合肥学院
HEFEI UNIVERSITY

Distributed Computing

Lesson 23: MapReduce with Hadoop

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1. MapReduce & Hadoop
2. Examples

website

Overview

- What is MapReduce?
- Distinguish use cases of Hadoop/MapReduce, MPI, Servlets
- Getting to know the MapReduce support of the Hadoop framework

HTTP, Web Services, and Java Servlets are ideal for

HTTP/Web Services/Java Servlet Use Case

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- We want to combine different applications in a heterogeneous system

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- Basically anything where we need lots of/repetitive interprocess communication *during* the computation.
- Size of data that needs to be transmitted is smaller in comparison to runtime of computations (see point 1).
- We are in a scientific environment and do not need to connect to other software such as enterprise systems.

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- Alternatively: Data is unstructured (e.g., text) and potentially huge. Communication will take up lots of time (and thus would eat up all advantages of MPI).
- Our data comes from and results need to be passed to other applications, such as enterprise systems, which may use stacks such as HTTP/Java Servlet/Web Service.

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- large-scale parallel image processing

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MapReduce with Hadoop

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- Conceptually similar to scatter/reduce in MPI

- Data is divided into smaller pieces, each piece corresponds to a problem part. The parts are solved separately and the separate solutions are combined to final results.

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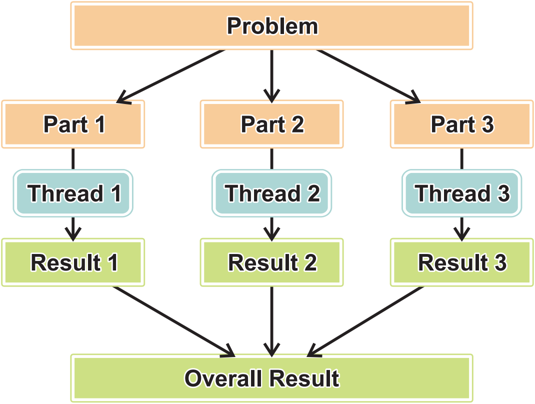


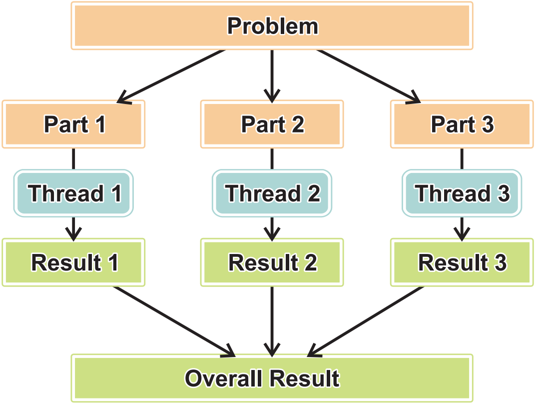
Partition = Divide

Conquer

Combine

image source: [5]

- solving of partial problems = mapping; combination of partial results to final results = reduce



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Mapping

Reducing

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- Due to time restrictions, we will *only* consider the MapReduce part

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- We can also do this locally on each node, after *Map* and before *Reduce*, to reduce the amount of communication needed (this is called *combination*)

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- If a word occurs multiple times in a line, one token is emitted for each occurrence.

Listing: The mapper class.

```java
package wordCount;
public class WordCountMapper
    extends Mapper<LongWritable, Text, Text, IntWritable> {

  public static final IntWritable ONE = new IntWritable(1);

  @Override
  protected void map(final LongWritable offset, final Text line,
      final Context context) throws IOException, InterruptedException {
    for (String word : line.toString()// replace punctuation and other
        .replace('.', '␣').replace(',', '␣').replace('/', '␣')// strange
        .replace(']', '␣').replace('[', '␣').replace('_', '␣')// chars
        .replace(')', '␣').replace('(', '␣').replace('#', '␣')// with
        .replace('!', '␣').replace('?', '␣').replace("-", "")// spaces
        .replace("\"", "").replace("\'", "").replaceAll("[0-9]+", "␣")//
        .replace(':', '␣').replace('\t', '␣').replace('\f', '␣')//
        .split("\\s+")) {// iterate over all space-separated words
      word = word.trim();
      if (word.length() > 0) {// emit one tuple <WORD, 1> for each WORD
        context.write(new Text(word.toLowerCase()), WordCountMapper.ONE);
      }
    }
  }
}
```

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Listing: The reducer class.

```
package wordCount;
public class WordCountReducer
    extends Reducer<Text, IntWritable, Text,
        IntWritable> {

  @Override
  protected void reduce(final Text key, final
      Iterable<IntWritable> values,
      final Context context) throws IOException,
        InterruptedException {
    // we receive tuples of the type <WORD,
        IntWritable> for each WORD
    int count = 0;
    for (final IntWritable current : values) { //
        we add up all the ints
      count += current.get();
    }
    context.write(key, new IntWritable(count));//
        and emit the final count
  }
}
```

WordCount Driver

- We put everything together in a "driver" class

Driver Class

Listing: The driver class.

```java
package wordCount;
public class WordCountDriver extends Configured implements Tool {

  public static void main(final String[] args) throws Exception {
    System.exit(ToolRunner.run(new Configuration(), //
        new WordCountDriver(), args));
  }

  @Override
  public int run(final String[] args) throws Exception {
    final Configuration conf;
    final Job job;

    conf = new Configuration();
    job = Job.getInstance(conf, "Word Count Map-Reduce");

    job.setJarByClass(WordCountDriver.class);

    if (args.length < 2) {
      return 1;
    }

    job.setMapperClass(WordCountMapper.class);// set mapper
    job.setReducerClass(WordCountReducer.class);// set reducer
    // a combiner performs something like a reduction step right after
    // mapping, on the mapper's computer, before sending on the data
    job.setCombinerClass(WordCountReducer.class);// set combiner

    job.setOutputKeyClass(Text.class);// set output key class
    job.setOutputValueClass(IntWritable.class);// set output value class

    job.setInputFormatClass(TextInputFormat.class);// set input format
    job.setOutputFormatClass(TextOutputFormat.class);// set output format

    FileInputFormat.setInputPaths(job, new Path(args[0]));
    FileOutputFormat.setOutputPath(job, new Path(args[1]));

    job.waitForCompletion(true);
    return 0;
  }
}
```

Maven Setup

- We can set up this project by using Maven

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- And create an executable `jar` with `mvn clean compile package`

pom.xml

Listing: [pom.xml] – Part 1: Basic Project Information

```
<project xmlns="http://maven.apache.org/POM/4.0.0"
    xmlns:xsi="http://www.w3.org/2001/XMLSchema-instance"
  xsi:schemaLocation="http://maven.apache.org/POM/4.0.0␣
      http://maven.apache.org/xsd/maven-4.0.0.xsd">
  <modelVersion>4.0.0</modelVersion>

  <groupId>thomasWeise</groupId>
  <artifactId>wordCount</artifactId>
  <version>0.8.0</version>
  <packaging>jar</packaging>
  <name>Hadoop Word Counting Example</name>
  <description>The famous word counting example for
      Hadoop.</description>
```

Listing: [pom.xml] – Part 2: Information about Organization

```xml
<url>http://www.it-weise.de/</url>
<organization>
  <url>http://www.it-weise.de/</url>
  <name>thomasWeise</name>
</organization>
```

pom.xml

Listing: [pom.xml] – Part 3: Information about Developer

```
<developers>
  <developer>
    <id>thomasWeise</id>
    <name>Thomas Weise</name>
    <email>tweise@ustc.edu.cn</email>
    <url>http://www.it-weise.de/</url>
    <organization>University of Science and Technology of
       China (USTC)</organization>
    <organizationUrl>http://www.ustc.edu.cn/</organizationUrl>
    <roles>
      <role>architect</role>
      <role>developer</role>
    </roles>
    <timezone>China Time Zone</timezone>
  </developer>
</developers>
```

pom.xml

Listing: [pom.xml] – Part 4: Properties for Rest of pom

```
<properties>
  <encoding>UTF-8</encoding>
  <project.build.sourceEncoding>${encoding}</project.build.sourceEncoding>
  <project.reporting.outputEncoding>${encoding}</project.reporting.outputEncoding>
  <jdk.version>1.7</jdk.version>
  <project.mainClass>wordCount.WordCountDriver</project.mainClass>
```

pom.xml

Listing: [pom.xml] – Part 5: Licensing

```
<licenses>
  <license>
    <name>GNU GENERAL PUBLIC LICENSE Version 3, 29 June
        2007</name>
    <url>http://www.gnu.org/licenses/gpl-3.0-standalone.html</url>
    <distribution>repo</distribution>
  </license>
</licenses>
```

pom.xml

Listing: [pom.xml] – Part 6: SCM, Issue Management, and Inception Year

```
<issueManagement>
  <url>https://github.com/thomasWeise/distributedComputingExamples/issues</url>
  <system>GitHub</system>
</issueManagement>

<scm>
  <connection>scm:git:git@github.com:thomasWeise/distributedComputingExamples.git</connection>
  <developerConnection>scm:git:git@github.com:thomasWeise/distributedComputingExamples.git</developerConn
  <url>git@github.com:thomasWeise/distributedComputingExamples.git</url>
</scm>

<inceptionYear>2016</inceptionYear>
```

pom.xml

Listing: [pom.xml] – Part 7: Dependencies

```
<dependencies>
  <dependency>
    <groupId>org.apache.hadoop</groupId>
    <artifactId>hadoop-client</artifactId>
    <version>2.7.2</version>
  </dependency>
</dependencies>
```

pom.xml

Listing: [pom.xml] – Part 8: Build

```
<build>
  <finalName>wordCount</finalName>

  <plugins>
    <plugin>
      <groupId>org.apache.maven.plugins</groupId>
      <artifactId>maven-compiler-plugin</artifactId>
      <version>3.1</version>
      <configuration>
        <source>${jdk.version}</source>
        <target>${jdk.version}</target>
        <encoding>${encoding}</encoding>
        <showWarnings>true</showWarnings>
        <showDeprecation>true</showDeprecation>
      </configuration>
    </plugin>

    <!-- This one is for building the fat jar. -->
    <plugin>
      <groupId>org.apache.maven.plugins</groupId>
      <artifactId>maven-shade-plugin</artifactId>
      <version>2.3</version>
      <executions>
        <execution>
          <phase>package</phase>
          <goals>
            <goal>shade</goal>
          </goals>
          <configuration>

            <minimizeJar>false</minimizeJar>
            <shadedArtifactAttached>true</shadedArtifactAttached>
            <createDependencyReducedPom>false</createDependencyReducedPom>
            <finalName>wordCount-full</finalName>

            <filters>
              <filter>
                <artifact>*:*</artifact>
                <excludes>
                  <exclude>META-INF/*.SF</exclude>
                  <exclude>META-INF/*.DSA</exclude>
                  <exclude>META-INF/*.RSA</exclude>
                </excludes>
              </filter>
            </filters>

            <transformers>
              <transformer
                implementation="org.apache.maven.plugins.shade.resource.ManifestResourceTransformer">
                <mainClass>${project.mainClass}</mainClass>
              </transformer>
              <transformer
                implementation="org.apache.maven.plugins.shade.resource.ApacheLicenseResourceTransformer" />
              <transformer
                implementation="org.apache.maven.plugins.shade.resource.ApacheNoticeResourceTransformer" />
              <transformer
                implementation="org.apache.maven.plugins.shade.resource.PluginXmlResourceTransformer" />
              <transformer
                implementation="org.apache.maven.plugins.shade.resource.ServicesResourceTransformer" />
            </transformers>
          </configuration>
        </execution>
      </executions>
    </plugin>
  </plugins>
</build>
```

Executing the Example

- Enter the `hadoop` folder and perform the following steps

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  9. `bin/hdfs dfs -copyToLocal output/part-r-00000`
  10. `sbin/stop-dfs.sh`

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- Try to find the interconnection between pages

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- Output of Reducer: List of URLs to *shared* resources and URLs (from Mapper input) referencing them
- Having this, we can find out which resources are fundamental in the web, which are shared between different pages, and how the most important pages in China are interconnected

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- We detect all references to other pages, CSS, and javscript in the page. Each reference corresponds to a URL, let's call it `B`
- We emit all tuples `<B as Text, A as Text>`
- The process is applied *recursively* (up to a maximum depth)
- So we have tuples of resources and the URLs referencing them

Listing: The mapper class.

```java
package webFinder;
/**
 * This is the Mapper component of the Web Finder example. Its input are
 * text lines, where each line stands for a website URL. It finds all
 * resources that are loaded by a given website URL and emits tuples of
 * kind {@code <resource URL, website URL>}.
 */
public class WebFinderMapper
    extends Mapper<LongWritable, Text, Text, Text> {

  /** the logger we use */
  private static Logger LOGGER = Logger.getLogger(WebFinderMapper.class);

  /**
   * Map tuples of type {@code <line number, website url text>} to tuples
   * of kind {@code <resource url text, website url text>}.
   */
  @Override
  protected void map(final LongWritable offset, final Text line,
      final Context context) throws IOException, InterruptedException {
    final URL baseUrl;
    final URI baseUri;
    final int maxDepth;
    final Text baseUrlText;
    final HashSet<URL> done;
    String str;

    str = WebFinderMapper.__prepare(line.toString(), true);
    if (str == null) {// prepare base url
      return;
    }
    // set maximum depth of spider
    maxDepth = context.getConfiguration().getInt("maxDepth", 1);

    baseUri = URI.create(str).normalize();
    baseUrl = baseUri.toURL();
    done = new HashSet<>();// URLs that have been processed
    done.add(baseUrl);
```

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- The input of the Reducer are tuples of resources and *lists* of URLs referencing them
- For each resource URL, we compute the set of unique URLs referencing them
- If the set contains more then one resource, we have a resource shared among multiple of the originally provided URLs
- We will only output such elements, as tuple `<URL, list of URLs referencing it>`

Listing: The reducer class.

```java
package webFinder;
/**
 * This is the reducer component of the web finder example. For each key (
 * {@code resource URL}) of the tuples produced by the mapper, it receives
 * the list of all values ({@code website URLs}). If such a list contains
 * more than one unique element, this means that the resource is shared by
 * multiple websites. This reducer emits tuples of the form
 * {@code <resource URL, list of website urls>}.
 */
public class WebFinderReducer
    extends Reducer<Text, Text, Text, List<Text>> {

  /**
   * The actual reduction step: From the tuples of form
   * {@code <resource URL, iterable of referencing website URLs>}, select
   * all resources referenced by more than one unique website. For these,
   * output tuples of the form {@code <resource URL, list of website URLs>}
   * .
   */
  @Override
  protected void reduce(final Text key, final Iterable<Text> values,
      final Context context) throws IOException, InterruptedException {
    final HashSet<URL> set;
    final int size;
    final ArrayList list;
    String string;
    URL add;
    int index;

    set = new HashSet<>();
    looper: for (final Text url : values) {
      string = url.toString();// convert value to a URL
      try {
        add = new URI(string).normalize().toURL();
      } catch (@SuppressWarnings("unused") final Throwable error) {
        try {
          add = new URL(string).toURI().normalize().toURL();
        } catch (@SuppressWarnings("unused") final Throwable error2) {
          try {
            add = new URL(string);
          } catch (@SuppressWarnings("unused") final Throwable error3) {
            continue looper;
          }
        }
      }
      set.add(add); // store value in set of URLs pointing to this resource
```

WebFinder Driver

- We put everything together in a “driver” class

The Driver Class

Listing: The driver class.

```
package webFinder;
/**
 * The driver of the web finder sets up the distributed computation by
 * defining what the mapper and reducer classes, amongst other things.
 */
public class WebFinderDriver extends Configured implements Tool {

  public static void main(final String[] args) throws Exception {
    try {
      final int res = ToolRunner.run(new Configuration(),
          new WebFinderDriver(), args);
      System.exit(res);
    } catch (final Exception e) {
      e.printStackTrace();
      System.exit(255);
    }
  }

  /** Setting up the computation. */
  @Override
  public int run(final String[] args) throws Exception {
    final Configuration conf;
    final Job job;

    conf = new Configuration();
    job = Job.getInstance(conf, "WebFinder MapReduce");

    job.setJarByClass(WebFinderDriver.class);// use current jar

    if (args.length < 2) {
      return 1;
    }
    if (args.length > 2) {// set max depth and pass parameter to mapper
      conf.setInt("maxDepth", Integer.parseInt(args[2]));
    }

    job.setMapperClass(WebFinderMapper.class);// set mapper
    job.setMapOutputKeyClass(Text.class);// set mapper output key type
    job.setMapOutputValueClass(Text.class); // set mapper output value type

    job.setReducerClass(WebFinderReducer.class);// set reducer
    job.setOutputKeyClass(Text.class);// set reducer output key type
    job.setOutputValueClass(List.class);// set reducer output value

    job.setInputFormatClass(TextInputFormat.class);// set input format
    job.setOutputFormatClass(TextOutputFormat.class);// set output format

    FileInputFormat.setInputPaths(job, new Path(args[0]));
    FileOutputFormat.setOutputPath(job, new Path(args[1]));
```

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  10. `sbin/stop-dfs.sh`

Listing: Output

```
http://c.youku.com/aboutcn/youtu  [http://www.tudou.com, http://www.youku.com]
http://c.youku.com/abouteg/youku  [http://www.tudou.com, http://www.youku.com]
http://c.youku.com/abouteg/youtu  [http://www.tudou.com, http://www.youku.com]
http://cbjs.baidu.com/js/m.js [http://www.baidu.com, http://www.qq.com]
http://css.tudouui.com/skin/__g/img/sprite.gif  [http://www.tudou.com, http://www.youku.com]
http://events.youku.com/global/scripts/jquery-1.8.3.js  [http://www.tudou.com, http://www.youku.com]
http://events.youku.com/global/scripts/youku.js [http://www.tudou.com, http://www.youku.com]
http://images.china.cn/images1/ch/appxz/2.jpg [http://www.qq.com, http://www.youku.com]
http://images.china.cn/images1/ch/appxz/3.jpg [http://www.qq.com, http://www.youku.com]
http://js.tudouui.com/v3/dist/js/lib_6.js [http://www.tudou.com, http://www.youku.com]
http://mail.qq.com  [http://www.baidu.com, http://www.qq.com]
http://minisite.youku.com/mini_common/urchin.js [http://www.tudou.com, http://www.youku.com]
http://player.youku.com/jsapi [http://www.tudou.com, http://www.youku.com]
http://qzone.qq.com [http://www.baidu.com, http://www.qq.com]
http://res.mfs.ykimg.com/051000004D92DF6197927339BA04E210.js  [http://www.tudou.com, http://www.youku.com]
http://static.youku.com/user/img/avatar/80/5.jpg  [http://www.tudou.com, http://www.youku.com]
http://static.youku.com/user/img/avatar/80/9.jpg  [http://www.tudou.com, http://www.youku.com]
http://weibo.com  [http://www.baidu.com, http://www.qq.com]
http://www.12377.cn [http://www.baidu.com, http://www.qq.com, http://www.youku.com]
http://www.12377.cn/node_548446.htm [http://www.qq.com, http://www.youku.com]
http://www.bjjubao.org  [http://www.baidu.com, http://www.youku.com]
http://www.china.com.cn/player/video.js [http://www.qq.com, http://www.youku.com]
http://www.ellechina.com  [http://www.qq.com, http://www.youku.com]
http://www.hao123.com [http://www.baidu.com, http://www.qq.com]
http://www.hd315.gov.cn/beian/view.asp?bianhao=010202006082400023 [http://www.tudou.com,
   http://www.youku.com]
http://www.miibeian.gov.cn  [http://www.qq.com, http://www.tudou.com, http://www.youku.com]
http://www.miibeian.gov.cn/publish/query/indexFirst.action  [http://www.tudou.com, http://www.youku.com]
http://www.pclady.com.cn  [http://www.baidu.com, http://www.qq.com]
http://www.qq.com [http://www.baidu.com, http://www.qq.com]
http://www.shjbzx.cn  [http://www.qq.com, http://www.tudou.com]
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http://www.youku.com  [http://www.baidu.com, http://www.tudou.com, http://www.youku.com]
http://www.youku.com/show_page/id_z8dc3fdeedcb911e3a705.html  [http://www.tudou.com, http://www.youku.com]
http://y.qq.com [http://www.baidu.com, http://www.qq.com]
https://www.alipay.com  [http://www.baidu.com, http://www.youku.com]
```

Summary

- MapReduce via Hadoop can cover a use case of distributed computing that neither MPI nor Java Servlets can
- Easy to use with Java and Maven
- Apache Hadoop has many more features, which we cannot cover here

谢谢

Thank you

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