Distributed Computing Framework for Big Data: MapReduce (Hadoop)

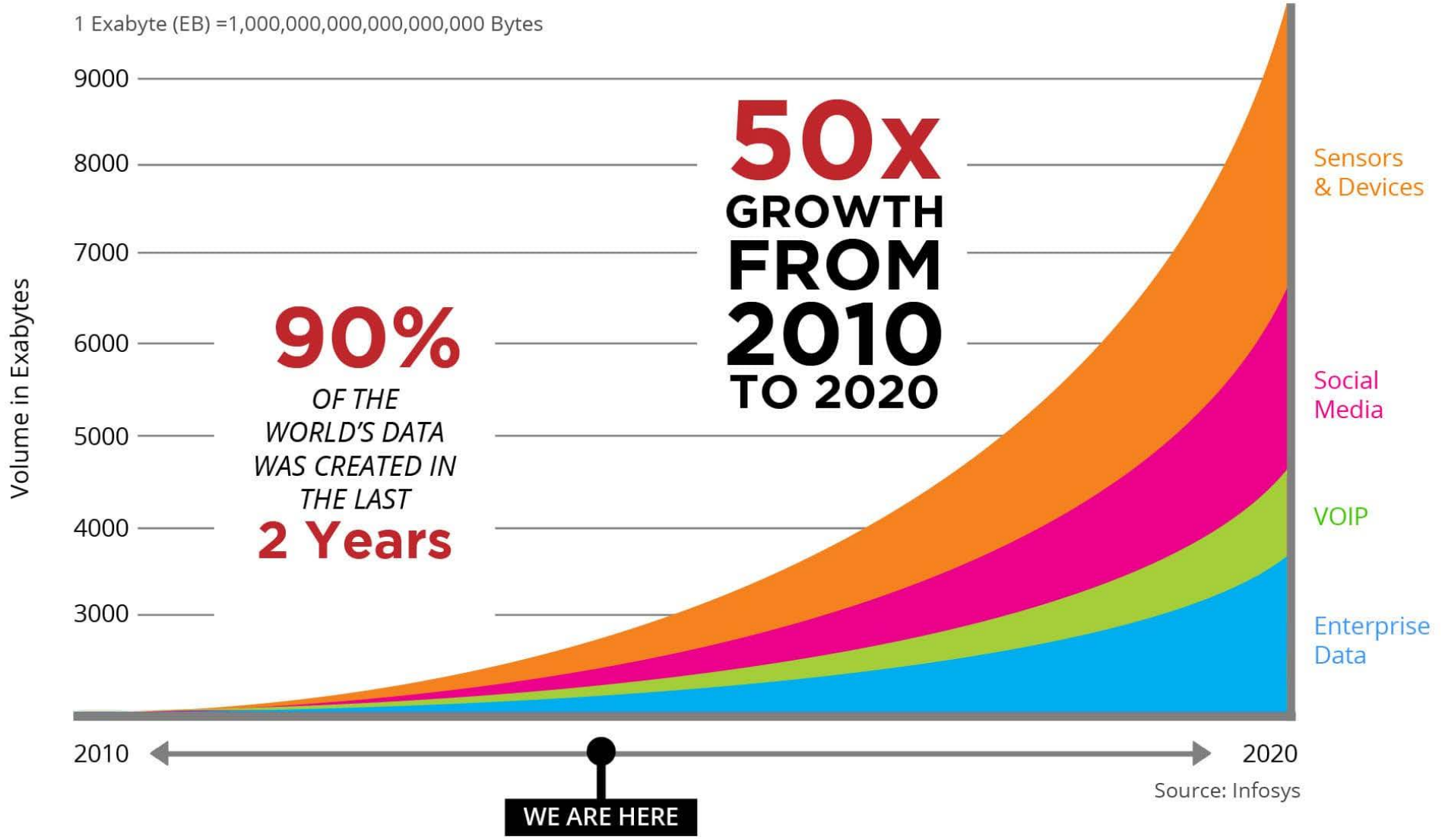
National Tsing Hua University

2018, Fall Semester

Outline

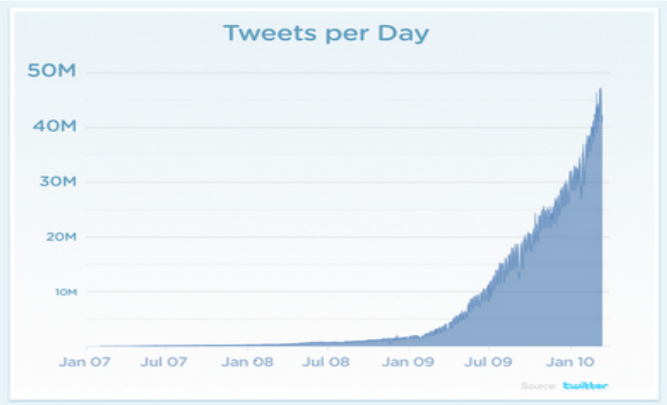
- Big Data
- MapReduce
- Hadoop Eco-system
- Hadoop Programming

Data Growth


1 Exabyte (EB) =1,000,000,000,000,000,000 Bytes
Volume in Exabytes
9000
8000
7000
6000
5000
4000
3000
50x
GROWTH
FROM
2010
TO 2020
90%
OF THE
WORLD'S DATA
WAS CREATED IN
THE LAST
2 Years
Sensors
& Devices
Social
Media
VOIP
Enterprise
Data
2010
2020
WE ARE HERE
Source: Infosys

The Explosion of Data

- A increased number and variety of **data sources** that generate large quantities of data
  - Sensors(e.g. measurements)
  - Mobile devices(e.g. phone)
  - Social Network (e.g. twitter, wikis)
  - OLTP (e.g. bank transactions)



Mobile device

Sensors

OLTP

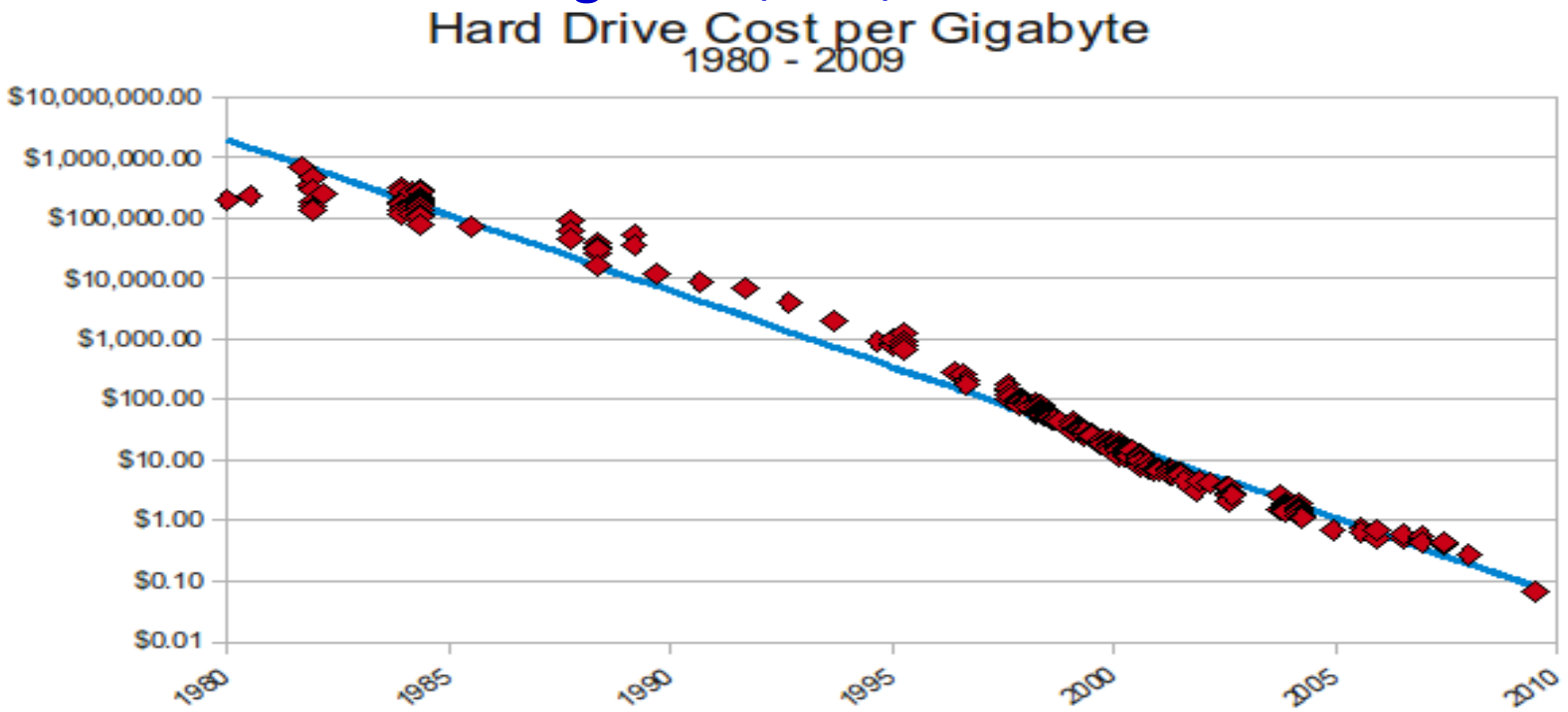
Social Networks

Scientific Devices

The Explosion of Data

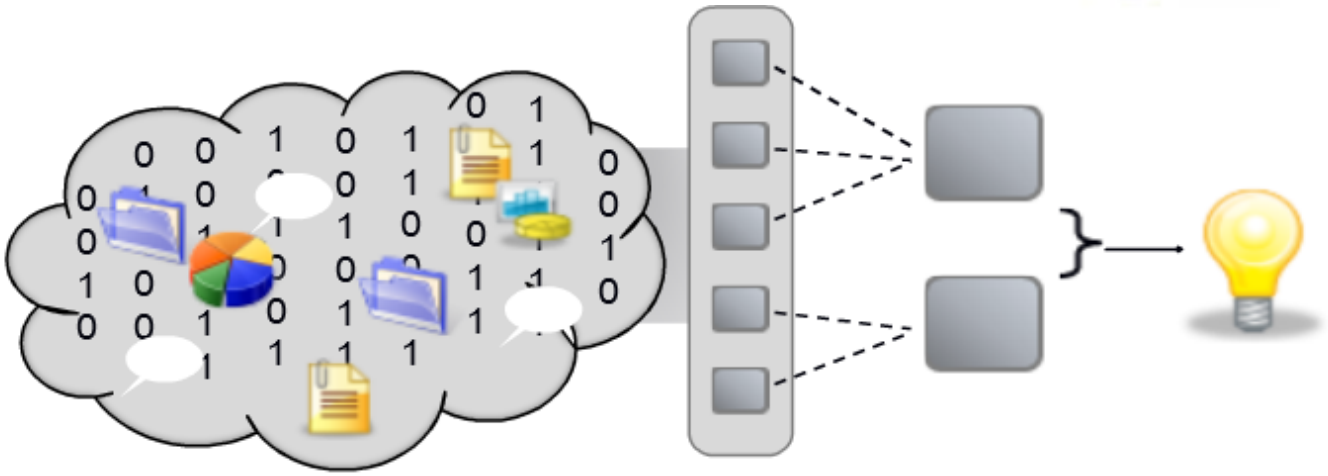
- Dramatic decline in the **cost of HW**,
  - The cost reduction is in the order of about 40-45% per year – which means it becomes half in 2 years

➔ It is FREE for storage: 1+1/2+1/4+… = 2 ≠ ∞



The Explosion of Data

- Realize data is “too valuable” to delete
  - Diagnose system
  - Understand user behavior
  - Evaluate merchandise & products
  - Make business decision



Data to Wisdom (DIKW Pyramid)

Wisdom:
Intelligent decision for creating values

Knowledge:
Analyzed info
(How & Why)

Information:
Data description
(What is it?)

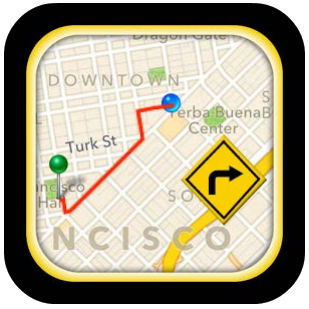
Data:
Symbols or Signs

Big Data /

Artificial Intelligent (AI)

行車影像

行車車距離、號誌



駕駛方式、路徑

智慧車輛

The Tales of Beers and Diapers

- A large supermarket chain, Wal-Mart, did an analysis of customers‘ buying habits and found a **statistically significant correlation between purchases of beer and purchases of diapers**

What Makes it Big Data?

*Extracting **values**(insight) from an immense volume, variety and velocity of data, in context, beyond what was previously possible*

Volume: Scale from Terabytes to Petabytes (1K TBs) to Zetabytes (1B TBs)

Variety: Manage the complexity of data in many different structures, ranging from relational, to logs, to raw text

Velocity: Streaming data and large volume data movement. How fast to process the data.

Technology Changes the World…

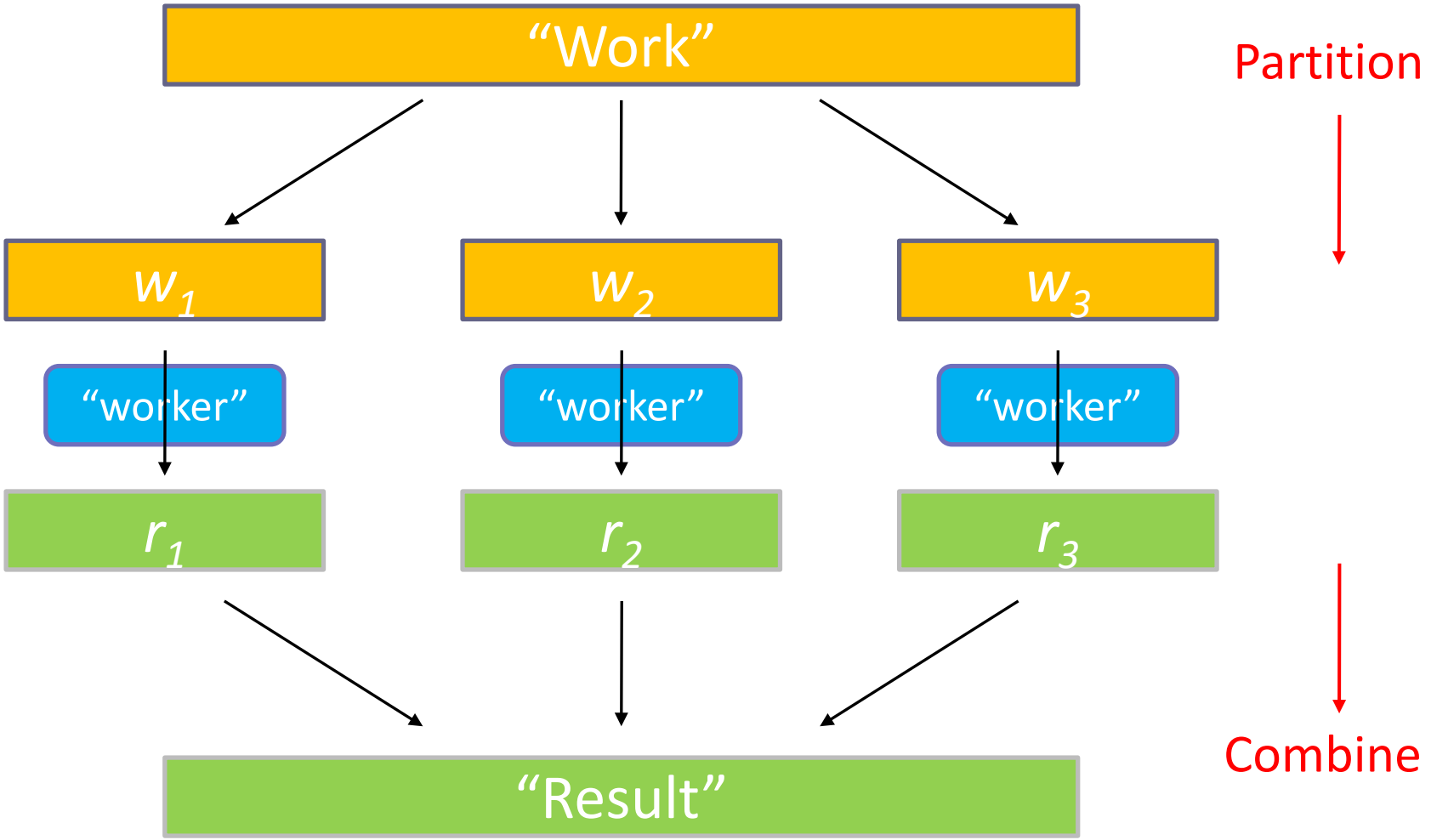
Outline

- Big Data
- MapReduce
- Hadoop Eco-system
- Hadoop Programming

MapReduce

- Developed by ***Google*** to process PB of data per data using datacenters (published in OSDI'04)
  - Program written in this functional style are **automatically parallelized and executed** on machines
- ***Hadoop*** is the open source (JAVA) implemented by Yahoo
- MapReduce has several meanings
  - A programming model
  - A implementation
  - A system architecture

Start with the Simplest Solution: Divide and Conquer



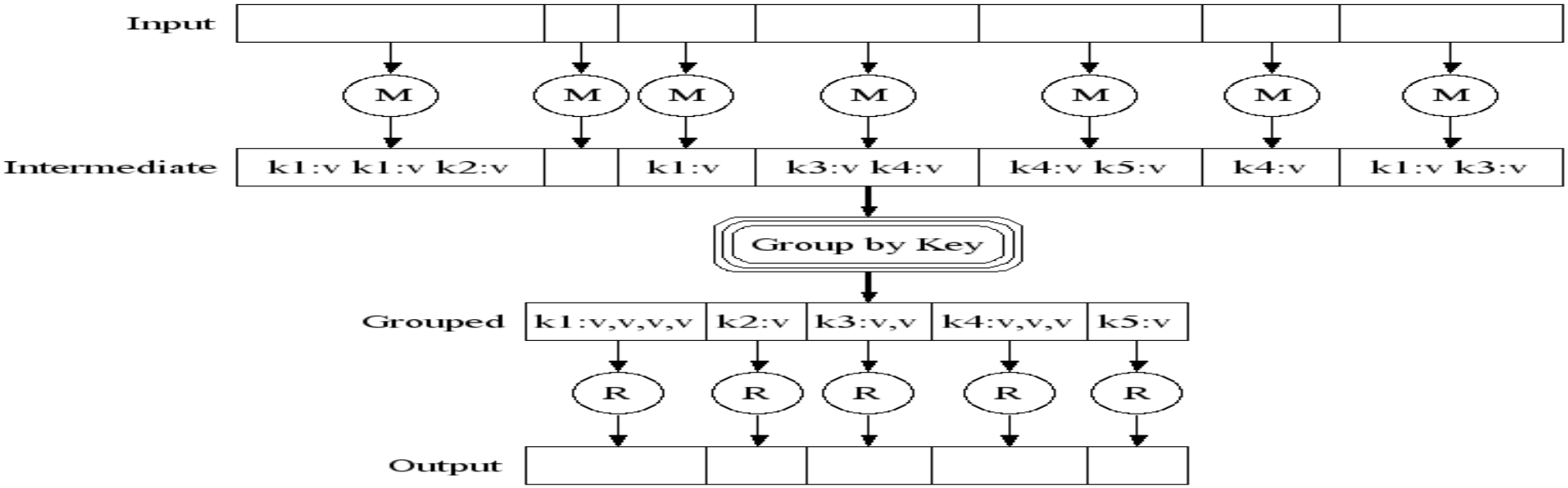
Typical Large-Data Problem

1. Iterate over a large number of records
2. Extract something of interest from each record *Map*
3. Shuffle and sort intermediate results
4. Aggregate intermediate results *Reduce*
5. Generate final output

Key idea: provide **a functional abstraction** for these two operations

MapReduce Programming Model

- A parallel programming model (divide-conquer)
  - Map: processes a key/value pair to generate a set of intermediate key/value pairs
  - Reduce: merges all intermediate values associated with the same intermediate key



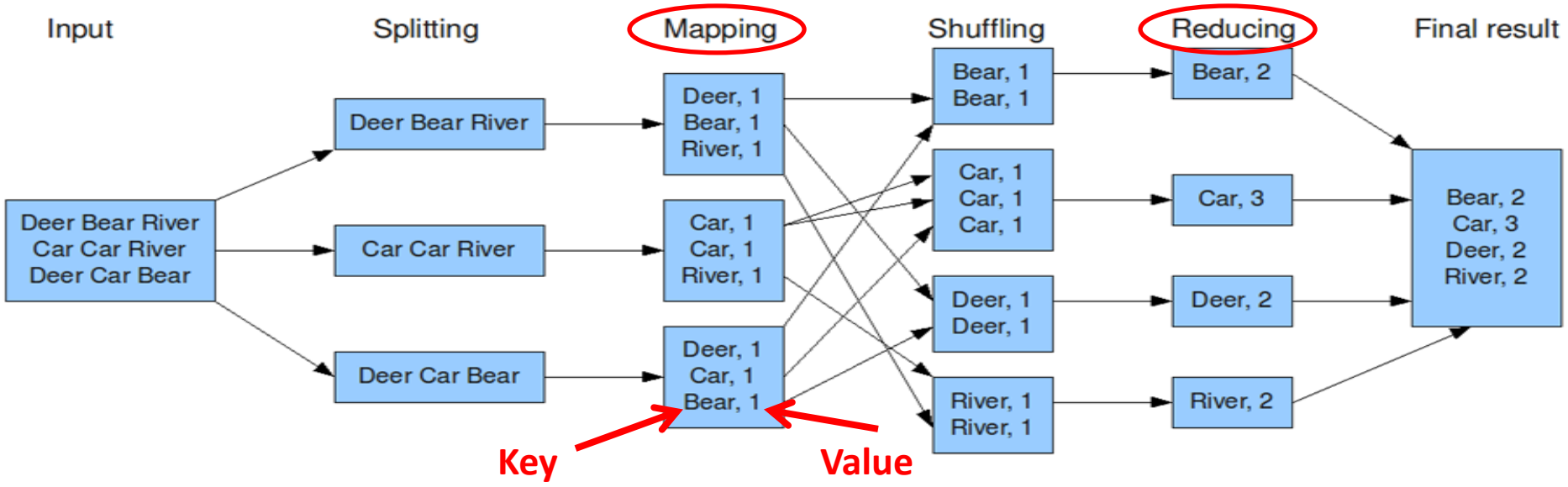
MapReduce Word Count Example

- User specify the ***map*** and ***reduce*** functions

```
Map(String docid, String text):
    for each word w in text:
        Emit(w, 1);
```

```
Reduce(String term, Iterator<Int> values):
    int sum = 0;
    for each v in values:
        sum += v;
    Emit(term, sum);
```

The overall MapReduce word count process

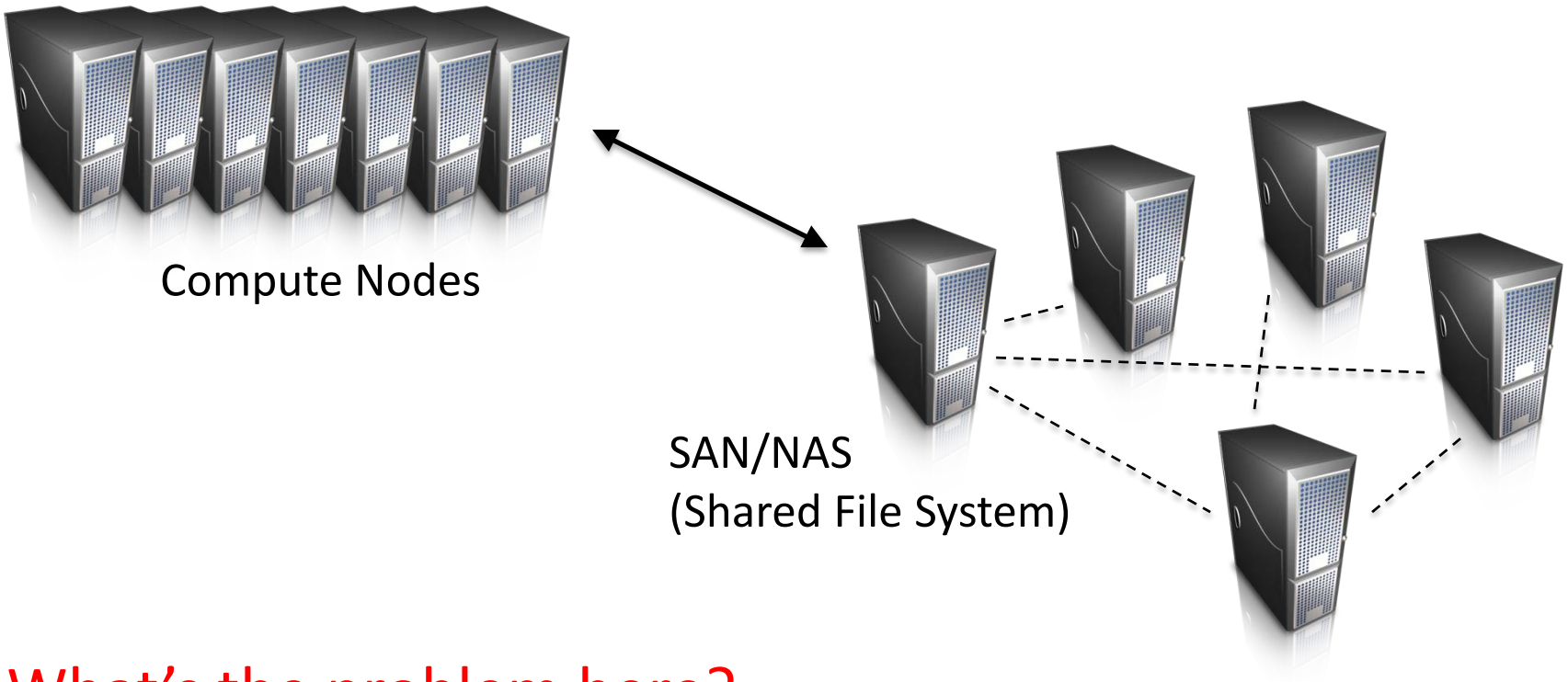


- The execution framework handles everything else…

MapReduce “Runtime”

- Handles scheduling
  - Assigns workers to map and reduce tasks
- Handles “data distribution”
  - Moves processes to data
- Handles synchronization
  - Gathers, sorts, and shuffles intermediate data
- Handles errors and faults
  - Detects worker failures and restarts
- Everything happens on top of a **distributed FS**

How do we get data to the workers?



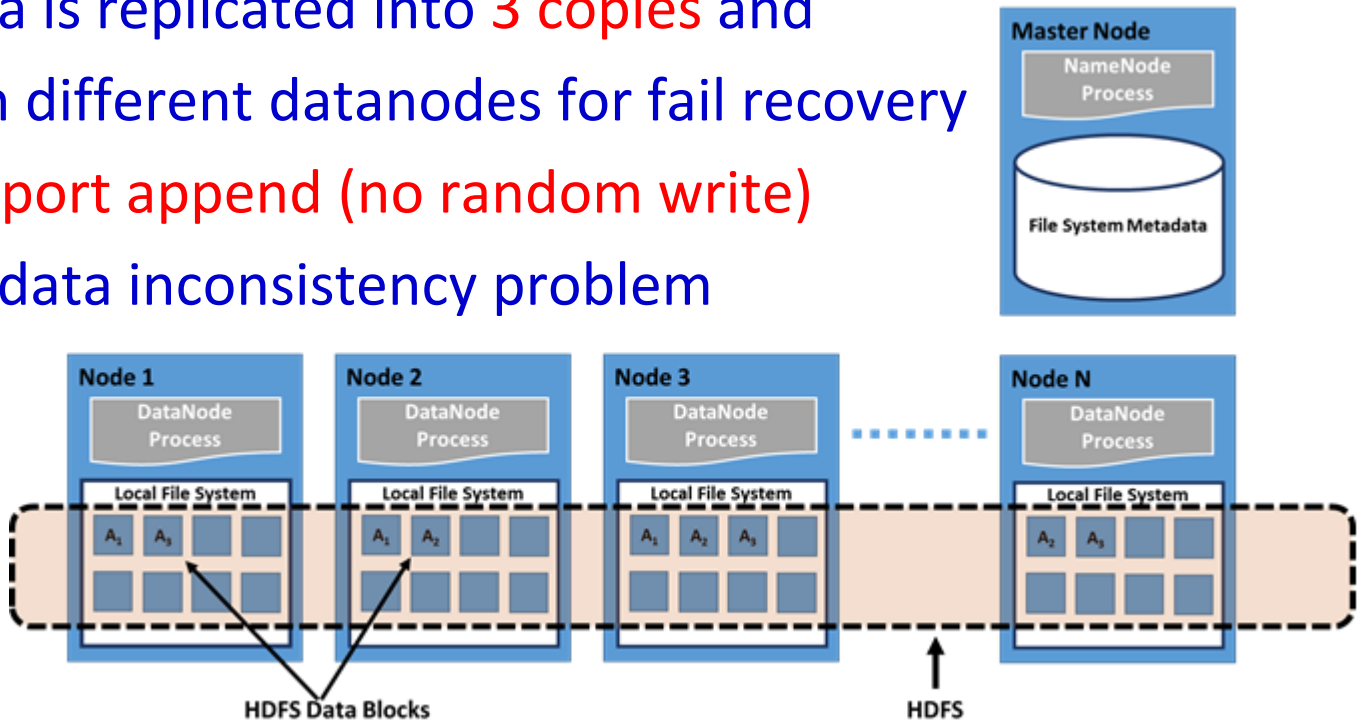
What's the problem here?

Distributed File System

- Don't move data to workers…
  move workers to the data!
  - A node act as both compute and storage node
  - Store data on the local disks of nodes in the cluster
  - Start up the workers on the node that has the data local
- A distributed file system is the answer
  - GFS (Google File System) for Google's MapReduce
  - HDFS (Hadoop Distributed File System) for Hadoop

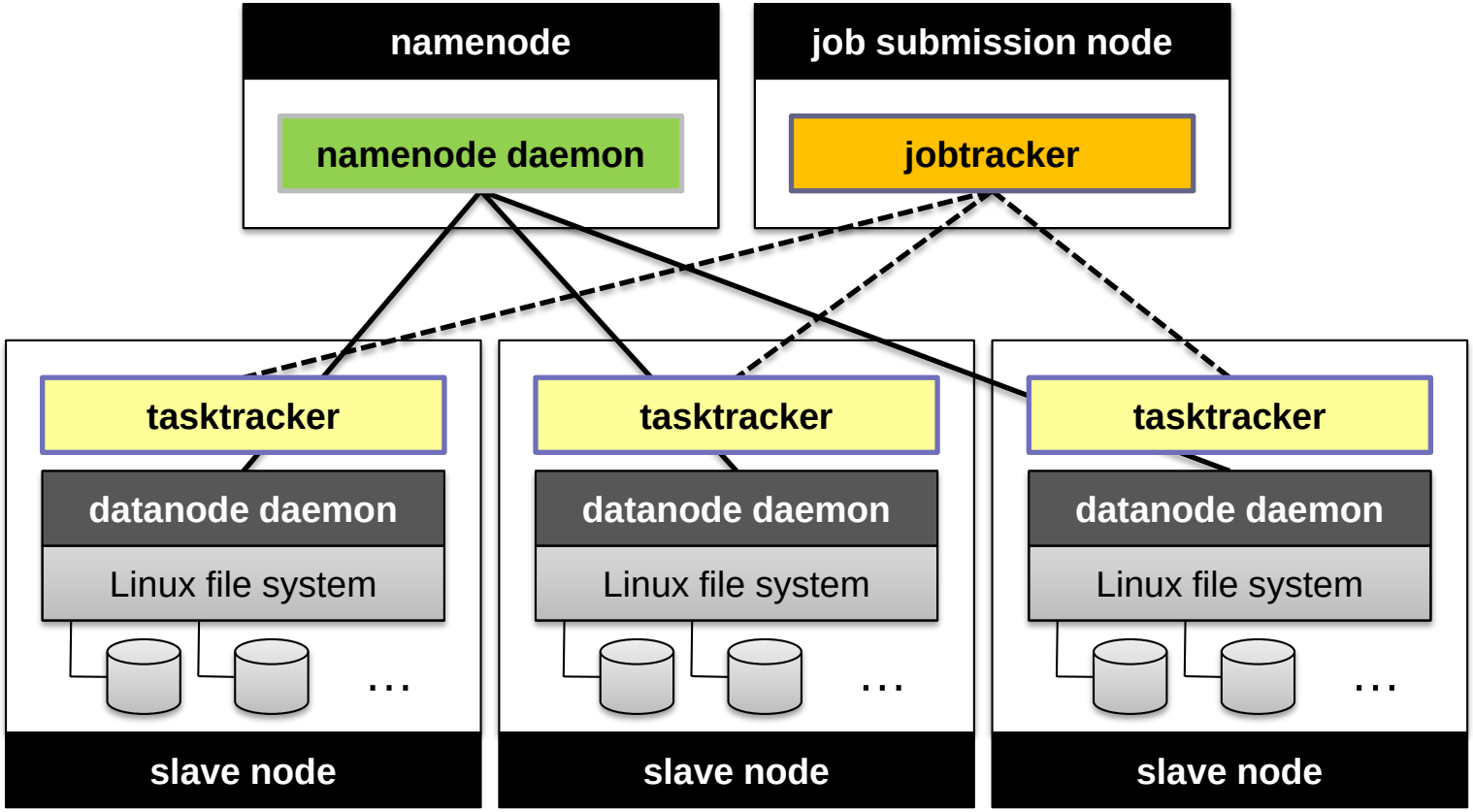
HDFS: Hadoop Distributed File System

- A distributed file system installed on top of native Linux FS
  - File is partitioned into 64MB data chunks for scalability
  - Each data is replicated into 3 copies and placed on different datanodes for fail recovery
  - Only support append (no random write) to avoid data inconsistency problem



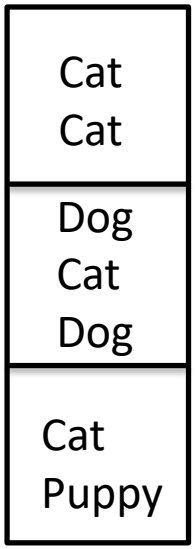
Putting everything together…

- Hadoop:
  - HDFS: Namenode/Datanode
  - Execution engine: Job/Task tracker



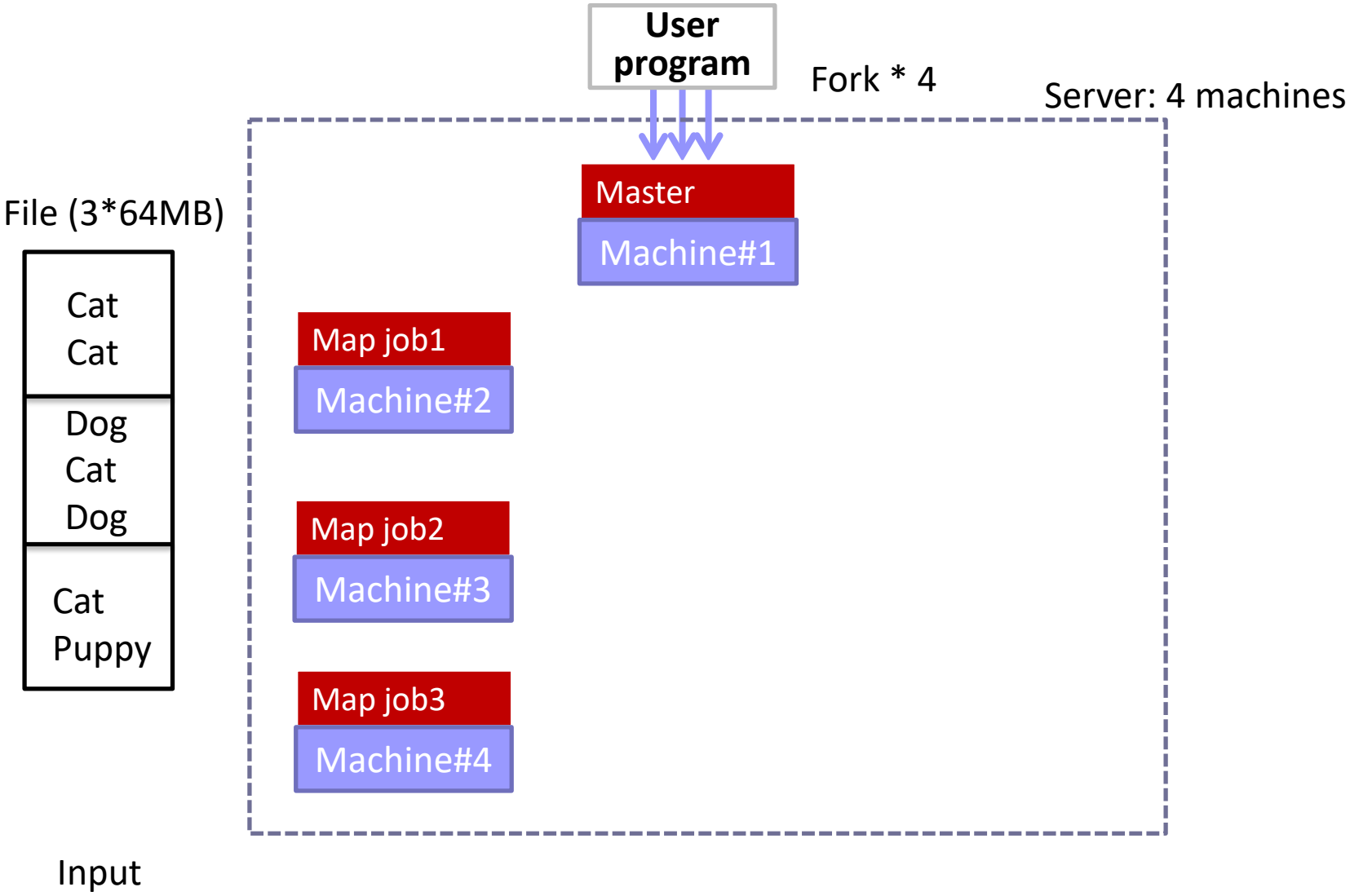
MapReduce in Action

File (3*64MB)

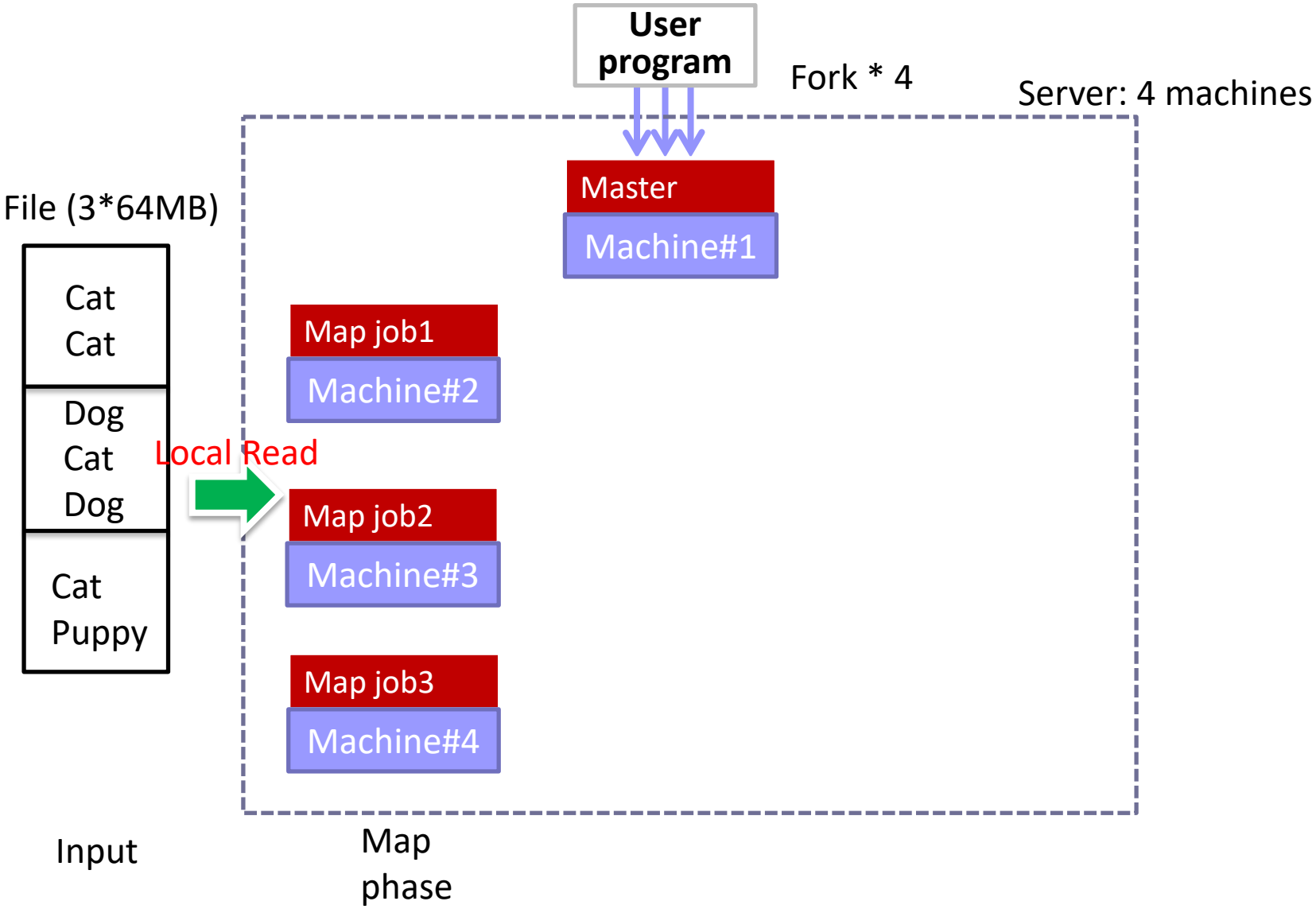


Input

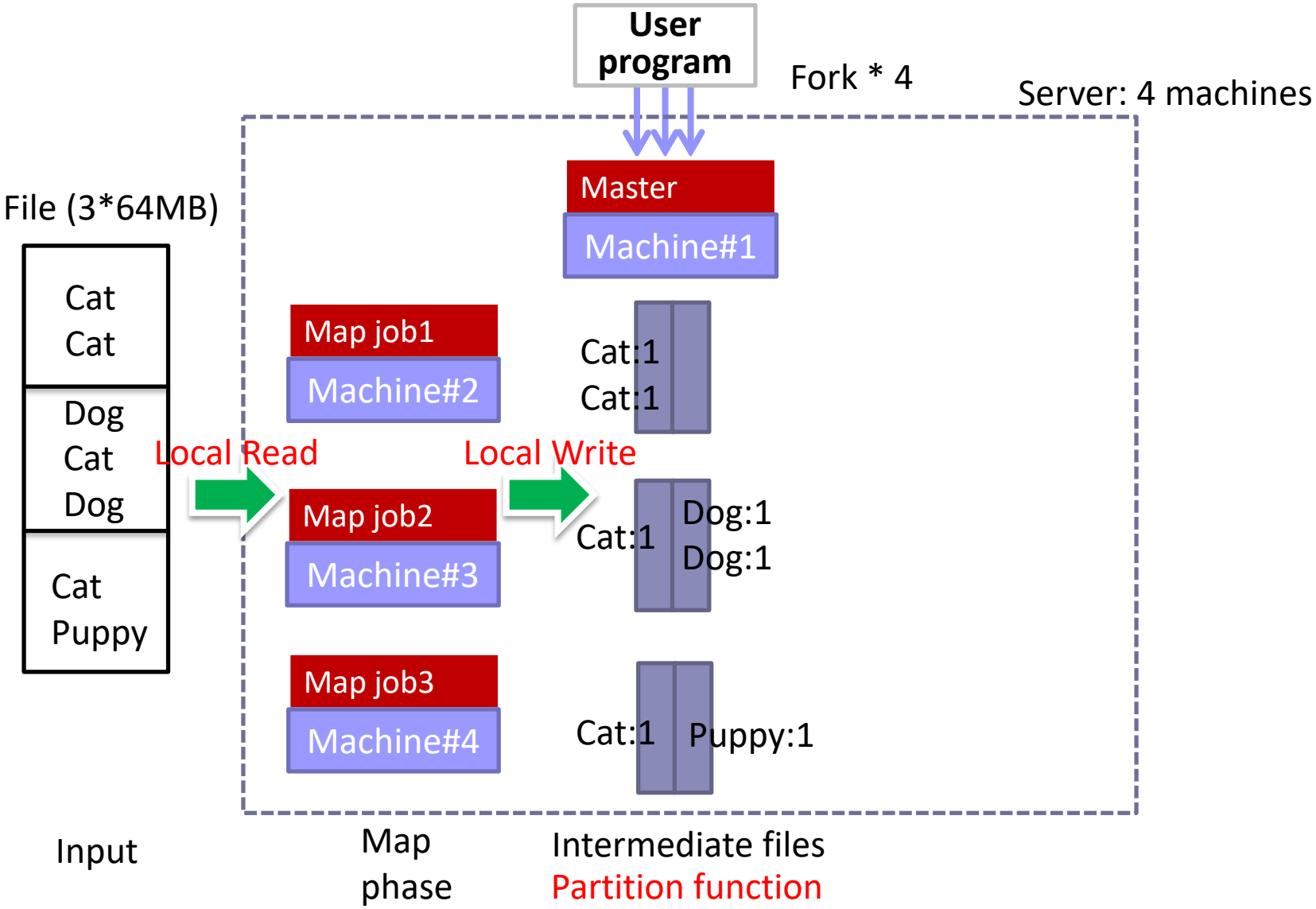
MapReduce in Action



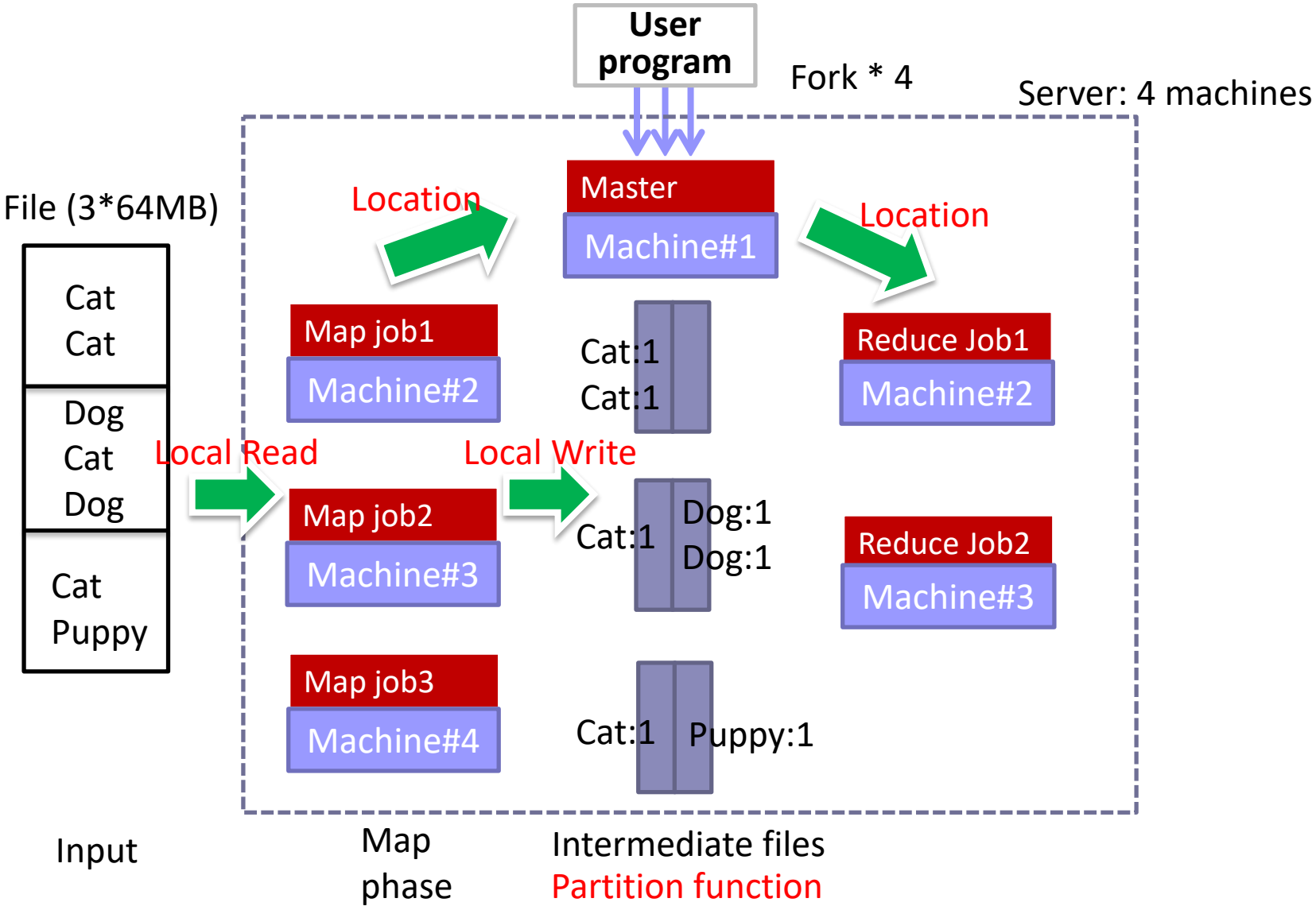
MapReduce in Action



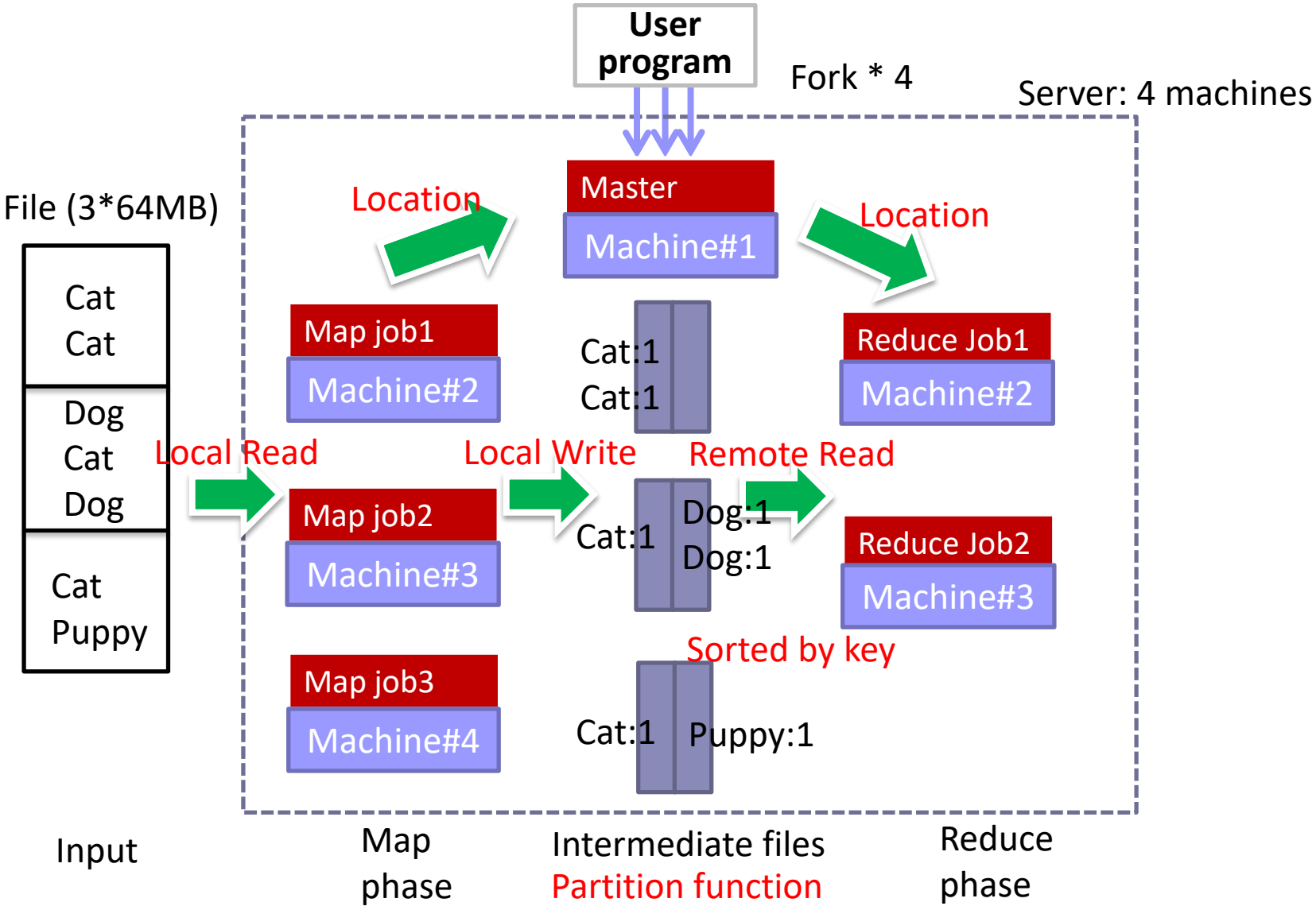
MapReduce in Action



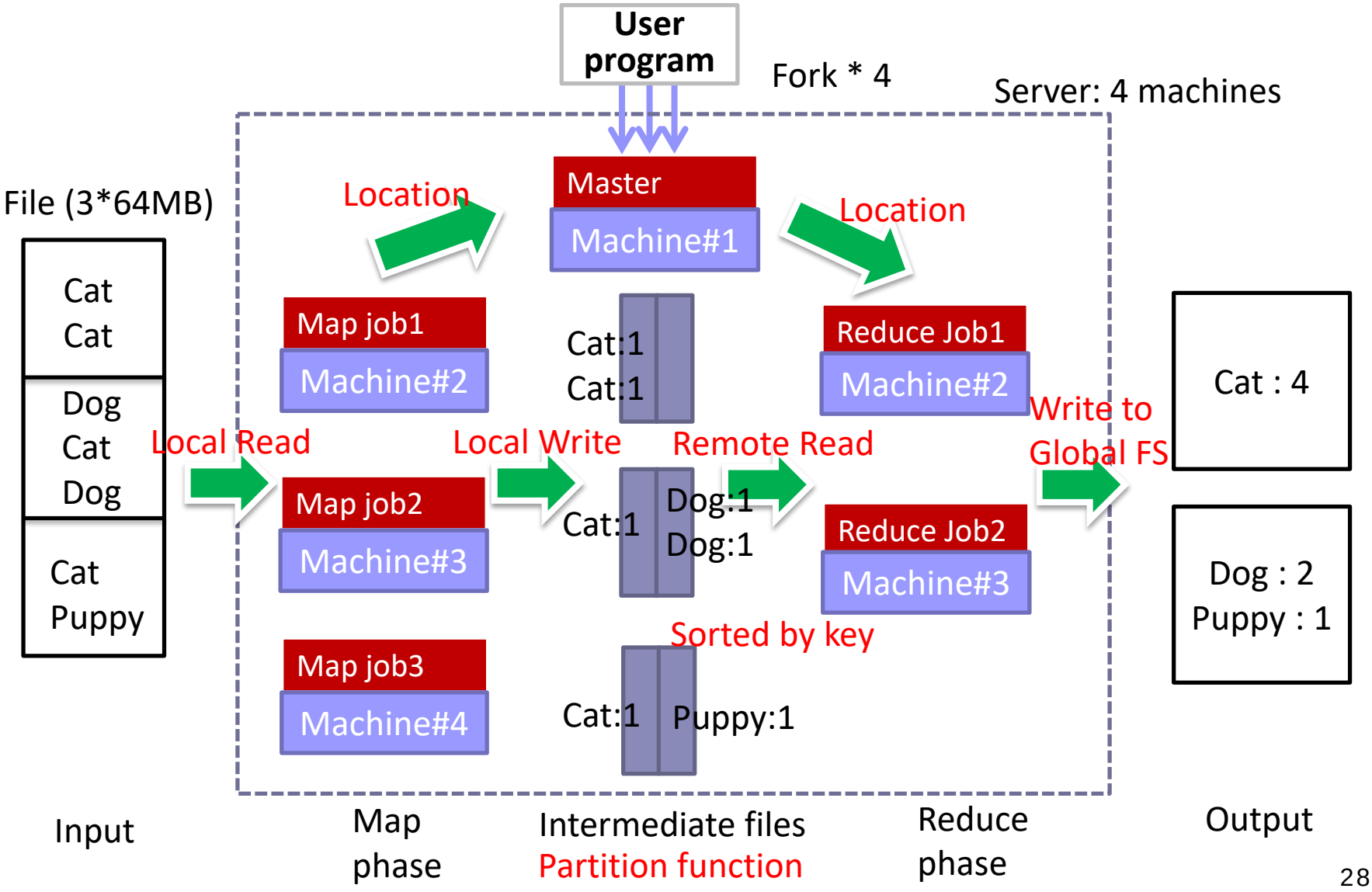
MapReduce in Action



MapReduce in Action



MapReduce in Action



Summary

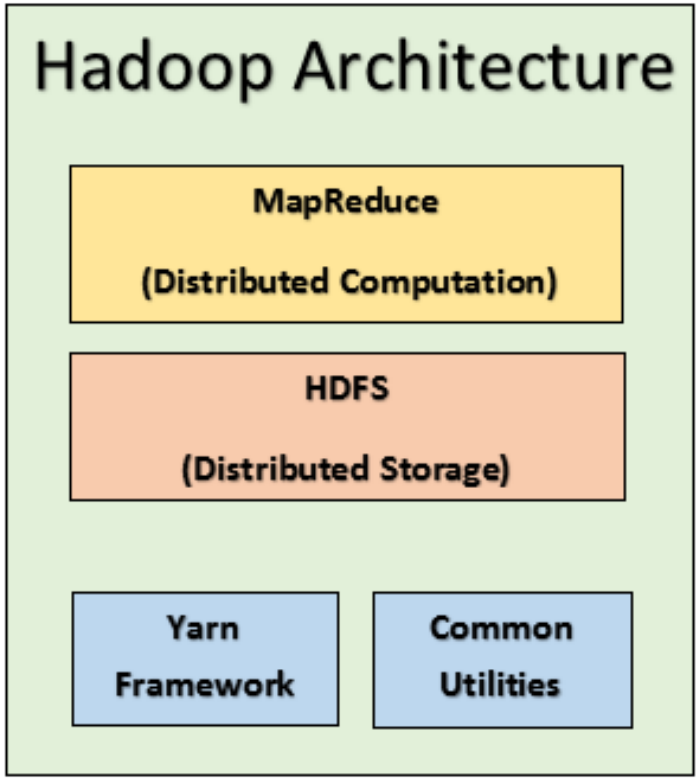
- MapReduce is a simplified programming model which allows the user to quickly write and test distributed systems to handle data with huge volume.
- Its efficient and automatic distribution of data and workload across machines. Moving process to data.
- Seamless scalability. Specifically, after a Mapreduce program is written and functioning on 10 nodes, very little (if any work) is required for making that same program run on 1000 nodes

Outline

- Big Data
- MapReduce
- Hadoop Eco-system
- Hadoop Programming

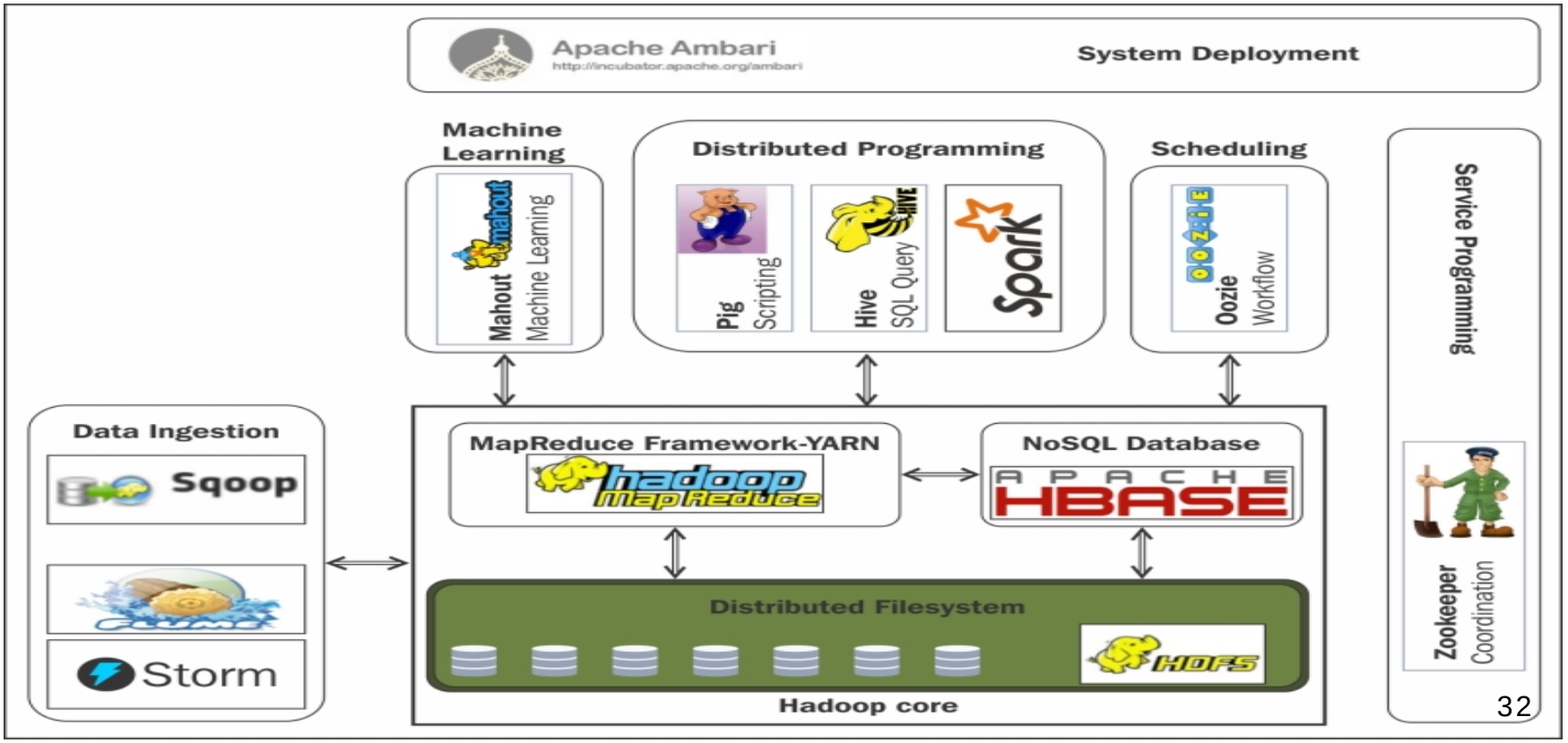
Hadoop

- The open source (JAVA) implementation of MapReduce by Yahoo
- Core services
  - MapReduce : Computation
  - HDFS: Storage
  - YARN: Resource



Hadoop Eco-system

- Software that built around the core service of Hadoop for Big Data, including **storage, processing, analytics, workflow management**, **data fusion,** etc.



Hive and Pig

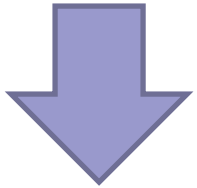
- Hive: data warehousing application in Hadoop
  - Query language is HQL, variant of SQL
  - Tables stored on HDFS as flat files
  - Developed by Facebook, now open source

- Pig: large-scale data processing system
  - Scripts are written in Pig Latin, a dataflow language
  - Developed by Yahoo!, now open source
  - Roughly 1/3 of all Yahoo! internal jobs
  - Similar to the role of SCALE for Spark

- Common idea:
  - Provide higher-level language to facilitate large-data processing
  - Higher-level language "compiles down" to Hadoop jobs

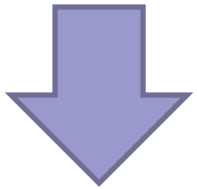
Hive: Behind the Scenes

```
SELECT s.word, s.freq, k.freq FROM shakespeare s
  JOIN bible k ON (s.word = k.word) WHERE s.freq >= 1 AND k.freq >= 1
  ORDER BY s.freq DESC LIMIT 10;
```



(Abstract Syntax Tree)

```
(TOK_QUERY (TOK_FROM (TOK_JOIN (TOK_TABREF shakespeare s) (TOK_TABREF bible k) (= (. (TOK_TABLE_OR_COL s) word) (.
(TOK_TABLE_OR_COL k) word)))) (TOK_INSERT (TOK_DESTINATION (TOK_DIR TOK_TMP_FILE)) (TOK_SELECT (TOK_SELEXPR (.
(TOK_TABLE_OR_COL s) word)) (TOK_SELEXPR (. (TOK_TABLE_OR_COL s) freq)) (TOK_SELEXPR (. (TOK_TABLE_OR_COL k) freq)))
(TOK_WHERE (AND (>= (. (TOK_TABLE_OR_COL s) freq) 1) (>= (. (TOK_TABLE_OR_COL k) freq) 1))) (TOK_ORDERBY
(TOK_TABSORTCOLNAMEDESC (. (TOK_TABLE_OR_COL s) freq))) (TOK_LIMIT 10)))
```

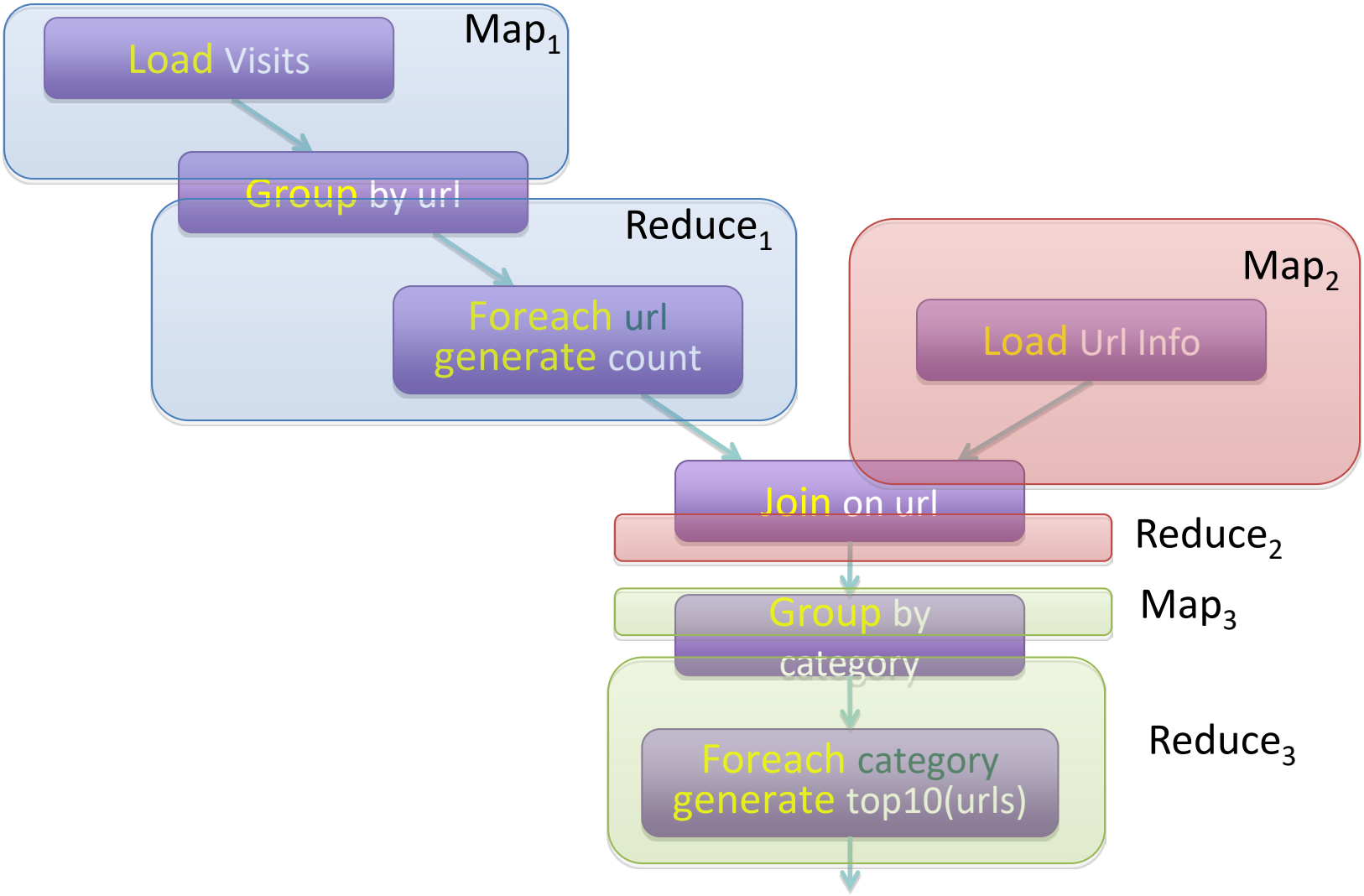


(one or more of MapReduce jobs)

Pig Script

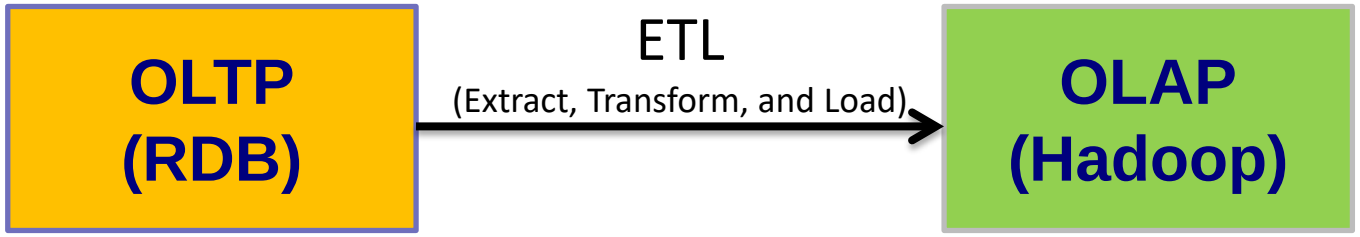
```
visits = load '/data/visits' as (user, url, time);
gVisits = group visits by url;
visitCounts = foreach gVisits generate url, count(visits);
urlInfo = load '/data/urlInfo' as (url, category, pRank);
visitCounts = join visitCounts by url, urlInfo by url;
gCategories = group visitCounts by category;
topUrls = foreach gCategories generate top(visitCounts,10);
store topUrls into '/data/topUrls';
```

Pig Script in Hadoop



Pig Slides adapted from Olston et al. (SIGMOD 2008)

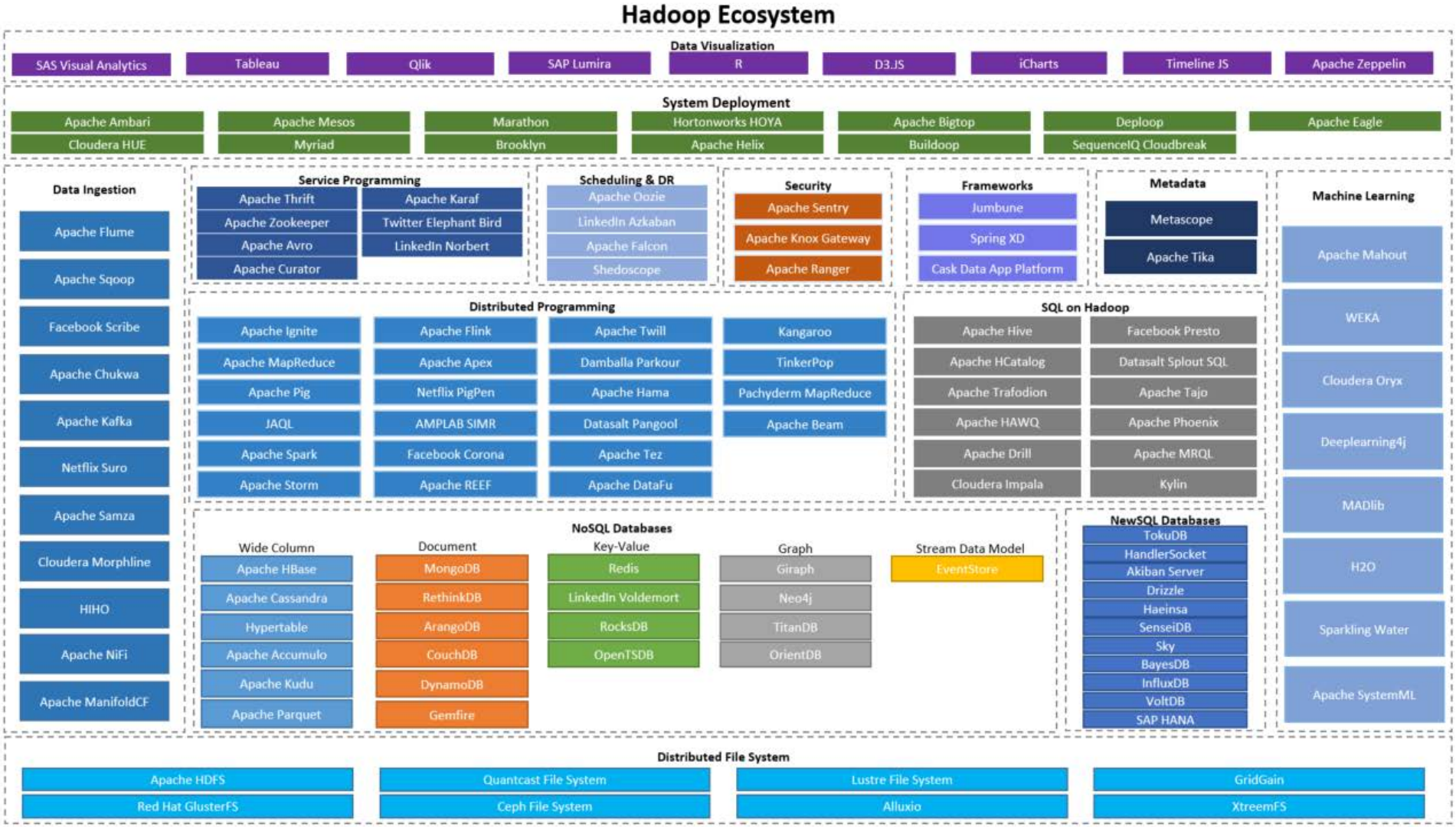
OLTP/OLAP Integration



- OLTP database for user-facing transactions
  - Retain records of all activity
  - Periodic ETL (e.g., nightly)
- Extract-Transform-Load (ETL)
  - Extract records from source
  - Transform: clean data, check integrity, aggregate, etc.
  - Load into OLAP database
- OLAP database for data warehousing
  - Business intelligence:
    - **Periodic reporting** as well as **ad hoc queries**
    - **Analysts, not programmers** (importance of tools and dashboards)
  - Feedback to improve OLTP services

Big Data

Hadoop Eco-system



Hadoop Distributions

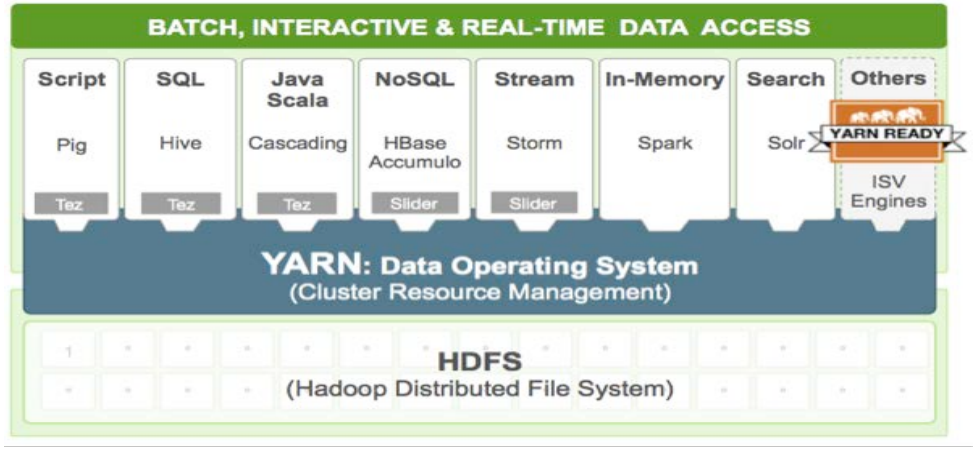
- A number of vendors have taken advantage of Hadoop open-ended framework and tweaked its codes to change or enhance its functionalities.
- Three major companies in the completion are:
  - Cloudera: the first company to develop and distribute Apache Hadoop-based software
  - Hortonworks: the only commercial vendor to distribute complete open source Apache Hadoop **without additional proprietary software**
  - MapR: MapR uses their proprietary file system MapR-FS instead of HDFS

Outline

- Big Data
- MapReduce
- Hadoop Eco-system
- Hadoop Programming
  - Basic Programming
    - WordCount Example
  - Advanced Programming
    - Secondarysort example

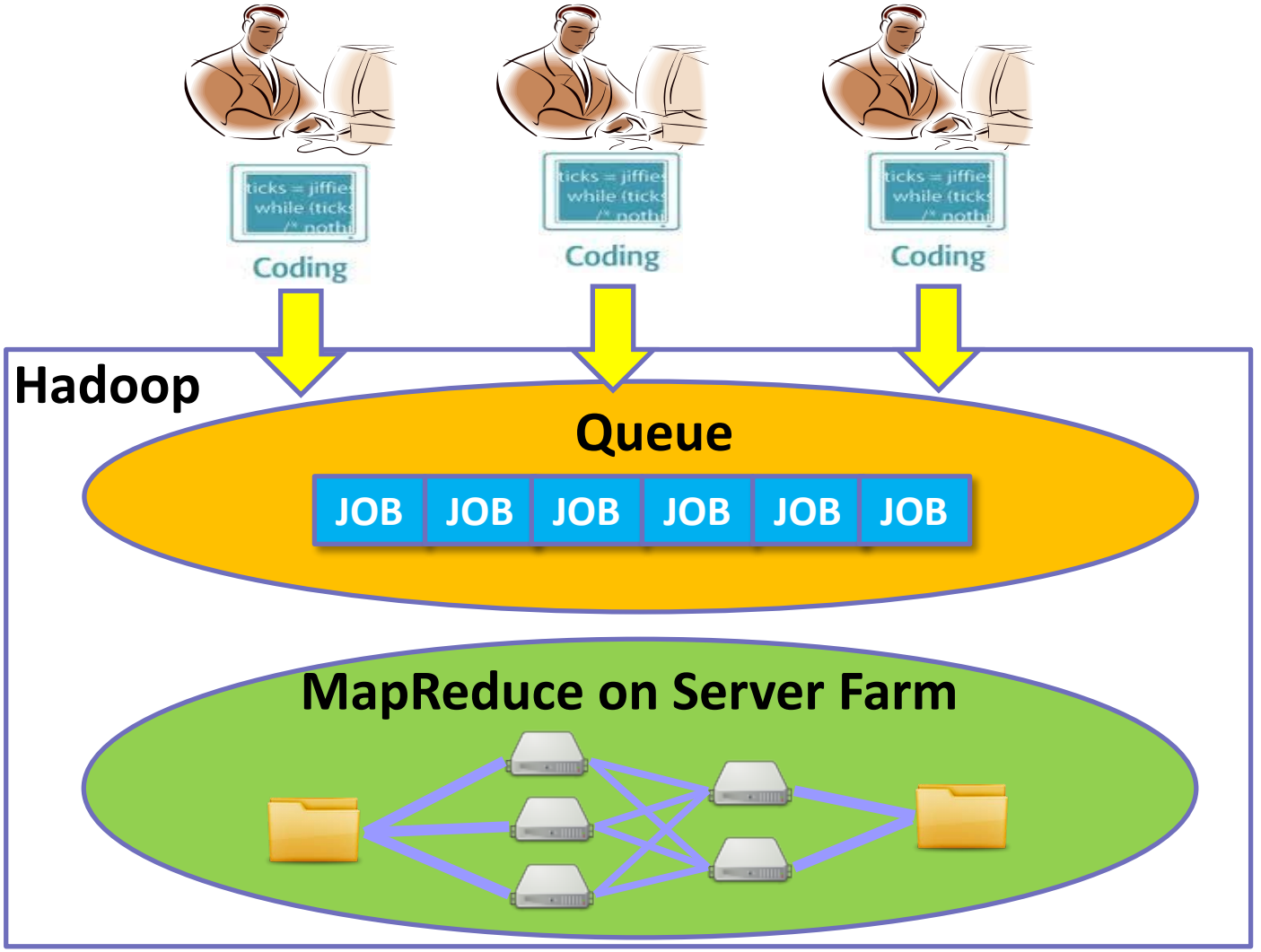
Hadoop Implementation

- Hadoop release 2.x
  - ***New version with YARN*** (resource manager)
  - Latest version is 2.8.2 (Oct. 2017)



- Java Language
  - Based on **inheritance and interface**
- Official Tutorial
  - https://hadoop.apache.org/docs/current/hadoop-mapreduce-client/hadoop-mapreduce-client-core/MapReduceTutorial.html

Hadoop Runtime



Basic HDFS Commands

Command	Description
-ls <args>	List directory
-mkdir <paths>	Create a directory
-put <localsrc> <HDFS_dest_Path>	Upload files
-get <hdfs_src> <localdst>	Download file
-cat <path[filename]>	See content of files
-cp <source> <dest>	Copy files in HDFS
-rm <arg>	Remove files or directories
-tail <path[filename]>	Display last few lines of a file
-getmerge [hdfs_src_dir] [hdfs_dst_file]	Merge files (from reducers)

- $/bin/hadoop fs [command]
- Ref: https://hadoop.apache.org/docs/r2.7.1/hadoop-project-dist/hadoop-common/FileSystemShell.html

Import hadoop package

Import classes in "***org.apache.hadoop.mapreduce***" package

- **import java.io.IOException; import java.util.StringTokenizer;**
- **import org.apache.hadoop.conf.Configuration;**
- **import org.apache.hadoop.fs.Path;**
- **import org.apache.hadoop.io.IntWritable;**
- **import org.apache.hadoop.io.Text;**
- **import org.apache.hadoop.mapreduce.Job;**
- **import org.apache.hadoop.mapreduce.Mapper;**
- **import org.apache.hadoop.mapreduce.Reducer;**
- **import org.apache.hadoop.mapreduce.lib.input.FileInputFormat;**
- **Import org.apache.hadoop.mapreduce.lib.output.FileOutputFormat;**
- **[Other necessary classes called by your code ……]**

Notice:

- **"mapreduce" package it not interchangable with "mapred" package**
- **Prevent using "Deprecated" methods**

Main Hadoop Classes

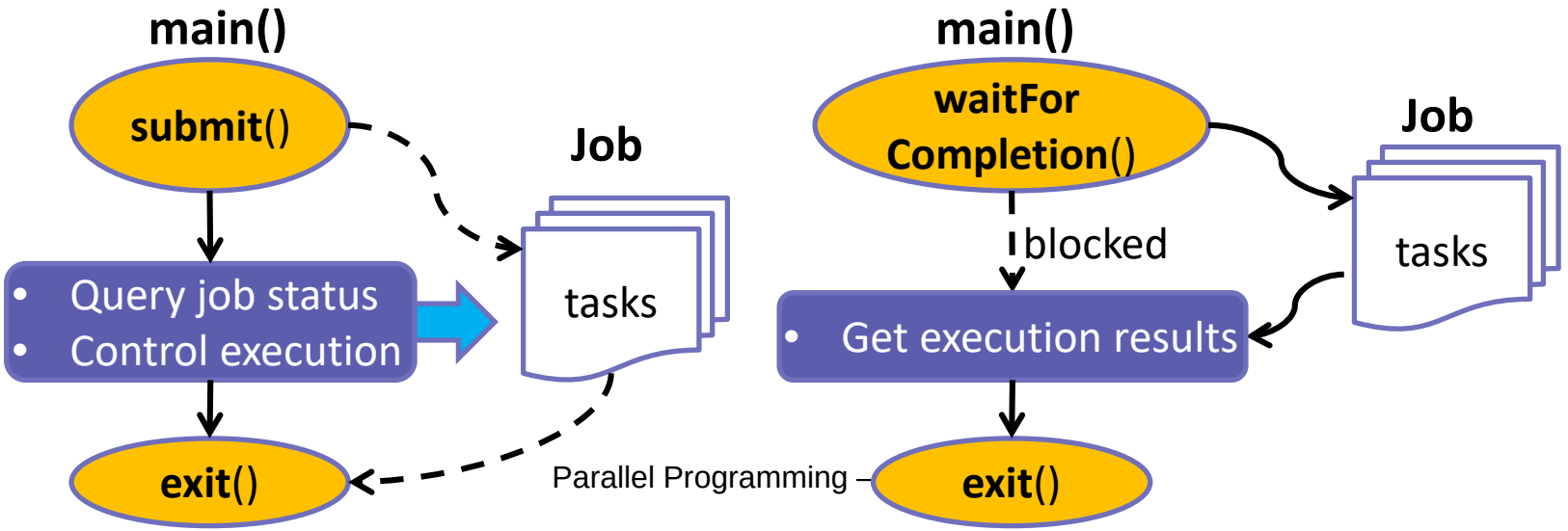
- **Configureation**
  - Hadoop **cluster** configuration
- **Job**
  - the primary interface for a user to describe a map-reduce **job** to the Hadoop framework for execution
- **Mapper**
  - maps input <K,V> pairs to intermediate <K,V> pairs
- **Reducer**
  - reduces intermediate values to a smaller set of values
- **Partitioner**
  - partitions the key of intermediate <K,V> pairs to reducer
- **Combiner**
  - combine map-outputs <K,V> pairs before being sent to reducers
- **RecordReader/RecordWriter**
  - Read input file & write output file

Job Class

- configure a job
  - Specify the class for mapper, reducer, combiner, etc.
- submit the job
  - **Submit the job to the cluster and return immediately**
  - **Or submit the job to the cluster and wait for it to finish**
- control its execution
  - Set the number of max attempts to run a reduce or map task.
  - Set scheduling priority.
  - Kill the running job, or specific task.
  - Turn speculative execution on or off for this job.
- query its state.
  - Get the *progress* of the job's map-tasks or reduce-tasks (between 0 and 1).
  - Returns the current state of the Job.
  - Get start time of the job.
  - Check if the job completed successfully.

Job Creation & Submission

Method	Description
getInstance (**Configuration** conf, **String** jobName)	Creates a new job with a given jobName.
setJarByClass(**Class**<?> cls)	Set the Jar by finding where a given class came from.
submit()	Submit the job to the cluster and return immediately. (non-blocking call)
waitForCompletion(boolean verbose)	Submit the job to the cluster and wait for it to finish. (blocking call)



Query & Control Job Execution

Method	Description
getStartTime()	Get start time of the job.
getFinishTime()	Get finish time of the job.
getStatus()	Returns a JobStatus object contain all the current job state info
mapProgress() **reduceProgress**()	Get the *progress* of the job. , as a float between 0.0 and 1.0.
getCounters()	Gets the counters object for this job
isComplete()	Check if the job is finished or not.

Method	Description
setPriority(JobPriority prio)	High/Low/Normal/Very_High/Very_Low
setNumReduceTasks(int n)	Set the requisite number of reduce tasks for this job. (notice: no method for map tasks)
setSpeculativeExecution(boolean flag)	Turn speculative execution on or off for this job.
killJob()	Kill the running job.
killTask(**TaskAttemptID** taskId)	Kill indicated task attempt.

Example

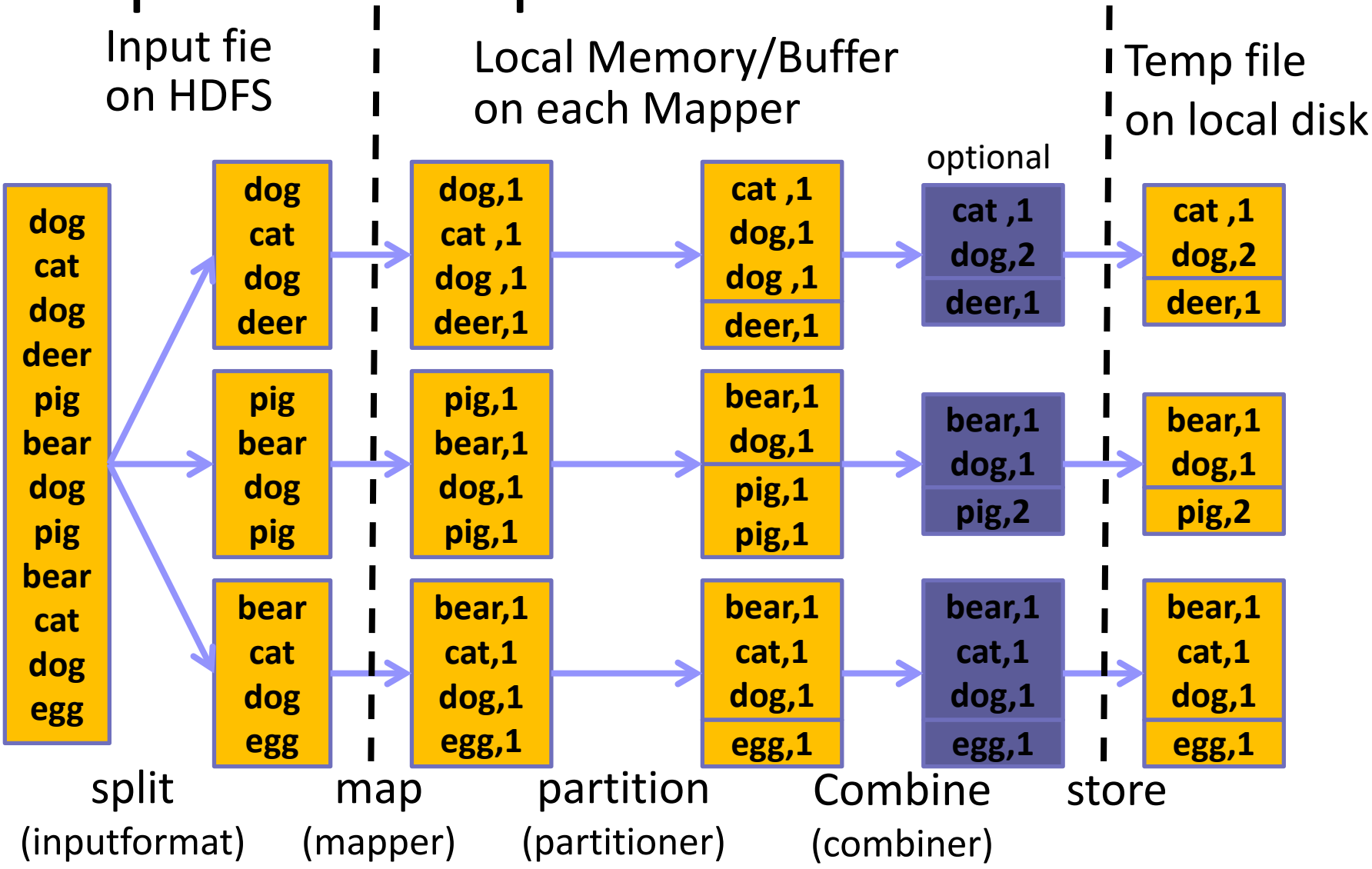
```
public class WordCount {
    public static void main(String[] args) throws Exception {
        Configuration conf = new Configuration();
        Job job = Job.getInstance(conf, “wordcount”);
        job.setJarByClass(WordCount.class);
        job.waitForCompletion(true); // Submit the job and wait for it to finish
    }
}
```

```
public class WordCount {
    public static void main(String[] args) throws Exception {
        Configuration conf = new Configuration();
        Job job = Job.getInstance(conf, “wordcount”);
        job.setJarByClass(WordCount.class);
        job.submit(); // Submit the job and return immediately
        while(job. isComplete()==false) {
            System.out.println(mapProgress());
        }
    }
}
```

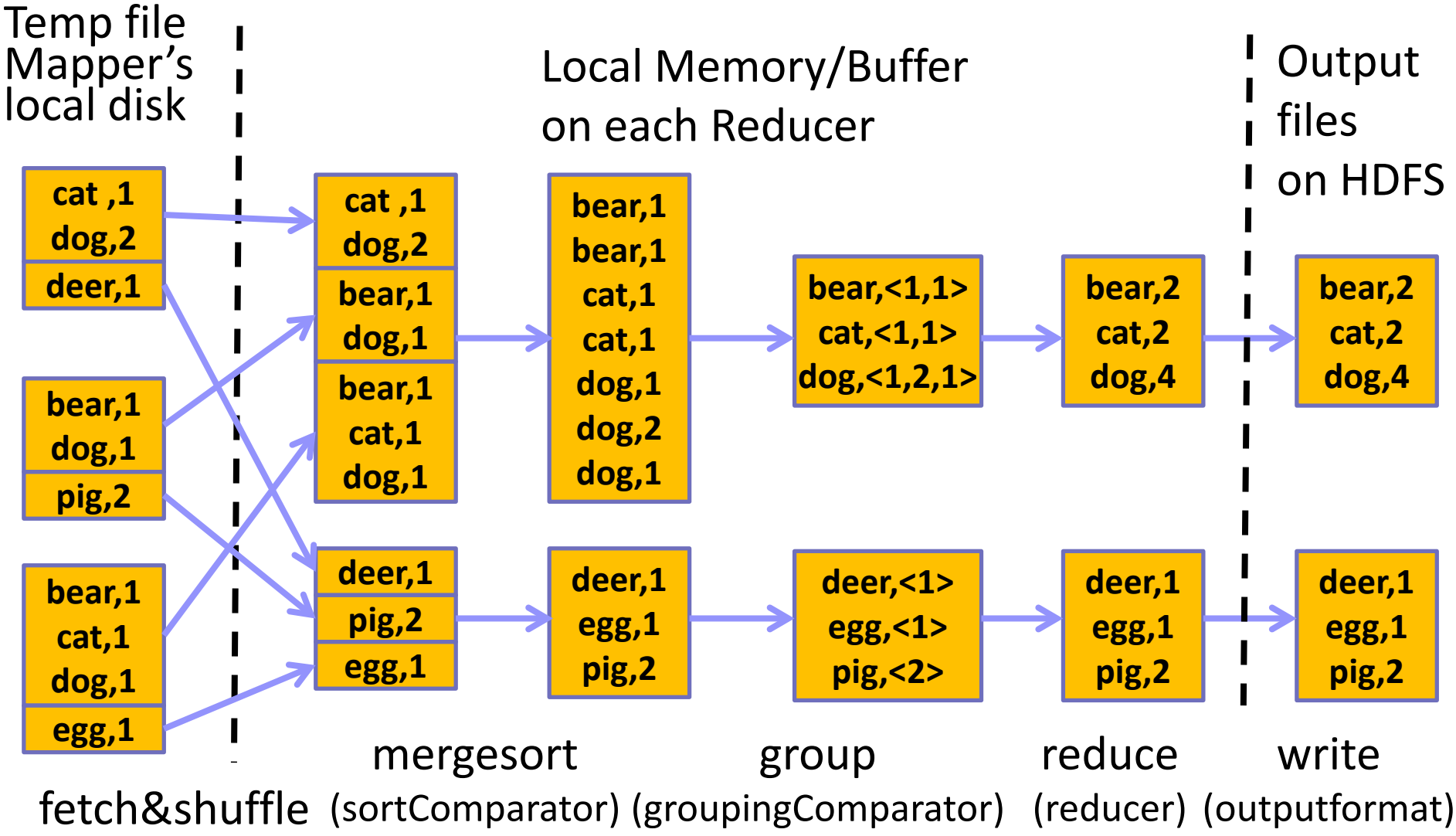
Job Configuration on Compute Functions

Method	Description
setMapperClass (Class<? extends Mapper>)	Set the Mapper class for the job
setReducerClass (Class<? extends Reducer>)	Set the Reducer class for the job.
setPartitionerClass (Class<? extends Partitioner>)	partition Mapper-outputs to be sent to the reducers
setCombinerClass (Class<? extends Reducer>)	combine map-outputs before being sent to the reducer It is an optional function during execution
setGroupingComparatorClass (Class<? extends RawComparator>)	Define the comparator that controls which keys are grouped together for a single call to reducer
setSortComparatorClass (Class<? extends RawComparator>)	Define the comparator that controls how the keys are sorted before they are passed to the reducer

Map Phase Steps

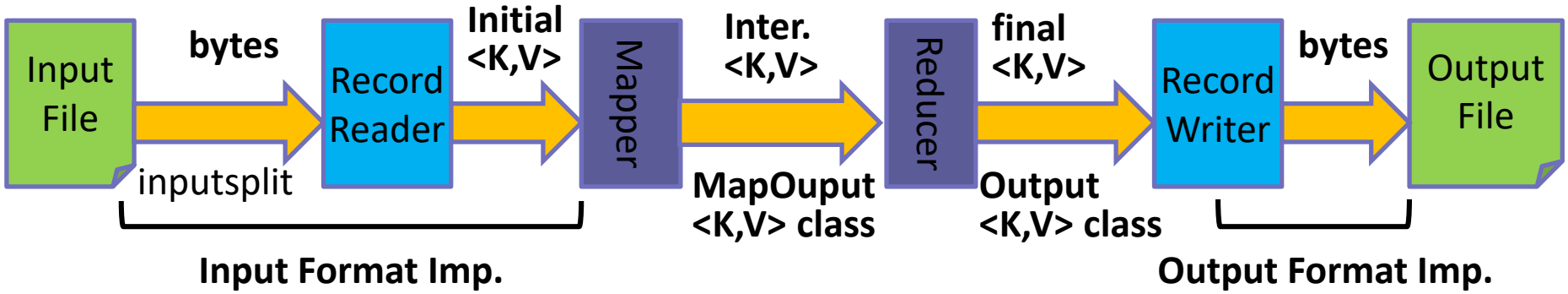


Reduce Phase Steps



Job Configuration on Data Type

Method	Description
setInputFormatClass()	Set the InputFormat **implementation** for the job
setMapOutputKeyClass()	Set the key class for the map output data **Same type as final output if not specify**
setMapOutputValueClass()	Set the value class for the map output data **Same type as final output if not specify**
setOutputKeyClass()	Set the key class for the job output data
setOutputValueClass()	Set the value class for job outputs
setOutputFormatClass()	Set the OutputFormat **implementation** for the job



How many Map/Reduce Tasks?

- The number of map tasks is controlled by the implementation of **inputsplit** in **inputFormat**
  - Default is to split by the **block size of files in HDFS**
  - But it can also be overwritten to split differently
- The number of reduce tasks is controlled by the job configuration: job.setNumReduceTasks(int n)
  - The right number of reduces seems to be 0.95 or 1.75 multiplied by #reduce_slots
  - More reducer ➔ higher framework overhead, better load balancing and lowers failure cost.

Input/Output Format Class

- The MapReduce operates **exclusively** on <K, V> pairs
  - It views the job input as a set of <key, value> pairs and produces a set of <key, value> pairs as the output of the job
- InputFormat: parse input file into a set of <key, value>
  - **TextInputFormat**: Keys are the **position** in the file, and values are the **line of text**.
  - **KeyValueTextInputFormat:** Each line is divided into key and value parts by a **separator byte**. If no such a byte exists, the key will be the entire line and value will be empty.
- OutputFormat: write a set of <key, value> to output file
  - **TextOutputFormat**: writes plain text: key, value, and "\r\n".

Key-Value Pair Class

- Both ***key*** and ***value*** must implement *Writiable* interface
  - *A* serializable object which implements a simple, efficient, serialization protocol, based on **DataInput** and **DataOutput**
- ***Key*** also implements the interface of *WritableComparable*
  - Because key must be sorted by the framework
- Default supported types includes:
  - BooleanWritable, BytesWritable, DoubleWritable, FloatWritable, IntWritable, LongWritable, Text, NullWritable

WordCount: Main()

```
public static void main(String[] args) throws Exception {
    Configuration conf = new Configuration();
    Job job = Job.getInstance(conf, “world count”);
    job.setJarByClass(WordCount.class);

    job.setMapperClass(Tokenizer.class); // Tokennizer is the mapper function
    job.setCombiner(IntSum.class);
    job.setReducerClass(IntSum.class); // IntSum is the reducer function

    //FileInputFormat is the base class for all file-based InputFormats
    FileInputFormat.addInputPaths(job, new Path(args[0]));
    FileOutputFormat.addOutputPath(job, new Path(args[1]));

    job.setInputFormat(TextInputFormat.class); // inputs are texts
    job.setOutputFormat(TextOutputFormat.class); // outputs are texts

    job.setOutputKeyClass(Text.class); // intermediate and final key is text
    job.setOutputValueClass(IntWritable.class); // intermediate and final value is int

    job.waitForCompletion(true); // Submit the job and wait for it to finish
}
```

Mapper

- Mapper maps input key/value pairs to a set of intermediate key/value pairs
  - The transformed intermediate records do **NOT** need to be the same type as the input records.
  - A given input pair may map to **zero** or **many** output pairs.
- Each key/value pair is applied with a map function:
  - **map**(WritableComparable, Writable, Context)
  - **<WritableComparable, Writable>** are the input key-value pairs generated by the **InputFormat class**
  - **context.write(K, V)** collects output key-value pairs

Mapper

Input <K,V> type from InputFormat

Default <K,V> type for final output

```
public static class Tokenizer extends Mapper <Object, Text, Text, IntWritable> {
    private final static IntWritable one = new IntWritable(1);
    private Text word = new Text();
    public void map(Object key, Text value,  Context context)
                    throws IOException {
        String line = value.toString();
        StringTokenizer iter = new StringTokenizer(line);
        while (iter.hasMoreTokens()) {   // each line has multiple words
            word.set(iter.nextToken());
            context.write(word, one);
        }
    }
}
```

<K,V> must be private var to the class

Set the var value
Don't declare a new var here

```
main():
    job.setOutputKeyClass(Text.class);
    job.setOutputValueClass(IntWritable.class);
    job.setMapperClass(Tokenizer.class);
    job.setInputFormat(TextInputFormat.class);
```

Reducer

- Reducer reduces a set of intermediate values which share a key to a smaller set of values.
  - The transformed intermediate records do **NOT** need to be the same type as the input records.
  - A given input pair may map to **zero** or **many** output pairs.
- Each **group** of (K,V) pair applied with a reduce func:
  - reduce(WritableComparable, **Iterator<**Writable**>**, Context)
  - **WritableComparable** is the input key-value pairs generated by the **mapper class**
  - **Iterator<**Writable**>** is the **list of values grouped by the same key**
  - **context.write(K, V)** collects output key-value pairs

Reducer

Output <K,V> type

```
public static class IntSum extends
        Reducer<Text, IntWritable, Text, IntWritable>
{
    private IntWritable result = new IntWritable();
    public void reduce(Text key, Iterator<IntWritable> values,
        Context context) throws IOException, InterruptedException
    {
      int sum = 0;
      while (values.hasNext())  sum += values.next().get();
      result.set(sum);
      context.write(key, result);
    }
}
```

Set the var value
Don't declare a new var here

```
main():
    job.setOutputKeyClass(Text.class);
    job.setOutputValueClass(IntWritable.class);
    job.setReducerClass(IntSum.class);
    job.setOutputFormat(TextInputFormat.class);
```

Compilation & Execution

- Input files:
  - $ bin/hadoop fs -cat /user/joe/wordcount/input/file01

    Hello World, Bye World!
  - $ bin/hadoop fs -cat /user/joe/wordcount/input/file02

    Hello Hadoop, Goodbye to hadoop.
- Compile WordCount.java and create a jar
  - $ bin/hadoop com.sun.tools.javac.Main WordCount.java
  - $ jar cf wc.jar WordCount*.class
- Run applications
  - bin/hadoop jar wc.jar WordCount
    /user/joe/wordcount/input
    /user/joe/wordcount/output
- Check output
  - $ bin/hadoop fs –cat /user/joe/wordcount/output/part-r-00000

Bye 1
Goodbye 1
Hadoop, 1
Hello 2
World! 1
World, 1
hadoop. 1
to 1

Print Out Message

- Hadoop comes with preconfigured log4j

```
import org.apache.commons.logging.Log;
import org.apache.commons.logging.LogFactory;
```

- define logger inside your mappers, or any other class

```
private static final Log LOG = LogFactory.getLog(MyClass.class);
```

- Log your info

```
LOG.info("My message");
```

- Check your log through YARN

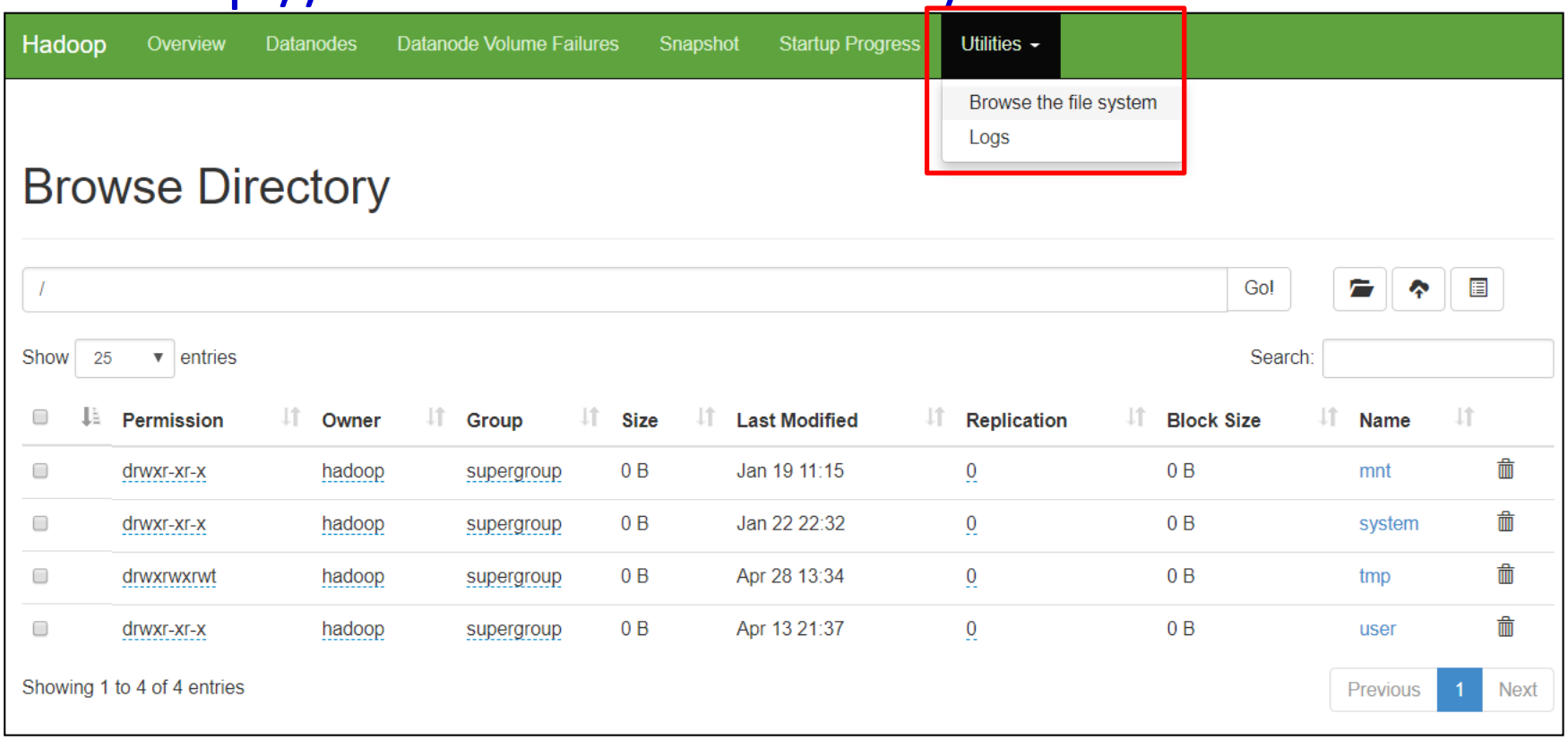
```
yarn logs -applicationId application_XXXXX_XXXX
```

Hadoop Web Portal

- HDFS Status
  - http://140.114.91.183:50070
- MapReduce Job Tracker
  - http://140.114.91.183:8088
- Job History
  - http://140.114.91.183:19888

HDFS Status

- Browser HDFS on web console
  - http://140.114.91.183:50070/dfshealth.html#tab-

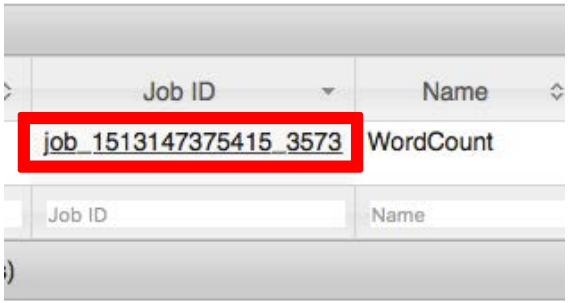


MapReduce Job History

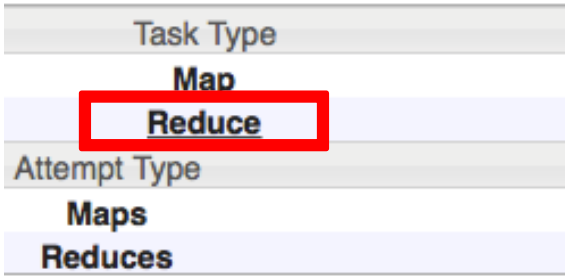
- Check the log file on web console
  - Access Job History Server:

http://140.114.91.183:19888/jobhistory

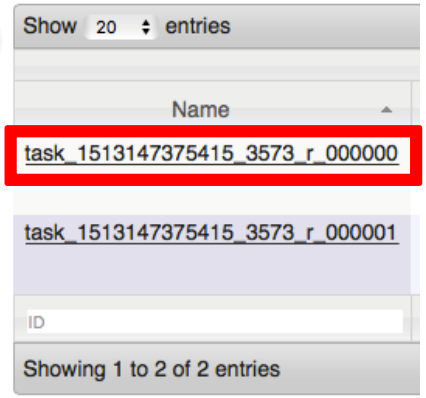
1



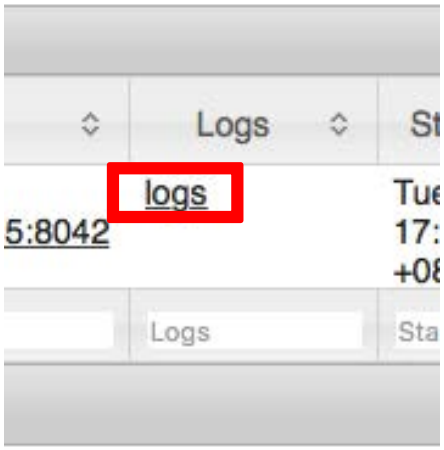
2



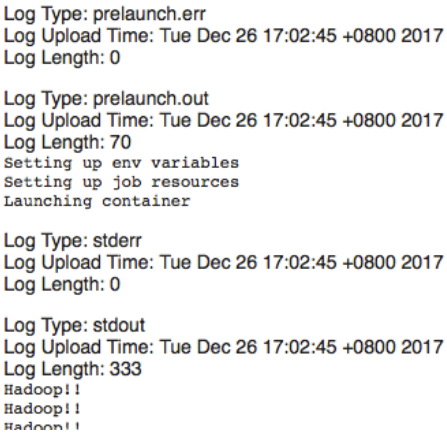
3



4



5



Custom key & value types

Combiner

Partitioner

GroupingComparator

SortComparator

ADVANCED PROG.

Custom Value Types

- *Value in* 3-dimensional coordinate

  struct point3d { float x; float y; float z; }

- Implement *Writable* interface
  - write: data serialization
  - readFields: data de-serialization

```
public class Point3D implements Writable {
    private float x; private float y; private float z;
    public Point3D(float x, float y, float z)  { this.x = x; this.y = y; this.z = z; }
    public void write(DataOutput out) throws IOException {
            out.writeFloat(x); out.writeFloat(y); out.writeFloat(z);
    }
    public void readFields(DataInput in) throws IOException
            { x = in.readFloat(); y = in.readFloat(); z = in.readFloat(); }
}
```

Custom Key Types

- *Key in* 3-dimensional coordinate

  struct point3d { float x; float y; float z; }

- Implement all functions in the ***writable*** interface
  - write(), readFields()
- Implement additional functions in the ***writablecomparable*** interface
  - compareTo(): used for **sorting**
    - Compares this object with the specified object for order. Returns a negative integer, zero, or a positive integer as this object is less than, equal to, or greater than the specified object.
  - hashCode(): used for **partitioning**

Custom Key Types

```
public class Point3D implements WritableComparable <Point3D> {
    private float x; private float y; private float z;
    public 3DPoint (){x=0.0f; y=0.0f; z=0.0f;}
    public void set(float x, float y, float z)  { this.x = x; this.y = y; this.z = z; }
    public float distanceFromOrigin() {
            return (float)Math.sqrt(x*x + y*y + z*z);
    }
    public int compareTo(Point3D other) {
            float myDistance = distanceFromOrigin();
            float otherDistance = other.distanceFromOrigin();
            return Float.compare(myDistance, otherDistance);
    }
    public int hashCode() {
            return Float.floatToIntBits(x) ^ Float.floatToIntBits(y) ^
            Float.floatToIntBits(z);
    }
    // overwrite other methods in Writable interface:  write & readFields
}
```

Use Case Example

- Given a list of 3D-coordinates, sort them in order in each of the output file:
  - **key type**: Point3D
  - **Value type**: NullWritable
  - **Mapper**: map each line to {<x,y,z>, Null}
  - **Reducer**: write key to file

➔Data is sorted automatically by Key in the MapReduce process

Point3D Sorting Example

```
public class TestPoint3D {
  public static class TokenizerMapper
      extends Mapper<Object, Text, Point3D, NullWritable>
  {
    private Point3D point = new Point3D();
    public void map(Object key, Text value, Context context
                ) throws IOException, InterruptedException {
       String line  = value.toString();
       String[] tokens = line.split(",");
       float x = Float.parseFloat(tokens[0]);
       float y = Float.parseFloat(tokens[1]);
       float z = Float.parseFloat(tokens[2]);
       point.set(x,y,z);
       context.write(point, NullWritable.get());
     }
  }
```

Input file:
0,0,0
1,0,2
4,4,4
2,2,2

Output file:
0,0,0
1,0,2
2,2,2
4,4,4

```
main():
    job.setOutputKeyClass(Point3D.class);
    job.setOutputValueClass(NullWritable.class);
    job.setMapClass(Tokenizer.class);
```

Custom key & value types

Combiner

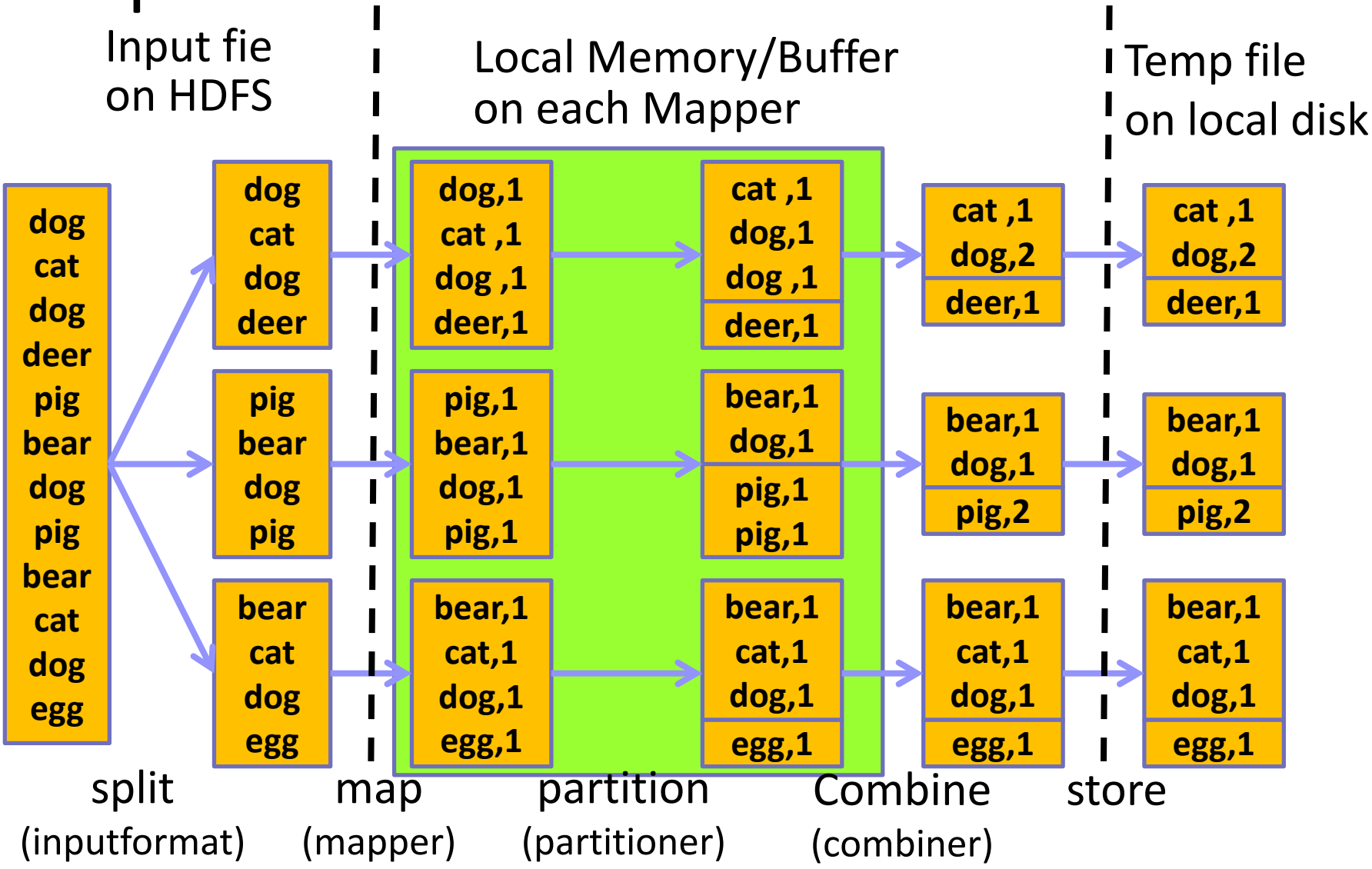
Partitioner

GroupingComparator

SortComparator

ADVANCED PROG.

Map Phase: Partitioner



Map Phase: Partitioner

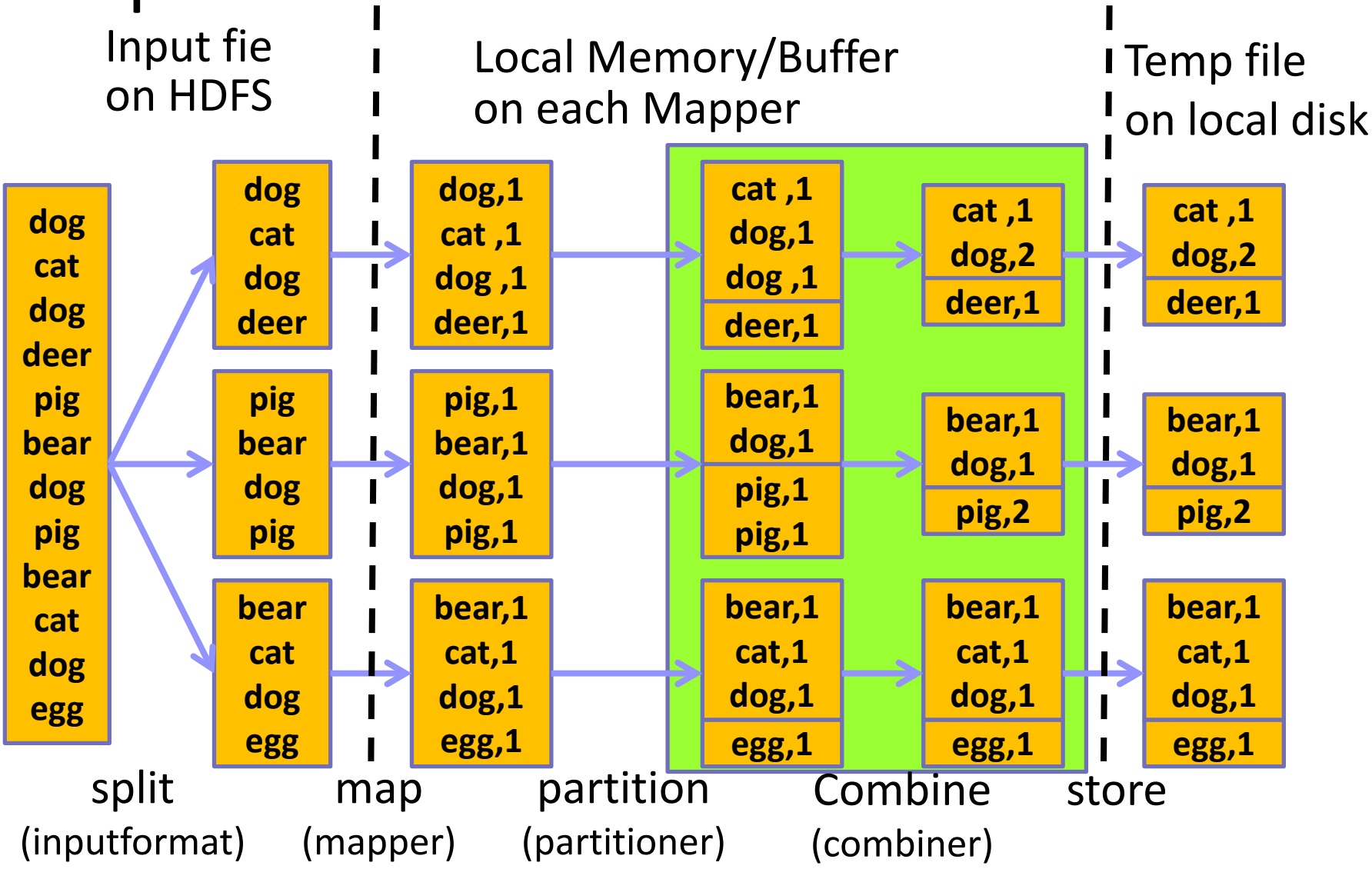
- Partitioner decides which intermediate (K,V) pair is sent to which reducer
- The total number of partitions is the same as the number of reduce tasks for the job.
- Default partitioner: "**HashPartitioner**"
- Write a custom Partitioner:

```
public class MyPartitioner implements Partitioner<Point3D, Writable> {
    public int getPartition(Point3D key, Writable value, int numPart) {
        return Math.abs(key.hashCode()) % numPart;
    }
}
```

Total number of partitions

```
main(){
    job.setPartitionerClass(MyPartitioner.class);
}
```

Map Phase: Combiner



Map Phase: Combiner

- An OPTIONAL **optimization** step in mapping phase
  - Combiner combines map-outputs before being sent to the reducers ➔ reduce intermediate file size and transfer time
  - Combiner could be run **many** or **ZERO** time ➔ program results can't depend on combiner
  - <K,V> data type must be the **same** for INPUT & OUTPUT
    - Reducer can emit a different output type to file
  - Reducer and combiner could be but NOT ALWAYS the same
    - E.g.: compute the avg of each key
    - MEAN({1,2,3,4,5}) ≠ MEAN(MEAN({1,2}),MEAN({3,4,5}))
  - Some problem can be difficult to apply combiner
    - E.g.: Find the median value of each key

Custom key & value types

Combiner

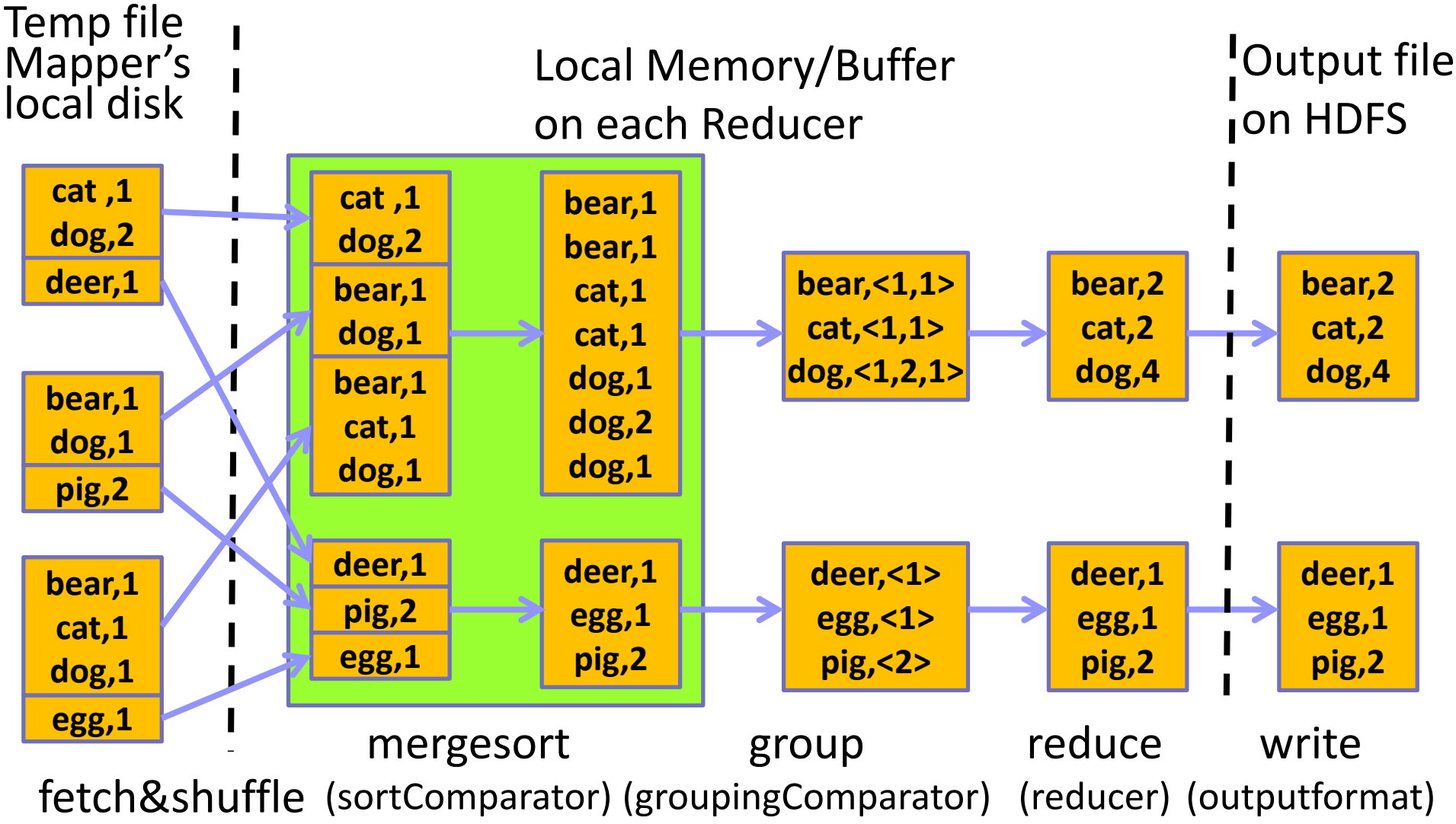
Partitioner

GroupingComparator

SortComparator

ADVANCED PROG.

Reduce Phase: sortComparator



Reduce Phase: sortComparator

- <K,V> pairs are sorted by ***key*** using a comparator class called the **sortComparator**
  - The comparator can be set by "**job.setSortComparatorClass()**"
  - The comparator must implement the "***rawComparator***" **interface** *or extend* "***writeComparator***" ***class***
    - Override the function: **compare**
- Implementation:
  - Mergesort is used by the framework to effectively merge the output from mappers, and sort the result in one stage

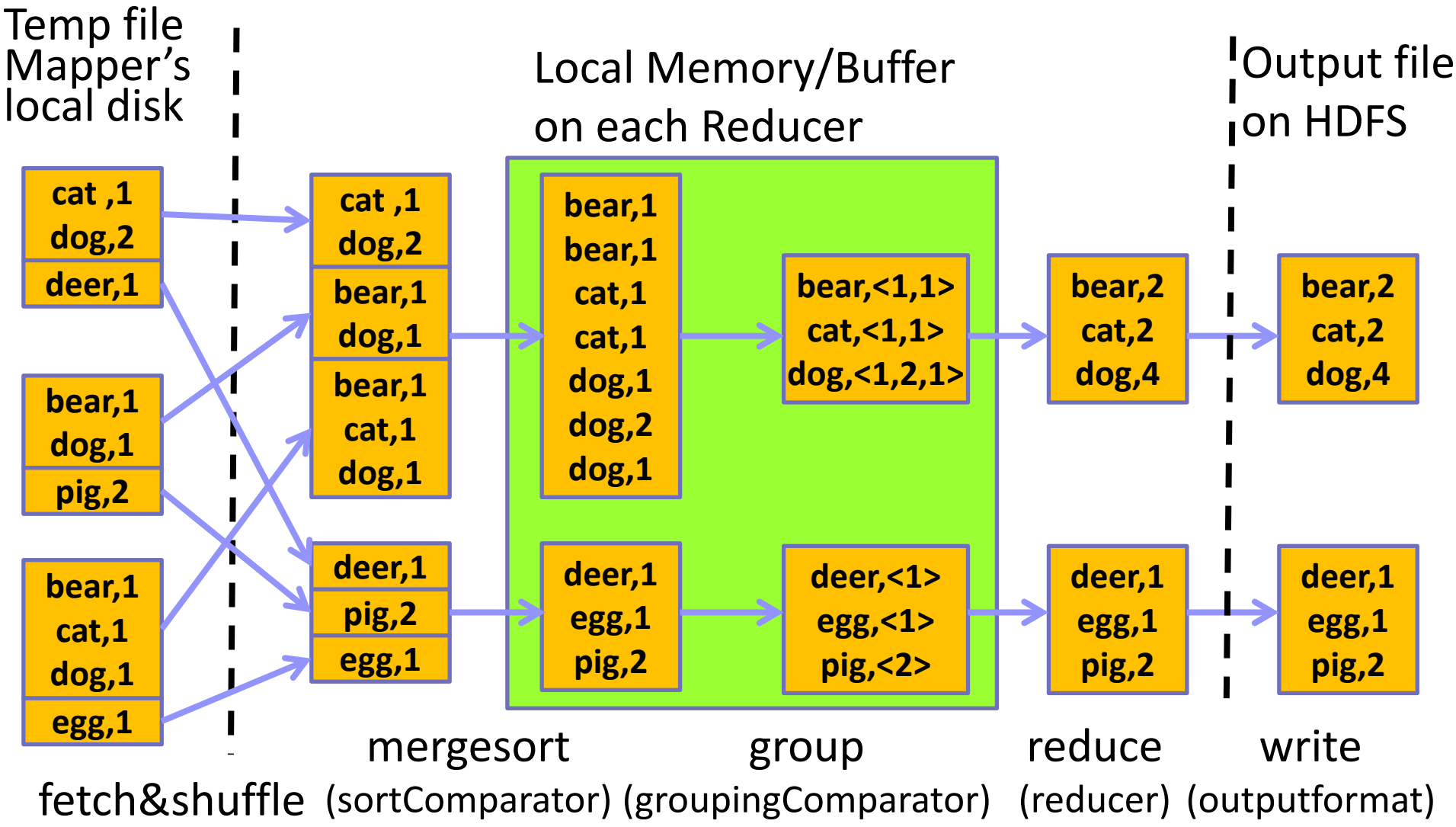
Reduce Phase: sortComparator

- Let keys in the form of <string1>:<string2>
- Sort keys in the ascending order of <string1>

```
public static class MySortComprator extends WritableComparator {
    protected MySortComprator() { super(Text.class, true); }
    public int compare(WritableComparable w1,
                       WritableComparable w2) {
        Text t1 = (Text) w1;
        Text t2 = (Text) w2;
        String[] t1Items = t1.toString().split(":");
        String[] t2Items = t2.toString().split(":");
        return t1Items[0].compareTo(t2Items[0]);
    }
}
```

```
main(){
    job.setSortComparatorClass(MySortComparator.class);
}
```

Reduce Phase: groupingComparator



Reduce Phase: groupingComparator

- <K,V> pairs are grouped together if their ***keys*** are compared as equal by using a comparator called **groupingComparator**
  - The comparator can be set by "**job.setGroupingComparatorClass()**"
  - The comparator must implement the "***rawComparator***" **interface** *or extend* "***writeComparator***" ***class***
    - Override the function: **compare**

- If multiple keys in the same group, "**sortComparator**" is used to decide the key for the group
  - Input: <A1, V1>, <A2, V2>, <A3, V3>, <B1, V4>, <B2, V5>
  - Grouping comparator to just compare the first letter
  - Output: (A1, {V1,V2,V3}); (B1, {V4,V5});

Reduce Phase: groupingComparator

- Only compare the first letter

```
public static class  MyGroupComp extends WritableComparator {
    protected MyGroupCom() { super(Text.class, true); }
    public int compare(WritableComparable w1,
                       WritableComparable w2) {
        Text t1 = (Text) w1;          Text t2 = (Text) w2;
        int t1char = t1.charAt(0);    int t2char = t2.charAt(0);
        if (t1char < t2char) return -1;
        else if (t1char > t2char) return 1;
        else return 0;
     }
}
```

```
main(){
   job.setGroupingComparatorClass(MyGroupComp.class);
}
```

SECONDARYSORT EXAMPLE

SecondarySort

- What is SecondarySort?
  - **Sorting values** associated with a key in the reduce phase
- Examples:
  - Input: A dump of the temperature data with 4 columns year, month, day, daily_temperature

```
2012, 01, 01, 5
2012, 01, 02, 45
2012, 01, 03, 35
…
2001, 11, 01, 46
2001, 11, 02, 47
2001, 11, 03, 48
```

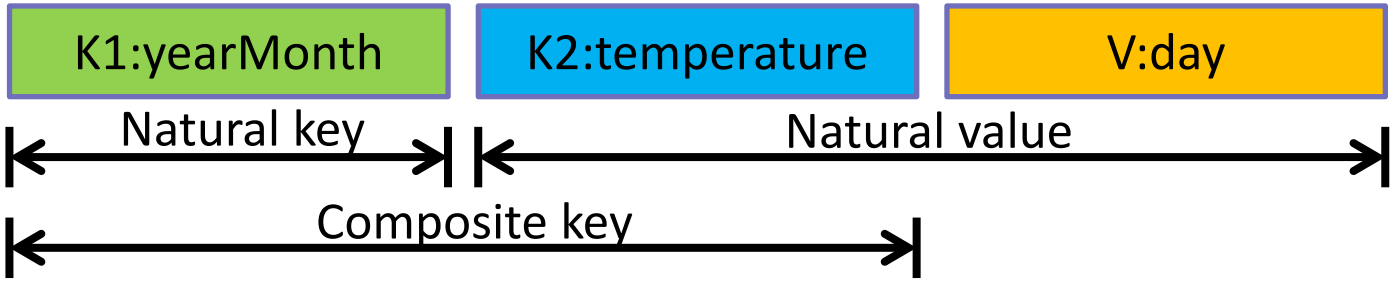
  - Output: The temperature for every year-month with the values sorted

```
2012-01: 5, 35, 45
2001-11, 46, 47, 48
….
```

SecondarySort

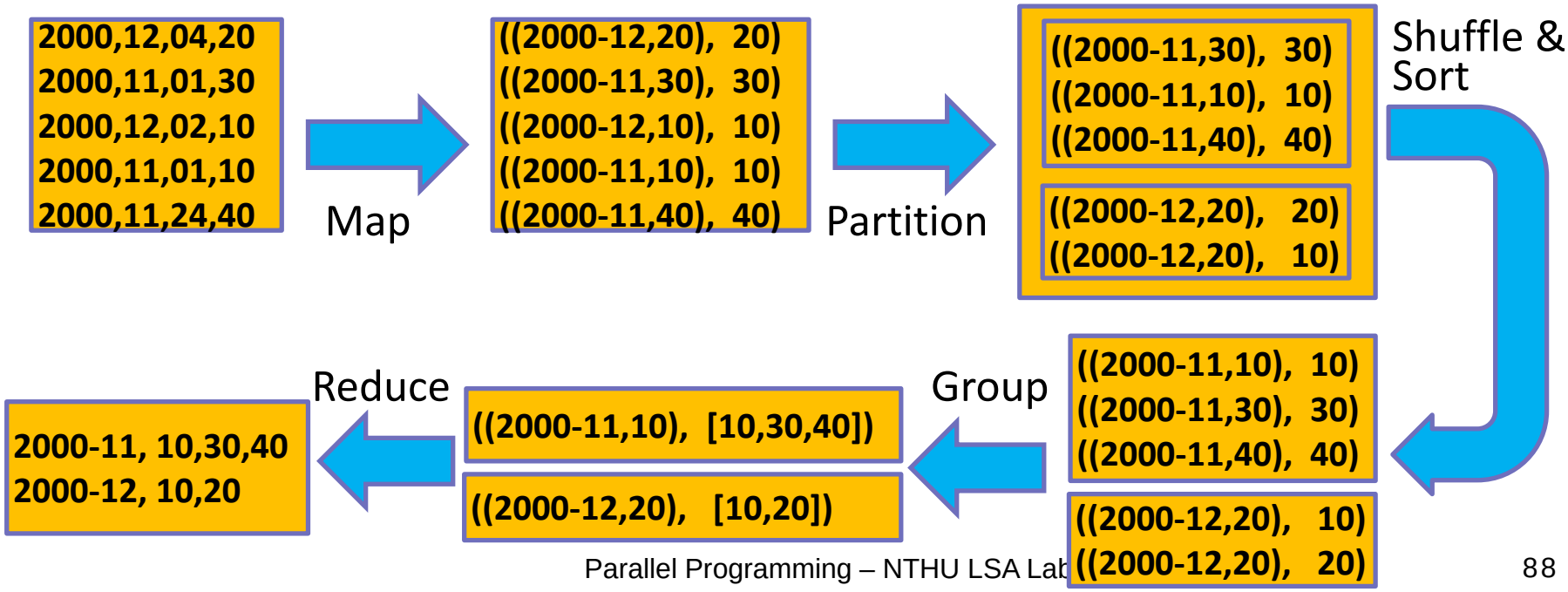
- Soltion1:
  - having the reducer **buffer all of the values** for a given *key*
  - then doing an **in-reducer sort** on the values

  ➔might cause the reducer to run out of memory
- Solution2:
  - Trick MapReduce to sort the reducer values
  - *Value-to-Key Conversion* design pattern: "Creating a **composite key** by adding a part of, or the entire value to, the natural key to achieve your sorting objectives"



SecondarySort

- Implementation details:
  - Map Output Key: {yearMonth}+{temperature}
  - Map Output Value: temperature
  - Partitioner: by yearMonth
  - sortComparator: by yearMonth and then ascending temp.
  - groupingComparator: by yearMonth



Reference

- Distributed system lecture slides from Gregory Kesden
- Jeffrey Dean and Sanjay Ghemawat. MapReduce: Simplified Data Processing on Large Clusters. Proceedings of the 6th Symposium on Operating System Design and Implementation (OSDI 2004), pages 137-150
- Hadoop tutorial:
  - https://hadoop.apache.org/docs/current/hadoop-mapreduce-client/hadoop-mapreduce-client-core/MapReduceTutorial.html

DistributedCache

- What is it?
  - A facility provided by the Map-Reduce framework to **cache read-only files** (text, archives, jars etc.) needed by applications on compute nodes
  - The framework will copy the necessary files on to the slave node before execution, and remove them automatically after execution
- What is it for?
  - Distribute dictionary text for mapper and reducer
  - Map-side join: cache the smaller table
  - As a rudimentary software distribution mechanism: jar files
- How to specify the cached files?
  - The files are specified via urls (hdfs:// or http://) of a **file system**
  - The url must be accessible by every machine in the cluster

Example

- Copy the requisite files to the FileSystem:

```
$ bin/hadoop fs -copyFromLocal [local_src_files] [hdfs_dst_dir]
```

- Setup the application's job in main()

```
job.addCacheFile(new URI("/myapp/lookup.dat"));
job.addCacheArchive(new URI("/myapp/map.zip");
job.addFileToClassPath(new Path("/myapp/mylib.jar"));
```

- Use the cached files in the Mapper or Reducer through the context object and

```
import org.apache.hadoop.fs.FileSystem;
import java.net.URI;
import java.io.BufferedReader;
import java.io.InputStreamReader;
```

```
Configuration conf = context.getConfiguration();
FileSystem fs = FileSystem.get(conf);
URI[] cacheFiles = context.getCacheFiles();
Path filePath = new Path(cacheFiles[0].getPath());
BufferedReader bf = new BufferedReader(
        new InputStreamReader(fs.open(filePath)));
```