CS 455: Introduction To Distributed Systems [MapReduce & Hadoop]

Does Shrideep write the poems on these title slides? Yes, he does.

These musing are resolutely on track
For obscurity shores, from whence they ain't coming back
For outside of CS, there are few who care
For how we conjure things in software
Of stripe sets and hash buckets
And how networks route packets
Or wonder why memory accesses are blazingly quick
But those to disks, so eternally slow
Or ponder what makes MapReduce tick
But don't you get complacent CS455ers, there' much more for you to know!

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Frequently asked questions from the previous class survey

- Does the Master node keep track of the copies of chunks?

Topics covered in this lecture

- Wrap-up of the MapReduce Paper
  - Backup tasks
  - Refinements
- Hadoop
  - Application development
  - API

Backup Tasks

Stragglers

- Machine that takes an **unusually long time** to complete a map or reduce operation
- Can slow down entire computation

How stragglers arise

- Machine with a **bad disk**
  - Frequent, correctable errors
  - Read performance drops from 30 MB/s to 1 MB/s
- Over **scheduling**
  - Many tasks executing on the same machine
  - *Competition* for CPU, memory, disk or network cycles
- **Bug** in machine initialization code
  - Processor caches may be disabled

Alleviating the problem of stragglers

- When a MapReduce operation is *close to completion*
- Schedule **backup** executions of *remaining* in-progress tasks
- Task completed when
  - Either the primary or backup finishes execution
- Significantly reduces time to complete large MapReduce operations

REFINEMENTS

Partitioning Function

- Users simply specify R
  - The number of output files
- Default partitioning
  - hash(key) **mod R**
- Sometimes output keys are URLs
  - Entries from a host must go to same output file
  - hash(Hostname(urlkey)) **mod R**

Ordering Guarantees

- Intermediate *key/pairs* are processed in **increasing** *key* order
- Easy to generate sorted output file

The Combiner function

- There is significant **repetition** in intermediate keys produced by each map task
- For word-frequencies
  - Each map may produce 100s or 1000s of <the, "1">
- All of these counts are sent over the network
- Combiner: Does **partial merging** of this data
  - *Before* it is sent to the reducer

Combiner function

- Executed on each machine that performs map task
- Code implementing combiner & reduce function
  - *Usually* the same … [We will see an example where this is not true.]
- Difference?
  - COMBINE: Output written to *intermediate* file
  - REDUCE: Output written to *final output* file

Input/Output Types: Support for reading input data in different formats

- `Text` mode treats every line as a <*key, value*> pair
  - Key: Offset in the file
  - Value: Contents of the line
- <*key, value*> pairs are sorted by *key*
- Each input type *knows how to split itself* for
  - Processing as separate map tasks
  - `Text` mode splitting occurs only at line boundaries

Side-effects

- Besides intermediate files, other auxiliary files may be produced
  - Side effects
- No atomic commits for multiple auxiliary files that are produced

Skipping Bad Records [1/3]

- Bugs in user code cause Map or Reduce functions to crash
  - Deterministically: On certain records
- Fix the bug?
  - Yes, but not always feasible
- Acceptable to ignore a few records

Skipping Bad Records [2/3]

- Optional mode of operation
  1. Detect records that cause *deterministic crashes*
  2. Skip them
- Each worker installs a **signal handler** to catch segmentation violations and bus errors

Skipping Bad Records [3/3]

- Signal handler sends *last gasp* UDP packet to the Master
  - Contains sequence number
- When Master sees more than 1 failure at that record
  - Indicates record should be skipped during next execution

Local Execution

- Support for **sequential execution** of MapReduce operation on a single machine
  - Helps with debugging, profiling, and testing
- Controls to *limit* computation to a particular map
- Invoke programs with a special flag
  - Use debugging and testing tools

Status Information

- Master runs internal HTTP Server
- Exports pages for viewing
- Show the progress of a computation
  - Number of tasks in progress
  - Number of tasks that completed
  - Bytes of input
  - Bytes of intermediate data
  - Processing rate

HADOOP

Hadoop

- Java-based open-source implementation of MapReduce
- Created by Doug Cutting
- Origins of the name Hadoop
  - Stuffed yellow elephant
- Includes HDFS [Hadoop Distributed File System]

Hadoop timelines

- Feb 2006
  - Apache Hadoop project officially started
  - Adoption of Hadoop by Yahoo! Grid team
- Feb 2008
  - Yahoo! Announced its search index was generated by a 10,000-core Hadoop cluster
- May 2009
  - 17 clusters with 24,000 nodes

Hadoop Releases

- There are five active releases
  - 2.6.x
  - 2.7.x
  - 2.8.x
  - 2.9.x
  - 3.0.0
- Last release from the 2.6.x branch (v2.6.5) was on October 08, 2016
- Other branches had releases in late 2017

Hadoop Evolution

- 0.20.x series became 1.x series
- 0.23.x was forked from 0.20.x to include some major features
- 0.23 series later became 2.x series
- 2.8.0 is branched off from 2.7.3
- 2.9.0 is branched off from 2.8.2
- 3.0.0 series is branched off from 2.7.0

0.23 included several major features

- New MapReduce runtime, called MapReduce 2, implemented on a new system called YARN
  - YARN: Yet Another Resource Negotiator
  - Replaces the "classic" runtime in previous releases
- HDFS federation
  - HDFS namespace can be dispersed across multiple name nodes
- HDFS high-availability
  - Removes name node as a single point of failure; supports standby nodes for failover

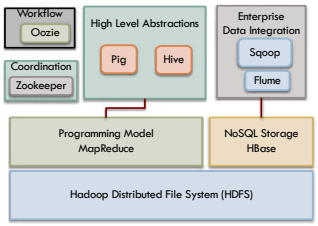
3.0.0 includes major features

- Support for erasure encoding in HDFS
  - Significant space savings compared to replication
    - Reed-Solomon encoding has 1.4x space overhead compared to the 3x overhead in default replication
- Support for more than 2 name nodes in standby mode
- Support for opportunistic containers and distributed scheduling
  - Lower priority containers than the default containers
  - Can be preempted, if needed, to make room for default containers
- Support for Microsoft Azure Data Lake and Aliyun Object Storage System file system connectors
  - As alternative Hadoop-compatible filesystems

Latest Release

- December 14, 2017
  - v2.7.5 released
- December 12, 2017
  - v2.8.3 released
- v2.9.0 and v3.0.0 were released on November 17, 2017 and December 13, 2017 respectively
  - Users are advised to wait for the next point releases before switching to these versions

The Hadoop Ecosystem



MapReduce Jobs

- A MapReduce **Job** is a unit of work
- Consists of:
  - Input Data
  - MapReduce program
  - Configuration information
- Hadoop runs the jobs by dividing it into **tasks**
  - Map tasks
  - Reduce tasks

Types of nodes that control the job execution process [Older Versions]

- **Job tracker**
  - *Coordinates all jobs* by scheduling tasks to run on task trackers
  - Records overall progress of each job
    - If task fails, reschedule on a different task tracker
- **Task tracker**
  - Run tasks and reports progress to job tracker

Types of nodes that control the job execution process [Newer Versions]

- Resource Manager
- Application Manager
- Node manager

Processing a weather dataset

- The dataset is from NOAA
- Stored using a line-oriented format
  - Each line is a record
- Lots of elements being recorded
- We focus on temperature
  - Always present with a fixed width

Format of a record in the dataset

```
0057
332130          # USAF weather station identifier
99999           # WBAN weather station identifier
19500101        # Observation date
300             # 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
…
-0128           # air temperature (degrees Celsius x 10)
1               # quality code
-0139           # dew point temperature (degree Celsius x 10)
```


Analyzing the dataset

- What's the highest recorded temperature for each year in the dataset?
- See how programs are written
  - Using Unix tools
  - Using MapReduce

Using awk
Tool for processing line-oriented data

```
#! /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
```


Sample output that is produced

```
% ./max_temperature.sh

1901        317
1902        244
1903        289
1904        256
1905        283
 …
```

To speed things up, we need to be able to do this processing on multiple machines

- STEP 1: **Divide** the work and execute concurrently on multiple machines
- STEP 2: **Combine** results from independent processes
- STEP 3: **Deal with failures** that might take place in the system

The Hollywood principle

Don't call us, we'll call you.

- Useful software development technique
- Object's (or component's) initial condition and **ongoing life cycle** is handled by its *environment*, rather than by the object itself
- Typically used for implementing a class/component that must fit into the constraints of an existing framework

Doing the analysis with Hadoop

- Break the processing into two phases
  - Map and Reduce
  - Each phase has <*key, value*> pairs as input and output
- Specify two functions
  - Map
  - Reduce

The map phase

- Choose a `Text` input format
  - Each line in the dataset is given as a text *value*
  - *key* is the offset of the beginning of the line from the beginning of the file
- Our map function
  - Pulls out year and the air temperature
  - Think of this as a data preparation phase
    - Reducer will work on data generated by the maps

How the data is represented in the actual file

```
0067011990999991950051507004...9999999N9+00001+99999999999...
0043011990999991950051512004...9999999N9+00221+99999999999...
0043011990999991950051518004...9999999N9-00111+99999999999...
0043012650999991949032412004...0500001N9+01111+99999999999...
0043012650999991949032418004...0500001N9+00781+99999999999...
```


How the lines in the file are presented to the map function by the framework

keys: Line offsets within the file

```
(0,   0067011990999991950051507004...9999999N9+00001+99999999999...)
(106, 0043011990999991950051512004...9999999N9+00221+99999999999...)
(212, 0043011990999991950051518004...9999999N9-00111+99999999999...)
(318, 0043012650999991949032412004...0500001N9+01111+99999999999...)
(424, 0043012650999991949032418004...0500001N9+00781+99999999999...)
```

The lines are presented to the map function as key-value pairs

Map function

- Extract year and temperature from each record and emit output

```
(1950, 0)
(1950, 22)
(1950, -11)
(1949, 111)
(1949, 78)
```


The output from the map function

- Processed by the MapReduce framework *before* being sent to the reduce function
  - **Sort** and **group** <*key, value*> pairs by key
- In our example, each year appears with a list of all its temperature readings

```
(1949, [111, 78])
(1950, [0, 22, -11])
...
```


What about the reduce function?

- All it has to do now is iterate through the list supplied by the maps and pick the max reading
- Example output at the reducer?

```
(1949, 111)
(1950,  22)
...
```


What does the actual code to do all of this look like?

1. Map functionality
2. Reduce functionality
3. Code to run the job

The map function is represented by an abstract `Mapper` class

- Declares an abstract `map()` method
- `Mapper` class is a generic type
  - 4 formal type parameters
  - Specifies input key, input value, output key, and output value

The `Mapper` for our example

```
public class MaxTemperatureMapper extends
    Mapper <LongWritable, Text, Text, IntWritable> {

  private final int MISSING = 9999;

  public void map(LongWritable key, Text value, Context context)
    throws IOException, InterruptedException {
      String line = value.toString();
      String year = line.substring(15, 19);
      int airTemperature;
      if (line.charAt(87) ==  `+` ) {
        airTemperature = Integer.parseInt(line.substring(88, 92));
      } else {
        airTemperature = Integer.parseInt(line.substring(87, 92));
      }
      String quality = line.substring(92, 93);
      if (airTemperature != MISSING && quality.matches("[01459]") {
        context.write(new Text(year), new IntWritable(airTemperature));
      }
  }
```

Rather than use built-in Java types, Hadoop uses its own set of basic types

- Optimized for **network serialization**
- These are in the `org.apache.hadoop.io` package
  - `LongWritable` corresponds to Java `Long`
  - `Text` corresponds to Java `String`
  - `IntWritable` corresponds to Java `Integer`

But the `map()` method also had `Context`

- You use this to write the output
- In our example
  - Year was written as a `Text` object
  - Temperature was wrapped as an `IntWritable`

More about Context

- A context object is available at any point of the MapReduce execution
- Provides a convenient mechanism for exchanging required system and job-wide information
- Context coordination happens only when an appropriate phase (driver, map, reduce) of a MapReduce job starts.
  - Values set by one mapper are not available in another mapper but is available in any reducer.

The reduce function is represented by an abstract `Reducer` class

- Declares an abstract `reduce()` method
- `Reducer` class is a generic type
  - 4 formal type parameters
  - Used to specify the input and output types of the reduce function
  - The input types should **match** the *output types of the map function*
    - In the example, `Text` and `IntWritable`

The Reducer

```
public class MaxTemperatureReducer extends
     Reducer <Text, IntWritable, Text, IntWritable> {

   public void reduce(Text key, Iterable<IntWritable> values,
                      Context context)
      throws IOException, InterruptedException {

      int maxValue = Integer.MIN_VALUE;
      for (IntWritable value : values) {
         maxValue = Math.max(maxValue, value.get());
      }
      context.write(key, new IntWritable(maxValue));
   }
}
```


The code to run the MapReduce job

```
public class MaxTemperature {
   public static main(String[] args) throws Exception {
      Job job = Job.getInstance();
      job.setJarByClass(MaxTemperature.class);
      job.setJobName("Max temperature");

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

      job.setMapperClass(MaxTemperatureMapper.class);
      job.setReducerClass(MaxTemperatureReducer.class);

      job.setOutputKeyClass(Text.class);
      job.setOutputValueClass(IntWritable.class);

      System.exit(job.waitForCompletion(true) ? 0: 1);
   }
}
```

Details about the Job submission [1/3]

- Code must be packaged in a JAR file for Hadoop to distribute over the cluster
  - `setJarByClass()` causes Hadoop *to locate relevant JAR file* by looking for JAR that contains this class
- Input and output paths must be specified next
  - `addInputPath()` can be *called more than once*
  - `setOutputPath()` specifies the output directory
    - Directory *should not exist* before running the job
    - Precaution to prevent data loss

Details about the Job submission [2/3]

- The methods `setOutputKeyClass()` and `setOutputValueClass()`
  - Control the output types of the map and reduce functions
  - If they are different?
    - Map output types can be set using `setMapOutputKeyClass()` and `setMapOutputValueClass()`

Details about the Job submission. [3/3]

- The `waitforCompletion()` method **submits** the job and **waits** for it to complete
  - The `boolean` argument is a *verbose* flag; if set, progress information is printed on the console
- Return value of `waitforCompletion()` indicates success (`true`) or failure (`false`)
  - In the example this is the program's exit code (0 or 1)

Contents of this slide set are based on the following references

- *Tom White. Hadoop: The Definitive Guide. 3rd Edition. Early Access Release. O'Reilly Press. ISBN: 978-1-449-31152-0. Chapters 1 and 2.*
- Boris Lublinsky, Kevin Smith, and Alexey Yakubovich. Professional Hadoop Solutions. Wiley Press. Chapter 3.