009. <https://www.cs.toronto.edu/~kriz/learning-features-2009-TR.pdf>
- ▶ To see original TensorFlow code, visit <https://github.com/tensorflow/tensorflow/tree/r0.11/tensorflow/models/image/cifar10>
- ▶ For more on local response normalization, please see, *ImageNet Classification with Deep Convolutional Neural Networks*, Krizhevsky, A., et. al. 2012. <http://papers.nips.cc/paper/4824-imagenet-classification-with-deep-convolutional-neural-networks>

## Retraining Existing CNNs models

Training a new image recognition from scratch requires a lot of time and computational power. If we can take a prior trained network and retrain it with our images, it could save us computational time. For this recipe, we will show how to use a pre-trained TensorFlow image recognition model and fine-tune it to work on a different set of images.

### Getting ready

Training a new image recognition from scratch requires a lot of time and computational power. If we can take a prior trained network and retrain it with our images, it could save us computational time. The idea is to reuse the weights and structure of a prior model from the convolutional layers and retrain the fully connected layers at the top of the network.

TensorFlow has created a tutorial about training on top of existing CNN models (refer to the first bullet point of the See also section). In this recipe, we will illustrate how to use the same methodology for CIFAR-10. The CNN network we are going to employ uses a very popular architecture called **Inception**. The Inception CNN model was created by Google and has performed very well in many image recognition benchmarks. For details, see the paper referenced in the second bullet point of See also section.

The main Python script we will cover shows how to download the CIFAR-10 image data and automatically separate, label, and save the images into the ten classes in each of the train and test folders. After that, we will reiterate how to train the network on our images.

## How to do it...

1. We'll start by loading the necessary libraries for downloading, unzipping, and saving the CIFAR-10 images:

```
import os
import tarfile
import _pickle as cPickle
import numpy as np
import urllib.request
import scipy.misc
```

2. We now declare the CIFAR-10 data link and make the temporary directory we will store the data in. We'll also declare the ten categories to reference for saving the images later on:

```
cifar_link = 'https://www.cs.toronto.edu/~kriz/cifar-10-python.tar.gz'
data_dir = 'temp'
if not os.path.isdir(data_dir):
 os.makedirs(data_dir)
objects = ['airplane', 'automobile', 'bird', 'cat', 'deer', 'dog',
'frog', 'horse', 'ship', 'truck']
```

3. Now we'll download the CIFAR-10 .tar data file, and un-tar the file:

```
target_file = os.path.join(data_dir, 'cifar-10-python.tar.gz')
if not os.path.isfile(target_file):
 print('CIFAR-10 file not found. Downloading CIFAR data (Size =
163MB)')
 print('This may take a few minutes, please wait.')
 filename, headers = urllib.request.urlretrieve(cifar_link,
target_file)
Extract into memory
tar = tarfile.open(target_file)
tar.extractall(path=data_dir)
tar.close()
```

4. We now create the necessary folder structure for training. The temporary directory will have two folders, `train_dir` and `validation_dir`. In each of these folders, we will create the ten sub-folders for each category:

```
Create train image folders
train_folder = 'train_dir'
if not os.path.isdir(os.path.join(data_dir, train_folder)):
 for i in range(10):
 folder = os.path.join(data_dir, train_folder, objects[i])
```

```
 os.makedirs(folder)
Create test image folders
test_folder = 'validation_dir'
if not os.path.isdir(os.path.join(data_dir, test_folder)):
 for i in range(10):
 folder = os.path.join(data_dir, test_folder, objects[i])
 os.makedirs(folder)
```

5. In order to save the images, we will create a function that will load them from memory and store them in an image dictionary:

```
def load_batch_from_file(file):
 file_conn = open(file, 'rb')
 image_dictionary = cPickle.load(file_conn, encoding='latin1')
 file_conn.close()
 return(image_dictionary)
```

6. With the above dictionary, we will save each of the files in the correct location with the following function:

```
def save_images_from_dict(image_dict, folder='data_dir'):

 for ix, label in enumerate(image_dict['labels']):
 folder_path = os.path.join(data_dir, folder,
objects[label])
 filename = image_dict['filenames'][ix]
 #Transform image data
 image_array = image_dict['data'][ix]
 image_array.resize([3, 32, 32])
 # Save image
 output_location = os.path.join(folder_path, filename)
 scipy.misc.imsave(output_location, image_array.transpose())
```

7. With the preceding functions, we can loop through the downloaded data files and save each image to the correct location:

```
data_location = os.path.join(data_dir, 'cifar-10-batches-py')
train_names = ['data_batch_' + str(x) for x in range(1,6)]
test_names = ['test_batch']
Sort train images
for file in train_names:
 print('Saving images from file: {}'.format(file))
 file_location = os.path.join(data_dir, 'cifar-10-batches-py',
file)
 image_dict = load_batch_from_file(file_location)
 save_images_from_dict(image_dict, folder=train_folder)
Sort test images
```

```
for file in test_names:
 print('Saving images from file: {}'.format(file))
 file_location = os.path.join(data_dir, 'cifar-10-batches-py',
file)
 image_dict = load_batch_from_file(file_location)
 save_images_from_dict(image_dict, folder=test_folder)
```

8. The last part of our script creates the label file, and this is the last piece of information that we will need. This file will let us interpret the outputs as labels instead of the numerical indices:

```
cifar_labels_file = os.path.join(data_dir, 'cifar10_labels.txt')
print('Writing labels file, {}'.format(cifar_labels_file))
with open(cifar_labels_file, 'w') as labels_file:
 for item in objects:
 labels_file.write("{}\n".format(item))
```

9. When the above script is run, it will download the images and sort them into the correct folder structure that the TensorFlow retraining tutorial expects. Once we have done this, we just follow the tutorial accordingly. First we should clone the tutorial repository:

```
git clone https://github.com/tensorflow/models/tree/master/
inception/inception
```

10. In order to use a prior trained model, we must download the network weights and apply it to our model:

```
me@computer:~$ curl -O http://download.tensorflow.org/models/
image/imagenet/inception-v3-2016-03-01.tar.gz
me@computer:~$ tar xzf inception-v3-2016-03-01.tar.gz
```

11. Now that we have the images in the correct folder structure, we have to turn them into a TFRecords object. We do this by running the following commands:

```
me@computer:~$ python3 data/build_image_data.py
--train_directory="temp/train_dir/"
--validation_directory="temp/validation_dir"
--output_directory="temp/" --labels_file="temp/cifar10_labels.txt"
```

12. Now we'll train the model using `bazel`, setting the parameter '`train`' to true. This script outputs the loss every 10 generations. We can kill this process at any time and the model output will be in the folder `temp/training_results`. We can load the model from this folder for evaluation:

```
me@computer:~$ bazel-bin/inception/flowers_train
--train_dir="temp/training_results" --data_dir="temp/data_dir"
```

```
--pretrained_model_checkpoint_path="model.ckpt-157585"
--fine_tune=True --initial_learning_rate=0.001
--input_queue_memory_factor=1
```

13. This should result in output similar to the following:

```
2016-09-18 12:16:32.563577: step 1290, loss = 2.02 (1.2 examples/
sec; 26.965 sec/batch)
2016-09-18 12:25:41.316540: step 1300, loss = 2.01 (1.2 examples/
sec; 26.357 sec/batch)
```

## How it works...

The official TensorFlow tutorial for training on top of a pre-trained CNN requires a folder setup that we created from the CIFAR-10 data. We then converted the data into the required TFRecords format and started training the model. Remember that we are fine-tuning the model and retraining the fully connected layers at the top to fit our 10-category data.

## See also

- ▶ Official Tensorflow Inception-v3 tutorial: <https://github.com/tensorflow/models/tree/master/inception>
- ▶ Googlenet Inception-v3 paper: <https://arxiv.org/abs/1512.00567>

## Applying StyleNet/Neural-Style

Once we have an image recognition CNN trained, we can use the network itself for some interesting data and image processing. StyleNet is a procedure that attempts to learn an image style from one picture and apply it to a second picture while keeping the second image structure (or content). This may be possible if we can find intermediate CNN nodes that correlate strongly with a style separately from the content of the image.

## Getting ready

StyleNet is a procedure that takes two images and applies the style of one image to the content of the second image. It is based on a famous paper in 2015, *A Neural Algorithm of Artistic Style* (refer to the first bullet point under See also section). The authors found a property of some CNNs where intermediate layers exist that seem to encode the style of a picture and some encode the content of the picture. To this end, if we train the style layers on the style picture and the content layers on the original image, and back-propagate those calculated losses, we can change the original image to be more like the style image.

In order to accomplish this, we will download the recommended network from the paper, called the imangenet-vgg-19. There is also an imangenet-vgg-16 network that works as well, but the paper recommends imangenet-vgg-19.

## How to do it...

1. First, we'll download the pretrained network in \*.mat format. The mat format is a matlab object, and the `scipy` package in Python has a method that can read it. The link to download the mat object is here. We save this model in the same folder our Python script is for reference:

```
http://www.vlfeat.org/matconvnet/models/beta16/imagenet-vgg-verydeep-19.mat
```

2. We'll start our Python script by loading the necessary libraries:

```
import os
import scipy.misc
import numpy as np
import tensorflow as tf
```

3. Then we can start a graph session and declare the locations of our two images: the original image and the style image. For our purposes, we will use the cover image of this book for the original image; for the style image, we will use *Starry Night* by Vincent van Gough. Feel free to use any two pictures you want here. If you choose to use these pictures, they are available on the book's github site, [https://github.com/nfmccclure/tensorflow\\_cookbook](https://github.com/nfmccclure/tensorflow_cookbook) (Navigate to stylenet section):

```
sess = tf.Session()
original_image_file = 'temp/book_cover.jpg'
style_image_file = 'temp/starry_night.jpg'
```

4. We'll set some parameters for our model: the location of the mat file, weights, the learning rate, number of generations, and how frequently we should output the intermediate image. For the weights, it helps to highly weight the style image over the original image. These hyperparameters should be tuned for changes in the desired result:

```
vgg_path ='imagenet-vgg-verydeep-19.mat'
original_image_weight = 5.0
style_image_weight = 200.0
regularization_weight = 50.0
learning_rate = 0.1
generations = 10000
output_generations = 500
```

5. Now we'll load the two images with `scipy` and change the style image to fit the original image dimensions:

```
original_image = scipy.misc.imread(original_image_file)
style_image = scipy.misc.imread(style_image_file)
Get shape of target and make the style image the same
target_shape = original_image.shape
style_image = scipy.misc.imresize(style_image, target_shape[1] /
style_image.shape[1])
```

6. From the paper, we can define the layers in order of how they appeared. We'll use the author's naming convention:

```
vgg_layers = ['conv1_1', 'relu1_1',
'conv1_2', 'relu1_2', 'pool1',
'conv2_1', 'relu2_1',
'conv2_2', 'relu2_2', 'pool2',
'conv3_1', 'relu3_1',
'conv3_2', 'relu3_2',
'conv3_3', 'relu3_3',
'conv3_4', 'relu3_4', 'pool3',
'conv4_1', 'relu4_1',
'conv4_2', 'relu4_2',
'conv4_3', 'relu4_3',
'conv4_4', 'relu4_4', 'pool4',
'conv5_1', 'relu5_1',
'conv5_2', 'relu5_2',
'conv5_3', 'relu5_3',
'conv5_4', 'relu5_4']
```

7. Now we'll define a function that will extract the parameters from the `mat` file:

```
def extract_net_info(path_to_params):
 vgg_data = scipy.io.loadmat(path_to_params)
 normalization_matrix = vgg_data['normalization'][0][0][0]
 mat_mean = np.mean(normalization_matrix, axis=(0,1))
 network_weights = vgg_data['layers'][0]
 return(mat_mean, network_weights)
```

8. From the loaded weights and the layer definitions, we can recreate the network in TensorFlow with the following function. We'll loop through each layer and assign the corresponding function with appropriate weights and biases, where applicable:

```
def vgg_network(network_weights, init_image):
 network = {}
 image = init_image
 for i, layer in enumerate(vgg_layers):
 if layer[1] == 'c':
```

```
weights, bias = network_weights[i][0][0][0][0]
weights = np.transpose(weights, (1, 0, 2, 3))
bias = bias.reshape(-1)
conv_layer = tf.nn.conv2d(image, tf.constant(weights),
(1, 1, 1, 1), 'SAME')
image = tf.nn.bias_add(conv_layer, bias)
elif layer[1] == 'r':
 image = tf.nn.relu(image)
else:
 image = tf.nn.max_pool(image, (1, 2, 2, 1), (1, 2, 2,
1), 'SAME')
network[layer] = image
return(network)
```

9. The paper recommends a few strategies of assigning intermediate layers to the original and style images. While we should keep `relu4_2` for the original image, we can try different combinations of the other `reluX_1` layer outputs for the style image:

```
original_layer = 'relu4_2'
style_layers = ['relu1_1', 'relu2_1', 'relu3_1', 'relu4_1',
'relu5_1']
```

10. Next, we'll run the above function to get the weights and mean. We'll also change the image shapes to have four dimensions by adding a dimension of size one to the beginning. TensorFlow's image operations act on four dimensions, so we must add the batch-size dimension:

```
normalization_mean, network_weights = extract_net_info(vgg_path)
shape = (1,) + original_image.shape
style_shape = (1,) + style_image.shape
original_features = {}
style_features = {}
```

11. Next, we declare the `image` placeholder and create the network with that placeholder:

```
image = tf.placeholder('float', shape=shape)
vgg_net = vgg_network(network_weights, image)
```

12. We now normalize the original image matrix and run it through the network:

```
original_minus_mean = original_image - normalization_mean
original_norm = np.array([original_minus_mean])
original_features[original_layer] = sess.run(vgg_net[original_layer],
feed_dict={image: original_norm})
```

13. We repeat the same procedure with each of the style layers that we chose in Step 9:

```
image = tf.placeholder('float', shape=style_shape)
vgg_net = vgg_network(network_weights, image)
style_minus_mean = style_image - normalization_mean
style_norm = np.array([style_minus_mean])
for layer in style_layers:
 layer_output = sess.run(vgg_net[layer], feed_dict={image:
style_norm})
 layer_output = np.reshape(layer_output, (-1, layer_output.
shape[3]))
 style_gram_matrix = np.matmul(layer_output.T, layer_output) /
layer_output.size
 style_features[layer] = style_gram_matrix
```

14. In order to create the combined image, we'll start with random noise and run it through the network:

```
initial = tf.random_normal(shape) * 0.05
image = tf.Variable(initial)
vgg_net = vgg_network(network_weights, image)
```

15. We now declare the first loss, the loss on the original image. We use the size-normalized L2-loss between the output of the normalized original image from step 12 and the output of the layer designated to represent the original content from step 9:

```
original_loss = original_image_weight * (2 * tf.nn.l2_loss(vgg_
net[original_layer] - original_features[original_layer]) /
original_features[original_layer].size)
```

16. Now we calculate the same type of loss for each style layer:

```
style_loss = 0
style_losses = []
for style_layer in style_layers:
 layer = vgg_net[style_layer]
 feats, height, width, channels = [x.value for x in layer.get_
shape()]
 size = height * width * channels
 features = tf.reshape(layer, (-1, channels))
 style_gram_matrix = tf.matmul(tf.transpose(features),
features) / size
 style_expected = style_features[style_layer]
 style_losses.append(2 * tf.nn.l2_loss(style_gram_matrix -
style_expected) / style_expected.size)
 style_loss += style_image_weight * tf.reduce_sum(style_losses)
```

17. The third loss term is called the total variation loss. This comes from calculating the total variation. It is similar to total variation denoising, in that true images have very low local variation, and images with high noise have high local variation. The key term in the following code is the `second_term_numerator`, which subtracts off nearby pixels. Images with high noise will have high differences and we can treat this as a loss function to minimize:

```
total_var_x = sess.run(tf.reduce_prod(image[:,1:,:,:].get_
shape()))
total_var_y = sess.run(tf.reduce_prod(image[:, :, 1:,:].get_
shape()))
first_term = regularization_weight * 2
second_term_numerator = tf.nn.l2_loss(image[:,1:,:,:] -
image[:, :, shape[1]-1,:,:])
second_term = second_term_numerator / total_var_y
third_term = (tf.nn.l2_loss(image[:, :, 1:,:]-
image[:, :, :, shape[2]-1,:,:]) / total_var_x)
total_variation_loss = first_term * (second_term + third_term)
```

18. The total loss we want to minimize is the combined original, style, and total variation loss:

```
loss = original_loss + style_loss + total_variation_loss
```

19. We next declare our optimizer and training step and initialize all the variables in the model.

```
optimizer = tf.train.GradientDescentOptimizer(learning_rate)
train_step = optimizer.minimize(loss)
sess.run(tf.initialize_all_variables())
```

20. We now loop through our training generations and print a status update every so often and save the temporary image. We'll save the temporary image because it is hard to determine how far to run this algorithm as it can vary, depending on the images chosen. It is best to err on the larger generation size, and stop when a temporary image appears to be a good stopping point:

```
for i in range(generations):
 sess.run(train_step)
 # Print update and save temporary output
 if (i+1) % output_generations == 0:
 print('Generation {} out of {}'.format(i + 1,
generations))
 image_eval = sess.run(image)
 best_image_add_mean = image_eval.reshape(shape[1:]) +
normalization_mean
 output_file = 'temp_output_{}.jpg'.format(i)
 scipy.misc.imsave(output_file, best_image_add_mean)
```

21. At the end of the algorithm, we'll save the final output:

```
image_eval = sess.run(image)
best_image_add_mean = image_eval.reshape(shape[1:]) +
normalization_mean
output_file = 'final_output.jpg'
scipy.misc.imsave(output_file, best_image_add_mean)
```

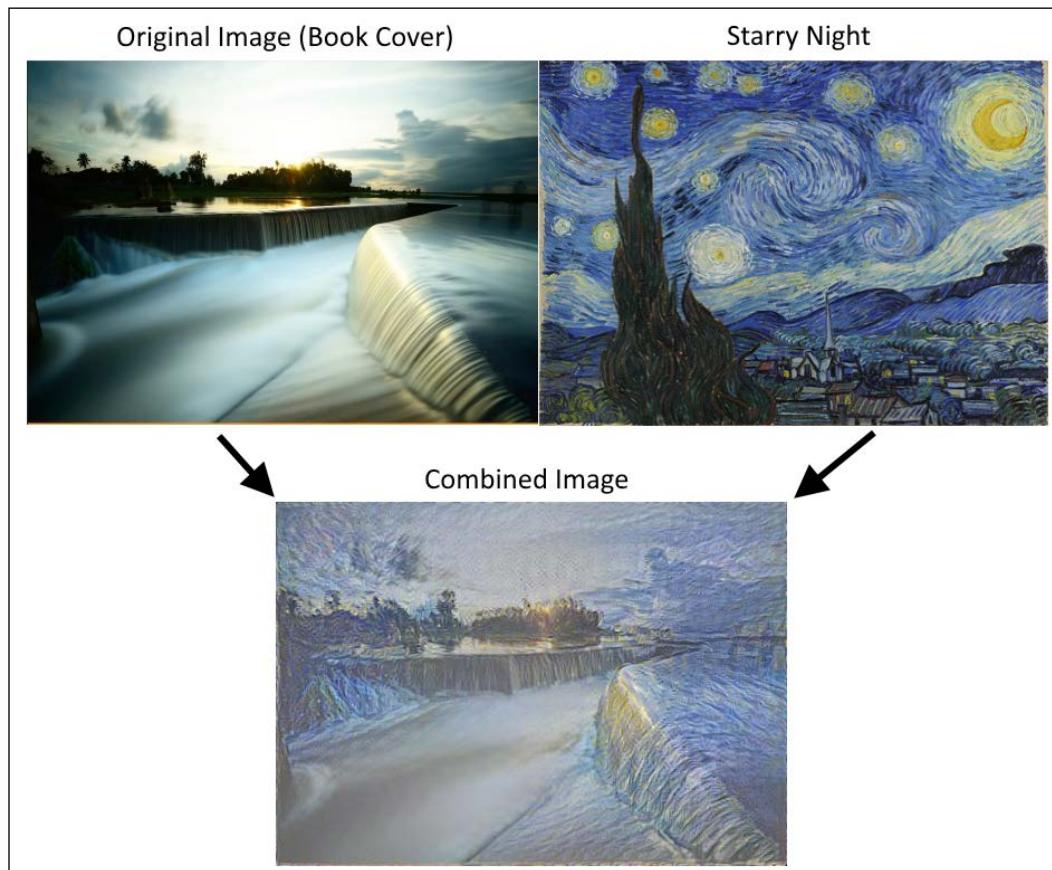


Figure 6: Using the stylenet algorithm to combine the book cover image with Starry Night. Note that different style emphases can be used by changing the weighting at the beginning of the script.

## How it works...

We first loaded the two images, then loaded the pre-trained network weights and assigned layers to the original and style images. We calculated three loss functions: an original image loss, a style loss, and a total variation loss. Then we trained random noise pictures to have the style of the style image and the content of the original image.

## See also

- ▶ *A Neural Algorithm of Artistic Style* by Gatys, Ecker, Bethge. 2015. <https://arxiv.org/abs/1508.06576>.

# Implementing DeepDream

Another usage of trained CNNs is exploiting the fact that some of the intermediate nodes detect features of labels (e.g. a cat ear or a feather of a bird). Using this fact, we can find ways to transform any image to reflect those node features of any node we choose. For this recipe, we will go through the DeepDream tutorial on TensorFlow's website. But for this recipe, we will go through the essential parts in much more detail. The hope is that we can prepare the reader to use the DeepDream algorithm for exploration of CNNs and features created in such CNNs.

## Getting ready

TensorFlow's official tutorials show how to implement DeepDream through a script (refer to the first bullet point of the See also section). The purpose of this recipe is to go through the script they provide and explain each line. While the tutorial is great, there are some parts that are skippable and some parts that could use more explanation. We hope to provide a more detailed line-by-line explanation. We also change the code to be Python 3 compliant where necessary.

## How to do it...

1. In order to get started with DeepDream, we need to download the GoogleNet, which is CNN trained on CIFAR-1000:

```
me@computer:~$ wget https://storage.googleapis.com/download.
tensorflow.org/models/inception5h.zip
me@computer:~$ unzip inception5h.zip
```

2. First, we'll start by loading the necessary libraries and starting a graph session:

```
import os
import matplotlib.pyplot as plt
import numpy as np
import PIL.Image
import tensorflow as tf
from io import BytesIO
graph = tf.Graph()
sess = tf.InteractiveSession(graph=graph)
```

3. We now declare the location of the unzipped model parameters (from step 1) and load the parameters into a TensorFlow graph:

```
Model location
model_fn = 'tensorflow_inception_graph.pb'
Load graph parameters
with tf.gfile.FastGFile(model_fn, 'rb') as f:
 graph_def = tf.GraphDef()
 graph_def.ParseFromString(f.read())
```

4. We create a placeholder for the input, save the `imagenet_mean` value of 117.0, and then we import the graph definition with the normalized placeholder:

```
Create placeholder for input
t_input = tf.placeholder(np.float32, name='input')
Imagenet average bias to subtract off images
imagenet_mean = 117.0
t_preprocessed = tf.expand_dims(t_input-imagenet_mean, 0)
tf.import_graph_def(graph_def, {'input':t_preprocessed})
```

5. Next, we will import the convolutional layers to visualize and use for DeepDream processing later:

```
Create a list of layers that we can refer to later
layers = [op.name for op in graph.get_operations() if
 op.type=='Conv2D' and 'import/' in op.name]
Count how many outputs for each layer
feature_nums = [int(graph.get_tensor_by_name(name+':0').get_
shape()[-1]) for name in layers]
```

6. Now we will pick a layer to visualize. We can pick others by name as well. We choose to look at feature number 139. The image starts with random noise:

```
layer = 'mixed4d_3x3_bottleneck_pre_relu'
channel = 139
img_noise = np.random.uniform(size=(224,224,3)) + 100.0
```

7. We declare a function that will plot an image array:

```
def showarray(a, fmt='jpeg'):
 # First make sure everything is between 0 and 255
 a = np.uint8(np.clip(a, 0, 1)*255)
 # Pick an in-memory format for image display
 f = BytesIO()
 # Create the in memory image
 PIL.Image.fromarray(a).save(f, fmt)
 # Show image
 plt.imshow(a)
```

8. We'll shorten some repetitive code by creating a function that retrieves a layer by name from the graph:

```
def T(layer):
 #Helper for getting layer output tensor
 return graph.get_tensor_by_name("import/%s:0"%layer)
```

9. The next function we will create is a wrapper function for creating placeholders according to the arguments we specify:

```
The following function returns a function wrapper that will
create the placeholder
inputs of a specified dtype
def tffunc(*argtypes):
 '''Helper that transforms TF-graph generating function into a
regular one.
 See "resize" function below.
 '''

 placeholders = list(map(tf.placeholder, argtypes))
 def wrap(f):
 out = f(*placeholders)
 def wrapper(*args, **kw):
 return out.eval(dict(zip(placeholders, args)),
session=kw.get('session'))
 return wrapper
 return wrap
```

10. We also need a function that resizes an image to a size specification. We do this with TensorFlow's built in image linear interpolation function, `tf.image.resize_bilinear()`:

```
Helper function that uses TF to resize an image
def resize(img, size):
 img = tf.expand_dims(img, 0)
 # Change 'img' size by linear interpolation
 return tf.image.resize_bilinear(img, size) [0,:,:,:]
```

11. Now we need a way to update the source image to be more like a feature we select. We do this by specifying how the gradient on the image is calculated. We define a function that will calculate gradients on subregions (`tiles`) over the image to make the calculations quicker. In order to prevent a tiled output, we will randomly shift, or roll, the image in the x and y direction, which will smooth out the tiling effect.

```
def calc_grad_tiled(img, t_grad, tile_size=512):
 '''Compute the value of tensor t_grad over the image in a tiled
way.
 Random shifts are applied to the image to blur tile boundaries
over
 multiple iterations.'''
```

```

Pick a subregion square size
sz = tile_size
Get the image height and width
h, w = img.shape[:2]
Get a random shift amount in the x and y direction
sx, sy = np.random.randint(sz, size=2)
Randomly shift the image (roll image) in the x and y
directions
img_shift = np.roll(np.roll(img, sx, 1), sy, 0)
Initialize the while image gradient as zeros
grad = np.zeros_like(img)
Now we loop through all the sub-tiles in the image
for y in range(0, max(h-sz//2, sz),sz):
 for x in range(0, max(w-sz//2, sz),sz):
 # Select the sub image tile
 sub = img_shift[y:y+sz,x:x+sz]
 # Calculate the gradient for the tile
 g = sess.run(t_grad, {t_input:sub})
 # Apply the gradient of the tile to the whole image
 grad[y:y+sz,x:x+sz] = g
Return the gradient, undoing the roll operation
return np.roll(np.roll(grad, -sx, 1), -sy, 0)

```

12. Now we can declare our DeepDream function. The objective of our algorithm is the mean of the feature we select. The loss operates on gradients, which will depend on the distance between the input image and the selected feature. The strategy is to separate the image into high and low frequency, and calculate gradients on the low part. The resulting high frequency image is split up again and the processes is repeated. The set of the original image and the low frequency images are called octaves. For each pass, we calculate the gradients and apply them to the images:

```

def render_deeppdream(t_obj, img0=img_noise,
 iter_n=10, step=1.5, octave_n=4, octave_
 scale=1.4):
 # defining the optimization objective, the objective is the
 # mean of the feature
 t_score = tf.reduce_mean(t_obj)
 # Our gradients will be defined as changing the t_input to get
 # closer to the values of t_score. Here, t_score is the mean of the
 # feature we select.
 # t_input will be the image octave (starting with the last)
 t_grad = tf.gradients(t_score, t_input)[0] # behold the power
 # of automatic differentiation!
 # Store the image
 img = img0

```

```
Initialize the image octave list
octaves = []
Since we stored the image, we need to only calculate n-1
octaves
for i in range(octave_n-1):
 # Extract the image shape
 hw = img.shape[:2]
 # Resize the image, scale by the octave_scale (resize by
 linear interpolation)
 lo = resize(img, np.int32(np.float32(hw)/octave_scale))
 # Residual is hi. Where residual = image - (Resize lo to
 be hw-shape)
 hi = img-resize(lo, hw)
 # Save the lo image for re-iterating
 img = lo
 # Save the extracted hi-image
 octaves.append(hi)

generate details octave by octave
for octave in range(octave_n):
 if octave>0:
 # Start with the last octave
 hi = octaves[-octave]
 #
 img = resize(img, hi.shape[:2])+hi
 for i in range(iter_n):
 # Calculate gradient of the image.
 g = calc_grad_tiled(img, t_grad)
 # Ideally, we would just add the gradient, g, but
 # we want do a forward step size of it ('step'),
 # and divide it by the avg. norm of the gradient, so
 # we are adding a gradient of a certain size each
 step.
 # Also, to make sure we aren't dividing by zero, we
 add 1e-7.
 img += g*(step / (np.abs(g).mean()+1e-7))
 print('.',end = ' ')
 showarray(img/255.0)
```

13. With all the function setup we have done, we now can perform the DeepDream algorithm.

```
Run Deep Dream
if __name__=="__main__":
 # Create resize function that has a wrapper that creates
 specified placeholder types
```

```

resize = tffunc(np.float32, np.int32)(resize)

Open image
img0 = PIL.Image.open('book_cover.jpg')
img0 = np.float32(img0)
Show Original Image
showarray(img0/255.0)
Create deep dream
render_deepparam(T(layer) [::, ::, 139], img0, iter_n=15)
sess.close()

```

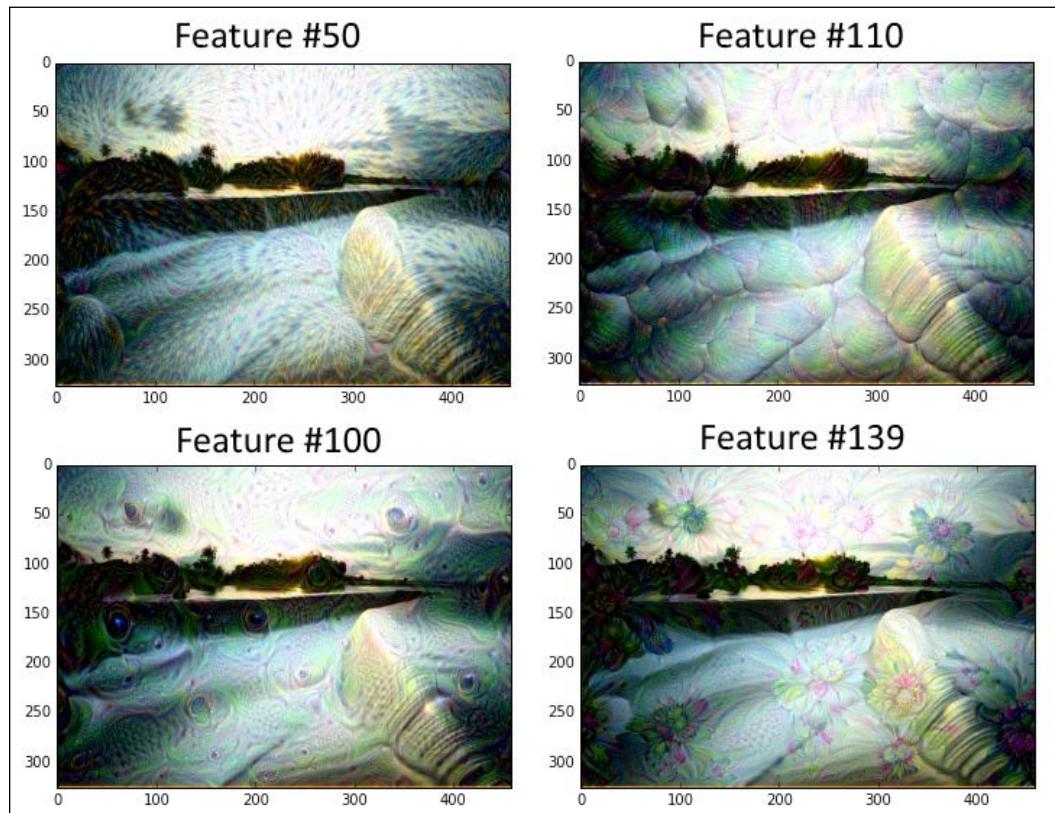


Figure 7: The cover of the book, run through the deep dream algorithm with feature layer numbers 50, 110, 100, and 139.

### There's more...

We urge the reader to visit the official DeepDream tutorials for more reference and also to visit the original Google research blog post on DeepDream (refer to the second bullet point of the See also section).

## **See also**

- ▶ The TensorFlow tutorial on DeepDream: <https://github.com/tensorflow/tensorflow/tree/master/tensorflow/examples/tutorials/deepdream>
- ▶ The original Google research blog post on DeepDream: <https://research.googleblog.com/2015/06/inceptionism-going-deeper-into-neural.html>



# 9

## Recurrent Neural Networks

In this chapter, we will cover **recurrent neural networks (RNNs)** and how to implement them in TensorFlow. We will start by demonstrating how to use an RNN to predict spam. We will then introduce a variant of RNNs for creating Shakespeare text. We will finish by creating an RNN sequence-to-sequence model to translate from English to German:

- ▶ Implementing RNNs for Spam Prediction
- ▶ Implementing an LSTM Model
- ▶ Stacking multiple LSTM Layers
- ▶ Creating Sequence-to-Sequence Models
- ▶ Training a Siamese Similarity Measure

As a note, all the code to this chapter can be found online at [https://github.com/nfmclure/tensorflow\\_cookbook](https://github.com/nfmclure/tensorflow_cookbook).

### Introduction

Of all the machine-learning algorithms we have considered thus far, none have considered data as a sequence. To take sequence data into account, we extend neural networks that store outputs from prior iterations. This type of neural network is called a **recurrent neural network (RNN)**. Consider the fully connected network formulation:

$$y = \sigma(Ax)$$

Here, the weights are given by  $A$  multiplied by the input layer,  $x$ , and then run through an activation function,  $\sigma$ , which gives the output layer,  $y$ . If we have a sequence of input data,  $x_1, x_2, x_3, \dots$ , we can adapt the fully connected layer to take prior inputs into account, as follows:

$$y_t = \sigma(By_{t-1} + Ax_t)$$

On top of this recurrent iteration to get the next input, we want to get the probability distribution output, as follows:

$$s_t = \text{softmax}(Cy_t)$$

Once we have a full sequence output,  $\{s_1, s_2, s_3, \dots\}$ , we can consider the target a number or category by just considering the last output. See the following figure for how a general architecture might work:

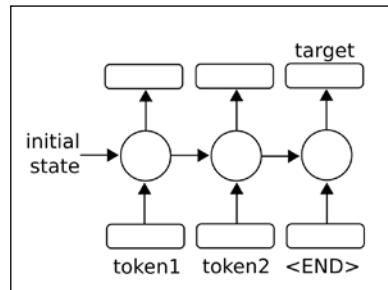


Figure 1: To predict a single number, or a category, we take a sequence of inputs (tokens) and consider the final output as the predicted output.

We can also consider the sequence itself as an output, as a sequence-to-sequence model:

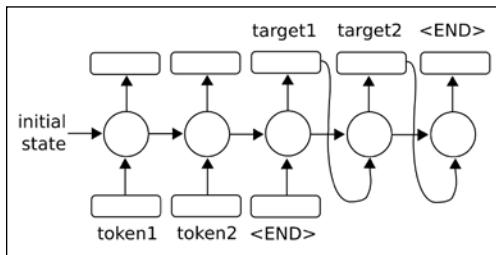


Figure 2: To predict a sequence, we may also feed the outputs back into the model to generate multiple outputs.

For arbitrarily long sequences, training with the back-propagation algorithm creates long time-dependent gradients. Because of this, there exists a *vanishing or exploding gradient problem*. Later in this chapter, we will explore a solution to this problem by expanding the RNN cell into what is called a **Long Short Term Memory(LSTM)** cell. The main idea is that the LSTM cell introduces another operation, called gates, which controls the flow of information through the sequence. We will go over the details in a later chapters.



When dealing with RNN models for NLP, **encoding** is a term used to describe the process of converting data (words or characters in NLP) into numerical RNN features. The term **decoding** is the process of converting the RNN numerical features into output words or characters.

## Implementing RNN for Spam Prediction

To start we will apply the standard RNN unit to predict a singular numerical output.

### Getting ready

In this recipe, we will implement a standard RNN in TensorFlow to predict whether or not a text message is spam or ham. We will use the SMS spam-collection dataset from the ML repository at UCI. The architecture we will use for prediction will be an input RNN sequence from the embedded text, and we will take the last RNN output as a prediction of spam or ham (1 or 0).

### How to do it...

1. We start by loading the libraries necessary for this script:

```
import os
import re
import io
import requests
import numpy as np
import matplotlib.pyplot as plt
import tensorflow as tf
from zipfile import ZipFile
```

- 
2. Next we start a graph session and set the RNN model parameters. We will run the data through 20 epochs, in batch sizes of 250. The maximum length of each text we will consider is 25 words; we will cut longer texts to 25 or zero pad shorter texts. The RNN will be of size 10 units. We will only consider words that appear at least 10 times in our vocabulary, and every word will be embedded in a trainable vector of size 50. The dropout rate will be a placeholder that we can set at 0.5 during training time or 1.0 during evaluation:

```
sess = tf.Session()
epochs = 20
batch_size = 250
max_sequence_length = 25
rnn_size = 10
embedding_size = 50
min_word_frequency = 10
learning_rate = 0.0005
dropout_keep_prob = tf.placeholder(tf.float32)
```

3. Now we get the SMS text data. First, we check if it was already downloaded and, if so, read in the file. Otherwise, we download the data and save it:

```
data_dir = 'temp'
data_file = 'text_data.txt'
if not os.path.exists(data_dir):
 os.makedirs(data_dir)
if not os.path.isfile(os.path.join(data_dir, data_file)):
 zip_url = 'http://archive.ics.uci.edu/ml/machine-learning-
databases/00228/smsspamcollection.zip'
 r = requests.get(zip_url)
 z = ZipFile(io.BytesIO(r.content))
 file = z.read('SMSSpamCollection')
 # Format Data
 text_data = file.decode()
 text_data = text_data.encode('ascii', errors='ignore')
 text_data = text_data.decode().split('\n')
 # Save data to text file
 with open(os.path.join(data_dir, data_file), 'w') as file_
conn:
 for text in text_data:
 file_conn.write("{}\n".format(text))
else:
 # Open data from text file
 text_data = []
 with open(os.path.join(data_dir, data_file), 'r') as file_
conn:
 for row in file_conn:
```

---

```

 text_data.append(row)
 text_data = text_data[:-1]
text_data = [x.split('\t') for x in text_data if len(x)>=1]
[text_data_target, text_data_train] = [list(x) for x in zip(*text_
data)]

```

4. To reduce our vocabulary, we will clean the input texts by removing special characters, extra white space, and putting everything in lowercase:

```

def clean_text(text_string):
 text_string = re.sub(r'([^\s\w]|_|[0-9])+', ' ', text_string)
 text_string = " ".join(text_string.split())
 text_string = text_string.lower()
 return(text_string)
Clean texts
text_data_train = [clean_text(x) for x in text_data_train]

```



Note that our cleaning step removes special characters. As an alternative, we could also have replaced them with a space.  
Ideally, this depends on the formatting of the dataset.



5. Now we process the texts with a built-in vocabulary processor function from TensorFlow. This will convert a text to an appropriate list of indices:

```

vocab_processor = tf.contrib.learn.preprocessing.
VocabularyProcessor(max_sequence_length,min_frequency=min_word_
frequency)
text_processed = np.array(list(vocab_processor.fit_transform(text_
data_train)))

```

6. Next we shuffle the data to randomize the data:

```

text_processed = np.array(text_processed)
text_data_target = np.array([1 if x=='ham' else 0 for x in text_
data_target])
shuffled_ix = np.random.permutation(np.arange(len(text_data_
target)))
x_shuffled = text_processed[shuffled_ix]
y_shuffled = text_data_target[shuffled_ix]

```

7. We also split the data into an 80-20 train-test dataset:

```

ix_cutoff = int(len(y_shuffled)*0.80)
x_train, x_test = x_shuffled[:ix_cutoff], x_shuffled[ix_cutoff:]
y_train, y_test = y_shuffled[:ix_cutoff], y_shuffled[ix_cutoff:]
vocab_size = len(vocab_processor.vocabulary_)
print("Vocabulary Size: {:d}".format(vocab_size))
print("80-20 Train Test split: {:d} -- {:d}".format(len(y_train),
len(y_test)))

```



For this recipe, we will not be doing any hyperparameter tuning. If the reader goes in this direction, remember to split up the dataset into train-test-valid sets before proceeding. A good option for this is the Scikit-learn function `model_selection.train_test_split()`.

8. Next we declare the graph placeholders. The x-input will be a placeholder of size `[None, max_sequence_length]`, which will be the batch size by the maximum allowed word length of the text messages. The y-output placeholder is just an integer, 0 or 1, or ham or spam:

```
x_data = tf.placeholder(tf.int32, [None, max_sequence_length])
y_output = tf.placeholder(tf.int32, [None])
```

9. We now create our embedding matrix and embedding lookup operation for the x-input data:

```
embedding_mat = tf.Variable(tf.random_uniform([vocab_size,
 embedding_size], -1.0, 1.0))
embedding_output = tf.nn.embedding_lookup(embedding_mat, x_data)
```

10. We declare our model as follows. First we initialize a type of RNN cell to use (RNN of size 10). Then we create the RNN sequence by making it a dynamic RNN. We then add dropout to the RNN:

```
cell = tf.nn.rnn_cell.BasicRNNCell(num_units = rnn_size)
output, state = tf.nn.dynamic_rnn(cell, embedding_output,
 dtype=tf.float32)
output = tf.nn.dropout(output, dropout_keep_prob)
```



Note, that the dynamic RNN allows for variable length sequences. Even though we are using a fixed sequence length in this example, it is usually preferred to use the `dynamic_rnn` in TensorFlow for two main reasons. The main reason is that, in practice, the dynamic RNN actually runs computationally faster and that, if we choose, we can run sequences of different lengths through the RNN.

11. Now to get our predictions, we have to rearrange the RNN and slice off the last output:

```
output = tf.transpose(output, [1, 0, 2])
last = tf.gather(output, int(output.get_shape()[0]) - 1)
```

12. To finish the RNN prediction, we convert from the `rnn_size` output to the two-category output via a fully connected network layer:

```
weight = tf.Variable(tf.truncated_normal([rnn_size, 2],
 stddev=0.1))
bias = tf.Variable(tf.constant(0.1, shape=[2]))
logits_out = tf.nn.softmax(tf.matmul(last, weight) + bias)
```

13. We declare our loss function next. Remember that with using the `sparse_softmax` function from TensorFlow, the targets have to be integer indices (of type `int`), and the logits have to be floats:

```
losses = tf.nn.sparse_softmax_cross_entropy_with_logits(logits_out, y_output)
loss = tf.reduce_mean(losses)
```

14. We also need an accuracy function so that we can compare the algorithm on the test and train set:

```
accuracy = tf.reduce_mean(tf.cast(tf.equal(tf.argmax(logits_out, 1), tf.cast(y_output, tf.int64)), tf.float32))
```

15. Next we create the optimization function and initialize the model variables:

```
optimizer = tf.train.RMSPropOptimizer(learning_rate)
train_step = optimizer.minimize(loss)
init = tf.initialize_all_variables()
sess.run(init)
```

16. Now we can start looping through our data and training the model. When looping through the data multiple times, it is good practice to shuffle the data every epoch to prevent over-training:

```
train_loss = []
test_loss = []
train_accuracy = []
test_accuracy = []
Start training
for epoch in range(epochs):
 # Shuffle training data
 shuffled_ix = np.random.permutation(np.arange(len(x_train)))
 x_train = x_train[shuffled_ix]
 y_train = y_train[shuffled_ix]
 num_batches = int(len(x_train)/batch_size) + 1
 for i in range(num_batches):
 # Select train data
 min_ix = i * batch_size
 max_ix = np.min([len(x_train), ((i+1) * batch_size)])
 x_train_batch = x_train[min_ix:max_ix]
 y_train_batch = y_train[min_ix:max_ix]

 # Run train step
 train_dict = {x_data: x_train_batch, y_output: y_train_batch, dropout_keep_prob:0.5}
```

```
sess.run(train_step, feed_dict=train_dict)

Run loss and accuracy for training
temp_train_loss, temp_train_acc = sess.run([loss, accuracy],
feed_dict=train_dict)
train_loss.append(temp_train_loss)
train_accuracy.append(temp_train_acc)

Run Eval Step
test_dict = {x_data: x_test, y_output: y_test, dropout_keep_
prob:1.0}
temp_test_loss, temp_test_acc = sess.run([loss, accuracy],
feed_dict=test_dict)
test_loss.append(temp_test_loss)
test_accuracy.append(temp_test_acc)
print('Epoch: {}, Test Loss: {:.2}, Test Acc: {:.2}'.format(epoch+1, temp_test_loss, temp_test_acc))
```

17. This results in the following output:

```
Vocabulary Size: 933
80-20 Train Test split: 4459 -- 1115
Epoch: 1, Test Loss: 0.59, Test Acc: 0.83
Epoch: 2, Test Loss: 0.58, Test Acc: 0.83
Epoch: 19, Test Loss: 0.46, Test Acc: 0.86
Epoch: 20, Test Loss: 0.46, Test Acc: 0.86
```

18. Here is the code to plot the train/test loss and accuracy:

```
epoch_seq = np.arange(1, epochs+1)
plt.plot(epoch_seq, train_loss, 'k--', label='Train Set')
plt.plot(epoch_seq, test_loss, 'r-', label='Test Set')
plt.title('Softmax Loss')
plt.xlabel('Epochs')
plt.ylabel('Softmax Loss')
plt.legend(loc='upper left')
plt.show()

Plot accuracy over time
plt.plot(epoch_seq, train_accuracy, 'k--', label='Train Set')
plt.plot(epoch_seq, test_accuracy, 'r-', label='Test Set')
plt.title('Test Accuracy')
plt.xlabel('Epochs')
plt.ylabel('Accuracy')
plt.legend(loc='upper left')
plt.show()
```

## How it works...

In this recipe, we created an RNN to category model to predict if an SMS text is spam or ham. We achieved about 86% accuracy on the test set. Here are the plots of accuracy and loss on both the test and training sets:

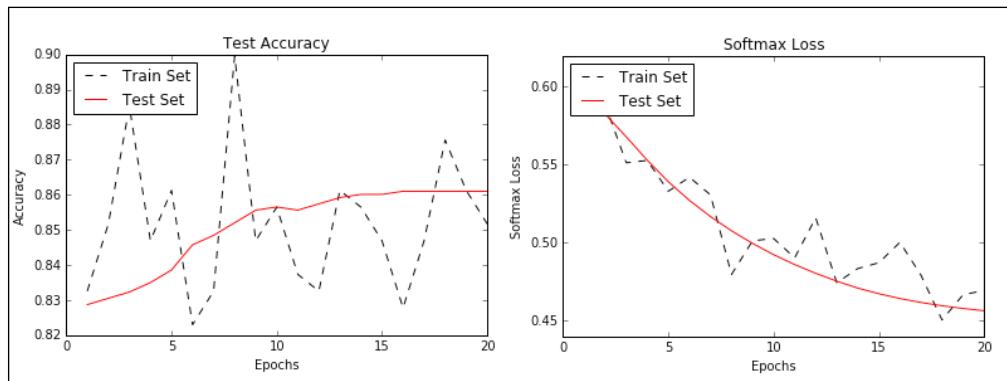


Figure 3: The accuracy (left) and loss (right) of the train and test sets.

## There's more...

It is highly recommended to go through the training dataset multiple times for sequential data (and is also recommended for non-sequential data, too). Each pass through the data is called an **epoch**. Also, it is very common and highly recommended to shuffle the data before each epoch.

## Implementing an LSTM Model

We will extend our RNN model to be able to use longer sequences by introducing the LSTM unit in this recipe.

### Getting ready

**Long Short Term Memory(LSTM)** is a variant of the traditional RNN. LSTM is a way to address the vanishing/exploding gradient problem that variable length RNNs have. To address this issue, LSTM cells introduce an internal forget gate, which can modify a flow of information from one cell to the next. To conceptualize how this works, we will walk through an unbiased version of LSTM one equation at a time. The first step is the same as for the regular RNN:

$$i_t = \sigma(B_i h_{t-1} + A_i x_t)$$

In order to figure out which values we want to forget or pass through, we will evaluate candidate values as follows. These values are often referred to as the memory cells:

$$C_t = \tanh(B_C h_{t-1} + A_C x_t)$$

Now we modify the candidate memory cells by a forget matrix, which is calculated as follows:

$$f_t = \sigma(B_f h_{t-1} + A_f x_t)$$

We now combine the forget memory with the prior memory step and add it to the candidate memory cells to arrive at the new memory values:

$$N_t = i_t \cdot C_t + f_t N_{t-1}$$

Now we combine everything to get the output of the cell:

$$O_t = \sigma(B_O h_{t-1} + A_O x_t + D_O N_t)$$

Then, for the next iteration, we update  $h$  as follows:

$$h_t = O_t \cdot \tanh(N_t)$$

The idea with LSTM is to have a self-regulating flow of information through the cells that can be forgotten or modified based on the information input to the cell.

 One great thing about using TensorFlow here is that we do not have to keep track of these operations and their corresponding back propagation attributes. TensorFlow will keep track of these and update the model variables here automatically, according to the gradients specified by our loss function, optimizer, and learning rates.

For this recipe, we will use a sequence RNN with LSTM cells to try to predict the next words, trained on the works of Shakespeare. To test how we are doing, we will feed the model candidate phrases, such as, *thou art more*, and see if the model can attempt to figure out what words should follow the phrase.

## How to do it...

1. To start, we load the necessary libraries for the script:

```
import os
import re
import string
import requests
import numpy as np
import collections
import random
import pickle
import matplotlib.pyplot as plt
import tensorflow as tf
```

2. Next, we start a graph session and set the RNN parameters

```
sess = tf.Session()
Set RNN Parameters
min_word_freq = 5
rnn_size = 128
epochs = 10
batch_size = 100
learning_rate = 0.001
training_seq_len = 50
embedding_size = rnn_size
save_every = 500
eval_every = 50
prime_texts = ['thou art more', 'to be or not to', 'wherefore art thou']
```

3. We set up the data and model folders and filenames, along with declaring punctuation to remove. We will want to keep hyphens and apostrophes because Shakespeare uses them frequently to combine words and syllables:

```
data_dir = 'temp'
data_file = 'shakespeare.txt'
model_path = 'shakespeare_model'
full_model_dir = os.path.join(data_dir, model_path)
Declare punctuation to remove, everything except hyphens and apostrophes
punctuation = string.punctuation
punctuation = ''.join([x for x in punctuation if x not in [',', "'"]])
```

- 
4. Next we get the data. If the data file doesn't exist, we download and save the Shakespeare text. If it does exist, we load the data:

```

if not os.path.exists(full_model_dir):
 os.makedirs(full_model_dir)
Make data directory
if not os.path.exists(data_dir):
 os.makedirs(data_dir)
print('Loading Shakespeare Data')
Check if file is downloaded.
if not os.path.isfile(os.path.join(data_dir, data_file)):
 print('Not found, downloading Shakespeare texts from www.gutenberg.org')
 shakespeare_url = 'http://www.gutenberg.org/cache/epub/100/pg100.txt'
 # Get Shakespeare text
 response = requests.get(shakespeare_url)
 shakespeare_file = response.content
 # Decode binary into string
 s_text = shakespeare_file.decode('utf-8')
 # Drop first few descriptive paragraphs.
 s_text = s_text[7675:]
 # Remove newlines
 s_text = s_text.replace('\r\n', '')
 s_text = s_text.replace('\n', '')

 # Write to file
 with open(os.path.join(data_dir, data_file), 'w') as out_conn:
 out_conn.write(s_text)
else:
 # If file has been saved, load from that file
 with open(os.path.join(data_dir, data_file), 'r') as file_conn:
 s_text = file_conn.read().replace('\n', '')

```

5. We clean the Shakespeare text by removing punctuation and extra whitespace:

```

s_text = re.sub(r'\{.\}', punctuation, ' ', s_text)
s_text = re.sub('\s+', ' ', s_text).strip().lower()

```

6. We now deal with creating the Shakespeare vocabulary to use. We create a function that will return the two dictionaries (word to index, and index to word) with words that appear more than a specified frequency:

```

def build_vocab(text, min_word_freq):
 word_counts = collections.Counter(text.split(' '))

```

```

limit word counts to those more frequent than cutoff
word_counts = {key:val for key, val in word_counts.items() if
val>min_word_freq}
Create vocab --> index mapping
words = word_counts.keys()
vocab_to_ix_dict = {key:(ix+1) for ix, key in
enumerate(words)}
Add unknown key --> 0 index
vocab_to_ix_dict['unknown']=0
Create index --> vocab mapping
ix_to_vocab_dict = {val:key for key,val in vocab_to_ix_dict.
items()}

return(ix_to_vocab_dict, vocab_to_ix_dict)
ix2vocab, vocab2ix = build_vocab(s_text, min_word_freq)
vocab_size = len(ix2vocab) + 1

```

 Note that when dealing with text, we have to be careful indexing words with the value of zero. We should save the zero value for padding, and potentially for unknown words as well.

- Now that we have our vocabulary, we turn the Shakespeare text into an array of indices:

```

s_text_words = s_text.split(' ')
s_text_ix = []
for ix, x in enumerate(s_text_words):
 try:
 s_text_ix.append(vocab2ix[x])
 except:
 s_text_ix.append(0)
s_text_ix = np.array(s_text_ix)

```

- In this recipe, we will show how to create a model in a class object. This will be helpful for us, because we would like to use the same model (with the same weights) to train on batches and to generate text from sample text. This will prove hard to do without a class with an internal sampling method. Ideally, this class code should sit in a separate Python file, which we can import at the beginning of this script:

```

class LSTM_Model():
 def __init__(self, rnn_size, batch_size, learning_rate,
 training_seq_len, vocab_size, infer=False):
 self.rnn_size = rnn_size
 self.vocab_size = vocab_size
 self.infer = infer

```

```
 self.learning_rate = learning_rate

 if infer:
 self.batch_size = 1
 self.training_seq_len = 1
 else:
 self.batch_size = batch_size
 self.training_seq_len = training_seq_len

 self.lstm_cell = tf.nn.rnn_cell.BasicLSTMCell(rnn_size)
 self.initial_state = self.lstm_cell.zero_state(self.batch_
size, tf.float32)

 self.x_data = tf.placeholder(tf.int32, [self.batch_size,
self.training_seq_len])
 self.y_output = tf.placeholder(tf.int32, [self.batch_size,
self.training_seq_len])

 with tf.variable_scope('lstm_vars'):
 # Softmax Output Weights
 W = tf.get_variable('W', [self.rnn_size, self.vocab_
size], tf.float32, tf.random_normal_initializer())
 b = tf.get_variable('b', [self.vocab_size],
tf.float32, tf.constant_initializer(0.0))

 # Define Embedding
 embedding_mat = tf.get_variable('embedding_mat',
[self.vocab_size, self.rnn_size], tf.float32, tf.random_normal_
initializer())

 embedding_output = tf.nn.embedding_lookup(embedding_
mat, self.x_data)
 rnn_inputs = tf.split(1, self.training_seq_len,
embedding_output)
 rnn_inputs_trimmed = [tf.squeeze(x, [1]) for x in rnn_
inputs]

 # If we are inferring (generating text), we add a 'loop'
 # function
 # Define how to get the i+1 th input from the i th output
 def inferred_loop(prev, count):
 prev_transformed = tf.matmul(prev, W) + b
 prev_symbol = tf.stop_gradient(tf.argmax(prev_
transformed, 1))
```

```

 output = tf.nn.embedding_lookup(embedding_mat, prev_
symbol)
 return(output)

decoder = tf.nn.seq2seq.rnn_decoder
outputs, last_state = decoder(rnn_inputs_trimmed,
 self.initial_state,
 self.lstm_cell,
 loop_function=inferred_loop
if infer else None)
Non inferred outputs
output = tf.reshape(tf.concat(1, outputs), [-1, self.rnn_
size])
Logits and output
self.logit_output = tf.matmul(output, W) + b
self.model_output = tf.nn.softmax(self.logit_output)

loss_fun = tf.nn.seq2seq.sequence_loss_by_example
loss = loss_fun([self.logit_output], [tf.reshape(self.y_
output, [-1])],
 [tf.ones([self.batch_size * self.training_seq_
len])],
 self.vocab_size)
self.cost = tf.reduce_sum(loss) / (self.batch_size * self.
training_seq_len)
self.final_state = last_state
gradients, _ = tf.clip_by_global_norm(tf.gradients(self.
cost, tf.trainable_variables()), 4.5)
optimizer = tf.train.AdamOptimizer(self.learning_rate)
self.train_op = optimizer.apply_gradients(zip(gradients,
tf.trainable_variables()))

def sample(self, sess, words=ix2vocab, vocab=vocab2ix, num=10,
prime_text='thou art'):
 state = sess.run(self.lstm_cell.zero_state(1, tf.float32))
 word_list = prime_text.split()
 for word in word_list[:-1]:
 x = np.zeros((1, 1))
 x[0, 0] = vocab[word]
 feed_dict = {self.x_data: x, self.initial_state:state}
 [state] = sess.run([self.final_state], feed_dict=feed_
dict)
 out_sentence = prime_text
 word = word_list[-1]

```

```

 for n in range(num):
 x = np.zeros((1, 1))
 x[0, 0] = vocab[word]
 feed_dict = {self.x_data: x, self.initial_state:state}
 [model_output, state] = sess.run([self.model_output,
 self.final_state], feed_dict=feed_dict)
 sample = np.argmax(model_output[0])
 if sample == 0:
 break
 word = words[sample]
 out_sentence = out_sentence + ' ' + word
 return(out_sentence)

```

9. Now we will declare the LSTM model as well as the test model. We will do this within a variable scope and tell the scope that we will reuse the variables for the test LSTM model:

```

with tf.variable_scope('lstm_model') as scope:
 # Define LSTM Model
 lstm_model = LSTM_Model(rnn_size, batch_size, learning_rate,
 training_seq_len, vocab_size)
 scope.reuse_variables()
 test_lstm_model = LSTM_Model(rnn_size, batch_size, learning_
rate,
 training_seq_len, vocab_size, infer=True)

```

10. We create a saving operation, as well as splitting up the input text into equal batch-size chunks. Then we will initialize the variables of the model:

```

saver = tf.train.Saver()
Create batches for each epoch
num_batches = int(len(s_text_ix)/(batch_size * training_seq_len)) + 1
Split up text indices into subarrays, of equal size
batches = np.array_split(s_text_ix, num_batches)
Reshape each split into [batch_size, training_seq_len]
batches = [np.resize(x, [batch_size, training_seq_len]) for x in batches]
Initialize all variables
init = tf.initialize_all_variables()
sess.run(init)

```

11. We can now iterate through our epochs, shuffling the data before each epoch starts. The target for our data is just the same data, but shifted by one value (using the `numpy.roll()` function):

```

train_loss = []
iteration_count = 1

```

```
for epoch in range(epochs):
 # Shuffle word indices
 random.shuffle(batches)
 # Create targets from shuffled batches
 targets = [np.roll(x, -1, axis=1) for x in batches]
 # Run a through one epoch
 print('Starting Epoch #{} of {}'.format(epoch+1, epochs))
 # Reset initial LSTM state every epoch
 state = sess.run(lstm_model.initial_state)
 for ix, batch in enumerate(batches):
 training_dict = {lstm_model.x_data: batch, lstm_model.y_
output: targets[ix]}
 c, h = lstm_model.initial_state
 training_dict[c] = state.c
 training_dict[h] = state.h

 temp_loss, state, _ = sess.run([lstm_model.cost, lstm_
model.final_state, lstm_model.train_op], feed_dict=training_dict)
 train_loss.append(temp_loss)

 # Print status every 10 gens
 if iteration_count % 10 == 0:
 summary_nums = (iteration_count, epoch+1, ix+1, num_
batches+1, temp_loss)
 print('Iteration: {}, Epoch: {}, Batch: {} out of {},'
Loss: {:.2f}'.format(*summary_nums))

 # Save the model and the vocab
 if iteration_count % save_every == 0:
 # Save model
 model_file_name = os.path.join(full_model_dir,
'model')
 saver.save(sess, model_file_name, global_step =
iteration_count)
 print('Model Saved To: {}'.format(model_file_name))
 # Save vocabulary
 dictionary_file = os.path.join(full_model_dir, 'vocab.
pkl')
 with open(dictionary_file, 'wb') as dict_file_conn:
 pickle.dump([vocab2ix, ix2vocab], dict_file_conn)

 if iteration_count % eval_every == 0:
```

```
 for sample in prime_texts:
 print(test_lstm_model.sample(sess, ix2vocab,
vocab2ix, num=10, prime_text=sample))

 iteration_count += 1
```

12. This results in the following output:

```
Loading Shakespeare Data
Cleaning Text
Building Shakespeare Vocab
Vocabulary Length = 8009
Starting Epoch #1 of 10.
Iteration: 10, Epoch: 1, Batch: 10 out of 182, Loss: 10.37
Iteration: 20, Epoch: 1, Batch: 20 out of 182, Loss: 9.54
...
Iteration: 1790, Epoch: 10, Batch: 161 out of 182, Loss: 5.68
Iteration: 1800, Epoch: 10, Batch: 171 out of 182, Loss: 6.05
thou art more than i am a
to be or not to the man i have
wherefore art thou art of the long
Iteration: 1810, Epoch: 10, Batch: 181 out of 182, Loss: 5.99
```

13. And finally, here is how we plot the training loss over the epochs.

```
plt.plot(train_loss, 'k-')
plt.title('Sequence to Sequence Loss')
plt.xlabel('Generation')
plt.ylabel('Loss')
plt.show()
```

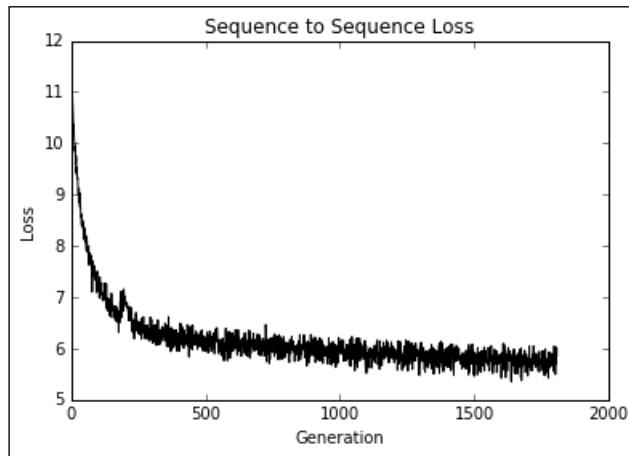


Figure 4: The sequence-to-sequence loss over all generations of the model.

## How it works...

In this example, we built an RNN model with LSTM units to predict the next word, based on Shakespearean vocabulary. There are a few things that could be done to improve the model, maybe increasing the sequence size, having a decaying learning rate, or training the model for more epochs.

## There's more...

For sampling, we implemented a greedy sampler. Greedy samplers can get stuck repeating the same phrases over and over. For example, it may get stuck saying *for the for the for the...* To prevent this, we could also implement a more random way of sampling words, maybe by doing a weighted sampler based on the logits or probability distribution of the output.

## Stacking multiple LSTM Layers

Just like we can increase the depth of neural networks or CNNs, we can increase the depth of RNN networks. In this recipe we apply a three layer deep LSTM to improve our Shakespeare language generation.

## Getting ready

We can increase the depth of recurrent neural networks by stacking them on top of each other. Essentially, we will be taking the target outputs and feeding them into another network. To get an idea of how this might work for just two layers, see the following figure:

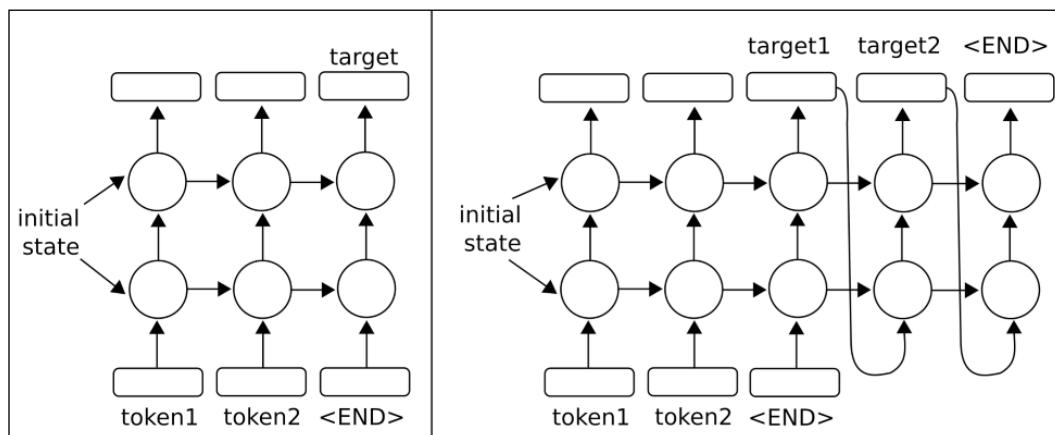


Figure 5: In the preceding figures, we have extended the one-layer RNNs to have two layers. For the original one-layer versions, see the figures in the prior chapter introduction.

TensorFlow allows easy implementation of multiple layers with a `MultiRNNCell()` function that accepts a list of RNN cells. With this behavior, it is easy to create a multi-layer RNN from one cell in Python with `MultiRNNCell([rnn_cell]*num_layers)`.

For this recipe, we will perform the same Shakespeare prediction that we performed in the previous recipe. There will be two changes: the first change will be having a three-stacked LSTM model instead of only one layer. The second change will be doing character-level predictions instead of words. Doing character-level predictions will greatly decrease our potential vocabulary to only 40 characters (26 letters, 10 numbers, 1 whitespace, and 3 special characters).

## How to do it...

Instead of relisting all the same code, we will illustrate where our code in this section will differ from the previous section. For the full code, please see the GitHub repository at [https://github.com/nfmccclure/tensorflow\\_cookbook](https://github.com/nfmccclure/tensorflow_cookbook):

1. We first need to set the number of layers for the model. We put this as a parameter at the beginning of our script, with the other model parameters:

```
num_layers = 3
min_word_freq = 5
rnn_size = 128
epochs = 10
```

2. The first major change is that we will load, process, and feed the text by characters, not by words. In order to accomplish this, after our cleaning of the text, we can separate the whole text by characters with Python's `list()` command:

```
s_text = re.sub(r'\[\{\}]'.format(punctuation), ' ', s_text)
s_text = re.sub('\s+', ' ', s_text).strip().lower()
Split up by characters
char_list = list(s_text)
```

3. We now need to change our LSTM model to have multiple layers. We take in the `num_layers` variable and create a multiple layer RNN model with TensorFlow's `MultiRNNCell()` function, as shown here:

```
class LSTM_Model():
 def __init__(self, rnn_size, num_layers, batch_size, learning_rate,
 training_seq_len, vocab_size, infer_sample=False):
 self.rnn_size = rnn_size
 self.num_layers = num_layers
 self.vocab_size = vocab_size
 self.infer_sample = infer_sample
```

```
 self.learning_rate = learning_rate
 ...
 self.lstm_cell = tf.nn.rnn_cell.BasicLSTMCell(rnn_size)
 self.lstm_cell = tf.nn.rnn_cell.MultiRNNCell([self.lstm_
cell] * self.num_layers)
 self.initial_state = self.lstm_cell.zero_state(self.batch_
size, tf.float32)

 self.x_data = tf.placeholder(tf.int32, [self.batch_size,
self.training_seq_len])
 self.y_output = tf.placeholder(tf.int32, [self.batch_size,
self.training_seq_len])
```

[  Note that TensorFlow's `MultiRNNCell()` function accepts a list of RNN cells. In this project, the RNN layers are all the same, but you can make a list of whichever RNN layers you would like to stack on top of each other. ]

4. Everything else is essentially the same. Here we can see some of the training output:

```
Building Shakespeare Vocab by Characters
Vocabulary Length = 40
Starting Epoch #1 of 10
Iteration: 9430, Epoch: 10, Batch: 889 out of 950, Loss: 1.54
Iteration: 9440, Epoch: 10, Batch: 899 out of 950, Loss: 1.46
Iteration: 9450, Epoch: 10, Batch: 909 out of 950, Loss: 1.49
thou art more than the
to be or not to the serva
wherefore art thou dost thou
Iteration: 9460, Epoch: 10, Batch: 919 out of 950, Loss: 1.41
Iteration: 9470, Epoch: 10, Batch: 929 out of 950, Loss: 1.45
Iteration: 9480, Epoch: 10, Batch: 939 out of 950, Loss: 1.59
Iteration: 9490, Epoch: 10, Batch: 949 out of 950, Loss: 1.42
```

5. Here is a sample of the final text output:

```
thou art more fancy with
to be or not to be for be
wherefore art thou art thou
```

- 
- Finally, here is how we plot the training loss over the generations:

```
plt.plot(train_loss, 'k-')
plt.title('Sequence to Sequence Loss')
plt.xlabel('Generation')
plt.ylabel('Loss')
plt.show()
```

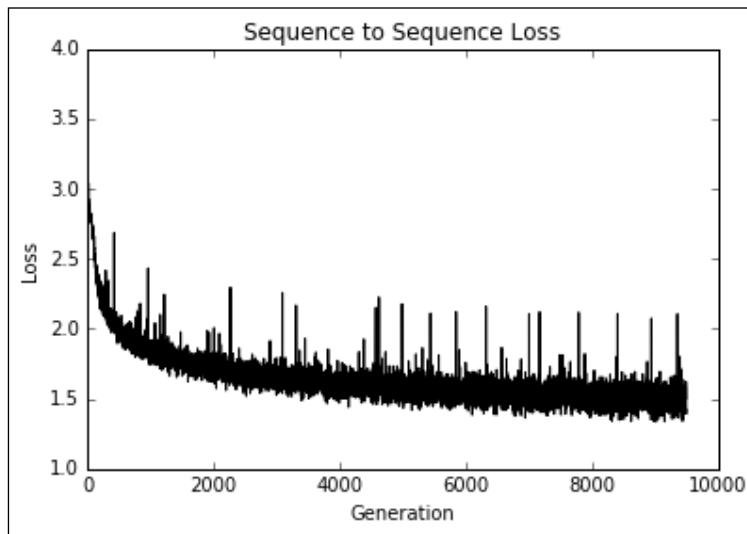


Figure 6: A plot of the training loss versus generations for the multiple-layer LSTM Shakespeare model.

### How it works...

TensorFlow makes it easy to extend an RNN layer to multiple layers with just a list of RNN cells. For this recipe, we used the same Shakespeare data as the previous recipe, but processed it by characters instead of words. We fed this through a triple-layered LSTM model to generate Shakespeare text. We can see that after only 10 epochs, we were able to generate archaic English like words.

## Creating Sequence-to-Sequence Models

Since every RNN unit we use also has an output, we can train RNN sequences to predict other sequences of variable length. For this recipe, we will take advantage of this fact to create an English to German translation model.

## Getting ready

For this recipe, we will attempt to build a language translation model to translate from English to German.

TensorFlow has a built-in model class for sequence-to-sequence training. We will illustrate how to train and use it on downloaded English–German sentences. The data we will use comes from a compiled ZIP file at <http://www.manythings.org/>, which compiles the data from the Tatoeba Project (<http://tatoeba.org/home>). This data is a tab-delimited English–German sentence translation. For example, a row might contain the sentence, *hello ./t hallo*. The data contains thousands of sentences of various lengths.

## How to do it...

1. We start by loading the necessary libraries and starting a graph session:

```
import os
import string
import requests
import io
import numpy as np
import matplotlib.pyplot as plt
import tensorflow as tf
from zipfile import ZipFile
from collections import Counter
from tensorflow.models.rnn.translate import seq2seq_model
sess = tf.Session()
```

2. Now we set the model parameters. We set the learning rate to be 0.1. Here, we will also decay the learning rate by 1% every 100 generations. This will help fine-tune the model in later generations. We set a cut-off for the maximum gradient size for the parameters as well. We use an RNN size of 500, and limit the English and German vocabulary to be the most frequent 10,000 words. We will lowercase both vocabularies and remove punctuation. We also normalize the German vocabulary by changing the umlauts (ä,ë,ï,ö, and ü) and eszetts (ß) to be alpha-numeric:

```
learning_rate = 0.1
lr_decay_rate = 0.99
lr_decay_every = 100
max_gradient = 5.0
batch_size = 50
num_layers = 3
rnn_size = 500
layer_size = 512
generations = 10000
```

```

vocab_size = 10000
save_every = 1000
eval_every = 500
output_every = 50
punct = string.punctuation
data_dir = 'temp'
data_file = 'eng_ger.txt'
model_path = 'seq2seq_model'
full_model_dir = os.path.join(data_dir, model_path)

```

3. We now set up three English phrases to test the translation model and see how it is performing:

```

test_english = ['hello where is my computer',
 'the quick brown fox jumped over the lazy dog',
 'is it going to rain tomorrow']

```

4. Next we create the model directories. We then check if the data has been downloaded, and either download and save it or load it from the file:

```

if not os.path.exists(full_model_dir):
 os.makedirs(full_model_dir)
Make data directory
if not os.path.exists(data_dir):
 os.makedirs(data_dir)
print('Loading English-German Data')
Check for data, if it doesn't exist, download it and save it
if not os.path.isfile(os.path.join(data_dir, data_file)):
 print('Data not found, downloading Eng-Ger sentences from www.manythings.org')
 sentence_url = 'http://www.manythings.org/anki/deu-eng.zip'
 r = requests.get(sentence_url)
 z = ZipFile(io.BytesIO(r.content))
 file = z.read('deu.txt')
 # Format Data
 eng_ger_data = file.decode()
 eng_ger_data = eng_ger_data.encode('ascii', errors='ignore')
 eng_ger_data = eng_ger_data.decode().split('\n')
 # Write to file
 with open(os.path.join(data_dir, data_file), 'w') as out_conn:
 for sentence in eng_ger_data:
 out_conn.write(sentence + '\n')
else:
 eng_ger_data = []
 with open(os.path.join(data_dir, data_file), 'r') as in_conn:
 for row in in_conn:
 eng_ger_data.append(row[:-1])

```

5. We process the data by removing the punctuation, splitting the English and German sentences, and lowercasing all of them:

```
eng_ger_data = [''.join(char for char in sent if char not in
punct) for sent in eng_ger_data]
Split each sentence by tabs
eng_ger_data = [x.split('\t') for x in eng_ger_data if len(x)>=1]
[english_sentence, german_sentence] = [list(x) for x in zip(*eng_
ger_data)]
english_sentence = [x.lower().split() for x in english_sentence]
german_sentence = [x.lower().split() for x in german_sentence]
```

6. Now we create the English and German vocabulary, picking the top 10,000 most common words in each. The rest of the words will be labeled as 0, for unknown. This is sometimes not a limiting factor, as most of the infrequent words are all proper pronouns (names and places):

```
all_english_words = [word for sentence in english_sentence for
word in sentence]
all_english_counts = Counter(all_english_words)
eng_word_keys = [x[0] for x in all_english_counts.most_
common(vocab_size-1)] # -1 because 0=unknown is also in there
eng_vocab2ix = dict(zip(eng_word_keys, range(1,vocab_size)))
eng_ix2vocab = {val:key for key, val in eng_vocab2ix.items()}
english_processed = []
for sent in english_sentence:
 temp_sentence = []
 for word in sent:
 try:
 temp_sentence.append(eng_vocab2ix[word])
 except:
 temp_sentence.append(0)
 english_processed.append(temp_sentence)
all_german_words = [word for sentence in german_sentence for word
in sentence]
all_german_counts = Counter(all_german_words)
ger_word_keys = [x[0] for x in all_german_counts.most_
common(vocab_size-1)]
ger_vocab2ix = dict(zip(ger_word_keys, range(1,vocab_size)))
ger_ix2vocab = {val:key for key, val in ger_vocab2ix.items()}
german_processed = []
for sent in german_sentence:
 temp_sentence = []
 for word in sent:
 try:
```

```

 temp_sentence.append(ger_vocab2ix[word])
 except:
 temp_sentence.append(0)
 german_processed.append(temp_sentence)

```

7. We also have to process the test vocabulary and change the test sentences we have chosen to vocabulary indices:

```

test_data = []
for sentence in test_english:
 temp_sentence = []
 for word in sentence.split(' '):
 try:
 temp_sentence.append(eng_vocab2ix[word])
 except:
 # Use '0' if the word isn't in our vocabulary
 temp_sentence.append(0)
 test_data.append(temp_sentence)

```

8. Since some of the sentences are very short and some are very long, we will want to create separate models for sentences that are different lengths. A reason to do this is to minimize the effect the padding character has on shorter sentences. One way to do this is to bucket the data into similar sized buckets. We have chosen the following cut-offs for the buckets in order to have a similar amount of sentences in each bucket:

```

x_maxs = [5, 7, 11, 50]
y_maxs = [10, 12, 17, 60]
buckets = [x for x in zip(x_maxs, y_maxs)]
bucketed_data = [[] for _ in range(len(x_maxs))]
for eng, ger in zip(english_processed, german_processed):
 for ix, (x_max, y_max) in buckets:
 if (len(eng) <= x_max) and (len(ger) <= y_max):
 bucketed_data[ix].append([eng, ger])
 break

```

9. Now we use TensorFlow's built in sequence-to-sequence model with our parameters, to create a function that will be used to create a trainable model and a testable model that share the same variables:

```

def translation_model(sess, input_vocab_size, output_vocab_size,
 buckets, rnn_size, num_layers, max_gradient,
 learning_rate, lr_decay_rate, forward_only):
 model = seq2seq_model.Seq2SeqModel(
 input_vocab_size,
 output_vocab_size,
 buckets,
 rnn_size,
 num_layers,
 max_gradient,
 batch_size,

```

```
 learning_rate,
 lr_decay_rate,
 forward_only=forward_only,
 dtype=tf.float32)
return(model)
```

10. We set a variable scope and create our trainable model, then tell TensorFlow to reuse the variables in that scope, and create the test model, which will have a batch size of 1:

```
input_vocab_size = vocab_size
output_vocab_size = vocab_size
with tf.variable_scope('translate_model') as scope:
 translate_model = translation_model(sess, vocab_size, vocab_size,
 buckets, rnn_size, num_layers,
 max_gradient, learning_rate,
 lr_decay_rate, False)
#Reuse the variables for the test model
scope.reuse_variables()
test_model = translation_model(sess, vocab_size, vocab_size,
 buckets, rnn_size, num_layers,
 max_gradient, learning_rate,
 lr_decay_rate, True)
test_model.batch_size = 1
```

11. Next we initialize the variables in the model:

```
init = tf.initialize_all_variables()
sess.run(init)
```

12. Finally, we can train our sequence-to-sequence model by calling the step function for every generation. TensorFlow's sequence-to-sequence model has a get\_batch() function that will retrieve a batch of sentences from a given bucket index. We also decay the learning rate, save the model, and evaluate on the test sentences when appropriate:

```
train_loss = []
for i in range(generations):
 rand_bucket_ix = np.random.choice(len(bucketed_data))

 model_outputs = translate_model.get_batch(bucketed_data, rand_bucket_ix)
 encoder_inputs, decoder_inputs, target_weights = model_outputs

 # Get the (gradient norm, loss, and outputs)
 _, step_loss, _ = translate_model.step(sess, encoder_inputs,
 decoder_inputs, target_weights, rand_bucket_ix, False)

 # Output status
```

```

 if (i+1) % output_every == 0:
 train_loss.append(step_loss)
 print('Gen #{} out of {}. Loss: {:.4}'.format(i+1,
generations, step_loss))

 # Check if we should decay the learning rate
 if (i+1) % lr_decay_every == 0:
 sess.run(translate_model.learning_rate_decay_op)

 # Save model
 if (i+1) % save_every == 0:
 print('Saving model to {}'.format(full_model_dir))
 model_save_path = os.path.join(full_model_dir, "eng_ger_
translation.ckpt")
 translate_model.saver.save(sess, model_save_path, global_
step=i)

 # Eval on test set
 if (i+1) % eval_every == 0:
 for ix, sentence in enumerate(test_data):
 # Find which bucket sentence goes in
 bucket_id = next(index for index, val in enumerate(x_
maxs) if val>=len(sentence))
 # Get RNN model outputs
 encoder_inputs, decoder_inputs, target_weights = test_
model.get_batch(
 {bucket_id: [(sentence, [])]}, bucket_id)
 # Get logits
 _, test_loss, output_logits = test_model.step(sess,
encoder_inputs, decoder_inputs, target_weights, bucket_id, True)
 ix_output = [int(np.argmax(logit, axis=1)) for logit
in output_logits]
 # If there is a 0 symbol in outputs end the output
there.
 ix_output = ix_output[0:[ix for ix, x in enumerate(ix_
output+[0]) if x==0][0]]
 # Get german words from indices
 test_german = [ger_ix2vocab[x] for x in ix_output]
 print('English: {}'.format(test_english[ix]))
 print('German: {}'.format(test_german))

```

13. This results in the following output:

```

Gen #0 out of 10000. Loss: 7.377
Gen #9800 out of 10000. Loss: 3.875
Gen #9850 out of 10000. Loss: 3.748
Gen #9900 out of 10000. Loss: 3.615
Gen #9950 out of 10000. Loss: 3.889

```

```
Gen #10000 out of 10000. Loss: 3.071
Saving model to temp/seq2seq_model.
English: hello where is my computer
German: ['wo', 'ist', 'mein', 'ist']
English: the quick brown fox jumped over the lazy dog
German: ['die', 'alte', 'ist', 'von', 'mit', 'hund', 'zu']
English: is it going to rain tomorrow
German: ['ist', 'es', 'morgen', 'kommen']
```

14. Here is the `matplotlib` code to plot the training loss that we saved on regular intervals:

```
loss_generations = [i for i in range(generations) if i%output_
every==0]
plt.plot(loss_generations, train_loss, 'k-')
plt.title('Sequence to Sequence Loss')
plt.xlabel('Generation')
plt.ylabel('Loss')
plt.show()
```

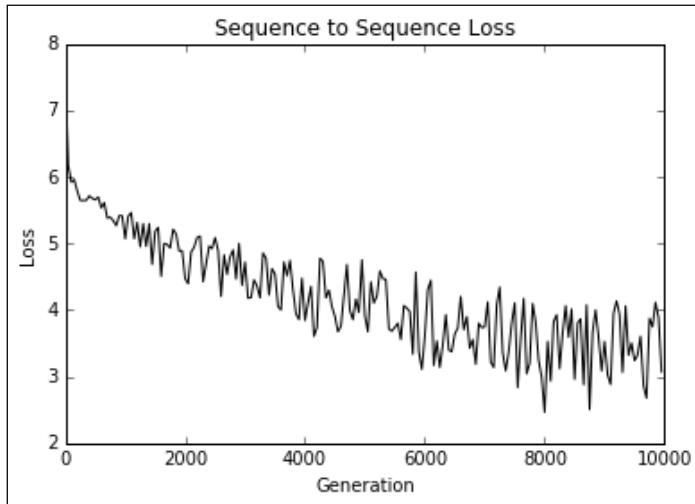


Figure 7: Here, we plot the training loss over the course of 10,000 generations of training the English–German sequence-to-sequence model.

## How it works...

For this recipe, we used TensorFlow's built in sequence-to-sequence model to translate from English to German.

As we did not get perfect translations on our test sentences, there is room for improvement. If we trained for longer, and potentially combined some buckets (for larger training data in each bucket), we might be able to improve our translations.

## There's more...

There are other similar bilingual sentence datasets hosted on the manythings website (<http://www.manythings.org/anki/>). Feel free to substitute any language dataset that appeals to you.

## Training a Siamese Similarity Measure

A great property of RNN models, as compared to many other models, is that they can deal with sequences of various lengths. Taking advantage of this fact and that they can generalize to sequences not seen before, we can create a way to measure how similar sequences of inputs are to each other. In this recipe, we will train a Siamese similarity RNN to measure the similarity between addresses for record matching.

### Getting ready

In this recipe, we will build a bidirectional RNN model that feeds into a fully connected layer that outputs a fixed length numerical vector. We create a bidirectional RNN layer for both input addresses and feed the outputs into a fully connected layer that outputs a fixed length numerical vector (length 100). We then compare the two vector outputs with the cosine distance, which is bounded between -1 and 1. We denote input data to be similar with a target of 1, and different with a target of -1. The predictions of the cosine distance is just the sign of the output (negative means dissimilar, positive means similar). We can use this network to do record matching by taking the reference address that scores the highest on the cosine distance from the query address. See the following network architecture diagram:

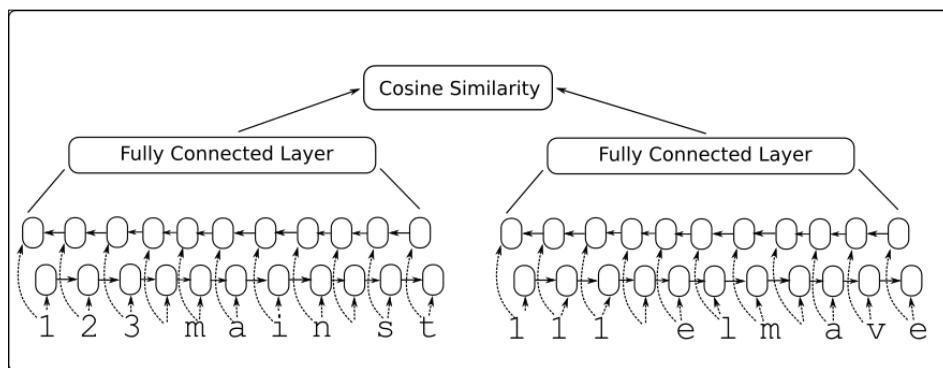


Figure 8: Siamese RNN similarity model architecture.

What is also great about this model, is that it accepts inputs that it has not seen before and can compare them with an output of -1 to 1. We will show this in the code by picking a test address that the model has not seen before and see if it can match it to a similar address.

## How to do it...

1. We start by loading the necessary libraries and starting a graph session:

```
import os
import random
import string
import numpy as np
import matplotlib.pyplot as plt
import tensorflow as tf
sess = tf.Session()
```

2. We now set the model parameters as follows:

```
batch_size = 200
n_batches = 300
max_address_len = 20
margin = 0.25
num_features = 50
dropout_keep_prob = 0.8
```

3. Next, we create the Siamese RNN similarity model class as follows:

```
def snn(address1, address2, dropout_keep_prob,
 vocab_size, num_features, input_length):

 # Define the siamese double RNN with a fully connected layer
 # at the end
 def siamese_nn(input_vector, num_hidden):
 cell_unit = tf.nn.rnn_cell.BasicLSTMCell

 # Forward direction cell
 lstm_forward_cell = cell_unit(num_hidden, forget_bias=1.0)
 lstm_forward_cell = tf.nn.rnn_cell.DropoutWrapper(lstm_
forward_cell, output_keep_prob=dropout_keep_prob)

 # Backward direction cell
 lstm_backward_cell = cell_unit(num_hidden, forget_
bias=1.0)
 lstm_backward_cell = tf.nn.rnn_cell.DropoutWrapper(lstm_
backward_cell, output_keep_prob=dropout_keep_prob)

 # Split title into a character sequence
 input_embed_split = tf.split(1, input_length, input_
vector)
```

```

 input_embed_split = [tf.squeeze(x, squeeze_dims=[1]) for x
in input_embed_split]

 # Create bidirectional layer
 outputs, _, _ = tf.nn.bidirectional_rnn(lstm_forward_cell,
 lstm_backward_
cell,
 input_embed_split,
 dtype=tf.float32)

 # Average The output over the sequence
 temporal_mean = tf.add_n(outputs) / input_length

 # Fully connected layer
 output_size = 10
 A = tf.get_variable(name="A", shape=[2*num_hidden, output_
size],
 dtype=tf.float32,
 initializer=tf.random_normal_
initializer(stddev=0.1))
 b = tf.get_variable(name="b", shape=[output_size],
 dtype=tf.float32,
 initializer=tf.random_normal_
initializer(stddev=0.1))

 final_output = tf.matmul(temporal_mean, A) + b
 final_output = tf.nn.dropout(final_output, dropout_keep_
prob)

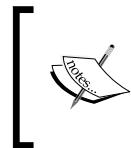
 return(final_output)

 with tf.variable_scope("siamese") as scope:
 output1 = siamese_nn(address1, num_features)
 # Declare that we will use the same variables on the
second string
 scope.reuse_variables()
 output2 = siamese_nn(address2, num_features)

 # Unit normalize the outputs
 output1 = tf.nn.l2_normalize(output1, 1)
 output2 = tf.nn.l2_normalize(output2, 1)
 # Return cosine distance
 # in this case, the dot product of the norms is the same.
 dot_prod = tf.reduce_sum(tf.mul(output1, output2), 1)

 return(dot_prod)

```



Note the usage of a variable scope to share parameters between the two parts of the Siamese network for the two address inputs. Also note that the cosine distance is achieved by the dot product of the normalized vectors.

- Now we will declare our prediction function, which is just the sign of the cosine distance as follows:

```
def get_predictions(scores):
 predictions = tf.sign(scores, name="predictions")
 return(predictions)
```

- Now we will declare our loss function as described before. Remember that we want to leave a margin (similar to a SVM model) for error. We will also have a loss term for true positives and true negatives. Use the following code for the loss:

```
def loss(scores, y_target, margin):
 # Calculate the positive losses
 pos_loss_term = 0.25 * tf.square(tf.sub(1., scores))
 pos_mult = tf.cast(y_target, tf.float32)

 # Make sure positive losses are on similar strings
 positive_loss = tf.mul(pos_mult, pos_loss_term)

 # Calculate negative losses, then make sure on dissimilar strings
 neg_mult = tf.sub(1., tf.cast(y_target, tf.float32))

 negative_loss = neg_mult*tf.square(scores)

 # Combine similar and dissimilar losses
 loss = tf.add(positive_loss, negative_loss)

 # Create the margin term. This is when the targets are 0.,
 # and the scores are less than m, return 0.

 # Check if target is zero (dissimilar strings)
 target_zero = tf.equal(tf.cast(y_target, tf.float32), 0.)
 # Check if cosine outputs is smaller than margin
 less_than_margin = tf.less(scores, margin)
 # Check if both are true
 both_logical = tf.logical_and(target_zero, less_than_margin)
 both_logical = tf.cast(both_logical, tf.float32)
 # If both are true, then multiply by (1-1)=0.
```

```

multiplicative_factor = tf.cast(1. - both_logical, tf.float32)
total_loss = tf.mul(loss, multiplicative_factor)

Average loss over batch
avg_loss = tf.reduce_mean(total_loss)
return(avg_loss)

```

6. We declare an accuracy function as follows:

```

def accuracy(scores, y_target):
 predictions = get_predictions(scores)
 correct_predictions = tf.equal(predictions, y_target)
 accuracy = tf.reduce_mean(tf.cast(correct_predictions,
tf.float32))
 return(accuracy)

```

7. We will create similar addresses by creating a typo in an address. We will denote these addresses (reference address and typo address) as similar:

```

def create_typos(s):
 rand_ind = random.choice(range(len(s)))
 s_list = list(s)
 s_list[rand_ind]=random.choice(string.ascii_lowercase +
'0123456789')
 s = ''.join(s_list)
 return(s)

```

8. The data that we will generate will be random combinations of street numbers, street names, and street suffixes. The names and suffixes are from the following lists:

```

street_names = ['abbey', 'baker', 'canal', 'donner', 'elm',
'fifth', 'grandvia', 'hollywood', 'interstate', 'jay', 'kings']
street_types = ['rd', 'st', 'ln', 'pass', 'ave', 'hwy', 'cir',
'dr', 'jct']

```

9. We generate test queries and references as follows:

```

test_queries = ['111 abbey ln', '271 doner cicle',
 '314 king avenue', 'tensorflow is fun']
test_references = ['123 abbey ln', '217 donner cir', '314 kings
ave', '404 hollywood st', 'tensorflow is so fun']

```



Note the last query and reference are not any addresses that the model will have seen before, but we hope that they will be what the model sees as most similar at the end.

10. We will now define how to generate a batch of data. Our batch of data will be half similar addresses (reference address and a typo address) and half dissimilar addresses. We generate the dissimilar addresses by taking half of the address list and shifting the targets by one position (with the function `numpy.roll()`):

```
def get_batch(n):
 # Generate a list of reference addresses with similar
 addresses that have
 # a typo.
 numbers = [random.randint(1, 9999) for i in range(n)]
 streets = [random.choice(street_names) for i in range(n)]
 street_suffs = [random.choice(street_types) for i in range(n)]
 full_streets = [str(w) + ' ' + x + ' ' + y for w,x,y in
zip(numbers, streets, street_suffs)]
 typo_streets = [create_typos(x) for x in full_streets]
 reference = [list(x) for x in zip(full_streets, typo_streets)]

 # Shuffle last half of them for training on dissimilar
 addresses
 half_ix = int(n/2)
 bottom_half = reference[half_ix:]
 true_address = [x[0] for x in bottom_half]
 typo_address = [x[1] for x in bottom_half]
 typo_address = list(np.roll(typo_address, 1))
 bottom_half = [[x,y] for x,y in zip(true_address, typo_
address)]
 reference[half_ix:] = bottom_half

 # Get target similarities (1's for similar, -1's for non-
 similar)
 target = [1]*(n-half_ix) + [-1]*half_ix
 reference = [[x,y] for x,y in zip(reference, target)]
 return(reference)
```

11. Next, we will define our address vocabulary and how to one-hot-encode the addresses to indices:

```
vocab_chars = string.ascii_lowercase + '0123456789 '
vocab2ix_dict = {char:(ix+1) for ix, char in enumerate(vocab_
chars)}
vocab_length = len(vocab_chars) + 1

Define vocab one-hot encoding
def address2onehot(address,
 vocab2ix_dict = vocab2ix_dict,
```

```

 max_address_len = max_address_len):
 # translate address string into indices
 address_ix = [vocab2ix_dict[x] for x in list(address)]

 # Pad or crop to max_address_len
 address_ix = (address_ix + [0]*max_address_len)[0:max_address_
len]
 return(address_ix)

```

12. After dealing with the vocabulary, we will start declaring our model placeholders and the embedding lookup. For the embedding lookup, we will be using one-hot-encoded embedding by using an identity matrix as the lookup matrix. Use the following code:

```

address1_ph = tf.placeholder(tf.int32, [None, max_address_len],
name="address1_ph")
address2_ph = tf.placeholder(tf.int32, [None, max_address_len],
name="address2_ph")
y_target_ph = tf.placeholder(tf.int32, [None], name="y_target_ph")
dropout_keep_prob_ph = tf.placeholder(tf.float32, name="dropout_
keep_prob")

Create embedding lookup
identity_mat = tf.diag(tf.ones(shape=[vocab_length]))
address1_embed = tf.nn.embedding_lookup(identity_mat, address1_ph)
address2_embed = tf.nn.embedding_lookup(identity_mat, address2_ph)

```

13. We will now declare the model, accuracy, loss, and prediction operations as follows:

```

Define Model
text_snn = model.snn(address1_embed, address2_embed, dropout_keep_
prob_ph,
 vocab_length, num_features, max_address_len)
Define Accuracy
batch_accuracy = model.accuracy(text_snn, y_target_ph)
Define Loss
batch_loss = model.loss(text_snn, y_target_ph, margin)
Define Predictions
predictions = model.get_predictions(text_snn)

```

14. Finally, before we can start training, we add the optimization and initialization operations to the graph as follows:

```

Declare optimizer
optimizer = tf.train.AdamOptimizer(0.01)
Apply gradients
train_op = optimizer.minimize(batch_loss)

```

```
Initialize Variables
init = tf.global_variables_initializer()
sess.run(init)
```

15. We will now iterate through the training generations and keep track of the loss and accuracy:

```
train_loss_vec = []
train_acc_vec = []
for b in range(n_batches):
 # Get a batch of data
 batch_data = get_batch(batch_size)
 # Shuffle data
 np.random.shuffle(batch_data)
 # Parse addresses and targets
 input_addresses = [x[0] for x in batch_data]
 target_similarity = np.array([x[1] for x in batch_data])
 address1 = np.array([address2onehot(x[0]) for x in input_
addresses])
 address2 = np.array([address2onehot(x[1]) for x in input_
addresses])

 train_feed_dict = {address1_ph: address1,
 address2_ph: address2,
 y_target_ph: target_similarity,
 dropout_keep_prob_ph: dropout_keep_prob}

 _, train_loss, train_acc = sess.run([train_op, batch_loss,
batch_accuracy],
 feed_dict=train_feed_dict)
 # Save train loss and accuracy
 train_loss_vec.append(train_loss)
 train_acc_vec.append(train_acc)
```

16. After training, we now process the testing queries and references to see how the model can perform:

```
test_queries_ix = np.array([address2onehot(x) for x in test_
queries])
test_references_ix = np.array([address2onehot(x) for x in test_
references])
num_refs = test_references_ix.shape[0]
best_fit.refs = []
for query in test_queries_ix:
 test_query = np.repeat(np.array([query]), num_refs, axis=0)
 test_feed_dict = {address1_ph: test_query,
```

```

 address2_ph: test_references_ix,
 y_target_ph: target_similarity,
 dropout_keep_prob_ph: 1.0}
test_out = sess.run(text_snn, feed_dict=test_feed_dict)
best_fit = test_references[np.argmax(test_out)]
best_fit_refs.append(best_fit)
print('Query Addresses: {}'.format(test_queries))
print('Model Found Matches: {}'.format(best_fit_refs))

```

17. This results in the following output:

```

Query Addresses: ['111 abbey ln', '271 doner cicle', '314 king
avenue', 'tensorflow is fun']
Model Found Matches: ['123 abbey ln', '217 donner cir', '314 kings
ave', 'tensorflow is so fun']

```

### There's more...

We can see from the test queries and references, that the model not only was able to identify the correct reference addresses, it was also able to generalize to a non-address phrase. We can also see how the model performed by looking at the loss and accuracy during training:

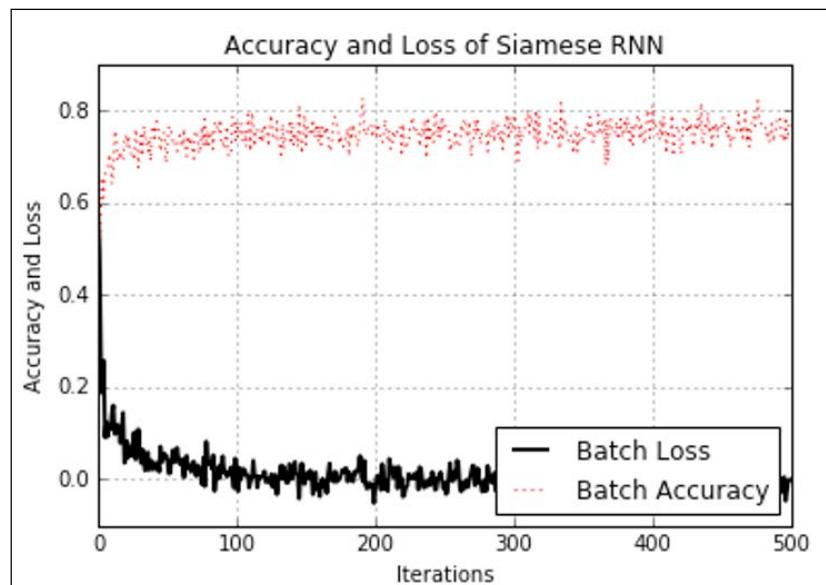


Figure 9: The accuracy and loss for the Siamese RNN similarity model during training.

Notice that we did not have a designated test set for this exercise. The reason is because of how we generated the data. We created a batch function that creates new batch data every time it is called so the model is always seeing new data. Because of this, we can use the batch loss and accuracy as proxies to the test loss and accuracies. But this is never true with a finite set of real data, as we would always have to have a train and test set to judge the performance of the model.



# 10

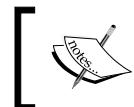
## Taking TensorFlow to Production

In this chapter, we will cover the following topics:

- ▶ Implementing Unit Tests
- ▶ Using Multiple Executors
- ▶ Parallelizing TensorFlow
- ▶ Taking TensorFlow to Production
- ▶ Productionalizing TensorFlow – An Example

### Introduction

Up to this point, we have covered how to train and evaluate various models in TensorFlow. In this chapter, we will show how to write code that is ready for production usage. There are various definitions of production-ready code but, for us, production code will be defined as code that has unit tests, separates the training and evaluation code, and efficiently saves and loads various needed parts of the data pipeline and created graph session.



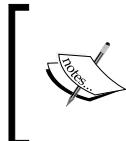
The Python scripts provided in this chapter should be run from the command line. This allows tests to be run, and device placements to be logged to the screen.

## Implementing unit tests

Testing code results in faster prototyping, more efficient debugging, faster changing, and makes it easier to share code. There are easy ways to implement unit tests in TensorFlow that we will cover in this recipe.

### Getting ready

When programming a TensorFlow model, it will help to have unit tests to check the functionality of the program. This helps us because, when we want to make changes to a program unit, tests will make sure that those changes do not break the model in unknown ways. In this recipe, we will create a simple CNN network that relies on the MNIST data. With it, we will implement three different types of unit test to illustrate how to write them in TensorFlow.



Note that Python has a great testing library called **Nose**. TensorFlow also has built-in testing functions, and we will illustrate how these make it easier to test the value of tensor objects without having to evaluate the values in a session.

1. We start by loading the necessary libraries and formatting the data:

```
import numpy as np
import tensorflow as tf
from tensorflow.contrib.learn.python.learn.datasets.mnist import
read_data_sets
from tensorflow.python.framework import ops
ops.reset_default_graph()
Start a graph session
sess = tf.Session()
Load data
data_dir = 'temp'
mnist = read_data_sets(data_dir)
Convert images into 28x28 (they are downloaded as 1x784)
train_xdata = np.array([np.reshape(x, (28,28)) for x in mnist.
train.images])
test_xdata = np.array([np.reshape(x, (28,28)) for x in mnist.test.
images])
Convert labels into one-hot encoded vectors
train_labels = mnist.train.labels
test_labels = mnist.test.labels
Set model parameters
batch_size = 100
```

```
learning_rate = 0.005
evaluation_size = 100
image_width = train_xdata[0].shape[0]
image_height = train_xdata[0].shape[1]
target_size = max(train_labels) + 1
num_channels = 1 # greyscale = 1 channel
generations = 100
eval_every = 5
conv1_features = 25
conv2_features = 50
max_pool_size1 = 2 # NxN window for 1st max pool layer
max_pool_size2 = 2 # NxN window for 2nd max pool layer
fully_connected_size1 = 100
dropout_prob = 0.75
```

2. We then declare our placeholders, variables, and model formulation:

```
Declare model placeholders
x_input_shape = (batch_size, image_width, image_height, num_
channels)
x_input = tf.placeholder(tf.float32, shape=x_input_shape)
y_target = tf.placeholder(tf.int32, shape=(batch_size))
eval_input_shape = (evaluation_size, image_width, image_height,
num_channels)
eval_input = tf.placeholder(tf.float32, shape=eval_input_shape)
eval_target = tf.placeholder(tf.int32, shape=(evaluation_size))
dropout = tf.placeholder(tf.float32, shape=())
Declare model parameters
conv1_weight = tf.Variable(tf.truncated_normal([4, 4, num_
channels, conv1_features],
 stddev=0.1,
 dtype=tf.float32))
conv1_bias = tf.Variable(tf.zeros([conv1_features], dtype=tf.
float32))
conv2_weight = tf.Variable(tf.truncated_normal([4, 4, conv1_
features, conv2_features],
 stddev=0.1,
 dtype=tf.float32))
conv2_bias = tf.Variable(tf.zeros([conv2_features], dtype=tf.
float32))
fully connected variables
resulting_width = image_width // (max_pool_size1 * max_pool_size2)
resulting_height = image_height // (max_pool_size1 * max_pool_
size2)
```

```
full1_input_size = resulting_width * resulting_height * conv2_
features
full1_weight = tf.Variable(tf.truncated_normal([full1_input_size,
fully_connected_size1],
 stddev=0.1, dtype=tf.float32))
full1_bias = tf.Variable(tf.truncated_normal([fully_connected_
size1], stddev=0.1, dtype=tf.float32))
full2_weight = tf.Variable(tf.truncated_normal([fully_connected_
size1, target_size],
 stddev=0.1,
 dtype=tf.float32))
full2_bias = tf.Variable(tf.truncated_normal([target_size],
 stddev=0.1, dtype=tf.float32))
Initialize Model Operations
def my_conv_net(input_data):
 # First Conv-ReLU-MaxPool Layer
 conv1 = tf.nn.conv2d(input_data, conv1_weight, strides=[1, 1,
1, 1], padding='SAME')
 relu1 = tf.nn.relu(tf.nn.bias_add(conv1, conv1_bias))
 max_pool1 = tf.nn.max_pool(relu1, ksize=[1, max_pool_size1,
max_pool_size1, 1],
 strides=[1, max_pool_size1, max_
pool_size1, 1], padding='SAME')
 # Second Conv-ReLU-MaxPool Layer
 conv2 = tf.nn.conv2d(max_pool1, conv2_weight, strides=[1, 1,
1, 1], padding='SAME')
 relu2 = tf.nn.relu(tf.nn.bias_add(conv2, conv2_bias))
 max_pool2 = tf.nn.max_pool(relu2, ksize=[1, max_pool_size2,
max_pool_size2, 1],
 strides=[1, max_pool_size2, max_
pool_size2, 1], padding='SAME')
 # Transform Output into a 1xN layer for next fully connected
 # layer
 final_conv_shape = max_pool2.get_shape().as_list()
 final_shape = final_conv_shape[1] * final_conv_shape[2] *
final_conv_shape[3]
 flat_output = tf.reshape(max_pool2, [final_conv_shape[0],
final_shape])
 # First Fully Connected Layer
 fully_connected1 = tf.nn.relu(tf.add(tf.matmul(flat_output,
full1_weight), full1_bias))
 # Second Fully Connected Layer
 final_model_output = tf.add(tf.matmul(fully_connected1, full2_
weight), full2_bias)

 # Add dropout
```

---

```

 final_model_output = tf.nn.dropout(final_model_output,
dropout)

 return(final_model_output)
model_output = my_conv_net(x_input)
test_model_output = my_conv_net(eval_input)

```

3. Next we create our loss function, prediction, and accuracy operations. Then we initialize the model variables:

```

Declare Loss Function (softmax cross entropy)
loss = tf.reduce_mean(tf.nn.sparse_softmax_cross_entropy_with_
logits(model_output, y_target))
Create a prediction function
prediction = tf.nn.softmax(model_output)
test_prediction = tf.nn.softmax(test_model_output)
Create accuracy function
def get_accuracy(logits, targets):
 batch_predictions = np.argmax(logits, axis=1)
 num_correct = np.sum(np.equal(batch_predictions, targets))
 return(100. * num_correct/batch_predictions.shape[0])
Create an optimizer
my_optimizer = tf.train.MomentumOptimizer(learning_rate, 0.9)
train_step = my_optimizer.minimize(loss)
Initialize Variables
init = tf.initialize_all_variables()
sess.run(init)

```

4. For our first unit test, we use the `tf.test.TestCase` class and create a way to test the values of a placeholder (or variable). For this test case, we make sure that the dropout probability (for keeping) is greater than 0.25, so that the model is not changed to attempt to train on more than 75% dropout:

```

Check values of tensors!
class drop_out_test(tf.test.TestCase):
 # Make sure that we don't drop too much
 def dropout_greaterthan(self):
 with self.test_session():
 self.assertGreater(dropout.eval(), 0.25)

```

5. Next, we will test that our accuracy function is behaving properly. We will create a sample array of probabilities and what we expect, and make sure that the test accuracy returns 100%:

```

Test accuracy function
class accuracy_test(tf.test.TestCase):
 # Make sure accuracy function behaves correctly

```

```
def accuracy_exact_test(self):
 with self.test_session():
 test_preds = [[0.9, 0.1], [0.01, 0.99]]
 test_targets = [0, 1]
 test_acc = get_accuracy(test_preds, test_targets)
 self.assertEqual(test_acc.eval(), 100.)
```

6. We can also make sure that a tensor is the shape that we expect. Next, we test that the model output is the expected shape of `batch_size` by `target_size`:

```
Test tensorshape
class shape_test(tf.test.TestCase):
 # Make sure our model output is size [batch_size, num_classes]
 def output_shape_test(self):
 with self.test_session():
 numpy_array = np.ones([batch_size, target_size])
 self.assertShapeEqual(numpy_array, model_output)
```

7. To perform these tests, we just put in the following command, followed by our training loop (or the rest of our program):

```
Perform unit tests
tf.test.main()
Start training loop
for i in range(generations):
 ...
```

8. If we run the program on the command line, we get the following output:

```
$python3 implementing_unit_tests.py
Ran 3 tests in 0.000s
OK
```

9. The full program can be found on the book's GitHub repository at [https://github.com/nfmccclure/tensorflow\\_cookbook/](https://github.com/nfmccclure/tensorflow_cookbook/).

## How it works...

We implemented three types of unit tests, tensor values, operations outputs, and tensor shapes. There are more types of unit test functions for TensorFlow, and they can be found here: [https://www.tensorflow.org/versions/master/api\\_docs/python/test.html](https://www.tensorflow.org/versions/master/api_docs/python/test.html).

Remember that a unit test helps us assure that code will function as expected, provide confidence in sharing code, and make reproducibility more accessible.

## Using Multiple Executors

It should be apparent to the reader that there are many features of TensorFlow and computational graphs that lend itself naturally to being computed in parallel. The computational graph can be broken up on different processors as well as processing different batches. We will address how to access different processors on the same machine in this recipe.

### Getting ready

For this recipe, we will show how to access multiple devices on the same system and train on them. This is a very common occurrence, as along with a CPU, a machine may have one or more GPUs that can share the computational load. If TensorFlow can access these devices, it will automatically distribute the computations to the multiple devices via a greedy process. But TensorFlow also allows the program to specify which operations will be on which devices via namescope placement.

In order to access GPU devices, the GPU version of TensorFlow must be installed. To install the GPU version of TensorFlow, visit [https://www.tensorflow.org/versions/master/get\\_started/os\\_setup.html#download-and-setup](https://www.tensorflow.org/versions/master/get_started/os_setup.html#download-and-setup) and follow the instructions for your specific system. Be aware that the GPU versions of TensorFlow require CUDA to use the GPU.

In this recipe, we will show you a range of commands that will allow you to access the various devices on your system, and find out which devices TensorFlow is using.

### How to do it...

1. In order to find out what devices TensorFlow is using for which operations, we can set a config in the Session parameters that sets `log_device_placement` to True. When we run the script from the command line, we will see specific device placements as the output:

```
import tensorflow as tf
sess = tf.Session(config=tf.ConfigProto(log_device_
placement=True))
a = tf.constant([1.0, 2.0, 3.0, 4.0, 5.0, 6.0], shape=[2, 3] ,
name='a')
b = tf.constant([1.0, 2.0, 3.0, 4.0, 5.0, 6.0], shape=[3, 2] ,
name='b')
c = tf.matmul(a, b)
Runs the op.
print(sess.run(c))
```

2. From the terminal, run the following command:

```
$python3 using_multiple_devices.py
Device mapping: no known devices.
I tensorflow/core/common_runtime/direct_session.cc:175] Device
mapping:
MatMul: /job:localhost/replica:0/task:0/cpu:0
I tensorflow/core/common_runtime/simple_placer.cc:818] MatMul: /
job:localhost/replica:0/task:0/cpu:0
b: /job:localhost/replica:0/task:0/cpu:0
I tensorflow/core/common_runtime/simple_placer.cc:818] b: /
job:localhost/replica:0/task:0/cpu:0
a: /job:localhost/replica:0/task:0/cpu:0
I tensorflow/core/common_runtime/simple_placer.cc:818] a: /
job:localhost/replica:0/task:0/cpu:0
[[22. 28.]
 [49. 64.]]
```

3. Sometimes, we would like to make sure TensorFlow is deciding the placements. This is useful when loading a prior saved model that had hard placements assigned in the graph and our machine has different devices to those the graph would have. We can set soft placements in the configuration as follows:

```
config = tf.ConfigProto()
config.allow_soft_placement = True
sess_soft = tf.Session(config=config)
```

4. When using GPUs, TensorFlow automatically takes up a large portion of the GPU memory. While this is usually desired, we can take steps to be more careful with the GPU memory allocation. While TensorFlow never releases GPU memory, we can slowly grow GPU memory allocation to the maximum limit (only when needed) by setting a GPU memory growth option as follows:

```
config.gpu_options.allow_growth = True
sess_grow = tf.Session(config=config)
```

5. If we want to put a hard limit on the percentage of GPU memory used by TensorFlow, we can use the config setting per\_process\_gpu\_memory\_fraction:

```
config.gpu_options.per_process_gpu_memory_fraction = 0.4
sess_limited = tf.Session(config=config)
```

6. Sometimes, we would like to write robust code that can determine if it is running with the GPU available or not. TensorFlow has a built-in function that can test this. This is helpful if we want to write code that can take advantage of the GPU when it is available and assign specific operations to it:

```
if tf.test.is_built_with_cuda():
```

7. We may wish to assign specific operations, say to the GPU. Here is an example of code that does some simple calculations and assigns them to the main CPU, and the two auxiliary GPUs:

```
with tf.device('/cpu:0'):
 a = tf.constant([1.0, 3.0, 5.0], shape=[1, 3])
 b = tf.constant([2.0, 4.0, 6.0], shape=[3, 1])

 with tf.device('/gpu:0'):
 c = tf.matmul(a,b)
 c = tf.reshape(c, [-1])

 with tf.device('/gpu:1'):
 d = tf.matmul(b,a)
 flat_d = tf.reshape(d, [-1])

 combined = tf.mul(c, flat_d)
print(sess.run(combined))
```

## How it works...

When we want to specify particular devices on our machine for TensorFlow operations, we will need to know how TensorFlow refers to such devices. Device names in TensorFlow follow the following conventions:

| Device     | Device name |
|------------|-------------|
| Main CPU   | /cpu:0      |
| Second CPU | /cpu:1      |
| Main GPU   | /gpu:0      |
| Second GPU | /gpu:1      |
| Third GPU  | /gpu:2      |

## There's more...

Running TensorFlow in the cloud is getting easier and easier. Many cloud computation service providers offer GPU instances that have a main CPU and a powerful GPU alongside it. **Amazon Web Services (AWS)** has G instances and P2 instances that allow usage of powerful GPUs that offer great speedup for TensorFlow processes. There are even **AWS Machine Images (AMIs)** that you can select for free that will boot up a selected instance with the GPU instance of TensorFlow installed.

## Parallelizing TensorFlow

To extend our reach for parallelizing TensorFlow, we can also perform separate operations of our graph on entirely different machines in a distributed manner. This recipe will show us how that is achieved.

### Getting ready

A few months after the release of TensorFlow, Google released **TensorFlow Distributed**. This was a big upgrade to the TensorFlow ecosystem, allowing a TensorFlow cluster to be set up (separate worker machines), to share the computational task of training and evaluating models. Using TensorFlow Distributed is as easy as setting up some parameters for workers and then assigning different jobs to different workers.

In this recipe, we will set up two local workers and assign them different jobs.

### How to do it...

1. To start, we load TensorFlow and define our two local workers with a configuration dictionary file (ports 2222 and 2223):

```
import tensorflow as tf
Cluster for 2 local workers (tasks 0 and 1):
cluster = tf.train.ClusterSpec({'local': ['localhost:2222',
 'localhost:2223']})
```

2. Now we join the two workers into the server and label them with task numbers:

```
server = tf.train.Server(cluster, job_name="local", task_index=0)
server = tf.train.Server(cluster, job_name="local", task_index=1)
```

3. Now we will have each worker do a task. The first worker will initialize two matrices (each 25 by 25). The second worker will sum all the elements. Then we auto assign the sum of the two sums and print the output:

```
mat_dim = 25
matrix_list = {}
with tf.device('/job:local/task:0'):
 for i in range(0, 2):
 m_label = 'm_{}'.format(i)
 matrix_list[m_label] = tf.random_normal([mat_dim, mat_dim])
Have each worker calculate the sums
sum_outs = {}
with tf.device('/job:local/task:1'):
```

```
for i in range(0, 2):
 A = matrix_list['m_{}'.format(i)]
 sum_outs['m_{}'.format(i)] = tf.reduce_sum(A)
Sum all the sums
summed_out = tf.add_n(list(sum_outs.values()))
with tf.Session(server.target) as sess:
 result = sess.run(summed_out)
print('Summed Values:{}\n'.format(result))
```

4. Now we can run the following at the command prompt:

```
$ python3 parallelizing_tensorflow.py
I tensorflow/core/distributed_runtime/rpc/grpc_channel.cc:197]
Initialize GrpcChannelCache for job local -> {0 -> localhost:2222,
1 -> localhost:2223}
I tensorflow/core/distributed_runtime/rpc/grpc_server_lib.cc:206]
Started server with target: grpc://localhost:2222
I tensorflow/core/distributed_runtime/rpc/grpc_channel.cc:197]
Initialize GrpcChannelCache for job local -> {0 -> localhost:2222,
1 -> localhost:2223}
I tensorflow/core/distributed_runtime/rpc/grpc_server_lib.cc:206]
Started server with target: grpc://localhost:2223
I tensorflow/core/distributed_runtime/master_session.cc:928] Start
master session 252bb6f530553002 with config:
Summed Values:-21.12611198425293
```

## How it works...

Using TensorFlow Distributed is quite easy. We just have to assign the worker IPs to the server with names. Then we can manually assign or auto assign operations to the workers.

## Taking TensorFlow to Production

If we want to use our machine learning scripts in a production setting, there are some points to consider for best practices. Here, we will help to point out some best practices.

### Getting ready

In this recipe, we want to summarize and condense various tips for bringing TensorFlow to production. We will cover how to best save and load vocabularies, graphs, variables, and model checkpoints. We will also talk about how to use TensorFlow's command-line argument parser and change the logging verbosity of TensorFlow.

## How to do it...

- When running a TensorFlow program, we may want to be sure that no other graph session is already in memory, or that we clear the graph session every time while debugging a program. We can accomplish this as follows:

```
from tensorflow.python.framework import ops
ops.reset_default_graph()
```

- When dealing with text (or any data pipeline), we need to be sure that we save how we process the data, so that we can process future evaluation data the same way. If we are dealing with text, we need to be sure we can save and load the vocabulary dictionary. See the following code for an example of saving the vocabulary dictionary with the JSON library:

```
import json
word_list = ['to', 'be', 'or', 'not', 'to', 'be']
vocab_list = list(set(word_list))
vocab2ix_dict = dict(zip(vocab_list, range(len(vocab_list))))
ix2vocab_dict = {val:key for key,val in vocab2ix_dict.items()}
Save vocabulary
import json
with open('vocab2ix_dict.json', 'w') as file_conn:
 json.dump(vocab2ix_dict, file_conn)
Load vocabulary
with open('vocab2ix_dict.json', 'r') as file_conn:
 vocab2ix_dict = json.load(file_conn)
```

[  We saved the vocabulary dictionary here in a JSON format. We can also save it in a text file, CSV, or even a binary format. If the vocabulary is large, a binary file is preferred. Look into using the pickle library to create a pkl binary file. Be aware though that pickle files do not translate well between library and Python versions. ]

- To save the model graph and variables, we create a `Saver()` operation and add that to the graph. It is recommended that the model is saved on a regular basis during training. See the following example code for saving the model regularly:

```
After model declaration, add a saving operations
saver = tf.train.Saver()
Then during training, save every so often, referencing the
training generation
for i in range(generations):
 ...
 if i%save_every == 0:
```

```

 saver.save(sess, 'my_model', global_step=step)
Can also save only specific variables:
saver = tf.train.Saver({'my_var': my_variable})

```

 Note that the `Saver()` operation also takes other parameters. As shown previously, it can take a dictionary of variables and tensors to save specific elements. It also can take `checkpoint_every_n_hours`, which performs the saving operation on a regular time basis, instead of a generation basis. By default, the saving operation only keeps the last five model saves (for space considerations). This can be changed with the `max_to_keep` option (default is 5).

4. Before saving a model, be sure to name important operations of the model. TensorFlow does not have an easy way to load specific placeholders, operations, or variables if they do not have a name. Most operations and functions in TensorFlow accept a `name` argument:

```

conv_weights = tf.Variable(tf.random_normal(), name='conv_weights')
loss = tf.reduce_mean(..., name='loss')

```

5. TensorFlow also makes it easy to perform arg-parsing on the command line with the `tf.app.flags` library. With these functions, we can define command-line arguments that are strings, floats, integers, or Booleans as shown here. With these flag definitions, we can just run `tf.app.run()` and this will run the `main()` function with these flag arguments:

```

tf.app.flags.DEFINE_string("worker_locations", "", "List of worker
addresses.")
tf.app.flags.DEFINE_float('learning_rate', 0.01, 'Initial learning
rate.')
tf.app.flags.DEFINE_integer('generations', 1000, 'Number of
training generations.')
tf.app.flags.DEFINE_boolean('run_unit_tests', False, 'If true, run
tests.')
Need to define a 'main' function for the app to run
def main():
 worker_ips = FLAGS.worker_locations.split(',')
 learning_rate = FLAGS.learning_rate
 generations = FLAGS.generations
 run_unit_tests = FLAGS.run_unit_tests
Run the Tensorflow app
if __name__ == "__main__":
 tf.app.run()

```

6. TensorFlow has built-in logging that we can set the level parameter for. The levels we can set it at are DEBUG, INFO, WARN, ERROR, and FATAL. The default is WARN:

```
tf.logging.set_verbosity(tf.logging.WARN)
WARN is the default value, but to see more information, you can
set it to
INFO or DEBUG
tf.logging.set_verbosity(tf.logging.DEBUG)
```

## How it works...

Here we provide tips for creating production level code in TensorFlow. We want to introduce these concepts of app-flags, model saving, and logging so that users can consistently write code with these tools and understand when they see these tools in other code. There are many other ways to write good production code, but a full example will be shown in the next recipe.

# Productionalizing TensorFlow – An Example

A good practice for productionalizing machine learning models is to separate the training and evaluation programs. Here, we illustrate an evaluation script expanded to include a unit test, model saving and loading, and evaluation.

## Getting ready

For this recipe, we will show how to implement an evaluation script, using the above production criteria. The code actually consists of a training script and an evaluation script, but for this recipe, we will only show the evaluation script. As a reminder, both scripts can be seen in the online GitHub repository, [https://github.com/nfmccclure/tensorflow\\_cookbook/](https://github.com/nfmccclure/tensorflow_cookbook/).

For the example, we will implement the first RNN example from *Chapter 9, Recurrent Neural Networks*, which attempts to predict if a text message is spam or ham. We will assume the RNN model is trained and saved, along with the vocabulary.

## How to do it...

1. We start by loading the necessary libraries and declaring the TensorFlow application flags:

```
import os
import re
import numpy as np
import tensorflow as tf
```

```
from tensorflow.python.framework import ops
ops.reset_default_graph()
tf.app.flags.DEFINE_string("storage_folder", "temp", "Where to
store model and data.")
tf.app.flags.DEFINE_string('model_file', False, 'Model file
location.')
tf.app.flags.DEFINE_boolean('run_unit_tests', False, 'If true, run
tests.')
FLAGS = tf.app.flags.FLAGS
```

2. We next declare a text cleaning function. This will be the same cleaning function used in the training script:

```
def clean_text(text_string):
 text_string = re.sub(r'([^\s\w]|_|[0-9])+', ' ', text_string)
 text_string = ''.join(text_string.split())
 text_string = text_string.lower()
 return(text_string)
```

3. Now we can load the vocabulary processing function:

```
def load_vocab():
 vocab_path = os.path.join(FLAGS.storage_folder, "vocab")
 vocab_processor = tf.contrib.learn.preprocessing.
VocabularyProcessor.restore(vocab_path)
 return(vocab_processor)
```

4. Now that we have a way to clean the text, and have a vocab processor, we can combine these to create a data-processing pipeline for a given text:

```
def process_data(input_data, vocab_processor):
 input_data = clean_text(input_data)
 input_data = input_data.split()
 processed_input = np.array(list(vocab_processor.
transform(input_data)))
 return(processed_input)
```

5. Next, we need a way to get data to evaluate. For this purpose, we will ask the user to type text onto the screen. Then we process the text and return the processed text:

```
def get_input_data():
 input_text = input("Please enter a text message to evaluate:
")
 vocab_processor = load_vocab()
 return(process_data(input_text, vocab_processor))
```



For this example, we have created evaluation data by asking the user to type it in. While many applications will get data by being supplied a file or an API request, we can change this input data function accordingly.

6. For a unit test, we will make sure that our text cleaning function behaves properly:

```
class clean_test(tf.test.TestCase):
 # Make sure cleaning function behaves correctly
 def clean_string_test(self):
 with self.test_session():
 test_input = '--Tensorflow\'s so Great! Don\'t you
think so? '
 test_expected = 'tensorflows so great don you think
so'
 test_out = clean_text(test_input)
 self.assertEqual(test_expected, test_out)
```

7. Now that we have our model and data, we can run the main function. The main function will get the data, set up the graph, load the variables, feed in the processed data, and print the output:

```
def main(args):
 # Get flags
 storage_folder = FLAGS.storage_folder
 # Get user input text
 x_data = get_input_data()

 # Load model
 graph = tf.Graph()
 with graph.as_default():
 sess = tf.Session()
 with sess.as_default():
 # Load the saved meta graph and restore variables
 saver = tf.train.import_meta_graph("{}{}.meta".
format(os.path.join(storage_folder, "model.ckpt")))
 saver.restore(sess, os.path.join(storage_folder,
"model.ckpt"))
 # Get the placeholders from the graph by name
 x_data_ph = graph.get_operation_by_name("x_data_ph").
outputs[0]
 dropout_keep_prob = graph.get_operation_by_
name("dropout_keep_prob").outputs[0]
 probability_outputs = graph.get_operation_by_
name("probability_outputs").outputs[0]
 # Make the prediction
```

```
eval_feed_dict = {x_data_ph: x_data, dropout_keep_
prob: 1.0}
probability_prediction = sess.run(tf.reduce_
mean(probability_outputs, 0), eval_feed_dict)

Print output (Or save to file or DB connection?)
print('Probability of Spam: {:.4}'.format(probability_
prediction[1]))
```

8. And here is how the `main()` function or unit tests get run:

```
if __name__ == "__main__":
 if FLAGS.run_unit_tests:
 # Perform unit tests
 tf.test.main()
 else:
 # Run evaluation
 tf.app.run()
```

## How it works...

For the evaluation of the model, we were able to load the command-line arguments with TensorFlow's app flags, load the model and vocabulary processor, and then we were able to run the processed data through the model and make a prediction.

Remember to run this script through the command line, and check that the training script is run before to create the model and vocabulary dictionary.



# 11

## More with TensorFlow

In this chapter, we'll cover the following recipes:

- ▶ Visualizing graphs in Tensorboard
- ▶ Working with a Genetic Algorithm
- ▶ Clustering Using K-Means
- ▶ Solving a System of ODEs

All the code that appears in this chapter is available online at [https://github.com/nfmccleure/tensorflow\\_cookbook](https://github.com/nfmccleure/tensorflow_cookbook).

### Introduction

Throughout this book, we have seen that TensorFlow is capable of implementing many models, but there is more that TensorFlow can do, and this chapter will show you a few of those things. We'll start by showing how to use the various aspects of Tensorboard, a capability that comes with TensorFlow that allows us to visualize summary metrics, graphs, and images even while our model is training. The remaining recipes in the chapter will show how to use TensorFlow's `group()` function to do stepwise updates. This function will allow us to implement a genetic algorithm, perform k-means clustering, and even solve a system of ODEs.

### Visualizing graphs in Tensorboard

Monitoring and troubleshooting machine learning algorithms can be a daunting task. Especially if you have to wait a long time for the training to complete before you know the results. To work around this, TensorFlow includes a computational graph visualization tool called Tensorboard. With Tensorboard, we can visualize and graph important values (loss, accuracy, batch training time, and so on) even during training.

## Getting ready

To illustrate the various ways we can use Tensorboard, we will reimplement the linear regression model from *The TensorFlow way of linear regression* recipe in Chapter 3, *Linear Regression*. We'll generate linear data with errors, and use TensorFlow loss and backpropagation to fit a line to the data. We will show how to monitor numerical values, histograms of sets of values, and how to create an image in Tensorboard.

## How to do it...

1. First, we'll load the libraries necessary for the script:

```
import os
import io
import time
import numpy as np
import matplotlib.pyplot as plt
import tensorflow as tf
```

2. We'll now initialize a session and create a summary writer that can write Tensorboard summaries to a Tensorboard folder:

```
sess = tf.Session()
Create a visualizer object
summary_writer = tf.train.SummaryWriter('tensorboard', tf.get_
default_graph())
```

3. We need to make sure that the Tensorboard folder exists for the summary writer to write the Tensorboard logs:

```
if not os.path.exists('tensorboard'):
 os.makedirs('tensorboard')
```

4. We'll now set the model parameters and generate the linear data for the model. Note that our true slope is 2, and we will visualize the changing slope over time and see it approach the true value:

```
batch_size = 50
generations = 100
Create sample input data
x_data = np.arange(1000)/10.
true_slope = 2.
y_data = x_data * true_slope + np.random.normal(loc=0.0, scale=25,
size=1000)
```

5. Next, we'll split the dataset into a `train` and `test` set:

```
train_ix = np.random.choice(len(x_data), size=int(len(x_data)*0.9), replace=False)
test_ix = np.setdiff1d(np.arange(1000), train_ix)
x_data_train, y_data_train = x_data[train_ix], y_data[train_ix]
x_data_test, y_data_test = x_data[test_ix], y_data[test_ix]
```

6. Now we can create the placeholders, variables, model operations, loss and optimizing operations:

```
x_graph_input = tf.placeholder(tf.float32, [None])
y_graph_input = tf.placeholder(tf.float32, [None])
Declare model variables
m = tf.Variable(tf.random_normal([1], dtype=tf.float32),
name='Slope')
Declare model
output = tf.mul(m, x_graph_input, name='Batch_Multiplication')
Declare loss function (L1)
residuals = output - y_graph_input
l2_loss = tf.reduce_mean(tf.abs(residuals), name="L2_Loss")
Declare optimization function
my_optim = tf.train.GradientDescentOptimizer(0.01)
train_step = my_optim.minimize(l2_loss)
```

7. We can now create a Tensorboard operation that will summarize a scalar value. The scalar value that we will summarize is the slope estimate of the model:

```
with tf.name_scope('Slope_Estimate'):
 tf.scalar_summary('Slope_Estimate', tf.squeeze(m))
```

8. Another summary we can add to Tensorboard is a histogram summary, which inputs multiple values in a tensor and outputs graphs and histograms:

```
with tf.name_scope('Loss_and_Residuals'):
 tf.histogram_summary('Histogram_Errors', l2_loss)
 tf.histogram_summary('Histogram_Residuals', residuals)
```

9. After creating these summary operations, we need to create a summary merging operation that will combine all the summaries, and then we can initialize the model variables:

```
summary_op = tf.merge_all_summaries()
Initialize Variables
init = tf.initialize_all_variables()
sess.run(init)
```

10. Now we can train the linear model, and write summaries every generation:

```
for i in range(generations):
 batch_indices = np.random.choice(len(x_data_train),
size=batch_size)
 x_batch = x_data_train[batch_indices]
 y_batch = y_data_train[batch_indices]
 _, train_loss, summary = sess.run([train_step, l2_loss,
summary_op],
feed_dict={x_graph_input: x_batch,
y_graph_input: y_batch})

 test_loss, test_resids = sess.run([l2_loss, residuals], feed_
dict={x_graph_input: x_data_test,
y_graph_input: y_data_test})

 if (i+1)%10==0:
 print('Generation {} of {}. Train Loss: {:.3}, Test Loss:
{:.3}'.format(i+1, generations, train_loss, test_loss))

 log_writer = tf.train.SummaryWriter('tensorboard')
 log_writer.add_summary(summary, i)
```

11. In order to put the final graph of the linear fit with the data points in Tensorboard, we have to create the graph image in protobuffer format. To start this, we will create a function that outputs a protobuffer graph:

```
def gen_linear_plot(slope):
 linear_prediction = x_data * slope
 plt.plot(x_data, y_data, 'b.', label='data')
 plt.plot(x_data, linear_prediction, 'r-', linewidth=3,
label='predicted line')
 plt.legend(loc='upper left')
 buf = io.BytesIO()
 plt.savefig(buf, format='png')
 buf.seek(0)
 return(buf)
```

12. Now we can create and add the protobuf image to Tensorboard:

```
slope = sess.run(m)
plot_buf = gen_linear_plot(slope[0])
Convert PNG buffer to TF image
image = tf.image.decode_png(plot_buf.getvalue(), channels=4)
Add the batch dimension
image = tf.expand_dims(image, 0)
Add image summary
image_summary_op = tf.image_summary("Linear Plot", image)
image_summary = sess.run(image_summary_op)
log_writer.add_summary(image_summary, i)
log_writer.close()
```



Be careful writing image summaries too often to Tensorboard. For example, if we were to write an image summary every generation for 10,000 generations, that would generate 10,000 images worth of summary data. This can eat up disk space very quickly.

## There's more...

Be sure to run the preceding script from the command line:

```
$ python3 using_tensorboard.py
```

```
Run the command: $tensorboard --logdir="tensorboard" Then navigate
to http://127.0.0.0:6006
Generation 10 of 100. Train Loss: 20.4, Test Loss: 20.5.
Generation 20 of 100. Train Loss: 17.6, Test Loss: 20.5.
Generation 90 of 100. Train Loss: 20.1, Test Loss: 20.5.
Generation 100 of 100. Train Loss: 19.4, Test Loss: 20.5.
```

We'll then run the preceding specified command to start Tensorboard:

```
$ tensorboard --logdir="tensorboard"
Starting TensorBoard b'29' on port 6006
(You can navigate to http://127.0.1.1:6006)
```

Here is a sample of what we can see in Tensorboard:

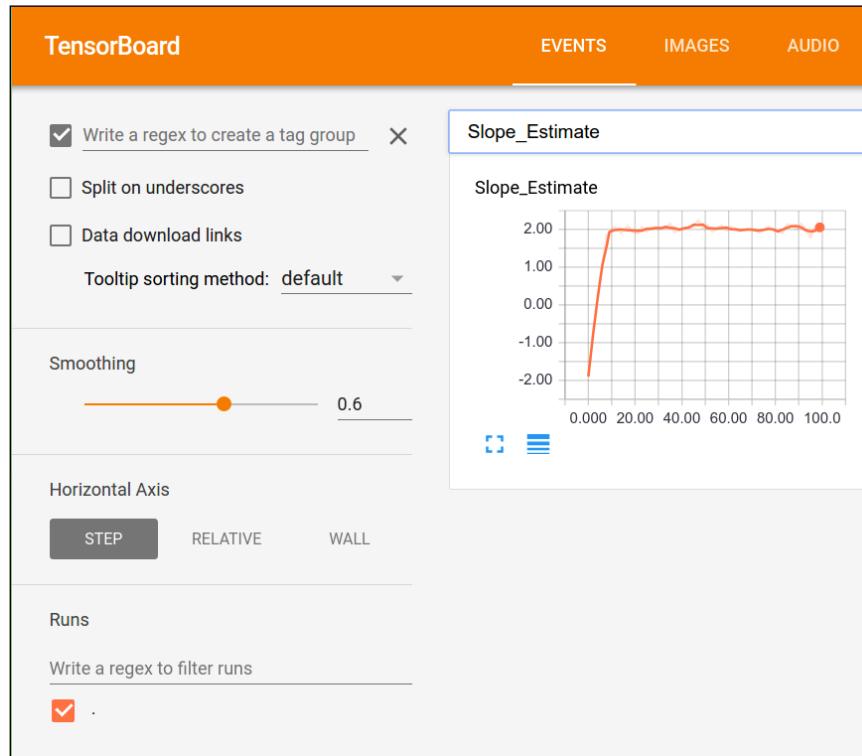


Figure 1: The scalar value, our slope estimate, visualized in Tensorboard.

Here, we can see a plot over the 100 generations of our scalar summary, the slope estimate. We can see that it does, in fact, approach the true value of 2:

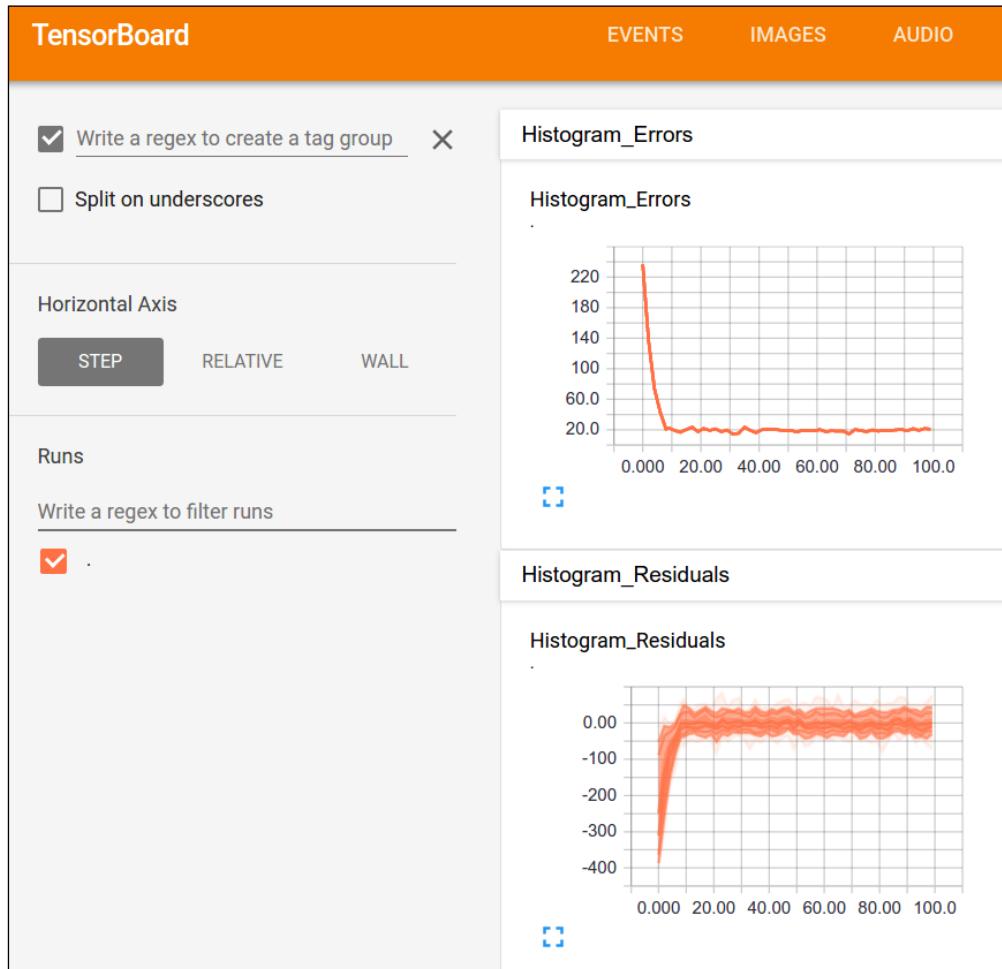


Figure 2: Here we visualize histograms of the errors and residuals for our model.

The preceding graph shows one way to view histogram summaries, which can be viewed as multiple line graphs:

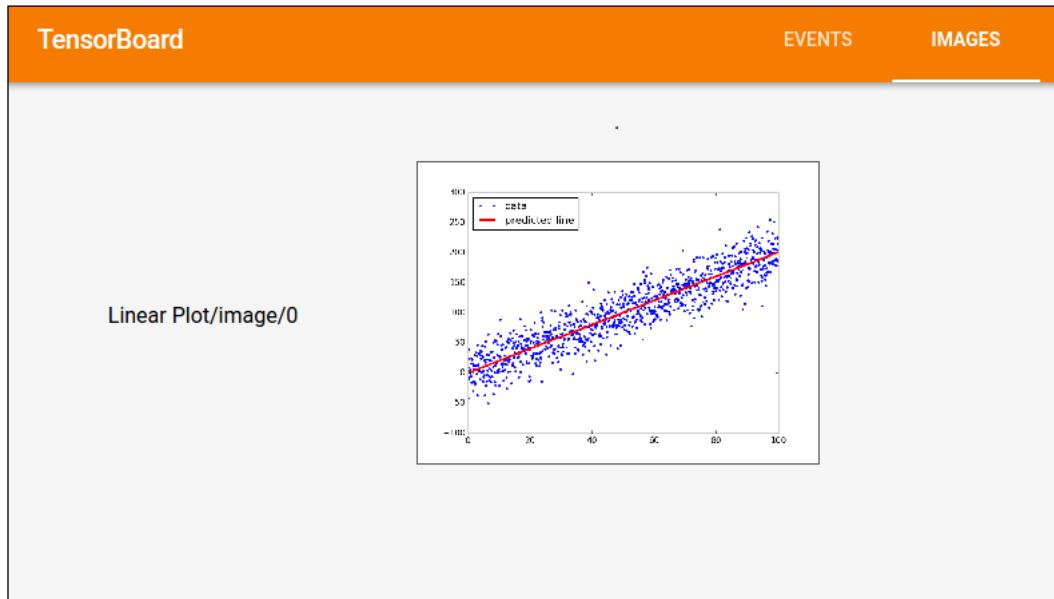


Figure 3: An inserted picture in Tensorboard.

Here is the final fit and data point graph that we put in protobuff format and inserted into an image summary in Tensorboard.

## Working with a Genetic Algorithm

TensorFlow can also be used to update any iterative algorithm that we can express in a computational graph. One such iterative algorithm is a genetic algorithm, an optimization procedure.

### Getting ready

In this recipe, we will illustrate how to implement a simple genetic algorithm. Genetic algorithms are a way to optimize over any parameter space (discrete, continuous, smooth, non-smooth, and so on.). The idea is to create a population of randomly initialized solutions, and apply selection, recombination, and mutation to generate new (and potentially better) child solutions. The whole idea rests on the fact that we can calculate the 'fitness' of an individual solution by seeing how well that individual solves the problem.

Generally, the outline for a genetic algorithm is to start with a randomly initialized population, rank them in terms of their fitness, and select the top fit individuals to randomly recombine (or cross over) to create new child solutions. These child solutions are then mutated slightly, to generate new and unseen improvements, and then added back into the parent population. After we have combined the children and parents, we repeat the whole process again.

Stopping criteria for genetic algorithms vary, but for our purposes we will just iterate for a fixed amount of generations. We could also stop when our best fit individual achieves a desired level of fitness or when the maximum fitness does not change after so many generations.

For this recipe, we will keep it simple to illustrate how to do this in TensorFlow. The problem we will be solving is to generate an individual (an array of 50 floating point numbers) that is the closest to the ground truth function,  $f(x) = \sin(\frac{2\pi x}{50})$ . The fitness will be the negative of the mean squared error (higher is better) between the individual and the ground truth.

## How to do it...

1. We'll start by loading the necessary libraries for the script:

```
import os
import numpy as np
import matplotlib.pyplot as plt
import tensorflow as tf
```

2. Next, we'll set the parameters of the genetic algorithm. Here, we will have 100 individuals, each with a length of 50. The selection percentage will be 20% (keeping the top 20 individuals). The mutation will be set to be the inverse of the number of features, a common place to start for the mutation. This means that we expect one feature per child solution to change. We will run the genetic algorithm for 200 generations:

```
pop_size = 100
features = 50
selection = 0.2
mutation = 1./ features
generations = 200
num_parents = int(pop_size*selection)
num_children = pop_size - num_parents
```

3. We'll initialize the graph session and create the ground truth function, which we will use to quickly calculate the fitness:

```
sess = tf.Session()
Create ground truth
truth = np.sin(2*np.pi*(np.arange(features, dtype=np.float32)) /
features)
```

4. Next we'll initialize the population as a TensorFlow variable with a random normal input:

```
population = tf.Variable(np.random.randn(pop_size, features),
 dtype=tf.float32)
```

5. We can now create the placeholders for the genetic algorithm. The placeholders are for the ground truth and also for data that will change for every generation. Since we want the crossover places between parents to change and the mutation probabilities/values to change, those will be the placeholders in our model:

```
truth_ph = tf.placeholder(tf.float32, [1, features])
crossover_mat_ph = tf.placeholder(tf.float32, [num_children,
 features])
mutation_val_ph = tf.placeholder(tf.float32, [num_children,
 features])
```

6. Now we will calculate the population fitness (negative mean squared error), and find the top performing individuals:

```
fitness = -tf.reduce_mean(tf.square(tf.sub(population, truth_ph)),
 1)
top_vals, top_ind = tf.nn.top_k(fitness, k=pop_size)
```

7. For results and plotting purposes, we also want to retrieve the best fit individual in the population:

```
best_val = tf.reduce_min(top_vals)
best_ind = tf.arg_min(top_vals, 0)
best_individual = tf.gather(population, best_ind)
```

8. Next, we sort the parent population and slice off the top performing individuals to make them parents for the next generation:

```
population_sorted = tf.gather(population, top_ind)
parents = tf.slice(population_sorted, [0, 0], [num_parents,
 features])
```

9. Now we'll create the children by creating two parent matrices that are randomly shuffled. Then we multiple and add the parent matrices by the crossover matrix of 1s and zeros that we will generate each generation for the placeholders:

```
Indices to shuffle-gather parents
rand_parent1_ix = np.random.choice(num_parents, num_children)
rand_parent2_ix = np.random.choice(num_parents, num_children)
Gather parents by shuffled indices, expand back out to pop_size
too
rand_parent1 = tf.gather(parents, rand_parent1_ix)
rand_parent2 = tf.gather(parents, rand_parent2_ix)
```

---

```

rand_parent1_sel = tf.mul(rand_parent1, crossover_mat_ph)
rand_parent2_sel = tf.mul(rand_parent2, tf.sub(1., crossover_mat_
ph))
children_after_sel = tf.add(rand_parent1_sel, rand_parent2_sel)

10. The last steps are to mutate the children, which we will do by adding a random
normal amount to approximately 1/feature fraction of entries in the children matrix
and concatenate this matrix back into the parent population:
mutated_children = tf.add(children_after_sel, mutation_val_ph)
Combine children and parents into new population
new_population = tf.concat(0, [parents, mutated_children])

11. The final step in our model is to use TensorFlow's group() operation to assign the
new population to the old population variable:
step = tf.group(population.assign(new_population))

12. We can now initialize the model variables:
init = tf.initialize_all_variables()
sess.run(init)

13. Finally, we loop through the generations, recreating the random crossover and
mutation matrices and updating the population each generation:
for i in range(generations):
 # Create cross-over matrices for plugging in.
 crossover_mat = np.ones(shape=[num_children, features])
 crossover_point = np.random.choice(np.arange(1, features-1,
step=1), num_children)
 for pop_ix in range(num_children):
 crossover_mat[pop_ix, 0:crossover_point[pop_ix]] = 0.
 # Generate mutation probability matrices
 mutation_prob_mat = np.random.uniform(size=[num_children,
features])
 mutation_values = np.random.normal(size=[num_children,
features])
 mutation_values[mutation_prob_mat >= mutation] = 0

 # Run GA step
 feed_dict = {truth_ph: truth.reshape([1, features]),
 crossover_mat_ph: crossover_mat,
 mutation_val_ph: mutation_values}
 step.run(feed_dict, session=sess)
 best_individual_val = sess.run(best_individual, feed_
dict=feed_dict)

 if i % 5 == 0:

```

```
best_fit = sess.run(best_val, feed_dict = feed_dict)
print('Generation: {}, Best Fitness (lowest MSE): {:.2f}'.
format(i, -best_fit))
```

14. This results in the following output:

```
Generation: 0, Best Fitness (lowest MSE): 1.5
Generation: 5, Best Fitness (lowest MSE): 0.83
Generation: 10, Best Fitness (lowest MSE): 0.55
Generation: 185, Best Fitness (lowest MSE): 0.085
Generation: 190, Best Fitness (lowest MSE): 0.15
Generation: 195, Best Fitness (lowest MSE): 0.083
```

## How it works...

In this recipe, we have shown you how to use TensorFlow to run a simple genetic algorithm. To verify that it is working, we can also look at the most fit individual solution and the ground truth on a plot:

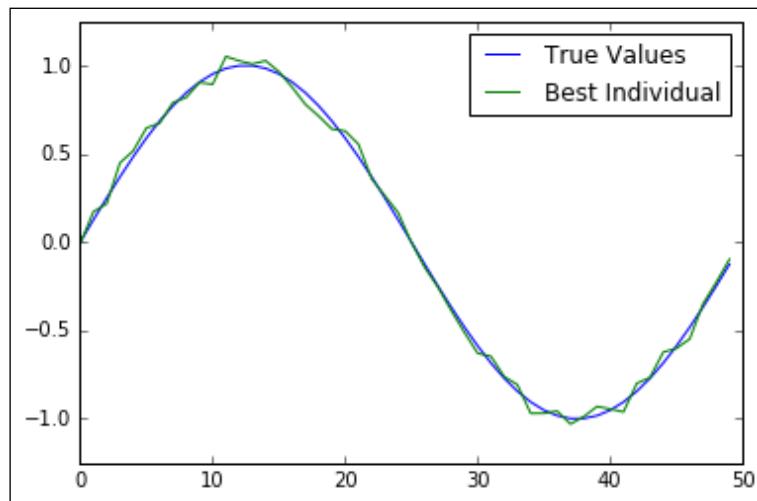


Figure 4: A plot of the ground truth and the best fit individual after 200 generations. We can see that the best fit individual is very close to the ground truth.

### There's more...

There are many variations to genetic algorithms. We can have two parent populations with two different fitness criteria (for example, lowest MSE and smoothness). We could impose restrictions on the mutation values to not be greater than 1 or less than -1. There are many different changes we could make, and these changes vary greatly, depending on the problem we are trying to optimize. For this contrived problem, the fitness was easily calculated, but for most genetic algorithms, calculating the fitness is an arduous task. For example, if we wanted to use a genetic algorithm to optimize the architecture of a convolutional neural network, we could have an individual be an array of parameters. The parameters could stand for the filter sizes, stride sizes, and so on of each convolutional layer. The fitness of such an individual would be the accuracy of classification after a fixed amount of iterations through a dataset. If we have 100 individuals in this population, we would have to evaluate 100 different CNN models for each generation. This is very computationally intense.

Before using a genetic algorithm to solve your problem, it is wise to figure out how long it takes to calculate the fitness of an individual. If this operation is time-consuming, genetic algorithms may not be the best tool to use.

## Clustering Using K-Means

TensorFlow can also be used to implement iterative clustering algorithms such as k-means. In this recipe, we show an example of using k-means on the `iris` dataset.

### Getting ready

Almost all of the machine learning models we have explored in this book have been supervised models. TensorFlow is ideal for these types of problems. But we can also implement unsupervised models if we wish. As an example, this recipe will implement k-means clustering.

The dataset we will implement clustering on is the `iris` dataset. One of the reasons this is a good dataset is because we already know there are three different targets (three types of iris flowers). This gives us a leg up on knowing that we are looking for three different clusters in the data.

We will cluster the `iris` dataset into three groups, and then compare the accuracy of these clusters against the real labels.

## How to do it...

1. To start, we load the necessary libraries. We are also loading some PCA tools from `sklearn` so that we can change the resulting data from four dimensions to two dimensions for visualization purposes:

```
import numpy as np
import matplotlib.pyplot as plt
import tensorflow as tf
from sklearn import datasets
from scipy.spatial import cKDTree
from sklearn.decomposition import PCA
from sklearn.preprocessing import scale
```

2. We start a graph session and load the `iris` dataset:

```
sess = tf.Session()
iris = datasets.load_iris()
num_pts = len(iris.data)
num_feats = len(iris.data[0])
```

3. We'll now set the groups, generations, and create the variables we need for the graph:

```
k=3
generations = 25
data_points = tf.Variable(iris.data)
cluster_labels = tf.Variable(tf.zeros([num_pts], dtype=tf.int64))
```

4. The next variables we need are the centroids for each group. We will initialize the centroids for the k-means algorithm by randomly choosing three different points of the `iris` dataset:

```
rand_starts = np.array([iris.data[np.random.choice(len(iris.
data))]] for _ in range(k)])
centroids = tf.Variable(rand_starts)
```

5. Now we need to calculate the distances between each of the data points and each of the centroids. We do this by expanding the centroids into a matrix and the same for the data points. We'll then calculate the Euclidean distances between the two matrices:

```
centroid_matrix = tf.reshape(tf.tile(centroids, [num_pts, 1]),
[num_pts, k, num_feats])
point_matrix = tf.reshape(tf.tile(data_points, [1, k]), [num_pts,
k, num_feats])
distances = tf.reduce_sum(tf.square(point_matrix - centroid_
matrix), reduction_indices=2)
```

6. The centroid assignment is then the closest centroid (smallest distance) to each data point:

```
centroid_group = tf.argmin(distances, 1)
```

7. Now we have to calculate the group average to get the new centroid:

```
def data_group_avg(group_ids, data):

 # Sum each group
 sum_total = tf.unsorted_segment_sum(data, group_ids, 3)
 # Count each group
 num_total = tf.unsorted_segment_sum(tf.ones_like(data), group_ids, 3)
 # Calculate average
 avg_by_group = sum_total/num_total
 return(avg_by_group)

means = data_group_avg(centroid_group, data_points)
update = tf.group(centroids.assign(means), cluster_labels.
assign(centroid_group))
```

8. We next initialize the model variables:

```
init = tf.initialize_all_variables()
sess.run(init)
```

9. We'll iterate through the generations and update the centroids for each group accordingly:

```
for i in range(generations):
 print('Calculating gen {}, out of {}'.format(i, generations))
 _, centroid_group_count = sess.run([update, centroid_group])
 group_count = []
 for ix in range(k):
 group_count.append(np.sum(centroid_group_count==ix))
 print('Group counts: {}'.format(group_count))
```

10. This results in the following output:

```
Calculating gen 0, out of 25.
Group counts: [50, 28, 72]
Calculating gen 1, out of 25.
Group counts: [50, 35, 65]
Calculating gen 23, out of 25.
Group counts: [50, 38, 62]
Calculating gen 24, out of 25.
Group counts: [50, 38, 62]
```

11. To verify our clustering, we can use the clusters to make predictions. We now see how many data points are in a similar cluster of same `iris` species:

```
[centers, assignments] = sess.run([centroids, cluster_labels])
def most_common(my_list):
 return(max(set(my_list), key=my_list.count))
label0 = most_common(list(assignments[0:50]))
label1 = most_common(list(assignments[50:100]))
label2 = most_common(list(assignments[100:150]))
group0_count = np.sum(assignments[0:50]==label0)
group1_count = np.sum(assignments[50:100]==label1)
group2_count = np.sum(assignments[100:150]==label2)
accuracy = (group0_count + group1_count + group2_count)/150.
print('Accuracy: {:.2}'.format(accuracy))
```

12. This results in the following output:

```
Accuracy: 0.89
```

13. To visually see our groupings and if they have indeed separated out the `iris` species, we will transform the four dimensions to two dimensions using PCA, and plot the data points and groups. After the PCA decomposition, we create predictions on a grid of x-y values for plotting a color graph:

```
pca_model = PCA(n_components=2)
reduced_data = pca_model.fit_transform(iris.data)
Transform centers
reduced_centers = pca_model.transform(centers)
Step size of mesh for plotting
h = .02
x_min, x_max = reduced_data[:, 0].min() - 1, reduced_data[:, 0].max() + 1
y_min, y_max = reduced_data[:, 1].min() - 1, reduced_data[:, 1].max() + 1
xx, yy = np.meshgrid(np.arange(x_min, x_max, h), np.arange(y_min,
y_max, h))
Get k-means classifications for the grid points
xx_pt = list(xx.ravel())
yy_pt = list(yy.ravel())
xy_pts = np.array([[x,y] for x,y in zip(xx_pt, yy_pt)])
mytree = cKDTree(reduced_centers)
dist, indexes = mytree.query(xy_pts)
indexes = indexes.reshape(xx.shape)
```

14. And here is `matplotlib` code to combine our findings on one graph. This plotting section of code is heavily adapted from a demo on the `sklearn` documentation website ([http://scikit-learn.org/stable/auto\\_examples/cluster/plot\\_kmeans\\_digits.html](http://scikit-learn.org/stable/auto_examples/cluster/plot_kmeans_digits.html)).

```
plt.clf()
```

```

plt.imshow(indexes, interpolation='nearest',
 extent=(xx.min(), xx.max(), yy.min(), yy.max()),
 cmap=plt.cm.Paired,
 aspect='auto', origin='lower')
Plot each of the true iris data groups
symbols = ['o', '^', 'D']
label_name = ['Setosa', 'Versicolour', 'Virginica']
for i in range(3):
 temp_group = reduced_data[(i*50):(50)*(i+1)]
 plt.plot(temp_group[:, 0], temp_group[:, 1], symbols[i],
 markersize=10, label=label_name[i])
Plot the centroids as a white X
plt.scatter(reduced_centers[:, 0], reduced_centers[:, 1],
 marker='x', s=169, linewidths=3,
 color='w', zorder=10)
plt.title('K-means clustering on Iris Dataset\n'
 'Centroids are marked with white cross')
plt.xlim(x_min, x_max)
plt.ylim(y_min, y_max)
plt.legend(loc='lower right')
plt.show()

```

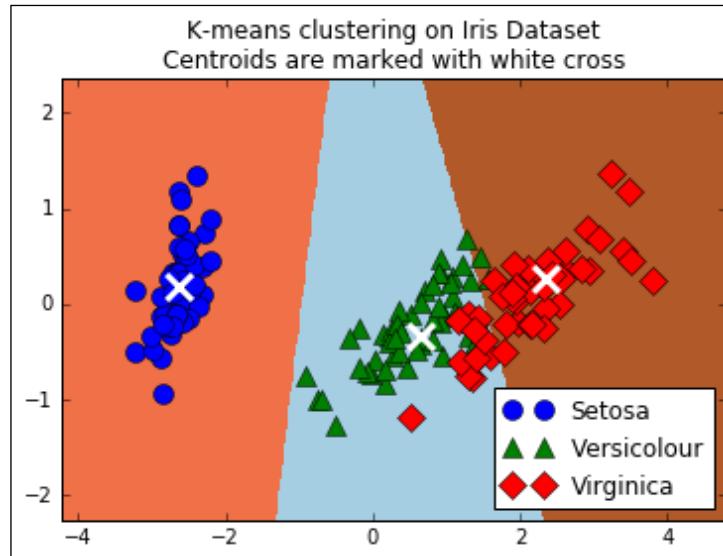


Figure 5: Figure showing how the unsupervised classification algorithm of k-means, can be used to group together the three iris flower species. The three k-means groups are the three shaded regions, and the three different points (circles, triangles, and diamonds) are the three true species classification.

## There's more...

For this recipe, we clustered the `iris` dataset into three groups using TensorFlow. Then we calculated the percentage of data points that fell into similar groups (89%) and plotted a graph of the resulting k-means groups. Since k-means as a classification algorithm is locally linear (linear separator up close), it will be hard to learn the naturally non-linear boundary between *I. versicolor*, and *I. virginica*. But one advantage is that the k-means algorithm did not need labelled data at all to perform.

## Solving a System of ODEs

TensorFlow can be used for many algorithmic implementations and procedures. A great example of TensorFlow's versatility is implementing an ODE solver. Solving an ODE numerically is a iterative procedure that can be easily described in a computational graph. For this recipe, we will solve the Lotka-Volterra predator-prey system.

### Getting ready

This recipe will illustrate how to solve a system of **ordinary differential equations (ODEs)**. We can use similar methods to the previous two sections to update values as we iterate through and solve an ODE system.

The ODE system we will consider is the famous Lotka-Volterra predator-prey system. This system shows how a predator-prey system can be oscillating, given specific parameters.

The Lotka-Volterra system was published in a paper in 1920 (see also 1). We will use similar parameters to show that an oscillating system can occur. Here is the system represented in a mathematically discrete way:

$$f(x) = \sin\left(\frac{2\pi x}{50}\right)$$

$$X_{t+1} = X_t + (aX_t + bX_t Y_t)\Delta t$$

$$Y_{t+1} = Y_t + (cY_t + dX_t Y_t)\Delta t$$

Here,  $X$  is the prey and  $Y$  will be the predator. We determine which is the prey and which is the predator by the values of  $a$ ,  $b$ ,  $c$ , and  $d$ : For the prey,  $a>0$ ,  $b<0$ , and for the predator,  $c<0$ ,  $d>0$ . We will implement this discrete version in the TensorFlow solution to the system.

## How to do it...

1. We'll start by loading the libraries and starting a graph session:

```
import matplotlib.pyplot as plt
import tensorflow as tf
sess = tf.Session()
```

2. We then declare our constants and variables in the graph:

```
x_initial = tf.constant(1.0)
y_initial = tf.constant(1.0)
X_t1 = tf.Variable(x_initial)
Y_t1 = tf.Variable(y_initial)
Make the placeholders
t_delta = tf.placeholder(tf.float32, shape=())
a = tf.placeholder(tf.float32, shape=())
b = tf.placeholder(tf.float32, shape=())
c = tf.placeholder(tf.float32, shape=())
d = tf.placeholder(tf.float32, shape=())
```

3. Next, we will implement the prior introduced discrete system and then update the X and Y populations:

```
X_t2 = X_t1 + (a * X_t1 + b * X_t1 * Y_t1) * t_delta
Y_t2 = Y_t1 + (c * Y_t1 + d * X_t1 * Y_t1) * t_delta
Update to New Population
step = tf.group(
 X_t1.assign(X_t2),
 Y_t1.assign(Y_t2))
```

4. We now initialize the graph and run the discrete ODE system with specific parameters to illustrate a cyclic behavior:

```
init = tf.initialize_all_variables()
sess.run(init)
Run the ODE
prey_values = []
predator_values = []
for i in range(1000):
 # Step simulation (using constants for a known cyclic
 solution)
 step.run({a: (2./3.), b: (-4./3.), c: -1.0, d: 1.0, t_delta:
0.01}, session=sess)
 # Store each outcome
 temp_prey, temp_pred = sess.run([X_t1, Y_t1])
 prey_values.append(temp_prey)
 predator_values.append(temp_pred)
```



A steady state (and cyclic) solution to this specific system, the Lotka-Volterra equations, very much depends on specific parameters and population values. We encourage the reader to try different parameters and values to see what can happen.

- Now we can plot the predator and prey values:

```
plt.plot(prey_values, label="Prey")
plt.plot(predator_values, label="Predator")
plt.legend(loc='upper right')
plt.show()
```

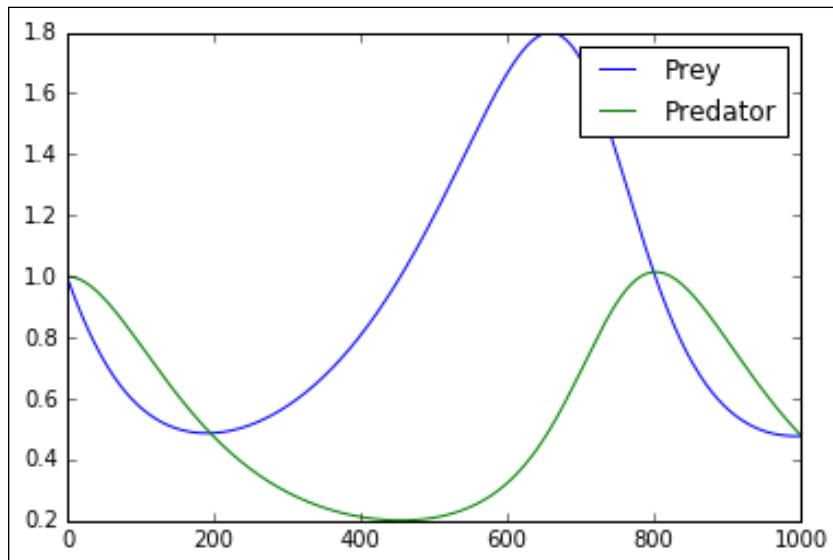


Figure 6: Here we plot the predator and prey values for the ODE solution. We can see that, indeed, cycles do occur.

## How it works...

We used TensorFlow to incrementally solve a discrete version of an ODE system. For specific parameters, we saw that the predator-prey system can indeed have cyclic solutions. This would make sense in our system biologically, because if there are too many predators, the prey start to die off, and then there is less food for the predators and they will die off, and so on.

## See also

Lotka, A. J., *Analytical note on certain rhythmic relations in organic systems*. Proc. Nat. Acad. 6 (1920) (<https://www.ncbi.nlm.nih.gov/pmc/articles/PMC1084562/>).

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