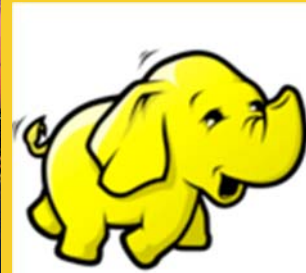




# Map Reduce 2.0 Input and Output

Originals of slides and source code for examples: <http://www.coreservlets.com/hadoop-tutorial/>  
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# Agenda

- **MapReduce Theory**
- **Types of Keys and Values**
- **Input and Output Formats**
- **Discuss Anatomy of**
  - Mappers
  - Reducers
  - Combiners
  - Partitioners

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# MapReduce Theory

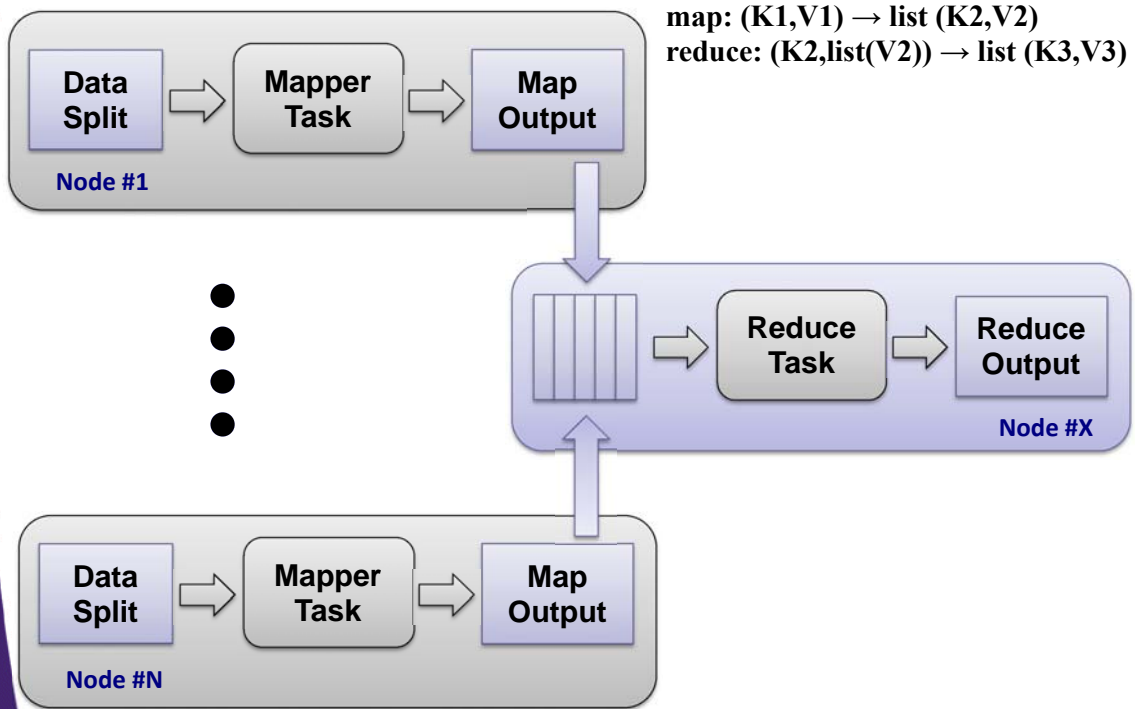
- **Map and Reduce functions produce input and output**
  - Input and output can range from Text to Complex data structures
  - Specified via Job's configuration
  - Relatively easy to implement your own
- **Generally we can treat the flow as**  
  

```
map: (K1,V1) → list (K2,V2)
reduce: (K2,list(V2)) → list (K3,V3)
```

  - Reduce input types are the same as map output types

5

# Map Reduce Flow of Data



# Key and Value Types

- **Utilizes Hadoop's serialization mechanism for writing data in and out of network, database or files**
  - Optimized for network serialization
  - A set of basic types is provided
  - Easy to implement your own
- **Extends Writable interface**
  - Framework's serialization mechanisms
  - Defines how to read and write fields
  - org.apache.hadoop.io package

# Key and Value Types

- **Keys must implement WritableComparable interface**
  - Extends Writable and java.lang.Comparable<T>
  - Required because keys are sorted prior reduce phase
- **Hadoop is shipped with many default implementations of WritableComparable<T>**
  - Wrappers for primitives (String, Integer, etc...)
  - Or you can implement your own

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# WritableComparable<T> Implementations

Hadoop's Class	Explanation
BooleanWritable	Boolean implementation
BytesWritable	Bytes implementation
DoubleWritable	Double implementation
FloatWritable	Float implementation
IntWritable	Int implementation
LongWritable	Long implementation
NullWritable	Writable with no data

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# Implement Custom WritableComparable<T>

- **Implement 3 methods**

- write(DataOutput)
  - Serialize your attributes
- readFields(DataInput)
  - De-Serialize your attributes
- compareTo(T)
  - Identify how to order your objects
  - If your custom object is used as the key it will be sorted prior to reduce phase

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# BlogWritable – Implementation of WritableComparable<T>

```
public class BlogWritable implements
    WritableComparable<BlogWritable> {

    private String author;
    private String content;
    public BlogWritable(){}
    public BlogWritable(String author, String content) {
        this.author = author;
        this.content = content;
    }
    public String getAuthor() {
        return author;
    }

    public String getContent() {
        return content;
    }
}
```

...

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# BlogWritable – Implementation of WritableComparable<T>

```
...
...
@Override
public void readFields(DataInput input) throws IOException {
    author = input.readUTF();
    content = input.readUTF();
}

@Override
public void write(DataOutput output) throws IOException {
    output.writeUTF(author);
    output.writeUTF(content);
}

@Override
public int compareTo(BlogWritable other) {
    return author.compareTo(other.author);
}
}
```

1. How the data is read

2. How to write data

3. How to order BlogWritables

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# Mapper

- **Extend Mapper class**
  - Mapper<KeyIn, ValueIn, KeyOut, ValueOut>
- **Simple life-cycle**
  1. The framework first calls setup(Context)
  2. for each key/value pair in the split:
    - map(Key, Value, Context)
  3. Finally cleanup(Context) is called

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# InputSplit

- **Splits are a set of logically arranged records**
  - A set of lines in a file
  - A set of rows in a database table
- **Each instance of mapper will process a single split**
  - Map instance processes one record at a time
    - `map(k,v)` is called for each record
- **Splits are implemented by extending InputSplit class**

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# InputSplit

- **Framework provides many options for InputSplit implementations**
  - Hadoop's FileSplit
  - HBase's TableSplit
- **Don't usually need to deal with splits directly**
  - InputFormat's responsibility

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# InputFormat

- **Specification for reading data**
- **Creates Input Splits**
  - Breaks up work into chunks
- **Specifies how to read each split**
  - Divides splits into records
  - Provides an implementation of RecordReader

```
public abstract class InputFormat<K, V> {  
    public abstract  
        List<InputSplit> getSplits(JobContext context)  
                                throws IOException, InterruptedException;  
  
    public abstract  
        RecordReader<K,V> createRecordReader(InputSplit split,  
                                                TaskAttemptContext context )  
                                throws IOException, InterruptedException;  
}
```

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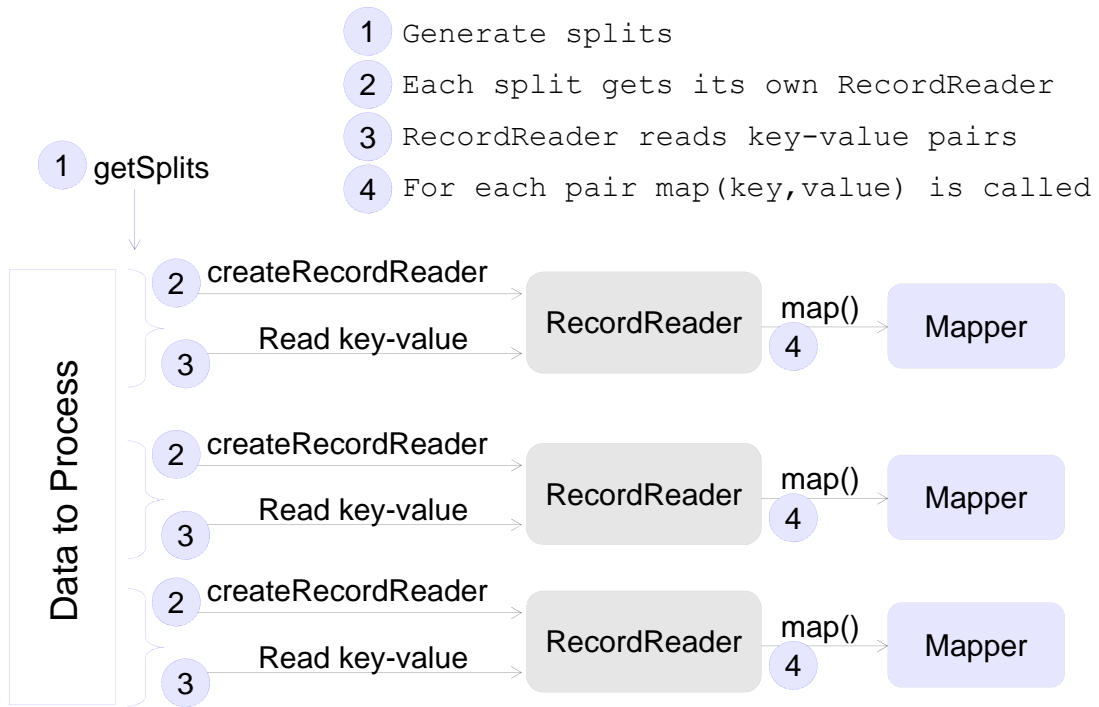
# Framework's Usage of InputFormat Implementation

- 1. Calculate splits by calling `InputFormat.getSplits`**
- 2. For each split schedule a map task**
  - Distributed between the cluster
  - Each Map executes in its own JVM
- 3. For each Mapper instance a reader is retrieved by `InputFormat.createRecordReader`**
  - Takes `InputSplit` instance as a parameter
- 4. RecordReader generates key-value pairs**
- 5. `map()` method is called for each key-value pair**

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# Framework's Usage of InputFormat Implementation



# Hadoop's InputFormats

- **Hadoop eco-system is packaged with many InputFormats**
  - TextInputFormat
  - NLineInputFormat
  - DBInputFormat
  - TableInputFormat (HBASE)
  - StreamInputFormat
  - SequenceFileInputFormat
  - Etc...
- **Configure on a Job object**
  - `job.setInputFormatClass(XXXInputFormat.class);`

# TextInputFormat

- **Plaint Text Input**
- **Default format**

<b>Split:</b>	Single HDFS block (can be configured)
<b>Record:</b>	Single line of text; linefeed or carriage-return used to locate end of line
<b>Key:</b>	LongWritable - Position in the file
<b>Value:</b>	Text - line of text

\*\* Please see StartsWithCountJob for sample usage

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# NLineInputFormat

- **Same as TextInputFormat but splits equal to configured N lines**

<b>Split:</b>	N lines; configured via <i>mapred.line.input.format</i> or <i>NLineInputFormat.setNumLinesPerSplit(job, 100)</i> ;
<b>Record:</b>	Single line of text
<b>Key:</b>	LongWritable - Position in the file
<b>Value:</b>	Text - line of text

\*\* Please see StartsWithCountJob\_NLineInput for sample usage

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# Running TextInputFormat vs. NLineInputFormat

- Two separate runs StartsWithCountJob, one with TextInputFormat configured, next with NLineInputFormat configured
- Input is /training/playArea/hamlet.txt
  - 5159 lines
  - 206.3k

```
job.setInputFormatClass(TextInputFormat.class);
```

Job ID	Name	State	Map Progress	Maps Total
job_1338595987451_0003	StartsWithCount	RUNNING	<input type="text"/>	1

Showing 1 to 1 of 1 entries

```
job.setInputFormatClass(NLineInputFormat.class);
```

```
NLineInputFormat.setNumLinesPerSplit(job, 100);
```

Job ID	Name	State	Map Progress	Maps Total
job_1338595987451_0002	StartsWithCount	RUNNING	<input type="text"/>	52

Showing 1 to 1 of 1 entries

# of splits

22

# TableInputFormat

- Converts data in HTable to format consumable to MapReduce
- Mapper must accept proper key/values

**Split:** Rows in one HBase Region (provided Scan may narrow down the result)

**Record:** Row, returned columns are controlled by a provided scan

**Key:** ImmutableBytesWritable

**Value:** Result (HBase class)

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## StartCountJob – Input from HBase

- **Let's re-write StartWithCountJob to read input from HBase table**
  - 'HBaseSamples' table, 'count:word' family-column qualifier

```
$ hbase shell
hbase(main):005:0> scan 'HBaseSamples', {COLUMNS=>'count:word'}
ROW      COLUMN+CELL
count001  column=count:word, timestamp=1338605322765, value=Elephant
count002  column=count:word, timestamp=1338605412699, value=count
count003  column=count:word, timestamp=1338605412729, value=Updating
count004  column=count:word, timestamp=1338605412757, value=all
count005  column=count:word, timestamp=1338605412780, value=regions
count006  column=count:word, timestamp=1338605412809, value=with
count007  column=count:word, timestamp=1338605412835, value=the
count008  column=count:word, timestamp=1338605412856, value=new
count009  column=count:word, timestamp=1338605412888, value=updated
count010  column=count:word, timestamp=1338605412910, value=Done
count011  column=count:word, timestamp=1338605412933, value=seconds
count012  column=count:word, timestamp=1338605414526, value=row
12 row(s) in 0.1810 seconds
```

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## StartCountJob – Input from HBase

- 1. Re-configure Job to use HBase as input**
  - Read from table 'HBaseSamples' and column 'count:word'
  - Construct new Job 'StartWithCountJob\_HBaseInput'
  - Configure Job to use new Mapper
  - New mapper now has to accept HBase Writables
    - ImmutableBytesWritable for key
    - Result for value
  - Keep reducer and combiner the same
- 2. Implement a new Mapper**
  - Grab the value from Result and write-out Text and IntWritable
  - Output is the same as in the original StartWithCountJob

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# 1: Re-configure Job to use HBase as Input

```
public class StartWithCountJob_HBaseInput
    extends Configured implements Tool {

    protected final static String TABLE_NAME = "HBaseSamples";
    protected final static byte[] FAMILY = toBytes("count");
    protected final static byte[] COLUMN = toBytes("word");

    @Override
    public int run(String[] args) throws Exception {
        Job job = Job.getInstance(getConf(),
            "StartsWithCount-FromHBase");
        job.setJarByClass(getClass());
        ...
        ...
        ...
    }
}
```

Define table name, family  
and column to read from

26

# 1: Re-configure Job to use HBase as Input

```
...
...
job.setInputFormatClass(TableInputFormat.class);
job.setMapperClass(StartsWithCountMapper_HBase.class);

Add HBase configuration and tell
framework to add HBase jars to CLASSPATH

Configuration conf = job.getConfiguration();
HBaseConfiguration.merge(conf,
    HbaseConfiguration.create(conf));
TableMapReduceUtil.addDependencyJars(job);

Specify table and
column to read from

conf.set(TableInputFormat.INPUT_TABLE, TABLE_NAME);
conf.set(TableInputFormat.SCAN_COLUMNS, "count:word");
...
...
```

Set HBase ImportFormat

New Mapper to handle  
data from HBase

27

# 1: Re-configure Job to use HBase as Input

...  
...

Keep output the same – same reducer, combiner and output keys

```
// configure mapper and reducer
job.setCombinerClass(StartsWithCountReducer.class);
job.setReducerClass(StartsWithCountReducer.class);

// configure output
TextOutputFormat.setOutputPath(job, new Path(args[0]));
job.setOutputFormatClass(TextOutputFormat.class);
job.setOutputKeyClass(Text.class);
job.setOutputValueClass(IntWritable.class);

return job.waitForCompletion(true) ? 0 : 1;
}

public static void main(String[] args) throws Exception {
    int exitCode = ToolRunner.run(new
        StartsWithCountJob_HBaseInput(), args);
    System.exit(exitCode);
}
}
```

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# 2: Implement a New Mapper

```
public class StartsWithCountMapper_HBase
    extends TableMapper<Text, IntWritable> {
```

Extends TableMapper which assumes types for input key and value

```
private final static IntWritable countOne = new IntWritable(1);
private final Text reusableText = new Text();
```

```
@Override
```

```
protected void map(ImmutableBytesWritable key,
    Result value, Context context)
    throws IOException, InterruptedException {
```

```
    byte[] bytes = value.getValue(toBytes(FAMILY),
        toBytes(COLUMN));
    String str = Bytes.toString(bytes);
```

Retrieve value from input column

```
    reusableText.set(str.substring(0, 1));
    context.write(reusableText, countOne);
```

```
}
```

```
}
```

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# Run StartWithCountJob\_HBaseInput

```
$ yarn jar $PLAY_AREA/HadoopSamples.jar  
mr.wordcount.StartWithCountJob_HBaseInput /training/playArea/wordCount
```

```
$ hdfs dfs -cat /training/playArea/wordCount/part-r-00000
```

```
D      1  
E      1  
U      1  
a      1  
c      1  
n      1  
r      2  
s      1  
t      1  
u      1  
w      1
```

Reducer's output



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## Combiner

- **Runs on output of map function**
- **Produces output for reduce function**

```
map: (K1,V1) → list (K2,V2)
```

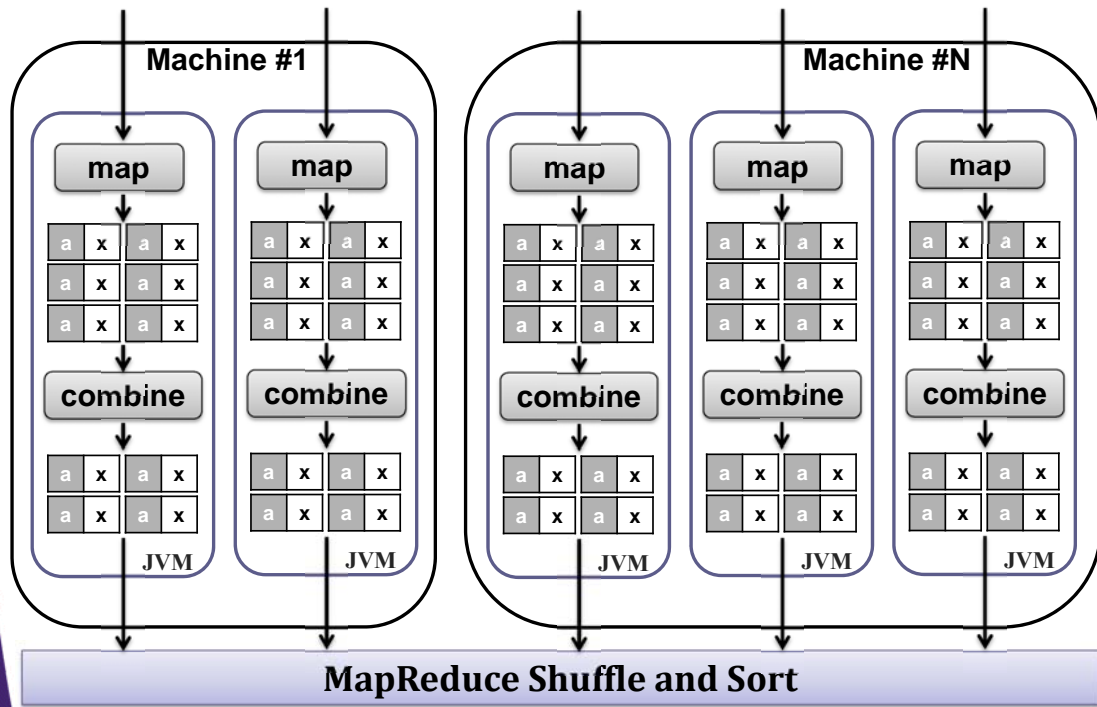
```
combine: (K2,list(V2)) → list (K2,V2)
```

```
reduce: (K2,list(V2)) → list (K3,V3)
```

- **Optimization to reduce bandwidth**
  - NO guarantees on being called
  - Maybe only applied to a sub-set of map outputs
- **Often is the same class as Reducer**
- **Each combine processes output from a single split**

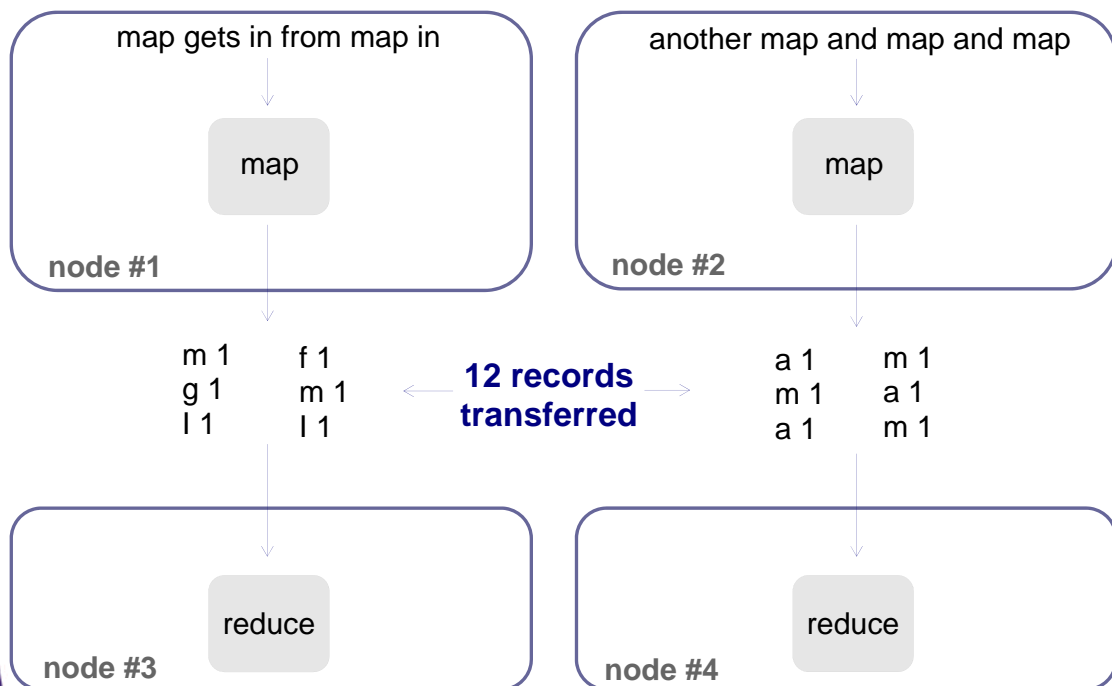
31

# Combiner Data Flow



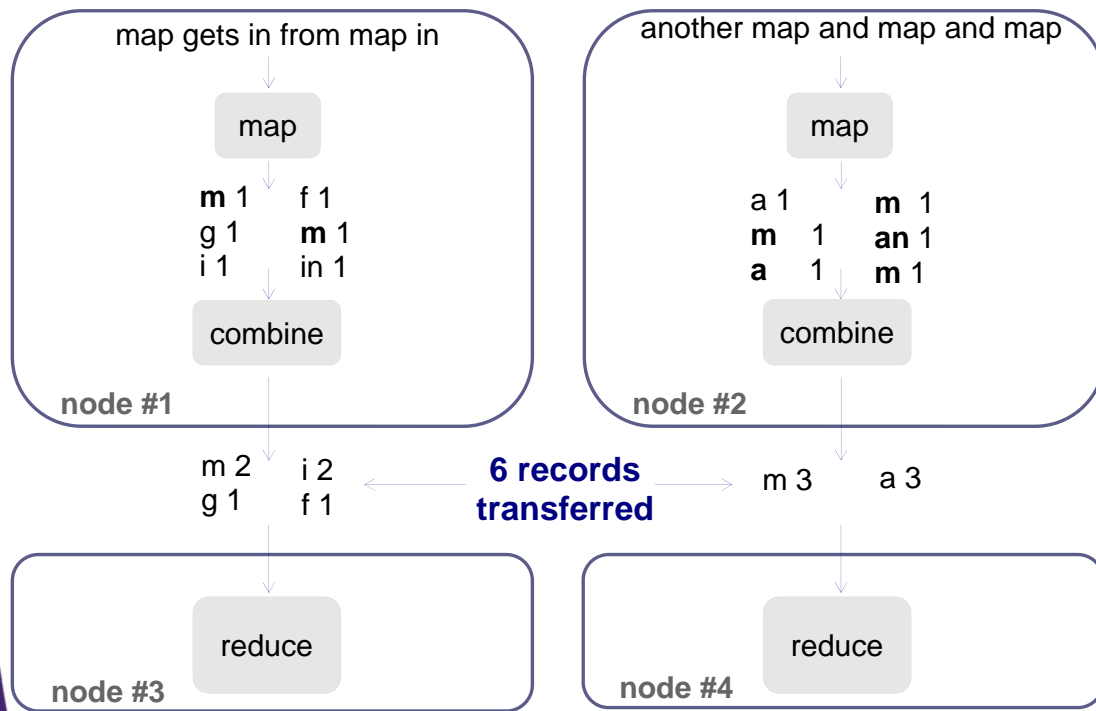
32

# Sample StartsWithCountJob Run without Combiner



33

# Sample StartsWithCountJob Run with Combiner



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## Specify Combiner Function

- To implement Combiner extend Reducer class
- Set combiner on Job class
  - `job.setCombinerClass(StartsWithCountReducer.class);`

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# Reducer

- **Extend Reducer class**
  - `Reducer<KeyIn, ValueIn, KeyOut, ValueOut>`
  - `KeyIn` and `ValueIn` types must match output types of mapper
- **Receives input from mappers' output**
  - Sorted on key
  - Grouped on key of key-values produced by mappers
  - Input is directed by `Partitioner` implementation
- **Simple life-cycle – similar to Mapper**
  - The framework first calls `setup(Context)`
  - for each key → `list(value)` calls
    - `reduce(Key, Values, Context)`
  - Finally `cleanup(Context)` is called

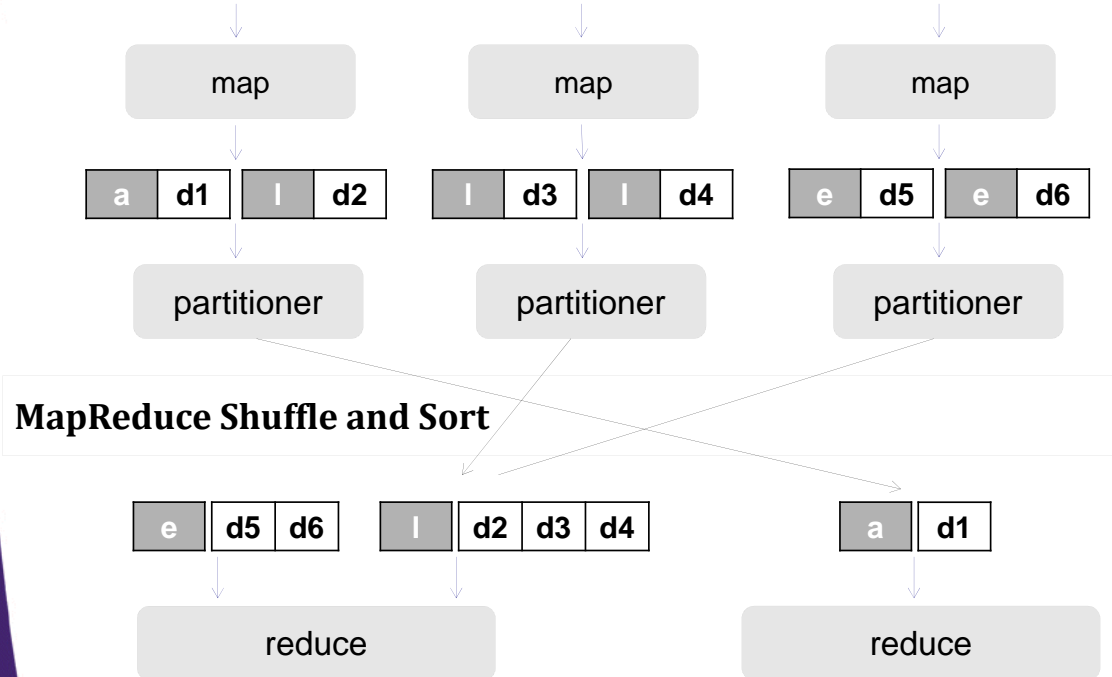
36

# Reducer

- **Can configure more than 1 reducer**
  - `job.setNumReduceTasks(10);`
  - `mapreduce.job.reduces` property
    - `job.getConfiguration().setInt("mapreduce.job.reduces", 10)`
- **Partitioner implementation directs key-value pairs to the proper reducer task**
  - A partition is processed by a reduce task
    - # of partitions = # or reduce tasks
  - Default strategy is to hash key to determine partition implemented by `HashPartitioner<K, V>`

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# Partitioner Data Flow



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Source: Jimmy Lin, Chris Dyer. [Data-Intensive Text Processing with MapReduce](#). Morgan & Claypool. 2010

# HashPartitioner

```
public class HashPartitioner<K, V> extends Partitioner<K, V> {  
    public int getPartition(K key, V value, int numReduceTasks) {  
        return (key.hashCode() & Integer.MAX_VALUE) % numReduceTasks;  
    }  
}
```

- **Calculate Index of Partition:**
  - Convert key's hash into non-negative number
    - Logical AND with maximum integer value
  - Modulo by number of reduce tasks
- **In case of more than 1 reducer**
  - Records distributed evenly across available reduce tasks
    - Assuming a good hashCode() function
  - Records with same key will make it into the same reduce task
  - Code is independent from the # of partitions/reducers specified

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# Custom Partitioner

```
public class CustomPartitioner
    extends Partitioner<Text, BlogWritable>{
    @Override
    public int getPartition(Text key, BlogWritable blog,
        int numReduceTasks) {
        int positiveHash =
            blog.getAuthor().hashCode() & Integer.MAX_VALUE;

        return positiveHash % numReduceTasks;
    }
}
```

Use author's hash only, AND with  
max integer to get a positive value

Assign a reduce task by index

- **All blogs with the same author will end up in the same reduce task**

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# OutputFormat

- **Specification for writing data**
  - The other side of InputFormat
- **Implementation of OutputFormat<K,V>**
- **TextOutputFormat is the default implementation**
  - Output records as lines of text
  - Key and values are tab separated “Key /t value”
    - Can be configured via  
“mapreduce.output.textoutputformat.separator” property
  - Key and Value may of any type - call .toString()

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# OutputFormat

- **Validates output specification for that job**
  - You may have seen annoying messages that output directory already exists
- **Creates implementation of RecordWriter**
  - Responsible for actually writing data
- **Creates implementation of OutputCommitter**
  - Set-up and clean-up Job's and Tasks' artifacts (ex. Directories)
  - Commit or discard tasks output

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# OutputFormat Interface

```
public abstract class OutputFormat<K, V> {  
  
    public abstract RecordWriter<K, V>  
        getRecordWriter(TaskAttemptContext context  
            ) throws IOException, InterruptedException;
```

Provide implementation of  
RecordReader

```
    public abstract void checkOutputSpecs(JobContext context  
        ) throws IOException, InterruptedException;
```

Provide  
implementation of  
OutputCommitter

Validates output specification for  
that job

```
    public abstract  
        OutputCommitter getOutputCommitter(TaskAttemptContext context  
            ) throws IOException, InterruptedException;
```

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# Hadoop's OutputFormats

- **Hadoop eco-system is packaged with many OutputFormats**
  - TextOutputFormat
  - DBOutputFormat
  - TableOutputFormat (HBASE)
  - MapFileOutputFormat
  - SequenceFileOutputFormat
  - NullOutputFormat
  - Etc...
- **Configure on Job object**
  - `job.setOutputFormatClass(XXXOutputFormat.class);`
  - `job.setOutputKeyClass(XXXKey.class);`
  - `job.setOutputValueClass(XXXValue.class);`

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# TextOutputFormat

- **Outputs plain text**
- **Saves key-value pairs separated by tab**
  - Configured via `mapreduce.output.textoutputformat.separator` property
- **Set output path**
  - `TextOutputFormat.setOutputPath(job, new Path(myPath));`

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# TableOutputFormat

- Saves data into HTable
- Reducer output key is ignored
- Reducer output value must be HBase's Put or Delete objects

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# TableOutputFormat

```
public class StartWithCountJob_HBase
    extends Configured implements Tool {

    protected final static String TABLE_NAME = "HBaseSamples";
    protected final static String FAMILY = "count";
    protected final static String INPUT_COLUMN = "word";

    protected final static String RESULT_COLUMN = "result";

    @Override
    public int run(String[] args) throws Exception {
        Job job =
            Job.getInstance(getConf(), "StartsWithCount-HBase");
        job.setJarByClass(getClass());
    }
}
```

Input and output column resides  
Under the same family (doesn't have to)

Name the job

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# TableOutputFormat

```
Scan scan = new Scan();
scan.addColumn(toBytes(FAMILY), toBytes(INPUT_COLUMN));
TableMapReduceUtil.initTableMapperJob(
    TABLE_NAME,
    scan,
    StartsWithCountMapper_HBase.class,
    Text.class,
    IntWritable.class,
    job);

TableMapReduceUtil.initTableReducerJob(
    TABLE_NAME,
    StartsWithCountReducer_HBase.class,
    job);
job.setNumReduceTasks(1);
return job.waitForCompletion(true) ? 0 : 1;
}
public static void main(String[] a) throws Exception {
    int code = ToolRunner.run(new StartWithCountJob_HBase(), a);
    System.exit(code);
}
}
```

Utilize HBase's TableMapReduceUtil to setup the job; internally delegate to job.XXX methods

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# TableOutputFormat

```
public class StartsWithCountReducer_HBase extends
    TableReducer<Text, IntWritable, ImmutableBytesWritable> {

    @Override
    protected void reduce(Text key, Iterable<IntWritable> counts,
        Context context)
        throws IOException, InterruptedException {
        int sum = 0;

        for (IntWritable count : counts) {
            sum += count.get();
        }

        Put put = new Put(key.copyBytes());
        put.add(toBytes(FAMILY), toBytes(RESULT_COLUMN),
            toBytes(Integer.toString(sum)));
        context.write(null, put);
    }
}
```

Reducer must output either Put or Delete object

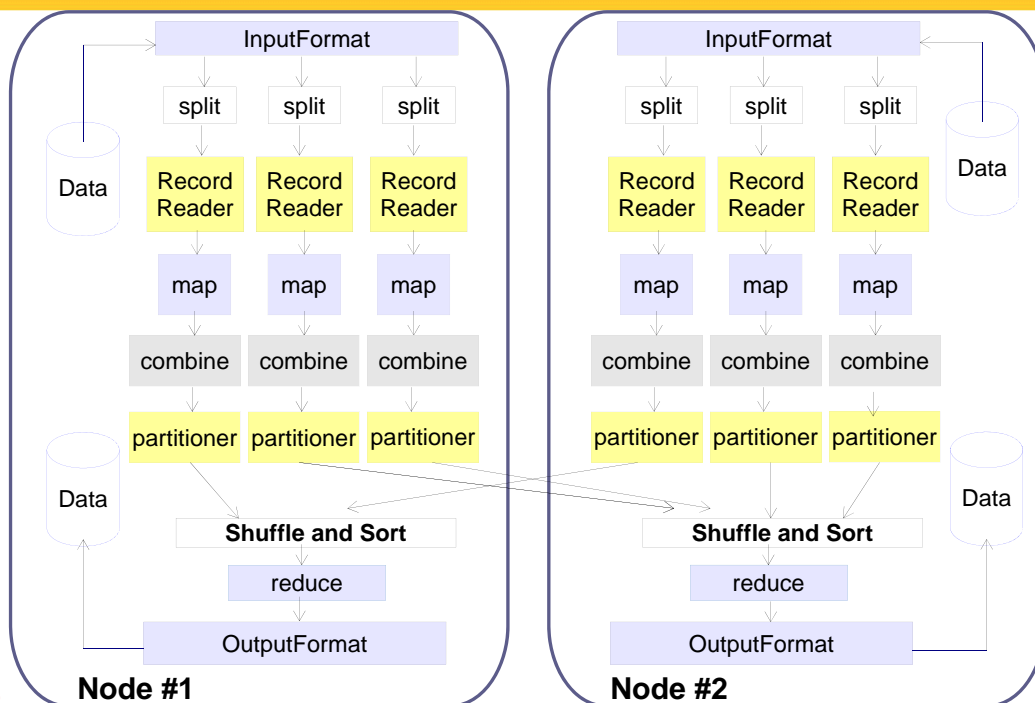
49

# TableOutputFormat

```
$ yarn jar $PLAY_AREA/HadoopSamples.jar mr.wordcount.StartWithCountJob_HBase
$ hbase shell
hbase(main):029:0> scan 'HBaseSamples', {COLUMN=>'count:result'}
ROW          COLUMN+CELL
D            column=count:result, timestamp=1338951024384, value=1
E            column=count:result, timestamp=1338951024384, value=1
U            column=count:result, timestamp=1338951024384, value=1
a            column=count:result, timestamp=1338951024384, value=1
c            column=count:result, timestamp=1338951024386, value=1
n            column=count:result, timestamp=1338951024386, value=1
r            column=count:result, timestamp=1338951024386, value=2
s            column=count:result, timestamp=1338951024386, value=1
t            column=count:result, timestamp=1338951024386, value=1
u            column=count:result, timestamp=1338951024386, value=1
w            column=count:result, timestamp=1338951024386, value=1
12 row(s) in 0.0530 seconds
```

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# Component Overview



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Source: Yahoo! Inc. "Hadoop Tutorial from Yahoo!". 2012



# Wrap-Up

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## Summary

- **In this lecture we learned about**
  - MapReduce Theory
  - Types of Keys and Values
  - Input and Output Formats
  - Anatomy of
    - Mappers
    - Reducers
    - Combiners
    - Partitioners





# Questions?

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