ISIT312 Big Data Management

Java MapReduce Application

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Common building blocks of MapReduce program

Mapper, Reducer, Combiner, and Partitioner classes correspond to their counterparts in the MapReduce model

- These classes implement the MapReduce logic

The Driver or ToolRunner in a MapReduce program represents the client program

- The main method of a MapReduce program is in the Driver or ToolRunner
- The code of the two is very standard

An elementary MapReduce program consists of a Mapper class, a Reducer class and a Driver

As the main method is contained in the Driver, sometimes (but not always) it is convenient to make Mapper and Reducer as inner classes in Driver, which contains routine codes

Driver

Driver is the program which sets up and starts a MapReduce application

Driver code is executed on the client; this code submits the application to the ResourceManager along with the application's configuration

Driver can submit the job asynchronously (in a non-blocking fashion) or synchronously (waiting for the application to complete before performing another action)

Driver can also configure and submit more than one application; for instance, running a workflow consisting of multiple MapReduce applications

Mapper

Mapper Java class contains a `map()` method

Its object instance iterates through the input split to execute a `map()` method, using the InputFormat and its associated RecordReader

The number of HDFS blocks for the file determines the number of input splits, which, in turn, determines the number of Mapper objects (or Map tasks) in a MapReduce application

Mappers can also include setup and cleanup code to run in any given object lifespan

Mappers do most of the heavy lifting in data processing in MapReduce, as they read the entire input file for the application

Reducer

Reducer runs against a partition and each key and its associated values are passed to a `reduce()` method inside Reducer class

Reduce's InputFormat matches Mapper's OutputFormat

While Mapper usually do the data preparation, for example, filtering and extracting), Reducer usually contains the main application logic

- For example, summation, counting, and averaging operations are implemented in Reducers

The runtime of Reducer instances is usually faster (and much faster in some cases) than the runtime of Mapper instances

Word Count: The "Hello, World" of MapReduce

WordCount: Read a text file and count occurrences of each word

Consider a text document containing a fragment of the works of Shakespeare

Romeo and Juliet

```
O Romeo, Romeo! wherefore art thou Romeo?
Deny thy father, and refuse thy name
```

The input format is `TextInputFormat`

After the text is read, the input to Map task, i.e. the process running Mapper is the following

Romeo and Juliet

```
(0, 'O Romeo , Romeo ! wherefore art thou Romeo ?')
(45, 'Deny thy father, and refuse thy name')
```

Word Count: The "Hello, World" of MapReduce

The output of the Map task is the following

- It is possible to filter out in Mapper some trivial words such as "a" and "and"

Key–Value pairs

```
('O', 1)
('Romeo', 1)
('Romeo', 1)
('wherefore', 1)
('art', 1)
('thou', 1)
('Romeo', 1)
('Deny', 1)
('thy', 1)
('father', 1)
('and', 1)
('refuse', 1)
('thy', 1)
('name', 1)
```

Word Count: The "Hello, World" of MapReduce

Before sending data to Reduce task, there is a shuffle-and-sort stage

Shuffle-and-sort is usually hidden from a programmer

The following is the input to Reduce task

Key–value pairs after shuffle–and sort

```
('and', [1])
('art', [1])
('Deny', [1])
('father', [1])
('name', [1])
('O', [1])
('refuse', [1])
('Romeo', [1,1,1])
('thou', [1])
('thy', [1,1])
('wherefore', [1])
```

Word Count: The "Hello, World" of MapReduce

The following is the final output from Reduce task:

- Note that we use plain texts to illustrate the data passing through the MapReduce stages, but in the Java implementation, all texts are wrapped in some object that implements the Writable interface

Final output from Reduce

```
('and', 1)
('art', 1)
('Deny', 1)
('father', 1)
('name', 1)
('O', 1)
('refuse', 1)
('Romeo', 3)
('thou', 1)
('thy', 2)
('wherefore', 1)
```

Hadoop data type objects

In most programming languages, when defining most data elements, we usually use simple, or primitive, datatypes such as `int`, `long`, or `char`

However, in Hadoop a key or a value is an object that is an instantiation of a class, with attributes and defined methods

A key or a value contains (or encapsulates) the data with methods defined for reading and writing data from and to the object

Writable interface

Hadoop serialisation format is `Writable` interface

For example, a class that implements `Writable` is `IntWritable`, which a wrapper for a Java `int`

One can create such a class and set its value in the following way

Creating IntWritable object

```
IntWritable writable = new IntWritable();
writable.set(163);
```

Alternatively, we can write

Creating IntWritable object

```
IntWritable writable = new IntWritable(163);
```

WritableComparable interface

`IntWritable` implements `WritableComparable` interface

It is interface of `Writable` and `java.lang.Comparable` interfaces

Creating WritableComparable interface

```
package org.apache.hadoop.io;
public interface WritableComparable  extends Writable, Comparable { ... }
```

Comparison is crucial for MapReduce, because MapReduce contains a sorting phase during which keys are compared with one another

`WritableComparable` permits to compare records read from a stream without deserialising them into objects, thereby avoiding any overhead of object creation

Hadoop primitive Writable wrappers

Writable Wrappers

Writable Wrapper	Java Primitive
BooleanWritable	boolean
ByteWritable	byte
IntWritable	int
FloatWritable	float
LongWritable	long
DoubleWritable	double
NullWritable	null
Text	String

Input and output formats

`FileInputFormat` (the base class of `InputFormat`) reads data (keys and values) from a given path, using the default or user-defined format

- The default input format is `LongWritable` for the keys and `Text` for the values

`FileOutputFormat` (the base class of `OutputFormat`) writes data into a file in a given path

- The output format is usually defined by a programmer
- For example, the output format is `Text` for the keys and `IntWritable` for the values

Some imported package members

Imported package members

```
import java.io.IOException;
import org.apache.hadoop.conf.Configuration;
import org.apache.hadoop.fs.Path;
import org.apache.hadoop.io.IntWritable;
import org.apache.hadoop.io.Text;
import org.apache.hadoop.mapreduce.Job;
import org.apache.hadoop.mapreduce.Mapper;
import org.apache.hadoop.mapreduce.Reducer;
import org.apache.hadoop.mapreduce.lib.input.FileInputFormat;
import org.apache.hadoop.mapreduce.lib.output.FileOutputFormat;
```

Java code of Driver

Java code of Driver

```
public class WordCount {
  public static void main(String[] args) throws Exception {
    Configuration conf = new Configuration();
    Job job = Job.getInstance(conf, "word count");
    job.setJarByClass(WordCount.class);
    job.setMapperClass(MyMapper.class);   //the Mapper class
    job.setReducerClass(MyReducer.class); //the Reducer class
    job.setOutputKeyClass(Text.class);
    job.setOutputValueClass(IntWritable.class);
    FileInputFormat.addInputPath(job, new Path(args[0]));
    FileOutputFormat.setOutputPath(job, new Path(args[1]));
    System.exit(job.waitForCompletion(true) ? 0 : 1);
  }
}
```

Job object and configuration

`Driver` class instantiates a `Job` object

A `Job` object creates and stores the configuration options for a `Job`, including the classes to be used as `Mapper` and `Reducer`, input and output directories, etc

The configuration options are specified in (one or more of) the following places

- Hadoop defaults (`*-default.xml`, e.g., `core-default.xml`)
- A default configuration is documented in the Apache Hadoop documentation
- The `*-site.xml` files on the client node where `Driver` code is processed
- The `*-site.xml` files on the slave nodes where `Mapper` runs on
- `Configuration` properties set at the command line as arguments to a MapReduce application (in a `ToolRunner` object)
- `Configuration` properties set explicitly in code and compiled through a `Job` object

Driver routines

Parses the command line for positional arguments - `input` file(s)/directory and `output` directory

Creates a new `Job` object instance, using `getConf()` method to obtain configuration from the various sources (`*-default.xml` and `*-site.xml`)

Gives a `Job` a friendly name (the name you will see in the ResourceManager UI)

Sets the `InputFormat` and `OutputFormat` for a `Job` and determines the input splits for a `Job`

Defines Mapper and Reducer classes to be used for a Job (They must be available in the Java classpath where Driver is run - typically these classes are packaged alongside the Driver)

Sets the final output key and value classes, which will be written out files in the output directory

Submits a `Job` object through `job.waitForCompletion(true)`

Java code of Mapper

Java code of Mapper

```
public static class MyMapper
extends Mapper{
   private final static IntWritable one = new IntWritable(1);
   private Text wordObject = new Text();
   public void map(Object key, Text value, Context context
            ) throws IOException, InterruptedException {
         String line = value.toString();
         for (String word : line.split("\\W+")) {
           if (word.length() > 0) {
                wordObject.set(word);
                context.write(wordObject, one);
           }
         }
   }
}
```

Mapper class

A class `MyMapper` extends a base `Mapper` class included within the Hadoop libraries

In the example, the four generics in `Mapper<Object, Text, Text, IntWritable>`represent `<map_input_key, map_input_value, map_output_key, map_output_value>`

These generics must correspond to

- Key-value pair types as defined by `InputFormat` in Driver (may be the default one)
- `job.setMapOutputKeyClass` and `job.setMapOutputValueClass` defined in Driver
- Input and output to the `map()` method

Mapper class

In `map()` method, before performing any functions against a key or a value (such as `split()`), we need to get the value contained in the serialised `Writable` or `WritableComparable` object, by using the `value.toString()` method

After performing operations against the input data (key-value pairs), the output data (intermediate data, also key-value pairs) are `WritableComparable` and `Writable objects`, both of which are emitted using a `Context` object

In the case of a Map-only job, the output from Map phase, namely the set of key-value pairs emitted from all `map()` methods in all map tasks, is the final output, without intermediate data or Shuffle-and-Sort phase

Context object

A Context object is used to pass information between processes in Hadoop

We mostly invoke its `write()` method to write the output data from Mapper and Reducer

Other functions of Context object are the following

- It contains configuration and state needed for processes within the MapReduce application, including enabling parameters to be passed to distributed processes
- It is used in the optional `setup()` and `cleanup()` methods within a Mapper or Reducer

Java code of Reducer

```sql
public static class MyReducer
         extends Reducer {
   private IntWritable result = new IntWritable();
   public void reduce(Text key, Iterable values,
         Context context)
                  throws IOException, InterruptedException {
         int sum = 0;
         for (IntWritable val : values) {
             sum += val.get();
         }
         result.set(sum);
         context.write(key, result);
   }
}
```

Reducer class

A class `MyReducer` extends the based `Reducer` class included with the Hadoop libraries.

The four generics in `Reducer<Text, IntWritable, Text, IntWritable<` represents `<reduce_input_key, reduce_input_value,reduce_output_key, reduce_output_value>`

A `reduce()` method accepts a key and an `Iterable` list of values as input, denoted by the angle brackets `<>`, for example `Iterable<IntWritable>`

As in Mapper, to operate or perform Java string or numeric operations against keys or values from the input list of values, we first extract a value included in Hadoop object

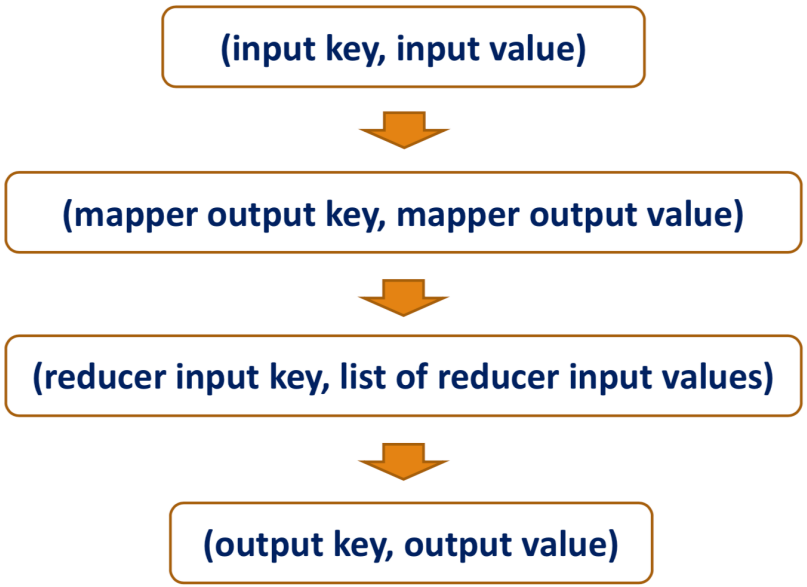
Also, the emit of key-value pairs in the form of `WritableComparable` objects for keys and values uses a `Context` object

Reducer class

Reducer class implements the main application logic

For example, the actually counting of `WordCount` is implemented in Reducer

Data flow of keys and values



ToolRunner

Despite optional, Driver can leverage a class called `ToolRunner`, which is used to parse command-line options

A class ToolRunner

```
// ... Originally imported package members of WordCount
import org.apache.hadoop.util.Tool;
import org.apache.hadoop.util.ToolRunner;
import org.apache.hadoop.conf.Configured;
public class WordCountTR extends Configured implements Tool {
       public static void main(String[] args)
                throws Exception {
          int res = ToolRunner.run(new Configuration(), new
                        WordCount(), args);
          System.exit(res);
       }
// "run" method of ToolRunner (in the next slide)
}
```

ToolRunner

`run` method of `ToolRunner`

run method of ToolRunner

```
@Override
public int run(String[] args) throws Exception {
  Configuration conf = this.getConf();
  Job job = Job.getInstance(conf, "word count with ToolRunner");
  job.setJarByClass(WordCountTR.class);
  job.setMapperClass(MyMapper.class); //the Mapper class
  job.setReducerClass(MyReducer.class); //the Reducer class
  job.setOutputKeyClass(Text.class);
  job.setOutputValueClass(IntWritable.class);
  FileInputFormat.addInputPath(job, new Path(args[0]));
  FileOutputFormat.setOutputPath(job, new Path(args[1]));
  return job.waitForCompletion(true) ? 0 : 1;
}
```

ToolRunner in the command line

`ToolRunner` enables flexibility in supplying configuration parameters at the command line when submitting a MapReduce job

The following submission has a command to specify the number of Reduce tasks from the command line

ToolRunner in a command line

```
hadoop jar mr.jar MyDriver -D mapreduce.job.reduces=10 myinputdir myoutputdir
```

The following submission specifies the location of HDFS

ToolRunner in a command line

```
hadoop jar mr.jar MyDriver
      -D fs.defaultFS=hdfs://localhost:9000 myinputdir myoutputdir
```

Setting up a local running environment

A local running environment is often convenient in MapReduce application development

- Before sending it out to the whole cluster.
- Used for debugging and testing

Create a configuration file, say, `hadoop-local.xml`

hadoop-local.xml

```
<property>
  <name>fs.defaultFS</name>
  <value>file:///</value>
</property>
<property>
  <name>mapreduce.framework.name</name>
  <value>local</value>
</property>
```

Setting local environment

```
hadoop jar mr.jar MyDriver -conf hadoop-local.xml myinputdir myoutputdir
```

Combiner API

Combiner functions can decrease the amount of intermediate data sent between Mappers and Reducers as part of a Shuffle-and-Sort process

- In a sense, Combiner is the "map-side reducers"

One can reuse Reducer code to implement Combiner if

- A `combiner()` function is identical to a `reduce()` function defined in your Reducer class
- The output key and value object types from a `map()` function implemented in Mapper match the input to the function used in Combiner
- The output key and value object types from the function used in Combiner match the input key and value object types used in Reducer's `reduce()` method
- The operation to be performed is commutative and associative.

Partitioner API

Partitioner divides the output keyspace for a MapReduce application, controlling which Reducers get which intermediate data

- It is useful in process distribution or load balancing, for example, getting more Reduce tasks running in parallel
- It can be used to to segregate the outputs, for example, creating a file for monthly data in a year

A default Partitioner is a `HashPartitioner`, which arbitrarily hashes the key space such that

- the same keys go to the same Reducers and
- the keyspace is distributed roughly equally among the number of Reducers when determined by a programmer

In case of one Reduce task (default in pseudo-distributed mode), the Partitioner is "academic" because all intermediate data goes to the same Reducer

Example: LetterPartitioner

LetterPartitioner

```
// ... other imported package members
import org.apache.hadoop.mapreduce.Partitioner;
public static class LetterPartitioner
                extends Partitioner  {
        @Override
        public int getPartition(Text key, IntWritable value, int
                        numReduceTasks) {
                String word = key.toString();
                if (word.toLowerCase().matches("^[a-m].*$")) {
//                if word starts with a to m, go to the first Reducer or partition
                   return 0;
                } else {
//                  else go to the second Reducer or partition
                  return 1;
                }
        }
}
```

Declare Combiner and Partitioner in a Driver

Declaring Combiner and Partitioner in a Driver

```
public class WordCountWithLetPar {
  public static void main(String[] args) throws Exception {
    ...
    job.setMapperClass(MyMapper.class);    // Mapper class
    job.setCombinerClass(MyReducer.class); // Combiner class, which is
                                              same as Reducer class in this program
    job.setPartitionerClass(MyPartitioner.class); // Partitioner class
    job.setReducerClass(MyReducer.class);  // Reducer class
    ...
  }
}
```

ToolRunner options

ToolRunner options

Option	Description
`-D property=value`	Sets the given Hadoop configuration property to the given value. Overrides any default or site properties in the configuration and any properties set via the `-conf` option.
`-conf filename ...`	Adds the given files to the list of resources in the configuration. This is a convenient way to set site properties or to set a number of properties at once.
`-fs uri`	Sets the default filesystem to the given URI. Shortcut for `-D fs.defaultFS=uri`.
`-jt host:port`	Sets the YARN resource manager to the given host and port. (In Hadoop 1, it sets the jobtracker address, hence the option name.) Shortcut for `-D yarn.resourcemanager.address=host:port`.

ToolRunner options

Option	Description
`-files file1, file2, ...`	Copies the specified files from the local filesystem (or any filesystem if a scheme is specified) to the shared filesystem used by MapReduce (e.g. HDFS) and makes them available to MapReduce programs in the working directory of task.
`-archives archive1, archive2, ...`	Copies the specified archives from the local filesystem (or any filesystem if a scheme is specified) to the shared filesystem used by MapReduce (usually HDFS), unarchives them, and makes them available to MapReduce programs in the working directory of task.
`-libjars jar1, jar2, ...`	Copies the specified JAR files from the local filesystem (or any filesystem if a scheme is specified) to the shared filesystem used by MapReduce (usually HDFS) and adds them to the MapReduce classpath of task. This option is a useful way of shipping JAR files that a job is dependent on.

References

White T., Hadoop The Definitive Guide: Storage and Analysis at Internet Scale, O'Reilly, 2015