CSx55: Distributed Systems [MapReduce/Hadoop]

What's this hullabaloo about an elephant?

No, not the one named Horton
    Who has fun in the Jungle of Nool

This one's named Hadoop, and is just as cool
    Crunching through data and having fun

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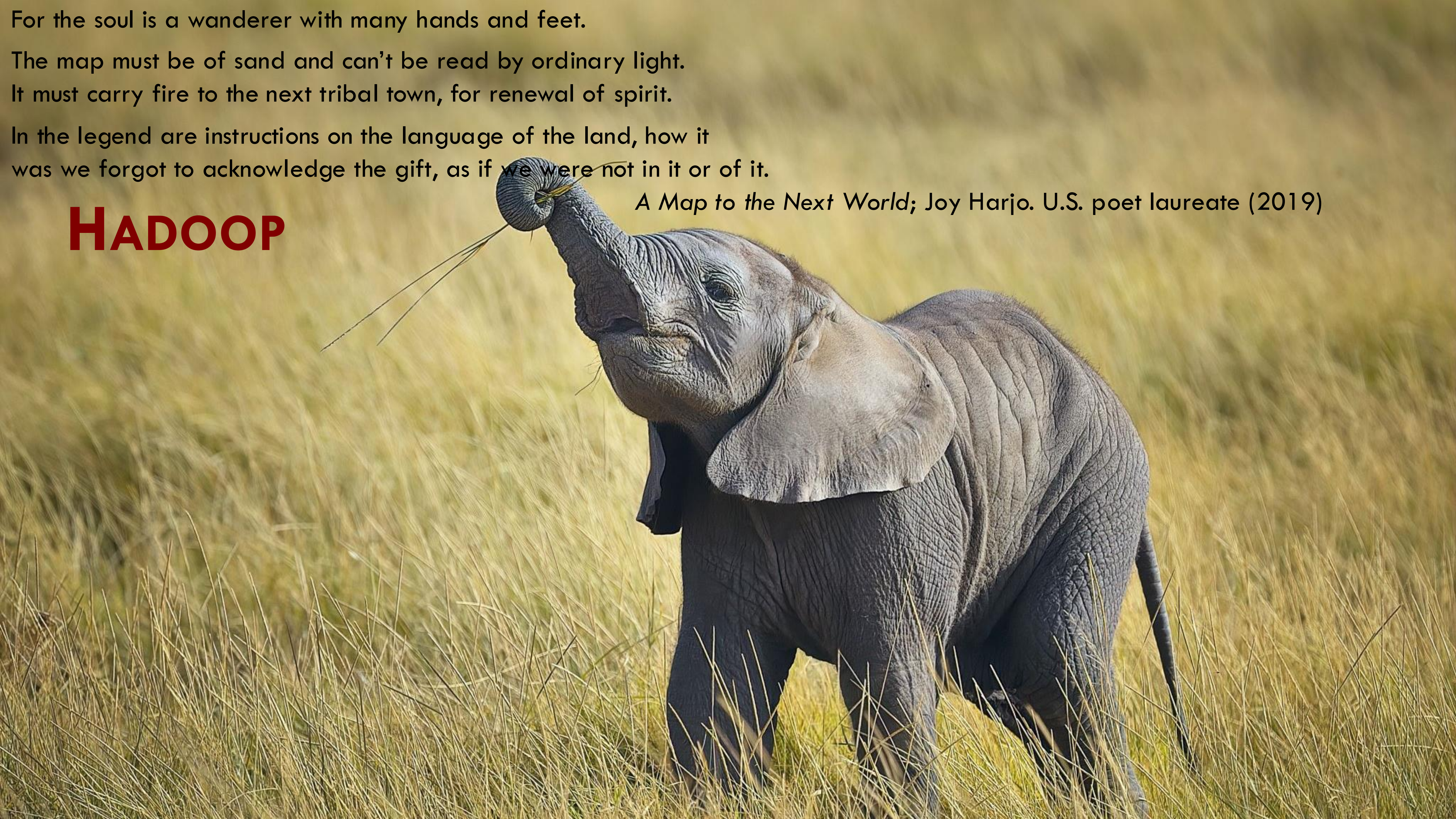
Frequently asked questions from the previous class survey

- If there are 3 copies of a chunk, does it mean that there are 3 copies of a mapper?
- What if both the map task, and its "speculative" back-up finish at the same time?
- Analogy for why the speculative/backup tasks ensure faster completion?
- How does the reducer know which intermediate file (or partition) to "pull" from a given mapper?
- Consider the case where there are 200,000 mappers and 5,000 reducers. Does it mean that each of the 5,000 reducers will pull intermediate outputs from each of the 200,000 mappers?
  - Yes!
- What is the deeper reason why "pushing" computations to data is better than "pulling" data to the computation?
- Is GFS distributed and running on multiple machines? How does it work?

Topics covered in today's lecture

- MapReduce
- Hadoop



For the soul is a wanderer with many hands and feet.

The map must be of sand and can't be read by ordinary light.
It must carry fire to the next tribal town, for renewal of spirit.

In the legend are instructions on the language of the land, how it
was we forgot to acknowledge the gift, as if we were not in it or of it.

A Map to the Next World; Joy Harjo. U.S. poet laureate (2019)

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 two active releases at the moment
  - 2.10.x
  - 3.4.x

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
- 3.1.0 series is branched off from 3.0.0
- 3.2.0 is branched off from 3.1.0
- 3.3.0 introduced the Software Bill of Materials (SBOM) artifacts
  - Provides a complete inventory of its components and dependencies

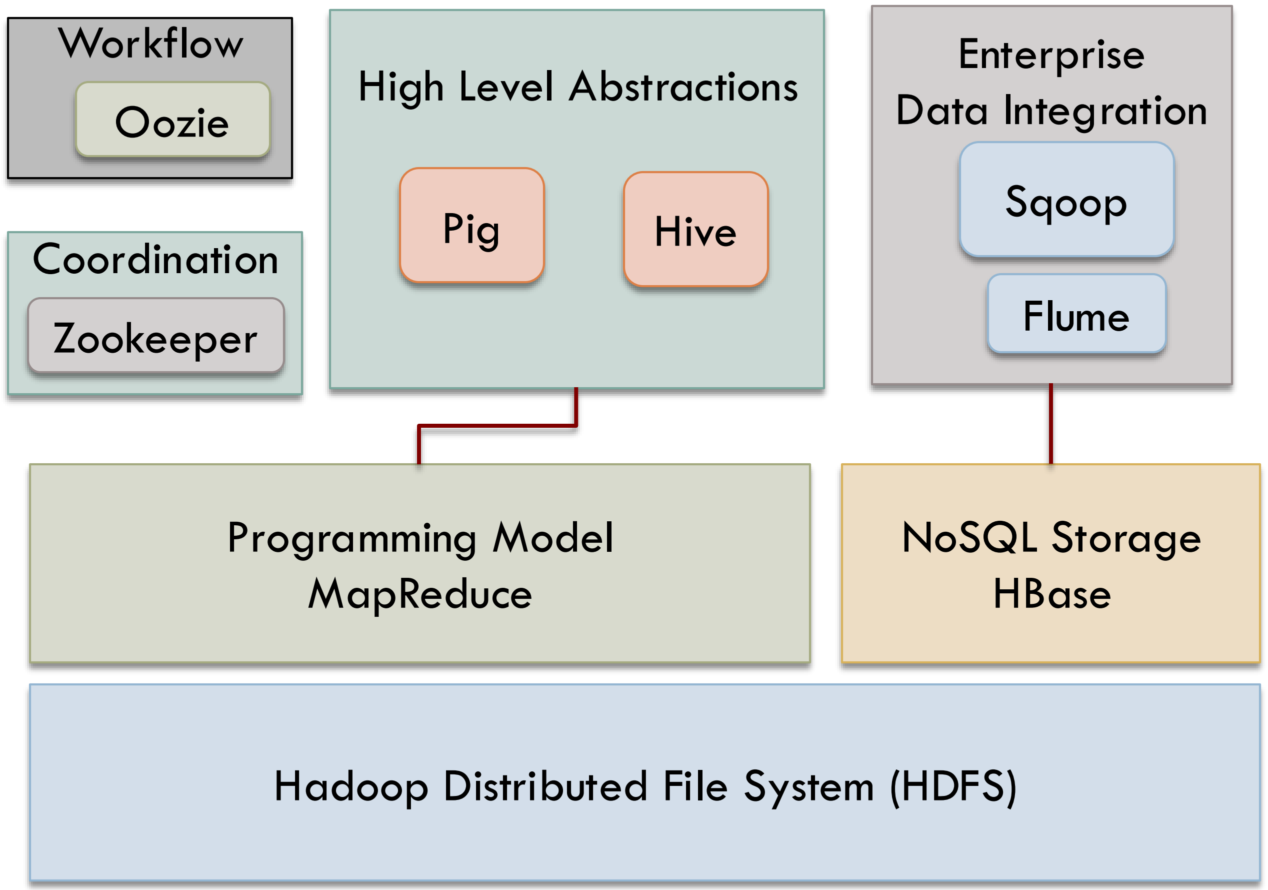
0.23 included several major features

- 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.x includes major features

- Hadoop Submarine support
  - Hadoop Submarine orchestrates Tensorflow programs without modifications on Yarn and provide access to data stored on HDFS
  - Support for GPUs and Docker images
- Erasure coding in HDFS
- New/Improved storage connectors
  - ADLS (Azure Datalake Generation 2), Amazon S3, and Amazon DynamoDB
- HDFS storage policies
  - Hierarchical storage – Archival, Disk (default), SSD, and RamDisk
  - Users can define the type of storage when storing data
  - Blocks can be moved between different storage types

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

I etched the face of a stopwatch on the back of a raindrop
And did a swap for the sand in an hourglass
I heard an unhappy ending, it sort of sounds like you leaving
I heard the piledriver waltz, it woke me up this morning
Piledriver Waltz; Alex Turner; Arctic Monkeys

PROCESSING A WEATHER DATASET

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, at the reducer, 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)

API DIFFERENCES

The old and new MapReduce APIs

- The new API favors abstract classes over interfaces
  - Make things easier to evolve
- New API is in `org.apache.hadoop.mapreduce` package
  - Old API can be found in `org.apache.hadoop.mapred`
- New API makes use of context objects
  - `Context` unifies roles of `JobConf`, `OutputCollector`, and `Reporter` from the old API

The old and new MapReduce APIs

- In the new API, job control is done using the `Job` class rather than using the `JobClient`
- Output files are named slightly differently
  - Old API: Both map and reduce outputs are named part-nnnn
  - New API: Map outputs are named part-**m**-nnnn and reduce outputs are named part-**r**-nnnn

The old and new MapReduce APIs

- The new API's `reduce()` method passes values as `Iterable` rather than as `Iterator`
  - Makes it **easier to iterate** over values using the for-each loop construct

```
for (VALUEIN value: values) {
    …
}
```

The contents of this slide-set are based on the following references

- Jeffrey Dean, Sanjay Ghemawat: *MapReduce: Simplified Data Processing on Large Clusters*. OSDI 2004: 137-150
- Jeffrey Dean, Sanjay Ghemawat: MapReduce: simplified data processing on large clusters. Commun. ACM 51(1): 107-113 (2008)
- *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.