# CS286 Solving Big Data Problems – Exam #1 Study Guide

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## Lecture #01 – Introduction to Big Data

### Data Categories

**Quantitative**
- Observable and **measureable**
- Structured and **objective**
- Numerical

**Example:** Income, Height

**Qualitative**
- Observable but **NOT measureable**
- Unstructured and subjective
- **Descriptive**

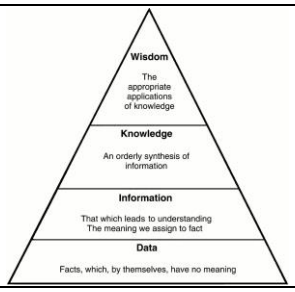
**Example:** Favorite Color

**Data** – Raw values

**Information** – Set of data with meaning

**Knowledge** –Interpretation of the data with meaning.

**Wisdom** – Appropriate application of knowledge.




### Storage Terminology

**Directly Attached Storage (DAS)**
- Storage attached directly to the processing node.
- Lowest capacity
- Minimal data sharing
- **Highest Speed.**

**Network Attached Storage (NAS)**
- Storage accessible via a network connection.
- **Capable of using NFS**

**Relational Database Management System (RDBMS)**
- Traditional database providers.
- **Examples:** Oracle, MySQL, IBM DB2

**Storage Area Network (SAN)**
- Storage accessible via a network connection.
- Uses different protocols than NAS.

**Network File System (NFS)**
Allows a computer to view and store data on remote disk as if that disk was directly attached to the local computer.

**Access Transparency** – Access data the same way whether it is remote or local.

### Data Analysis Categories

**Descriptive**
- **Backward** looking.
- Hindsight
- Explain a previous phenomenon.
- Analysis

**Predictive**
- **Forward** looking
- Foresight
- Investigate future trends.
- Mining

**Four Steps in Traditional Data Mining**

1. Problem Definition
2. Data gathering and preparation
3. Model building and evaluation
4. Knowledge Deployment

Process is **cyclical** and **may repeat multiple times**.

### Big Data

**Big Data** – Data whose scale, diversity, and complexity require new architecture, techniques, algorithms, and analytics to manage it and to extract value and hidden knowledge from it.

#### 3 V's of Big Data

**Volume** – The amount of data is too large for traditional database software tools to cope with.

**Example:** Image server

**Velocity** – The data is being produced at a rate that is beyond the performance limits of traditional systems.

**Example:** Social media site

**Variety** – Data lacks the structure to make it suitable for storage and analysis in traditional databases and data warehouses.

**Example:** Data organization variety.

#### Data Organization

**Structured** – **Every piece of data and its format is known**. Fits in a database.

**Example:** RDBMS

**Semi-structured** – **For some fields, data may not exist and some fields can have different formats**. Not in a typical database but has structure.

**Example:** XML, CSV, JSON

**Unstructured** – Does not fit into a database well. Most data is in this category.

**Examples:** Text document, multimedia content.

#### Scaling to Process Big Data

**Scale Up**

**Limitations:**
- Large capital and operating expense.
- Lower availability and scalability.

**Example:** Monolithic Database

**Scale Out**

**Limitations:**
- Synchronization overhead
- Programming Complexity
- Specialized hardware.

**Example:** Grid Cluster

**Sampling**

**Limitation:**
- Lower accuracy and precision.

**Example:** Any approach

**Exploiting Locality of Reference** – In Big Data, accessing the data can be very time consuming. **Solution:** Keep the data and program close together.

**Distribute Data and Computation** – Map the data to multiple nodes and the program with it to decrease execution time.

#### Three Laws of Big Data

**Moore's Law** – Every two years, the number of transistors per chip doubles.

**Kryder's Law** – Every two years, storage capacity doubles. (**Storage version of Moore's Law**)

**Amdahl's Law** – The extent to which a program's execution can be sped up is dependent on its level of parallelism.

**Murphy's Law** – What can go wrong will go wrong.

**Big data must be resistant to failures.**

# Hadoop

| Summary of the Hadoop Strategy | | |
|---|---|---|
| **Distribute Data**<br>Processing nodes share no data. | **Distribute Computation**<br>Achieve **parallelism without synchronization.** | **Tolerate Failures**<br>Eliminate **single points of failure**. |

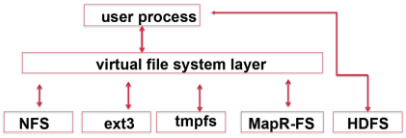
| Core of Hadoop | Name Node | Job Tracker |
|---|---|---|
| 1. **Hadoop File System (HDFS)** – Storage level<br>2. **MapReduce** – Compute Level | Key component in HDFS that **stores the location of distributed data in the file system**. | Manages **computation tasks in the Hadoop system**. |

# Lecture #02 – Introduction to HDFS and MapR-FS

| File System | Storage in a File System | Block Structure in an ext2 File System | | | | |
|---|---|---|---|---|---|---|
| Like a database. **A system to store data so that the data can be accessed later.**<br><br>**Typical Structure:** A rooted tree. | **Data** – Actual file in the FS.<br><br>**Metadata** – Information about the data/file.<br>**Example:** Size, location | **Hadoop Block Size:** 64MB | **Inode** – Data structure used to represent a file system object. This includes the location of the disk block location. | **Direct Block** – File block location **pointed to directly by the inode**. | **Indirect Block** – Block **pointed to by the inode through exactly one intermediary block**. | **Double Indirect Block** – Block **pointed to by the inode through exactly two intermediary blocks**. |

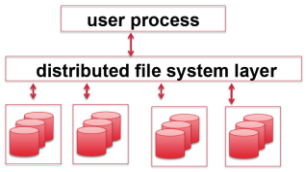
## Virtual File System

- **Transition layer** between a generic file system and a real file system.
- Virtualizes different file system types into a single common interface.
- **Enables standard POSIX** file access.
- **HDFS is not compatible with a virtual file system while MapR-FS is.**

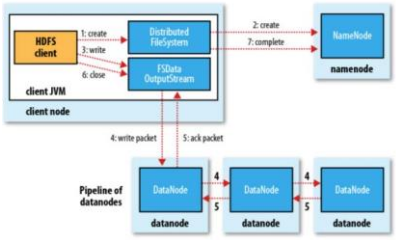



## Distributed File System

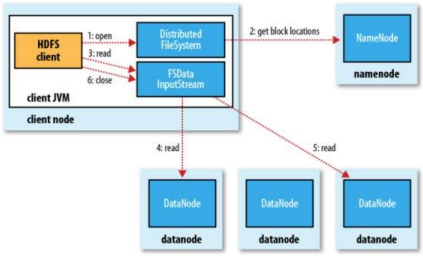
- **Centrally stores metadata** (e.g. **name node**) **and distributes actual data** (e.g. **data node**)
- Overcomes **space, performance, and availability limitations of a single machine.**
- **Location Transparency** – Abstracts data locality from client access.




## Hadoop Data Write




## Hadoop Data Read



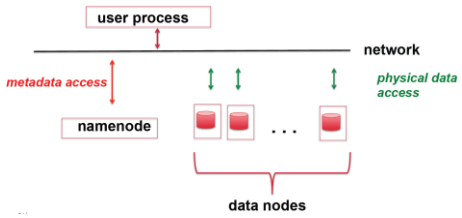

**Hadoop Write Pipeline** – Before a write can be acknowledged to the client, it must be acknowledged by the name node.

- Each replicate write is sequential **through a pipeline where one data node writes to the next**.

**Sequential Block Reading** – **Each file block is read sequentially** even if the blocks reside on multiple data nodes and could theoretically be read in parallel.

- **Block size:** 64MB

## Hadoop Distributed File System (HDFS) Architecture




| User Process | Name Node – Master | Data Node – Slave |
|---|---|---|
| • Connected to HDFS through the network.<br>• **Communicates with the name node to know where to read and write data**. | • **Manages file names and locations on disk. Provides metadata information**<br>• **All data is persisted in memory (RAM)**<br>• May have a **secondary name node used to offload processing (e.g. writing logs) off the primary. Secondary is not for high availability.**<br>• All writes must be acknowledged by the name node before they can be acknowledged to the user process. | • Persistent storage disks for the data.<br>• Data is replicated across multiple data nodes if possible across multiple racks. |

## Limitations of HDFS

| Mutability | Block Size | POSIX Semantics | Availability | Scalability | Performance |
|---|---|---|---|---|---|
| Data is write once, read many. | Single block size (e.g. **64MB**) for disk I/O, replication and sharding | Must use the command "`hadoop fs`" to access the data. **Example POSIX Commands:** Open, close, read, write. | No snapshot or built-in mirroring capability. | Name node only scales to 100M files. This is **due to the single name node persisting all data in RAM**. | Written in **Java** and runs on a block device |

## Overview of MapR File System (MapR-FS)

| | | | | |
|---|---|---|---|---|
| **Physical Disk** – A single hard drive.<br><br>**Storage Pool** – Three striped physical disks. Striping is used to increase write performance. | **Node** – A set of storage pools.<br><br>**Topology** – A set of nodes. | **Container** – **Unit of shared storage**. It is the size of replicated data. A **storage pool has multiple containers**. Each container belongs to only one volume. | **Volume** – A tree of files and directories grouped for the purpose of applying a policy or set of policies. | |

## MapR-FS Volume Features

| Topologies | Compression | Mirroring | Snapshots | Quotas | Permissions | Replication |
|---|---|---|---|---|---|---|
| Provide data placement policies. | Compress data as it is written to disk. | Copy data locally or remotely for protection **in real time for load balancing, backup, and disaster readiness.** | Maintain point-in-time data and updates. | Restrict total capacity per-user or per-group. | Restrict access to users or groups. | Replicate containers in a volume across the cluster |

## Differences between MapR-FS and HDFS

| Block Size | Mutability | Access | POSIX Support | Availability | Scalability | Performance |
|---|---|---|---|---|---|---|
| MapR-FS supports different block sizes for sharding, replication, and performing I/O. | MapR-FS has full read write capability. | MapR-FS volumes can be NFS-mounted. | MapR-FS supports native OS commands to access data. | MapR-FS supports snapshots and local/remote mirroring support. | No limit to the number of files. | **MapR-FS is written in C** and **runs on a raw device (i.e. no filesystem overhead).** |

### Block Size Comparison between HDFS and MapR-FS

| Storage Unit | HDFS | MapR-FS |
|---|---|---|
| Unit of Sharding | Block=64MB | Chunk=256MB |
| Unit of Replication | Block=64MB | Container = 16-32GB |
| Unit of I/O | Block=64MB | Block=8KB |

MapR-FS allows for different storage unit sizes to optimize performance.

**Role of a Single Sharding Unit** (e.g. **Block/Chunk**) – In Map Reduce, **each mapper is assigned a single shard** (e.g. block/chunk) to analyze.

**Relationship between Container and Volume** – In MapR-FS, a container is assigned to a single volume and a volume is made up of one or more containers.

**Example Block/Chunk Count Calculation**: If a Map Reduce file has 300MB of data, it will required 5 blocks in HDFS and 2 chunks in MapR-FS.

### Using the "`hadoop fs`" Command Line Interface (CLI)

**Format:**

```
hadoop fs -<command> [args]
```

**Examples:**

```
hadoop fs -mkdir newDirectory

hadoop fs -rm my_file.txt
```

**Not Supported Command:**

```
hadoop fs -cd …
```

**This command has no directory state so must use absolute path.**

**`hadoop mfs [command] [args]`**

Performs MapR-FS operations similar to `hadoop fs`.

# Lecture #03 – Introduction to MapReduce

**Map Reduce Underlying Principle: Divide and Conquer**

**Derives from Lisp**

```
map(String key, String value):
    // key: document or shard name
    // value: document or shard contents
    for each word w in value:
        EmitIntermediate((w,"1"));  // key value pair
```

```
reduce(String key, Iterator values):
    // key: a word
    // values: a list of word counts
    int results = 0
    for each v in values:
        results += ParseInt(v)
    Emit(AsString(result))
```

**Reduce is called one on each key NOT each partition.**

### Key Methods

**EmitIntermediate** – Output of the mapper function. Writes an intermediary key-value pair to be analyzed by a reducer.

**Emit** – Outputs the result of the reducer.

### Three Phases of Map Reduce

1. **Map**
2. **Sort/Shuffle/Merge**
3. **Reduce**

### Map

- One mapper is assigned per input split. The **"map" function is called once for each key-value pair** (i.e. **record**).
- Each mapper processes a local data set and can **output a set of intermediary key-value pairs**.
- "**Send the compute to where the data is**."
- **Outputs zero or more key-value pairs.**

### Sort/Shuffle/Merge

- Transfer results from mappers to reducers.
- Creates ***n*** partitions where ***n*** is equal to the number of reducers.
- Divides intermediary key value pairs into the ***n*** partitions.
- May run a "**Combiner**" function to merge results from the Map stage to reduce the amount of data to transfer over the network.
- After keys are partitioned and merge, the keys in the partition are sorted.
- Partitions are sent over the network to the reducers. Hadoop uses HTTP while MapR-FS uses RPC.

### Reduce

- One reducer per input partition. The "**reduce" method is called once per key**.
- **Outputs zero or more key value pairs.**
- Reads one list of values for each key.
- **No data locality exploitation in reduce**.

### Responsibilities of the Map Reduce Framework

- **Split the incoming input file and read the records.**
- **Schedules, runs, and reruns map/reduce tasks.**
- **Transfers map outputs to reduce inputs.**
- **Collects and writes status and results.**

### Map Reduce Block and Record Splitting

- The Map Reduce framework divides an input file to one or more **splits\block**.
- A split\block contains one or more (typically many) **records**. **Default record delimiter is "\n".**
- **The map function is called once per record**.

### Map Record Key-Value Format

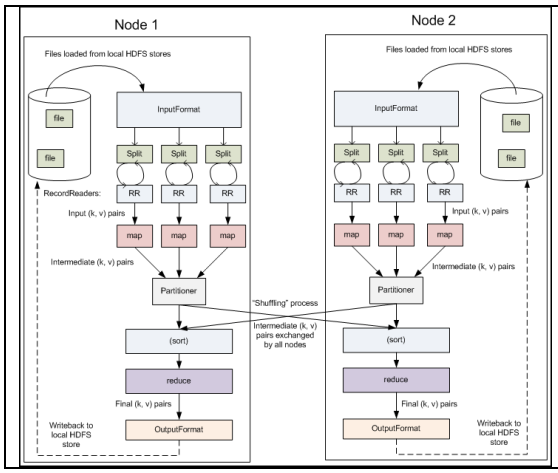
- **key** – **Byte offset** for start of record
- **value** – Record data in the split.

### Typical Map Reduce Workflow

1. **Load the data into the cluster.**
   - **HDFS** – Uses WORM (write once read many). Preload only.
   - **MapR-FS** – POSIX + network file system (NFS) access. Preload or persistent storage.
2. **Analyze the data**
3. **Store the results in the cluster** (e.g. in HDFS/MapR-FS)

**Read the results from the cluster.**

# MapReduce Complete Flow




**Map Reduce Complete Flow**

1. Data is loaded into HDFS
2. The job decides the input format of the data.
3. Data is split between different mappers running on all the nodes.
4. **Record readers** (RR) parse out the data key-value pairs serve as inputs into the map() methods.

**Map Reduce Complete Flow**

5. The map() method produces key-value pairs that are sent to the **Partitioner**.
6. When there are multiple reducers, the partition mapper creates one partition for each reduce task.
7. The key-value pairs are **sorted** by key within each partition.

**Map Reduce Complete Flow**

8. The reduce() method is take the intermediary key value pairs in the partition and reduces them to a **final list of key value pairs**.
9. The job defines the output format of the data.

**Example Partition Function**

$$Part\# = hash(key)\ \%\ \#Partitions$$

# Hadoop Classes

### `InputFormat`

- Checks if the input file exists.
- Splits the input file into one or more `InputSplit` objects.
- Instantiates `RecordReader` to partition splits into records which are turned into key-value pairs.
  - **Key is byte offset** of the start of the record.

### `Mapper`

- Implements the map() method.
- One `Mapper` object is created for each input split.
- Processes keys and/or values.
- Updates status in reporter.
- Writes output.

### `Partitioner`

- Takes the output(s) generated by the map() method and **creates partitions based on the hashed key**.
- Each partition is assigned to a single reducer.
- **All records with the same key are assigned to the same partition**.

### `Combiner` (Optional)

- Has **no default behavior**.
- **Motivation**: Reduce the intermediate values of the mappers before they are sent over the network.
- **Often the reducer can be repurposed as a combiner**.

### `Reducer`

- Implements the reduce() method.
- Each `Reducer` object is assigned one partition.
- Executes the reduce method on each key in the partition.
- Updates status in reporter.
- Writes output.

### Outputs of a MapReduce Job

- **_SUCCESS** – Empty file indicating the job was completed successfully.
- **part-m-00000** – First intermediate results output file from a map task.
- **part-r-00000** – First intermediate results output file from a single reducer.

## Hadoop Job Execution Framework

### JobClient

- Instantiated by the client. Submits job to the JobTracker. Runs inside a JVM.

### JobTracker

- Instantiates a Job object which gets sent to the TaskTracker(s). Runs inside a JVM.
- Reschedules tasks on failed TaskTrackers to other TaskTrackers.

### TaskTracker

- Launches a child process that runs a **MapTask** or a **ReduceTask**.
- **HeartBeat Messages** to JobTracker include:
  - **Task Status**
  - **Task Counter**
  - **Data read/write status**

### Hadoop Schedulers

- **Fair Scheduler** (**default**) – Resources shared evenly among pools.
  - Each user has a pool. Custom pools can be created. Supports Pre-emption.
- **Capacity Scheduler** – Resources shared among queues. Admin creates hierarchical queues. **Supports soft and hard capacity limits to users within a queue**.

### Hadoop Fair Scheduler

- **Pool** – Set of jobs.
- **User configures priority of jobs within a pool**.
- Default of one user per pool.
- "Over-using" users can be preempted.
- **Developed at Facebook.**

**Scheduling Algorithm**

- Divide each pool's min maps and reduces among jobs.
- When a slot is free, allocate a job that is below its minimum share (i.e. most starved).
- Preempt long running jobs to meet minimum guarantees.

### Hadoop Capacity Scheduler

- **Queue** – Set of Jobs
- Queues may be **hierarchically organized** (i.e. **a queue is made of other queues**).
- **Shares assigned to queues as a percentage of total resources**.
- Per-Queue and Per-User configurations.
- **Developed at Yahoo**.

**Scheduling Algorithm**

- Allocate slots to queues based on percentage of shares.
- **FIFO scheduling within each queue**.

**MCS** – MapR Control System

**CLDB** – Container Location Database.

# Limitations of the Hadoop Execution Framework

| Scalability | Availability | Inflexibility | Scheduler Optimization | Program Support |
|---|---|---|---|---|
| Single JobTracker restricts job throughput. | Only one JobTracker and one NameNode introduces single points of failure (SPOF). | Map and reduce jobs are not interchangeable. | Framework does not optimize scheduling of jobs. | Framework is limited to Map and Reduce programs. |

**Inflexibility and program support are addressed in Map Reduce version 2** (also known as **YARN**)

# Lecture #04 – Installing MapR

| Disk Provisioning | Network Configuration | | Joining Data |
|---|---|---|---|
| • **Dynamic** – Thin provisioning<br>• **Fixed** – Thick provisioning | • **NAT** – The VM does not have a separate IP from the host. Rather a separate private network is setup on the host machine and the VM gets an address in that network. Network traffic looks as though it came from the host PC. | • **Bridged** – Replicates another node on the physical network and the VM gets its own IP.<br>• **Host-Only** – The nested VM's network is within the host computer only. | Join can be done in the map and reduce stages. |

# Lecture #05 – Writing a MapReduce Program

## Common Map Reduce Applications

| Summarizing Data | Filtering Data | Organizing Data | Joining Data<br>Join can be done in the map and reduce stages. |
|---|---|---|---|

## MapReduce Program Imports

| | | | |
|---|---|---|---|
| **org.apache.hadoop.mapreduce.***<br>Includes the definition of the "**Mapper**", "**Reducer**", "**Job**", and "**Context**" classes. | **org.apache.hadoop.io.***<br>Includes the definition of the "**Text**", "**LongWritable**", and "**IntWritable**" classes. | **org.apache.hadoop.conf.***<br>Includes the definition of the "**Configured**" and "**Configuration**" classes. | **org.apache.hadoop.util.***<br>Includes the definition of the "**Tool**" interface and "**ToolRunner**" class. |
| **org.apache.hadoop.mapreduce.lib.input.***<br>Includes the definition of the "**TextInputFormat**" and "**FileInputFormat**" classes. | **org.apache.hadoop.fs.***<br>Includes the definition of the "**Path**" class. | **java.util.***<br>Includes the definition of the "**StringTokenizer**" class. | **java.io.***<br>Includes the definition of the "**IOException**" class. |
| **org.apache.hadoop.mapreduce.lib.output.***<br>Includes the definition of the "**FileOutputFormat**" class. | | | |

## MapReduce Class Definitions

### Mapper Class Definition

```
import java.util.*;
import java.io.*;
import org.apache.hadoop.mapreduce.*;
import org.apache.hadoop.io.*;

public class MyMapper
        extends Mapper <InputKeyClassName,
                        InputValueClassName,
                        OutputKeysClassName,
                        OutputValuesClassName> {

}
```

Must override the "**map**" method.

InputFormat – **TextInputFormat**
Key Class – **LongWritable**
Value Class – **Text**

### Reducer Class Definition

```
import java.util.*;
import java.io.*;
import org.apache.hadoop.mapreduce.*;
import org.apache.hadoop.io.*;

public class MyReducer
        extends Reducer <InputKeyClassName,
                         InputValueSClassName,
                         OutputKeysClassName,
                         OutputValuesClassName> {

}
```

Must override the "**reduce**" method.

**The input key and value types for the Reducer must match the output key and value types for the associated Mapper.**

### Driver Class Definition

```
import org.apache.hadoop.conf.*;
import org.apache.hadoop.io.*;
import org.apache.hadoop.mapreduce.*;
import org.apache.hadoop.mapreduce.lib.input.*;
import org.apache.hadoop.util.*;

public class ReceiptsDriver extends Configured
                implements Tool {

...
   public static void main(String[] args) throws Exception{
      Configuration conf = new Configuration();
      System.exit(ToolRunner.run(conf, new ReceiptsDriver(), args));
   }

}
```

- Must implement the "**run**" method.
- **Specifies whether the job is run synchronously or asynchronously** via the "**waitForCompletion**" command.
- **Specifies class types for mapper and reducer.**
- Verifies function input arguments.

# MapReduce Class Method Definitions

### map Function Format

```
@Override
public void map(LongWritable key, Text value,
                Context context)
               throws IOException, InterruptedException {

    StringTokenizer strToken = new StringTokenizer(value,
                                                   splitCriteria);

    // Iterate through all the tokens in the record
    while(strToken.hasMoreTokens()){
        String myStr = strToken.nextToken();
        …
    }

    // Emit any intermediate <key, value> pairs
    // Optional to emit any pairs.
    context.write(new OutputKeysClassName(…),
                  new OutputValuesClassName (…));
}
```

First two arguments in the `map` method are the input key and record value.

`Map` is **called once per input record**.

### reduce Function Format

```
@Override
public void reduce(Text key, Iterable<Text> value, Context context)
                   throws IOException, InterruptedException {

    // Parse the Iterable object
    for(Text value: values)
    }

    // Emit any intermediate <key, value> pairs
    // Optional to emit any pairs.
    context.write(new OutputKeysClassName(…),
                  new OutputValuesClassName (…));
}
```

`Reduce` is **called once per intermediate key**.

### run Function Format

```
@Override
public int run(String[] args) throws Exception {
    if(args.length != 2){
        System.err.printf("usage: %s [general options] <inputfile> <outputfile>\n",
                          getClass().getSimpleName());
        System.exit(1);
    }

    // Configure the job
    Job job = new Job ( getConf(), "job name");

    job.setJarByClass(MyDriver.class);
    job.setMapperClass(MyMapper.class);
    job.setReducerClass(MyReducer.class);

    // Define input file's format (e.g. text file)
    job.setInputFormatClass(TextInputFormat.class);

    // Setup the mapper output classes.
    // Mapper Input class are a LongWritable by default and Text
    job.setMapOutputKeyClass(MapperOutputKeysClassName.class);
    job.setMapOutputValueClass(MapperOutputValuesClassName.class);

    // Set the reducer's output class.
    job.setOutputKeyClass(ReduceOutputKeysClassName.class);
    job.setOutputKeyClass(ReduceOutputValuesClassName.class);

    // Set the reducer's output class.
    FileInputFormat.addInputFormat (job, new Path(<inputfilepath>);
    FileOutputFormat.setOutputFormat (job, new Path(<outputfolderpath>);


    // Wait for the job to finish.
    return job.waitForCompletion(true) ? 0 : 1;
}
```

# MapReduce Environment Variables

### HADOOP_HOME

- **Path:** /opt/mapr/hadoop/Hadoop-0.20.2
- Not required.
- **Useful when defining other environment variables.**

### LD_LIBRARY_PATH

- **Path:** $HADOOP_HOME/lib/native/Linux-amd64-64
- Not required.
- **Enables the use of libraries specifically compiled for MapR.**

### PATH

- **Path:** $HADOOP_HOME/bin:$PATH
- Not required.
- **Order in PATH variable is important** as earlier items in the list take precedence.
- **Provides path to Hadoop executables so user does not need to specify the absolute path.**

### CLASSPATH

- **Path:** $HADOOP_HOME/*:$HADOOP_HOME/lib/*
- Not required.
- **Points to all jars in the Hadoop distribution required to run a program.**

### HADOOP_CLASSPATH

- **Path:** $CLASSPATH
- Not required.
- **Makes it easier to run MapReduce applications from the `hadoop` command.**

### export

Bash command to add environment variables to the terminal.

# Command Line Instructions

### javac

- **Compiles a Java class from ASCII to byte code.**
- **Example:**

  **javac –d <*FolderName*> <*ClassName*>.java**

- **-d** – Allows for a custom output directory to be used.

### hadoop jar

- Launches a Hadoop job.
- **Example:**

  **hadoop jar <*JarNameAndPath*>.jar <*DriverClass*>**
  **file://<*InputPathAndFile*> <*outputDirectory*>**

- Arguments in the call correspond to the `args` argument in the driver.
- **-D** – Used to specify properties of the Hadoop jar operation.

### hadoop fs

- Enables POSIX style commands on HDFS
- **Example:**

  **hadoop fs -<CommandName> [args]**

- **Must precede POSIX command (e.g. ls, cat, rm, etc.) with a hyphen.**

### jar

- **Combines the different class files into a single Java Archive (JAR) File.**
- **Example #1: Create a New JAR File**

  **jar –cvf <jarname>.jar –C <classfolder>/.**

- **-c** – Create a new JAR file.
- **-v** – Generate a verbose output.
- **-f** – Specifies that the command includes the output JAR's file name.
- **-C** – Specifies the location of the source .class files.

- **Example #1: Updating an Existing JAR**

  **jar –uvf <jarname>.jar –C <classfolder>/.**

- **-u** – Update a JAR.

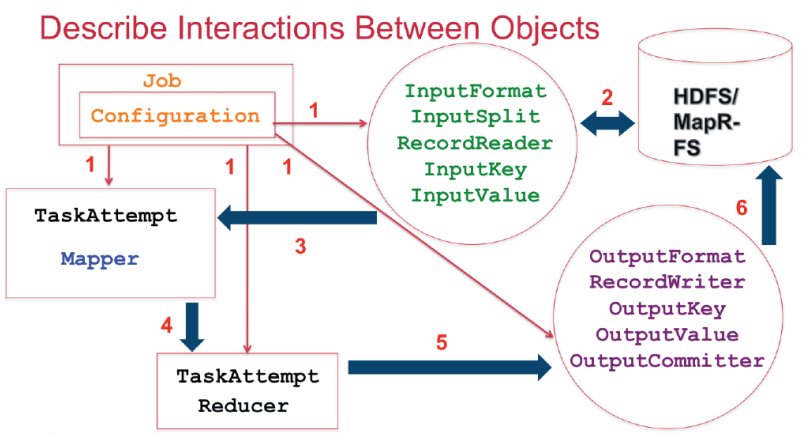
# Lecture #06 – Using the mapreduce API

| Hadoop and Mapr | Setting HADOOP_HOME PATH |
|---|---|
| • MapR 3.0.1 ships with version 0.20.2 of Hadoop. | HADOOP_HOME = /opt/mapr/hadoop/hadoop-0.20.2 |

## Comparison of the mapreduce and mapred Libraries

| | Supported on MapR | Deprecated | YARN-Compatible | Types | Objects |
|---|---|---|---|---|---|
| mapred | Yes | No | Yes | Interfaces | OutputCollector, Reporter, JobConf |
| mapreduce | Yes | No | Yes | Abstract Classes | Context |

| | Methods | Output Files | Reducer Input Values | Import Command |
|---|---|---|---|---|
| mapred | map(), reduce() | part-xxxxx | java.lang.iterator | import org.apache.hadoop.mapred.* |
| mapreduce | map(), reduce(), cleanup(), setup(), run() | part-m-xxxxx (Mapper)<br>part-r-yyyyy (Reducer) | Java.lang.Iterable | import org.apache.hadoop.mapreduce.* |



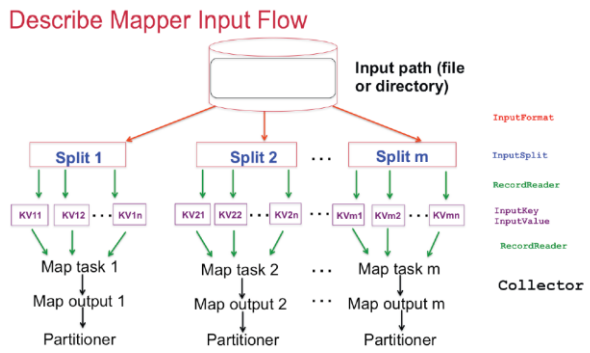

### Writable Types

- **All Key/Value types must implement the Writable Interface.**
- Used to serialize keys/values before they are written to disk.
- All Java primitives must have a wrapper class to be able to return/pass from map/reduce calls.
- Do not support commands on equivalent Java primitives. **Example:** cannot use "+" to add to LongWritables.

### Writable Interface Methods

- `void write(DataOutput out) throws IOException`
- `void readFields(DataInput in) throws IOException`

| Java Primitive | Hadoop Writable Type |
|---|---|
| boolean | BooleanWritable |
| long | LongWritable<br>new LongWritable(1) |
| double | DoubleWritable |
| string | Text (UTF-8 Format)<br>new Text("my String") |
| N/A | BytesWritable (Writable Binary) |




### WritableComparable

- **All keys must implement the Writable and Comparable Interfaces.**

### Comparable Interface

`int compareTo(WriteComparable o)`

- **compareTo** is used to provide a total ordering of keys in the Sort/Shuffle/Merge stage.
- Returns -1 if implicit parameter should be order first.
- Returns 0 if they are equal.
- Returns 1 if explicit parameter should be ordered first.

### InputFormat Class

- Valid input files/directories exists.
- Partitions the input file into splits.
- Instantiates `RecordReader` for parsing records in the splits.
- Throws `IOException`

#### Methods

```
public abstract List<InputSplit>
getSplits(JobContext)

public abstract RecordReader<K,V>
createRecordReader(InputSplit split,
TaskAttemptContext context)
```

#### Common Implementations

- `TextInputFormat` – Single Line Record Text Files. **Terminated by newline characters.**
- `SequenceFileInputFormat` – Binary Files

### InputSplit Class

- Object that encapsulates a single file split.
- Logical representation of a subset of the data.
- **Split size is defined by**:

$$\max(minSplitSize, \max(maxSplitSize, blockSize))$$

#### Methods

```
public abstract long getLength()
```

`public abstract String[] getLocations()` – Gets a list of host names where the split is located.

#### Common Implementations

- `FileSplit`

#### Split Versus Block Size

- Split Size is configurable in Hadoop and MapR.
- A split may be smaller, larger, or the same size as a block as defined by equation on the left.

#### Record Boundaries – Two Possibilities

- **Last Record Boundary Falls On Split Boundary** – Read whole first record in the next split.
- **Last Record Boundary Falls in the Next Split** – Record reader reads the next split until the end of the record (i.e. first delimiter).

### RecordReader Interface

- **Breaks up the data in an input split into Key-Value pairs**
- **Handles incomplete records**
  - **Discards first record in a split after the first split**
  - **Reads ahead to first delimiter in the next split (except the last split).**

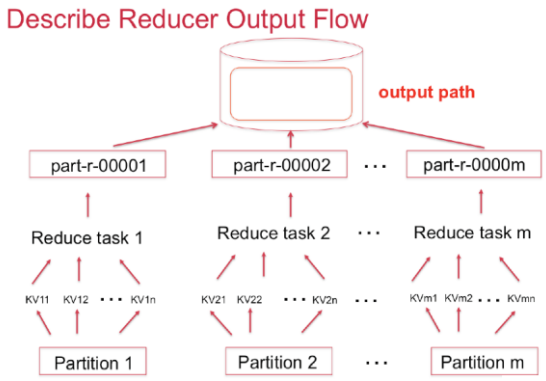
#### Methods

```
boolean next(K key, V value)
K createKey()
V createValue()
long getPos()
public void close()
float getProgress()
```

#### Common Implementations

- `LineRecordReader` – Used for text files. Key is byte offset and text is the line.
- `SequenceFileRecordReader` – Binary input files

# Reducer Output Classes




## `OutputFormat` Class

- Valid output file specifications via method **checkOutputSpecs**.
- Provide `RecordWriter` to write output files.

### Methods

```
public abstract RecordWriter<K,V>
getRecordWrite(TaskAttemptContext
context)

public abstract void
checkOutputSpecs(JobContext context)

public abstract OutputCommitter
getOuputCommitter(TaskAttemptContext
context)
```

### Common Implementations

- `FileOutputFormat` – Wrapper of OutputFormat.
- `TextOutputFormat` – Plain text file.
- `NullOutputFormat` – Send all outputs to /dev/null
- `SequenceFileOutputFormat` – Binary Files

## `RecordWriter` Class

- Writes the key value pairs to the output files.
- Can automatically compress the output streams as they are written to disk.

### Methods

```
public abstract void write(K key, V
value)

public abstract void
close(TaskAttemptContext)
```

### Common Implementations

- `TextOutputFormat.LineRecordWriter` – Writes Key-Value pairs to plain text files.

## `OutputCommitter` Class

- Initializes the Job at job start (in `setupJob`())
- Cleans up the job upon job completion (in `cleanJob`()).
- Sets up the task temporary outputs (in `setupTask`())
- Checks whether a tasks needs to be committed (in `needsTaskCommit`())
- Commit of the task output (in `commitTask`())
- Discard the task commit (in `abortTask`())

### Common Implementations

- `FileOutputCommitter` – Commits files to job output directory.

## `Mapper` Class

- Based off **Java Generics** since key and value types are generic.
- Primary method to override is **map**.
- `Context` object is used to output to intermediate files.
- `run` method calls `setup`, `map`, and `cleanup`.
- `setup` is called before `map` and `cleanup` is called after `map`.

### Methods

```
protected void cleanup(Context context)

protected void map(KEYIN key, VALUEIN
value, Context context)

void run(Context context)

protected void setup(Context context)
```

## Mapper and Reducer `run` Method

```
public void run(Context context){

   try{
      setup()
      while(context.nextKey()){
         map(context.getCurrentKey(),
               context.getCurrentValue(),
               context);
      }
   }
   finally{
      cleanup()
   }
}
```

## `Reducer` Class

- Based off **Java Generics** since key and value types are generic.
- If no `Reducer` class is specified, then `Mapper` outputs are sent directly as final outputs **after sorting by key**.
- Primary method to override is **reduce**.
- `Context` object is used to output to final files.
- `run` method calls `setup`, `reduce`, and `cleanup`.
- `setup` is called before `reduce` and `cleanup` is called after `reduce`. (**Similar to Mapper**)

### Methods

```
protected void cleanup(Context context)

protected void map(KEYIN key,
Iterable<VALUEIN> values, Context context)

void run(Context context)
```

- `protected void setup(Context context)`

## `Job` Class

- Wraps up the Map and Reduce classes and submits the job to the cluster.
- Allows a user to configure and submit a job, control its execution, and query its state.
- To get a job's configuration, you use the **getConf**() method.

### Constructors

```
Job()
Job(Configuration conf)
Job(Configuration conf, String jobName)
```

### Example Usage #1

```
Configuration conf = new Configuration();
Job job1 = new Job(conf, "Job1");
```

### Example Usage #2

```
Job job2 = new Job(getConf(), "Job2");
```

### Job Methods

`void failTask(TaskAttemptID taskID)` – Indicate task with specified ID failed.

`String getJar()` – Gets the Job's JAR file pathname.

`boolean isComplete()` – Gets whether the job has completed.

`boolean isSuccessful()` – Returns whether the job completed successfully.

`void killJob()` – Kills the job.

`void killTask(TaskAttemptID taskID)` – Kills the task with the specified ID failed.

`float mapProgress()` – Gets progress of the map tasks. Between 0 and 1.

`float reduceProgress()` – Gets progress of the reduce tasks. Between 0 and 1.

## More Job Class Methods

`void setJarByClass(Class cls)` – Specifies the driver class.

`void setInputFormatClass(Class cls)` – Sets the `InputFormat` type for the job.

`void setMapperClass(Class cls)` – Sets the class type for the `Mapper`.

`void setMapOutputKeyClass(Class cls)` – Sets the class type for the `Mapper` output key(s).

`void setMapOutputValueClass(Class cls)` – Sets the class type for the `Mapper` output value(s).

`void setOutputFormatClass(Class cls)` – Sets the `OutputFormat` type for the job.

`void setReducerClass(Class cls)` – Sets the class type for the `Reducer`.

`void setOutputKeyClass(Class cls)` – Sets the class type for the `Reducer` output key(s) and the `Mapper` if `setMapOutputKeyClass` is not called.

`void setOutputValueClass(Class cls)` – Sets the class type for the `Reducer` output value(s) and the `Mapper` if `setMapOutputValueClass` is not called.

`void submit()` – Submit the job to the cluster and return immediately.

`void waitForCompletion(boolean verbose)` – Submit the job to the cluster and wait for it to finish. **Often called within System.exit() with a ternary operator**.

- Returns "true" if the job succeeded.

**System.exit(job.waitForCompletion(True) ? 0: 1);**

- **When configuring the job, almost all method names end in "Class".**

## Implementing the Driver

```
public class MyDriver extends Configured
                      implements Tool{
  public static void main(){
    Configuration conf = new Configuration();
    System.exit(ToolRunner.run(conf,
                               new MyDriver(),
                               args);
  }

  public int run(String[] args) throws Exception{
    Job job = new Job(getConf(), "My Job");
    ...
    return job.waitForCompletion(True) ? 0 : 1;
  }
}
```

**Use ToolRunner to execute driver code.**

## Job Configuration Code Example

```
Job job = new Job(getConf(), "myJob");

job.setJarByClass(MyDriver.class);
job.setMapperClass(MyMapper.class);
job.setReducerClass(MyReducer.class);

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

job.setInputFormatClass(TextInputFormat.class);
job.setOutputFormatClass(TextOutputFormat.class);

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

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

**Drawback: Cannot be dynamically configured.**

**Levels of MapReduce Configuration Priority**

**Highest Priority**

1. **Driver Code**
2. **Command Line Parameters**
3. **Local XML Files**
4. **Global XML Files (i.e. within the Global Map Reduce folder)**
5. **Hadoop Framework Modifications**

**Lowest Priority**

# Lecture #07 – Managing, Monitoring, and Testing MapReduce Jobs

## MapReduce Counter Categories

| | | | |
|---|---|---|---|
| **File System** – Total number of bytes written and read during a Hadoop job. | **Job** – Summary of task cardinality and CPU time. | **Framework** – Granular summaries of CPU and memory consumption, records read & written, and bytes read & written in each phase of MapReduce | **Custom** – Completely specific to the application. |

## File System Counters

| | | |
|---|---|---|
| `FILE_BYTES_WRITTEN` – Total number of bytes written to the local file system. May occur during map, shuffle, or reduce phases. | `MAPRFS_BYTES_READ` – Total number of bytes read from MapR-FS. | `MAPRFS_BYTES_WRITTEN` – Total number of bytes written to MapR-FS. |

## Job Counters

| | | | |
|---|---|---|---|
| `DATA_LOCAL_MAPS` – Total number of map tasks executed on local data. | `FALLOW_SLOTS_MILLIS_MAPS` – Total time map tasks spend waiting after slots are reserved (**pre-emption**) | `FALLOW_SLOTS_MILLIS_REDUCES` – Total time reduce tasks spend waiting after slots are reserved (**pre-emption**) | `SLOTS_MILLI_MAPS` – Total time map tasks spent executing |
| `SLOTS_MILLI_REDUCES` – Total time reduce tasks spent executing | `TOTAL_LAUNCHED_MAPS` – Total number of map tasks launched, **including failed tasks**. | `TOTAL_LAUNCHED_REDUCES` – Total number of reduce tasks launched, **including failed tasks**. | |

## Framework Counters

| | | | |
|---|---|---|---|
| `COMBINE_INPUT_RECORDS` – Number of records **read** during the combine phase (**if used – otherwise 0**) | `COMBINE_OUTPUT_RECORDS` – Number of records **written** during the combine phase (**if used – otherwise 0**) | `CPU_MILLISECONDS` – Total CPU time spent on all tasks. | `GC_MILLISECONDS` – Total CPU time spent on **garbage collection**. |
| `MAP_INPUT_RECORDS` – Total number of records read in the Map phase. | `MAP_OUTPUT_RECORDS` – Total number of records written in the Map phase. | `PHYSICAL_MEMORY_BYTES` – Total physical memory consumed by all tasks. | `REDUCE_INPUT_GROUPS` – Total number of keys read in during reduce phase. |
| `REDUCE_INPUT_RECORDS` – Total number of records (i.e. **values**) read in during reduce phase. | `REDUCE_OUTPUT_RECORDS` – Total number of records written during the reduce phase. | `REDUCE_SHUFFLE_BYTES` – Total number of bytes of output from map tasks copied during shuffle to reducers. | `SPILLED_RECORDS` – Total number of records spilled to disk by all map and reduce tasks. |
| `SPLIT_RAW_BYTES` – Total number of bytes consumed for metadata (**offset and length**) during splits. | `VIRTUAL_MEMORY_BYTES` – Total number of virtual memory bytes consumed by tasks (RAM + swap) | | |

## Custom Counters

| | | | |
|---|---|---|---|
| **Example Uses of Custom Counters**<br>• **Counting specific (e.g. bad) records**<br>• **Keeping track of outliers**<br>• **Summations** | **Two Ways to Define Custom Counters**<br>1. **Enum** – **Compile time binding**.<br>2. **Context Variable** – **Run time binding**.<br><br>**Context based custom counters can be stored in groups.** | **Framework** – The JobTracker (MRV1)/Resource Manager (MRV2) **store custom counters in memory**. Recommended to keep the number of custom counters below 100. | **Example Syntax**<br>`context.getCounter("CounterGroupName", "CounterName").increment(1);`<br><br>Counters do not need to be declared or initialized. They are made the first time it is incremented. |

## Selecting MapReduce Version when MRV1 and MRV2 are on the Same System

| | Command Line | Environment Variables | Client | Cluster Wide |
|---|---|---|---|---|
| **MRV1** | hadoop1, hadoop -classic | MAPR_MAPREDUCE_MODE=classic | default_mode=classic | maprcli cluster mapreduce set –mode classic |
| **MRV2** | hadoop2, mapred, yarn | MAPR_MAPREDUCE_MODE=yarn | default_mode=yarn | maprcli cluster mapreduce set –mode yarn |

## Selecting MapReduce Version when MRV1 and MRV2 are on the Same System

| | Command Line | Environment Variables | Command Line Interface |
|---|---|---|---|
| **MRV1** | JobTracker, TaskTracker (**Separate Web UIs**) | **Uses** MapR Metrics Database | `hadoop job …`<br>**Used to monitor job status** |
| **MRV2** | HistoryServer, ResourceManager, NodeManager<br>(**Only HistoryServer runs a Web UI**) | **No** MapR Metrics Database | `mapred job …`<br>`yarn job …`<br>**Used to monitor job status** |

## Job Information

| | | | |
|---|---|---|---|
| **Job ID** – Every job has an ID in the format `job_yyyymmddhhMM_cccc` which align to the date/time when the job started and a counter for that minute. | **Information Stored About a Job**<br>• **Submit Time**<br>• **Start Time**<br>• **End Time**<br>• **Queue** | • **User**<br>• **Counter Information**<br>• **Configuration Settings** | **Get List of Currently Running Jobs**<br>`hadoop job -list`<br>**Get Individual Job Status**<br>`hadoop job -status job_yyyymmddhhMM_cccc`<br>**Kill a Currently Running Job**<br>`hadoop job -kill job_yyyymmddhhMM_cccc`<br>**Only this should be used to kill MapReduce jobs.**<br>**If OS level kill commands are used, TaskTracker will relaunch them.** |

# Modifying Job Priority in MRV1

**Using the Job API**

```
Configuration conf = new Configuration();
conf.set("mapred.job.priority", "VERY_HIGH");
Job job = new Job(conf, "JobName");
```

**XML Configuration**

```
<configuration>
  <property>
    <name>mapred.job.priority</name>
    <value>HIGH</value>
  </property>
</configuration>
```

**Command Line at Job Start**

hadoop jar –D mapred.job.priority=VERY_LOW

**Command Line While Job Is Running**

hadoop job –set-priority job_yyyymmddhhMM_cccc VERY_LOW

**Label Based Scheduling**

- Only available in MapR.
- Used to override default scheduling.
- **Nodes in the cluster are associated with labels.**
- **When jobs are submitted with a label, the job is only executed on those nodes associated with that label.**

**Starting a Job with a Label**

hadoop jar –D mapred.job.label=LabelName …

**"LabelName" must exist or the job will hang.**

**Showing All Job Labels**

hadoop job -showlabels

**Apache Commons Logging (JCL)**

- **JCL** – Pluggable logging interface for Apache Programs written in Java.
- **Examples:** Log4j, Avalon LogKit
- Logging is at multiple levels so users can specify what level of logging they want to use.

**Example:**

```
private static Log log = LogFactory.getLog(MyClass.class);
…
public void map(Key key, Value value){
  …
  log.debug("Debug level logging");
  …
  log.error("Error level logging");
  …
}
```

**Getting Job History**

```
Configuration conf = new Configuration();
conf.set("mapred.job.priority", "VERY_HIGH");
Job job = new Job(conf, "JobName");
```

**XML Configuration**

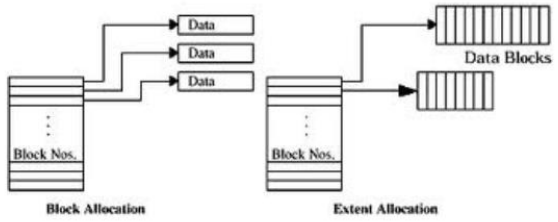
```
<configuration>
  <property>
    <name>mapred.job.priority</name>
    <value>HIGH</value>
  </property>
</configuration>
```

**Command Line at Job Start**

hadoop jar –D mapred.job.priority=VERY_LOW

**Command Line While Job Is Running**

hadoop job –set-priority job_yyyymmddhhMM_cccc VERY_LOW




***block vs extent-based allocation***