CHAPTER 2
MapReduce

MapReduce is a programming model for data processing. The model is simple, yet not too simple to express useful programs in. Hadoop can run MapReduce programs written in various languages; in this chapter, we look at the same program expressed in Java, Ruby, Python, and C++. Most important, MapReduce programs are inherently parallel, thus putting very large-scale data analysis into the hands of anyone with enough machines at her disposal. MapReduce comes into its own for large datasets, so let's start by looking at one.

A Weather Dataset

For our example, we will write a program that mines weather data. Weather sensors collect data every hour at many locations across the globe and gather a large volume of log data, which is a good candidate for analysis with MapReduce because it is semi-structured and record-oriented.

Data Format

The data we will use is from the National Climatic Data Center (NCDC, *http://www.ncdc.noaa.gov/*). The data is stored using a line-oriented ASCII format, in which each line is a record. The format supports a rich set of meteorological elements, many of which are optional or with variable data lengths. For simplicity, we focus on the basic elements, such as temperature, which are always present and are of fixed width.

Example 2-1 shows a sample line with some of the salient fields highlighted. The line has been split into multiple lines to show each field; in the real file, fields are packed into one line with no delimiters.

Example 2-1. Format of a National Climate Data Center record

```
0057
332130   # USAF weather station identifier
99999    # WBAN weather station identifier
19500101 # observation date
0300     # observation time
4
+51317   # latitude (degrees x 1000)
+028783  # longitude (degrees x 1000)
FM-12
+0171    # elevation (meters)
99999
V020
320      # wind direction (degrees)
1        # quality code
N
0072
1
00450    # sky ceiling height (meters)
1        # quality code
C
N
010000   # visibility distance (meters)
1        # quality code
N
9
-0128    # air temperature (degrees Celsius x 10)
1        # quality code
-0139    # dew point temperature (degrees Celsius x 10)
1        # quality code
10268    # atmospheric pressure (hectopascals x 10)
1        # quality code
```

Datafiles are organized by date and weather station. There is a directory for each year from 1901 to 2001, each containing a gzipped file for each weather station with its readings for that year. For example, here are the first entries for 1990:

```
% ls raw/1990 | head
010010-99999-1990.gz
010014-99999-1990.gz
010015-99999-1990.gz
010016-99999-1990.gz
010017-99999-1990.gz
010030-99999-1990.gz
010040-99999-1990.gz
010080-99999-1990.gz
010100-99999-1990.gz
010150-99999-1990.gz
```

Since there are tens of thousands of weather stations, the whole dataset is made up of a large number of relatively small files. It's generally easier and more efficient to process a smaller number of relatively large files, so the data was preprocessed so that each year's readings were concatenated into a single file. (The means by which this was carried out is described in Appendix C.)

Analyzing the Data with Unix Tools

What's the highest recorded global temperature for each year in the dataset? We will answer this first without using Hadoop, as this information will provide a performance baseline and a useful means to check our results.

The classic tool for processing line-oriented data is *awk*. Example 2-2 is a small script to calculate the maximum temperature for each year.

Example 2-2. A program for finding the maximum recorded temperature by year from NCDC weather records

```
#!/usr/bin/env bash
for year in all/*
do
  echo -ne `basename $year .gz`"\t"
  gunzip -c $year | \
    awk '{ temp = substr($0, 88, 5) + 0;
           q = substr($0, 93, 1);
           if (temp !=9999 && q ~ /[01459]/ && temp > max) max = temp }
         END { print max }'
done
```

The script loops through the compressed year files, first printing the year, and then processing each file using *awk*. The *awk* script extracts two fields from the data: the air temperature and the quality code. The air temperature value is turned into an integer by adding 0. Next, a test is applied to see whether the temperature is valid (the value 9999 signifies a missing value in the NCDC dataset) and whether the quality code indicates that the reading is not suspect or erroneous. If the reading is OK, the value is compared with the maximum value seen so far, which is updated if a new maximum is found. The `END` block is executed after all the lines in the file have been processed, and it prints the maximum value.

Here is the beginning of a run:

```
% ./max_temperature.sh
1901    317
1902    244
1903    289
1904    256
1905    283
...
```

The temperature values in the source file are scaled by a factor of 10, so this works out as a maximum temperature of 31.7°C for 1901 (there were very few readings at the beginning of the century, so this is plausible). The complete run for the century took 42 minutes in one run on a single EC2 High-CPU Extra Large Instance.