MapReduce: Ordering and Large Scale Indexing in Large Cluster

Iniyan Senthil Kumar .T¹, Poovaraghaan .R²

Computer Science and Engineering, SRM University, Ramapuram, Chennai-600089, India

Abstract: MapReduce is the program model and an association implementation for processing and generating large data sets. User specify a map function that process a key/value pair to generate a set of intermediate key/value pairs and a reduce function that merge all intermediate values associated with the same intermediate key. Our Implementation of MapReduce runs on a large cluster of commodity machines and is highly scalable; a typical MapReduce computation processes many terabytes of data of thousand machines.

Keywords: MapReduce, Hadoop, Cluster, Large scale indexing, ordering

1. Introduction

Google have implemented hundreds of special-purpose computations that process large amounts of raw data, such as crawled documents, web request logs, etc., to compute various kinds of derived data, such as inverted indices, various representations of the graph structure of web documents. However, the input data is usually large and the computations have to be distributed across hundreds or thousands of machines in order to finish in a reasonable amount of time. However, the input data is usually large and the computations have to be distributed across hundreds or thousands of machines in order to minimise in a reasonable amount of time. We realized that most of our computations involved applying a map operation to each logical .record. in our input in order to compute a set of intermediate key/value pairs, and then applying a reduce operation to all the values that shared the same key, in order to combine the derived data appropriately.

2. Programming Model

The computation takes a set of input key/value pairs, and produces a set of output key/value pairs. The user of the MapReduce library expresses the computation as two functions: Map and Reduce. Map, written by the user, takes an input pair and produces a set of intermediate key/value pairs. The MapReduce library groups together all intermediate values associated with the same intermediate key I and passes them to the Reduce function. The Reduce function, also written by the user, accepts an intermediate key I and a set of values for that key. It merges together these values to form a possibly smaller set of values. Typically just zero or one output value is produced per Reduce invocation.

The user would write code similar to the following pseudo-code:

map(String key, String value):
  // key: document name
  // value: document contents for each word w in value:
  EmitIntermediate(w, "1");
reduce(String key, Iterator values):
  // key: a word
  // values: a list of counts
  int result = 0; for each v in values:
  result += ParsesInt(v);

Emit(AsString(result));

3. More Examples

Here are a few simple examples of interesting programs that can be easily expressed as MapReduce computations.

a) Distributed Grep
   The map function emits a line if it matches a supplied pattern. The reduce function is an identity function that just copies the supplied intermediate data to the output.

b) Count of URL Access Frequency
   The map function processes logs of web page requests and outputs <URL, 1>. The reduce function adds together all values for the same URL and emits <URL; total count> pair.

c) ReverseWeb-Link Graph:
   The map function outputs <target, source> pairs for each link to a target URL found in a page named source. The reduce function concatenates the list of all source URLs associated with a given target URL and emits the pair: <target, list(source)>.

d) Inverted Index
   The map function parses each document, and emits a sequence of <word, document ID> pairs. The reduce function accepts all pairs for a given word, sorts the corresponding document IDs and emits a <word, list(document ID)> pair. The set of all output pairs forms a simple inverted index. It is easy to augment this computation to keep track of word positions.

4. Implementation

Many different implementations of the MapReduce interface are possible. The right choice depends on the environment. For example, one implementation may be suitable for a small shared-memory machine, another for a large NUMA multi- processor, and yet another for an even larger collection of networked machines.

This section describes an implementation targeted to the computing environment in wide use at Google: large clusters of commodity PCs connected together with switched Ethernet [4]. In our environment:

1) Machines are typically dual-processor x86 processors running Linux, with 2–4 GB of memory per machine.
2) Commodity networking hardware is used. Typically either 100 megabits/second or 1 gigabit/second at the machine level, but averaging considerably less in overall bisection bandwidth.

3) A cluster consists of hundreds or thousands of machines, and therefore machine failures are common.

4) Storage is provided by inexpensive IDE disks attached directly to individual machines. A distributed file system [8] developed in-house is used to manage the data stored on these disks. The file system uses replication to provide availability and reliability on top of unreliable hardware.

5) Users submit jobs to a scheduling system. Each job consists of a set of tasks, and is mapped by the scheduler to a set of available machines within a cluster.

A. Execution Overview

The Map invocations are distributed across multiple machines by automatically partitioning the input data into a set of M splits. The input splits can be processed in parallel by different machines. Reduce invocations are distributed by partitioning the intermediate key space into R pieces using a partitioning function (e.g., hash(key) mod R). The number of partitions (R) and the partitioning function are specified by the user.

B. Master Datastructure

The master keeps several data structures. For each map task and reduce task, it stores the state (idle, in progress, or completed), and the identity of the worker machine (for non-idle tasks). The master the conduit through which the location of intermediate file regions is propagated from map tasks to reduce tasks. Therefore, for each completed map task, the master stores the locations and sizes of the R intermediate file regions produced by the map task. Updates to this location and size information are received as map tasks are completed. The information is pushed incrementally, to workers that have in-progress reduce tasks.

C. Fault Tolerance

Since the MapReduce library is designed to help process very large amounts of data using hundreds or thousands of machines, the library must tolerate machine failures gracefully.

Worker Failure

The master pings every worker periodically. If no response is received from a worker in a certain amount of time, the master marks the worker as failed. Any map tasks completed by the worker are reset back to their initial idle state, and therefore become eligible for scheduling on other workers. Similarly, any map task or reduce task in progress on a failed worker is also reset to idle and becomes eligible for rescheduling.

Master Failure

It is easy to make the master write periodic checkpoints of the master data structures described above. If the master task dies, a new copy can be started from the last check pointed state. However, given that there is only a single master; its failure is unlikely; therefore our current implementation aborts the MapReduce computation if the master fails. Clients can check for this condition and retry the MapReduce operation if they desire.
D. Locality
The MapReduce master takes the location information of the input files into account and attempts to schedule a map task on a machine that contains a replica of the corresponding input data. Failing that, it attempts to schedule a map task near a replica of that task’s input data (e.g., on a worker machine that is on the same network switch as the machine containing the data). MapReduce operations on a significant fraction of the workers in a cluster, most input data is read locally and consumes no network bandwidth.

E. Backup Task
One of the common causes that lengthens the total time taken for a MapReduce operation is a straggler, a machine that takes an unusually long time to complete one of the last few map or reduce tasks in the computation. Stragglers can arise for a whole host of reasons. For example, a machine with a bad disk may experience frequent correctable errors that slow its read performance from 30 MB/s to 1 MB/s. The cluster scheduling system may have scheduled other tasks on the machine, causing it to execute the MapReduce code more slowly due to competition for CPU, memory, local disk, or network bandwidth.

5. Performance
In this section we measure the performance of MapReduce on two computations running on a large cluster of machines. One computation searches through approximately one terabyte of data looking for a particular pattern. The other computation sorts approximately one terabyte of data. These two programs are representative of a large subset of the real programs written by users of MapReduce. One class of programs shuffles data from one representation to another, and another class extracts a small amount of interesting data from a large data set.

A. Cluster Configuration
All of the programs were executed on a cluster that consisted of approximately 1800 machines. Each machine had two 2GHz Intel Xeon processors with Hyper-Threading enabled, 4GB of memory, two 160GB IDE disks, and a gigabit Ethernet link. The machines were arranged in a two-level tree-shaped switched network with approximately 100-200 Gbps of aggregate bandwidth available at the root. All of the machines were in the same hosting facility and therefore the round-trip time between any pair of machines was less than a millisecond.

B. Grep
The grep program scans through 1010 100-byte records, searching for a relatively rare three character pattern (the pattern occurs in 92,337 records). The input is split into approximately 64MB pieces (M = 15000), and the entire output is placed in one _le (R = 1).

The entire computation takes approximately 150 seconds from start to _finish. This includes about a minute of startup overhead. The overhead is due to the propagation of the program to all worker machines, and delays interacting with GFS to open the set of 1000 input _les and to get the information needed for the locality optimization.

C. Sort
The sort program sorts 1010 100-byte records (approximately 1 terabyte of data). This program is modelled after the Tera Sort benchmark [10]. The sorting program consists of less than 50 lines of user code. A three-line Map function extracts a 10-byte sorting key from a text line and emits the key and the original text line as the intermediate key/value pair. We used a built-in Identity function as the Reduce operator. This functions passes the intermediate key/value pair unchanged as the output key/value pair. As before, the input data is split into 64MB pieces (M = 15000). We partition the sorted output into 4000 _les (R = 4000). The partitioning function uses the initial bytes of the key to segregate it into one of R pieces.

6. Related Work
MapReduce can be considered a simplification and distillation of some of these models based on our experience with large real-world computations. More significantly, we provide a fault-tolerant implementation that scales to thousands of processors. In contrast, most of the parallel processing systems have only been implemented on smaller scales and leave the details of handling machine failures to the programmer. The MapReduce implementation relies on an in-house cluster management system that is responsible for distributing and running user tasks on a large collection of shared machines. Though not the focus of this paper, the cluster management system is similar in spirit to other systems such as Condor.
Our locality optimization draws its inspiration from techniques such as active disks [12, 15], where computation is pushed into processing elements that are close to local disks, to reduce the amount of data sent across I/O subsystems or the network. We run on commodity processors to which a small number of disks are directly connected instead of running directly on disk controller FS [5] has a very different programming model from MapReduce, and unlike MapReduce, is targeted to the execution of jobs across a wide-area network. However, there are two fundamental similarities. (1) Both systems use redundant execution to recover from data loss caused by failures. (2) Both use locality-aware scheduling to reduce the amount of data sent across congested network links.

7. Conclusion

The MapReduce programming model has been successfully used at Google for many different purposes. We attribute this success to several reasons. First, the model is easy to use, even for programmers without experience with parallel and distributed systems, since it hides the details of parallelization, fault-tolerance, locality optimization, and load balancing. Second, a large variety of problems are easily expressible as MapReduce computations. web search service, for sorting, for data mining, for machine learning, and many other systems. Third, we have developed an implementation of MapReduce that scales to large clusters of machines comprising thousands of machines. The implementation makes efficient use of these machine resources and therefore is suitable for use on many of the large computational problems encountered at Google. We have learned several things from this work. First, restricting the programming model makes it easy to parallelize and distribute computations and to make such computations fault-tolerant. Second, network bandwidth is a scarce resource. A number of optimizations in our system are therefore targeted at reducing the amount of data sent across the network: the locality optimization allows us to read data to local disks, and writing a single copy of the intermediate data to local disk saves networks bandwidth. Third, redundant execution can be used to reduce the impact of slow machines, and to handle machine failures and data loss.

Finally, we thank all the users of MapReduce within Google's engineering organization for providing helpful feedback, suggestions, and bug reports.

8. Acknowledgment

Josh Levenberg has been instrumental in revising and extending the user-level MapReduce API with a number of new features based on his experience with using MapReduce and other people's suggestions for enhancements. MapReduce reads its input from and writes its output to the Google File System [8]. We would like to thank Mohit Aron, Howard Gobioff, Markus Gut schke, David Kramer, Shun-Tak Leung, and Josh Redstone for their work in developing GFS. We would also like to thank Percy Liang and Olcan Sercinoglu for their work in developing the cluster management system used by MapReduce. Mike Burrows, Wilson Hsieh, Josh Levenberg, Sharon Perl, Rob Pike, and Debby Wallach provided helpful comments on earlier drafts of this paper. The anonymous OSDI reviewers, and our shepherd, Eric Brewer, provided many useful suggestions of areas where the paper could be improved.

References


