Western

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Reference

- Reference: Dean, J. and Ghemawat, S. **MapReduce: simplified data processing on large clusters.** *Communication of ACM* 51, 1 (Jan. 2008), 107-113.

Google Search Statistics

- Google now processes 40,000 search queries every second (on average)
- This is about 3.5 billion searches per day or 1.2 trillion searches per year

- Lots of data to process

Need ….

- A single machine cannot serve all the data
- You need a distributed system to store and process in parallel

However,….

- Parallel programming?
  - Communication between nodes
  - Handle machine failures
- Non-trivial!

Google’s answer

MapReduce and
Underlying infrastructure

MapReduce Overview

- What is it?
  - Programming model used by Google
  - A combination of the Map and Reduce operations
  - Used for analyzing large data sets

MapReduce Overview

- MapReduce is highly scalable and can be used across many computers.

- Many small machines can be used to process jobs that normally could not be processed by a large machine.

Before MapReduce

- Large scale data processing was difficult
  - Managing hundreds or thousands of processors
  - Managing parallelization and distribution
  - I/O scheduling
  - Status and monitoring
  - Fault/crash tolerance

Programming Model

- Programmers specify two functions
  - Map
  - Reduce
- Inspired from map and reduce operations commonly used in functional programming languages like Lisp
- Have multiple workers (processes) on multiple machines run either map or reduce

Map Operation

- Map: (key_i,$value_i$) -> (key_j,$value_j$)
  - Input: A key/value pair
  - Output: A key/value pair
- Evaluation
  - Function defined by user
  - Applies to every value in value input
    - Might need to parse input
- Produces a new list of key/value pairs
  - Can be of different type from input pair

Example Use of Map Operation

- Example Input:
  - Page 1: the weather is good
  - Page 2: today is good
  - Page 3: good weather is good.
- Essentially:
  - The page numbers are keys
  - The page contents are values

Key

Value

Example Use of Map Operation

- The map function is user defined and for this example:
  - Takes each word, w, on the page and creates an intermediate pair
    - (w,1)
- Assume each page is assigned to a worker (process)
  - Individual pages can be processed in parallel

Example Map output

- Worker 1:
  - (the 1), (weather 1), (is 1), (good 1)
- Worker 2:
  - (today 1), (is 1), (good 1)
- Worker 3:
  - (good 1), (weather 1), (is 1), (good 1)

Reduce Operation

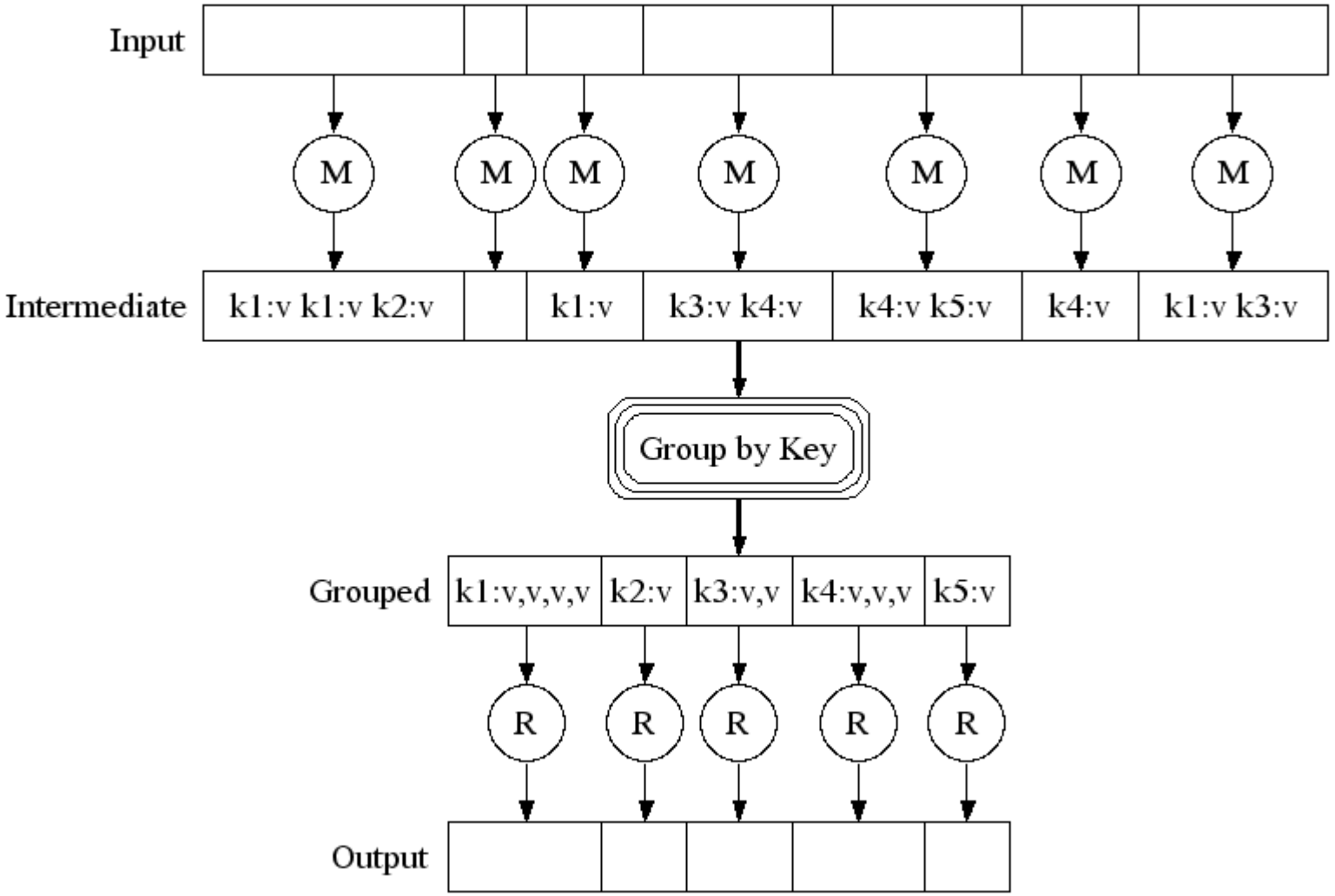
- Reduce: $(key_i, [val_i]) \rightarrow [val_k]$
- All the intermediate values for a given output key (resulting from the map operation) are combined together into a list for each intermediate key
  - $(key_j\ [val_j])$
- A reduce function is applied to $[val_j]$ resulting in $[val_k]$

Example: Intermediate Key Value Pairs

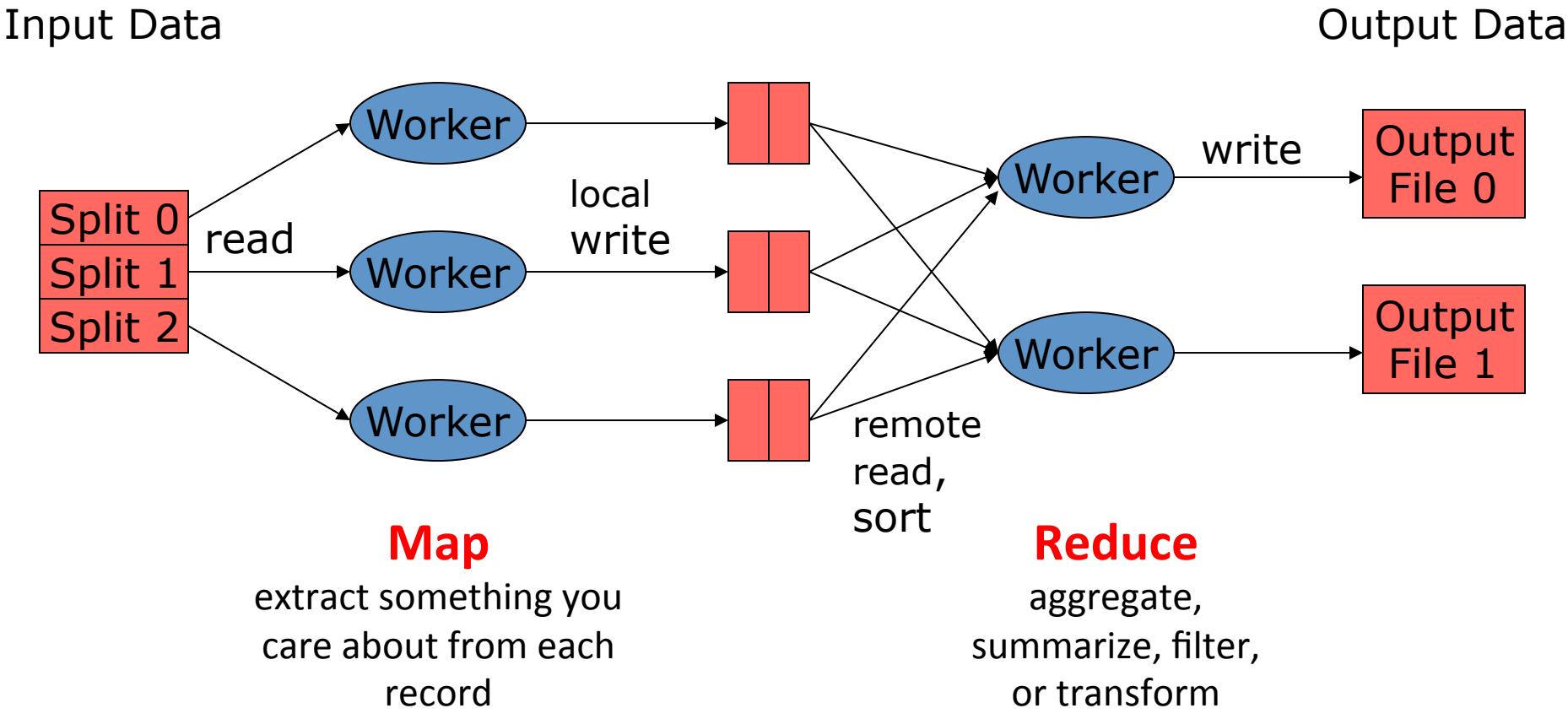
- (the [1])
- (is [1 1 1])
- (weather [1 1 1])
- (today [1])
- (good [1 1 1 1])

- The above is input to a reduce function which essentially sums the 1's

Execution


Input
M
M
M
M
M
M
M
Intermediate
k1:v k1:v k2:v
k1:v
k3:v k4:v
k4:v k5:v
k4:v
k1:v k3:v
Group by Key
Grouped
k1:v,v,v,v
k2:v
k3:v,v
k4:v,v,v
k5:v
R
R
R
R
R
Output

MapReduce Workflow



Example Code: Map

```
 public static class MapClass extends MapReduceBase
   implements Mapper<LongWritable, Text, Text, IntWritable>
{

   private final static IntWritable one = new IntWritable(1);
   private Text word = new Text();

   public void map(LongWritable key, Text value,
                   OutputCollector<Text, IntWritable> output,
                   Reporter reporter) throws IOException {
     String line = value.toString();
     StringTokenizer itr = new StringTokenizer(line);
     while (itr.hasMoreTokens()) {
       word.set(itr.nextToken());
       output.collect(word, one);
     }
   }
 }
```

Example Code: Code

```
/**
 * A reducer class that just emits the sum of the input values.
 */
public static class Reduce extends MapReduceBase
 implements Reducer<Text, IntWritable, Text, IntWritable> {

 public void reduce(Text key, Iterator<IntWritable> values,
                    OutputCollector<Text, IntWritable> output,
                    Reporter reporter) throws IOException {
   int sum = 0;
   while (values.hasNext()) {
     sum += values.next().get();
   }
   output.collect(key, new IntWritable(sum));
 }
}
```

You write…

- Map, reduce,
- Lauching program
  - Defines job
  - Submits job to cluster

More Examples

Example: Distributed Grep (1)

- Find all occurrences of a given pattern in a file (or set of files)
- Input
  - Key: (url+offset)
  - Value: Line
- Map function
  - If line contents match specified pattern, emit (line, 1)

Example: Distributed Grep (2)

- Intermediate key-value pair
  - key: (url+offset)
  - Intermediate value: the list of unique counts
- Reduce function
  - Example of input to reduce is essentially (line, [1,1,1,1])
  - Don't do anything; just emit line

Example: Count of URL Access Frequency

- Map function
  - Input: <log of web page requests, content of log>
  - Outputs: <URL, 1>
- Reduce function adds together all values for the same URL

Example: Web Structure

- Simple representation of WWW link graph
  - Map
    - Input: (URL, page-contents)
    - Output: (URL, list-of-URLs)
- Who maps to me?
  - Map
    - Input: (URL, list-of-URLS)
    - Output: For each u in list-of-URLS output <u,URL>
  - Reduce: Concatenates the list of all source URLs associated with u and emits (u, list(URL))

Big Data

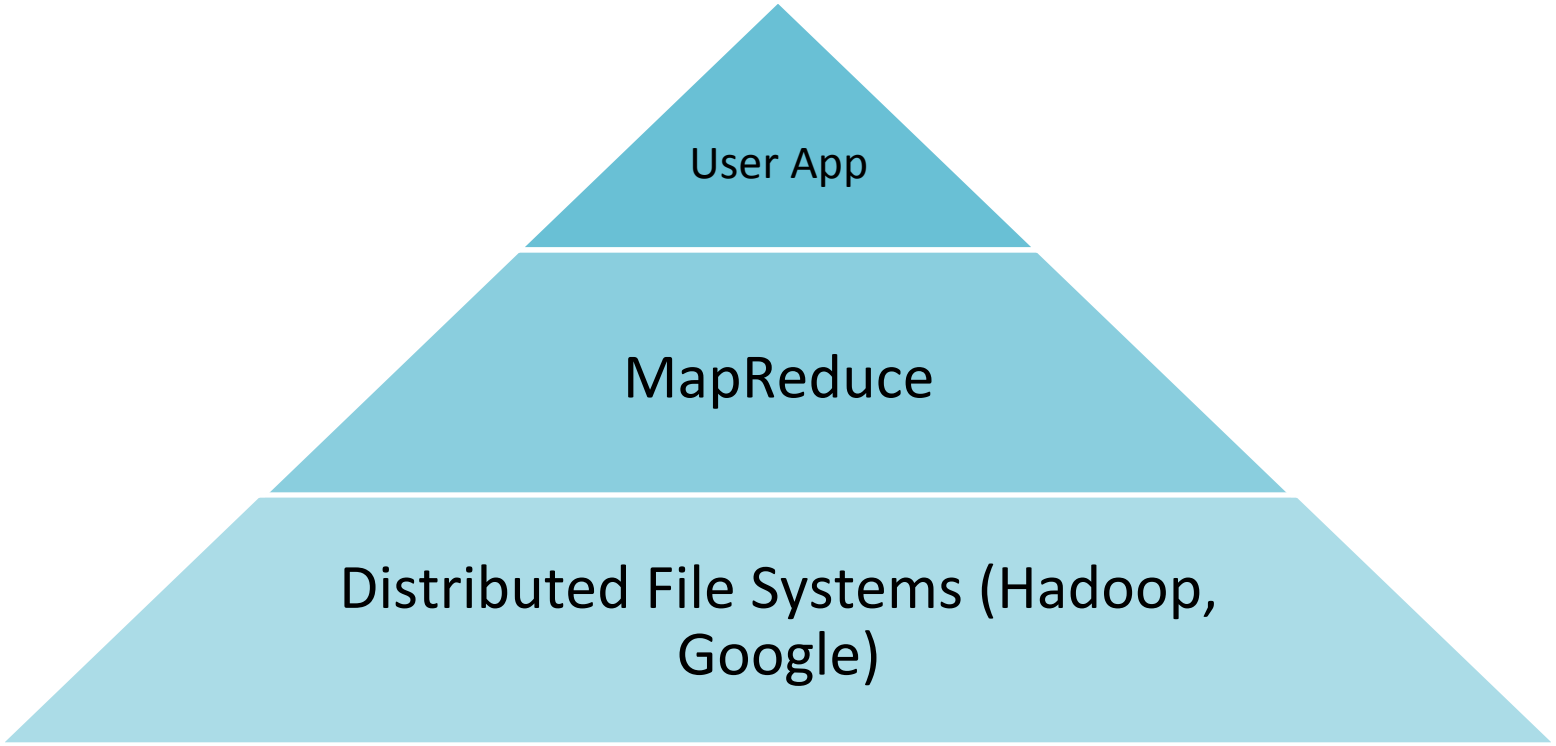
- Google knows how to deal with “big data”
- Not just for Google
- Can be used for any data analysis with
  - Large amounts of data that can be split into pieces for processing

Limitations

- Not for real-time analysis
- Not good for streaming data
- Not all data analysis is suitable for MapReduce
  - Example: SVM
- Too many keys – sort is high

Support for MapReduce

Systems Support for MapReduce



The Infrastructure

- Large clusters of commodity PCs and networking hardware
- Clusters consist of 100/1000s of machines
  - Failures are common
- Google File System (GFS)
  - Distributed file system
  - Provides replication of the data

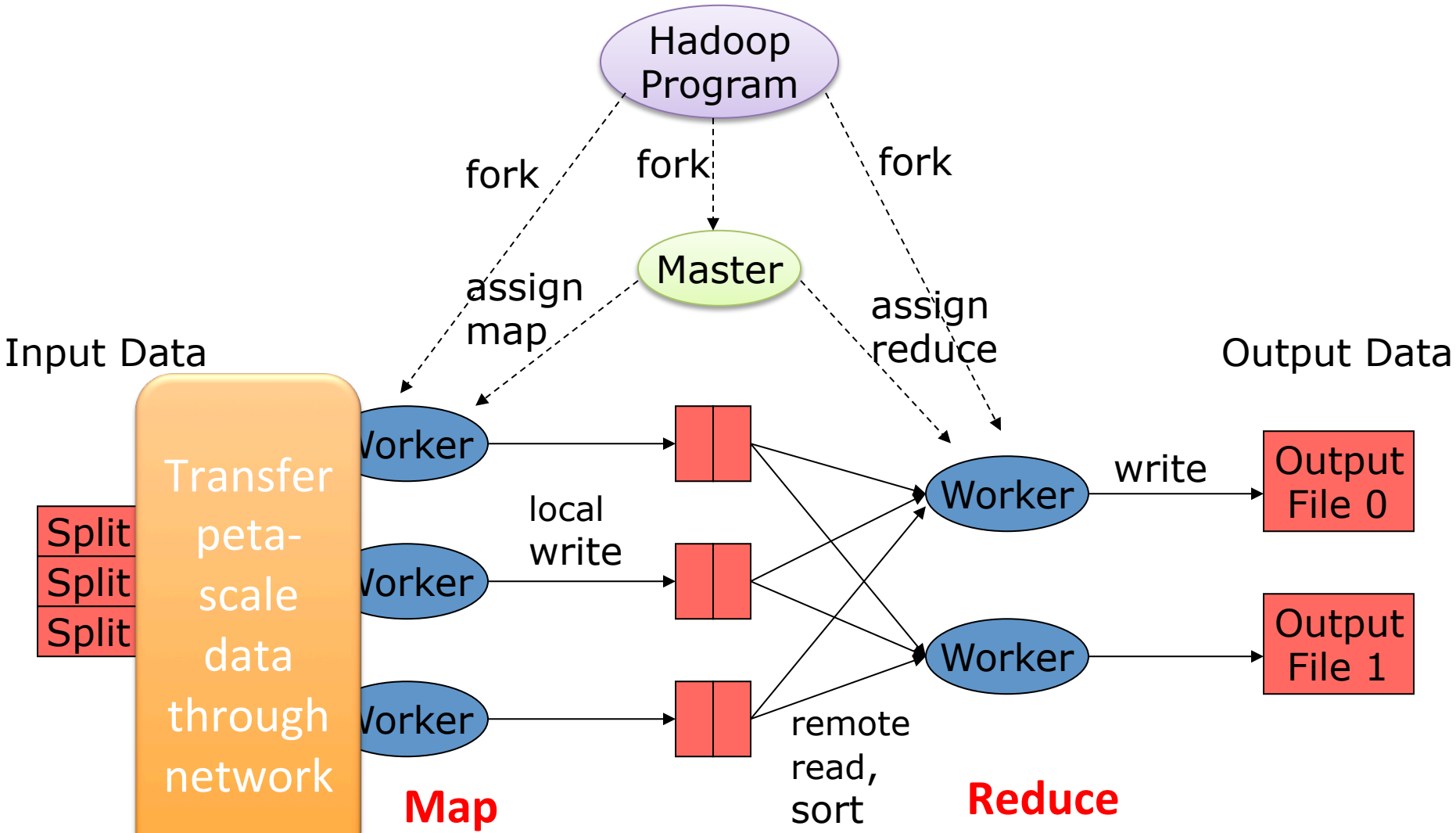
Infrastructure

- Users submit jobs to a scheduling system
- Possible partitions of data can be based on files, databases, file lines, database records, etc

Execution

- Map invocations are distributed across multiple machines by automatically partitioning the input data into a set of M splits
- The input splits can be processed in parallel by different machines
- Reduce invocations are distributed by partitioning the intermediate key space into R pieces using a hash function: hash(key) mod R
- R is specified by the programmer

MapReduce


Hadoop Program
fork
fork
fork
Master
assign map
assign reduce
Input Data
Output Data
Split
Split
Split
Transfer peta-scale data through network
Worker
Worker
Worker
local write
Worker
Worker
write
Output File 0
Output File 1
remote read, sort
Map
Reduce

Failure in MapReduce

- Failures are the norm in commodity hardware
- Worker failure
  - Detect failure via periodic heartbeats
  - Re-execute task
- Master Failure
  - Single point of failure; resume from execution log
- Robust
  - Google's experience: Lost 1600 of 1800 machines but finished fine