# Map Reduce and Hadoop

# In this Lecture:

- Outline:
  - What is Big Data?
  - Issues with Big Data
  - What is Hadoop ?
  - What is Map Reduce ?
  - Example Map Reduce program.

# Motivation: Google Example

- 20+ billion web pages x 20KB = 400+ TB
- 1 computer reads 30-35 MB/sec from disk
  - ~4 months to read the web
- ~1,000 hard drives to store the web
- Takes even more to do something useful with the data!
- Today, a standard architecture for such problems is emerging:
  - Cluster of commodity Linux nodes
  - Commodity network (ethernet) to connect them

# Large-scale Computing

- Large-scale computing for data mining problems on commodity hardware
- Challenges:
  - How do you distribute computation?
  - How can we make it easy to write distributed programs?
  - Machines fail:
    - One server may stay up 3 years (1,000 days)
    - If you have 1,000 servers, expect to loose 1/day
    - People estimated Google had ~1M machines in 2011
  - 1,000 machines fail every day!

# Big Data Challenges

- Scalability: processing should scale with increase in data.
- Fault Tolerance: function in presence of hardware failure
- Cost Effective: should run on commodity hardware
- Ease of use: programs should be small
- Flexibility: able to process unstructured data
- **Solution: Map Reduce !**

# Idea and Solution

- **Issue:** Copying data over a network takes time
- **Idea:**
  - Bring computation close to the data
  - Store files multiple times for reliability
- Map-reduce addresses these problems
  - Elegant way to work with big data
  - Storage Infrastructure – File system
    - Google: GFS. Hadoop: HDFS
  - Programming model
    - Map-Reduce

# Storage Infrastructure

- **Problem:**
  - If nodes fail, how to store data persistently?
- **Answer:**
  - Distributed File System:
- Provides global file namespace
- Google GFS; Hadoop HDFS;
- Typical usage pattern
  - Huge files (100s of GB to TB)
  - Data is rarely updated in place
  - Reads and appends are common

# What is Hadoop ?

- A scalable fault-tolerant distributed system for data storage and processing.
- Core Hadoop:
  - Hadoop Distributed File System (HDFS)
  - Hadoop YARN: Job Scheduling and Cluster Resource Management
  - Hadoop Map Reduce: Framework for distributed data processing.
- Open Source system with large community support.
  - https://hadoop.apache.org/

# What is Map Reduce ?

- Method for distributing a task across multiple servers.
- Proposed by Dean and Ghemawat, 2004.
- Consists of two developer created phases:
  - Map
  - Reduce
- In between Map and Reduce is the Shuffle and Sort phase.
- User is responsible for casting the problem into map – reduce framework.
- Multiple map-reduce jobs can be “chained”

# Programming Model: MapReduce

- Warm-up task:
- We have a huge text document
- Count the number of times each distinct word appears in the file
- Sample application:
  - Analyze web server logs to find popular URLs

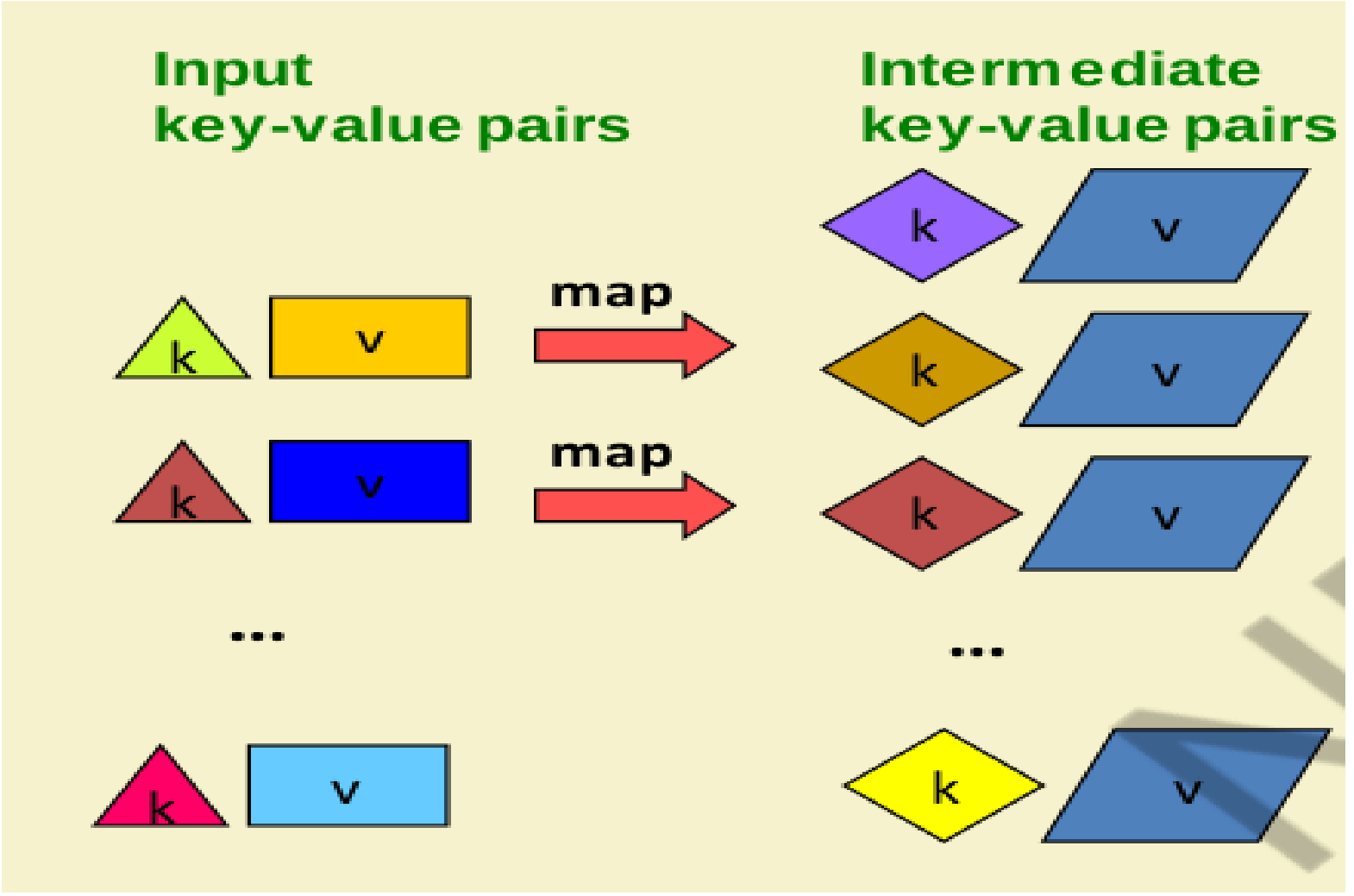
# Task: Word Count

- Case 1:
  - File too large for memory, but all <word, count> pairs fit in memory
- Case 2:
- Count occurrences of words:
    - words(doc.txt) | sort | uniq -c
      - where words takes a file and outputs the words in it, one per a line
- Case 2 captures the essence of MapReduce
  - Great thing is that it is naturally parallelizable

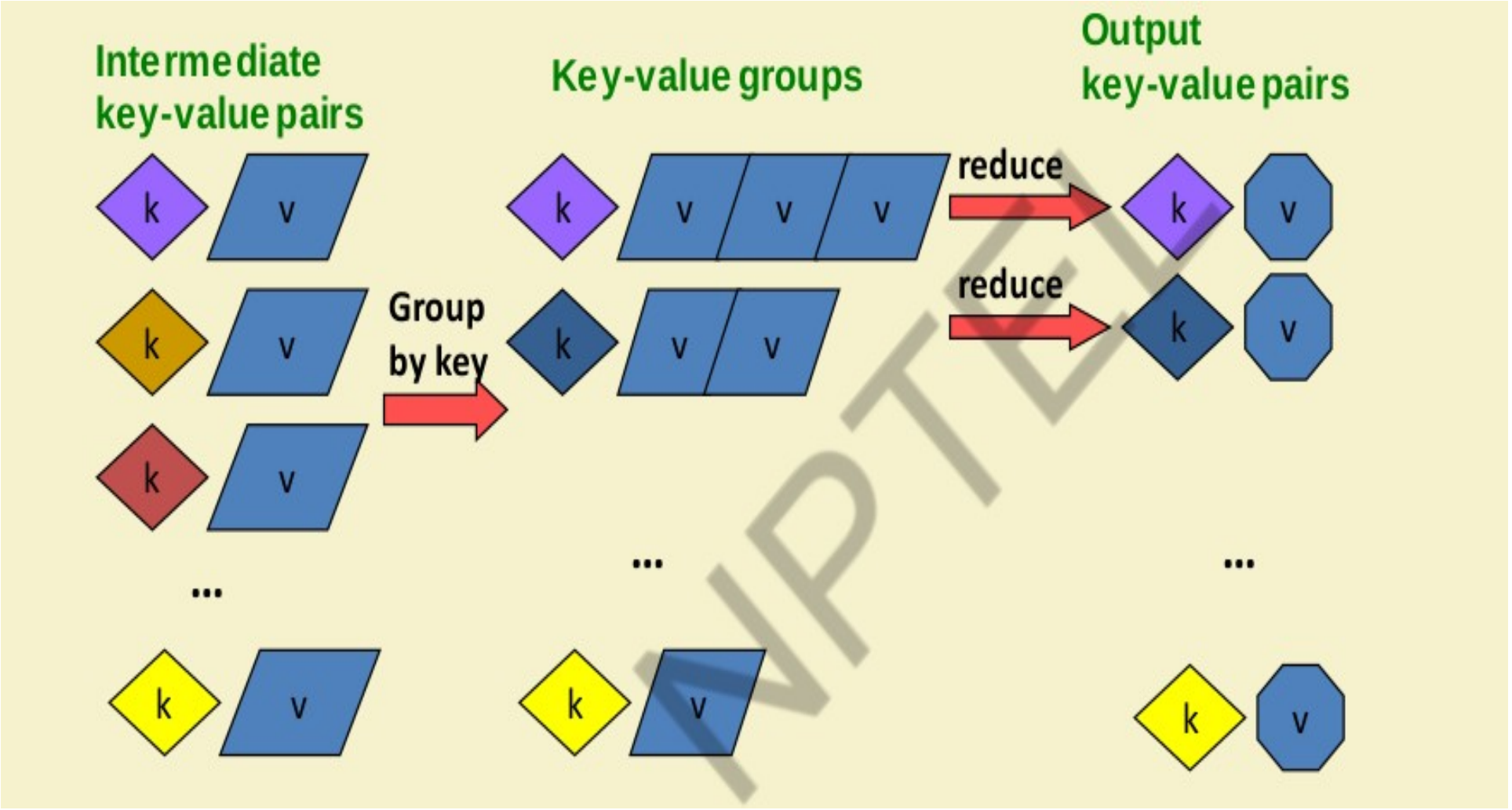
# MapReduce: Overview

- Sequentially read a lot of data
- Map:
  - Extract something you care about
- Group by key: Sort and Shuffle
- Reduce:
  - Aggregate, summarize, filter or transform
- Write the result
- **Outline stays the same, Map and Reduce change to fit the problem**

# MapReduce: The Map Step



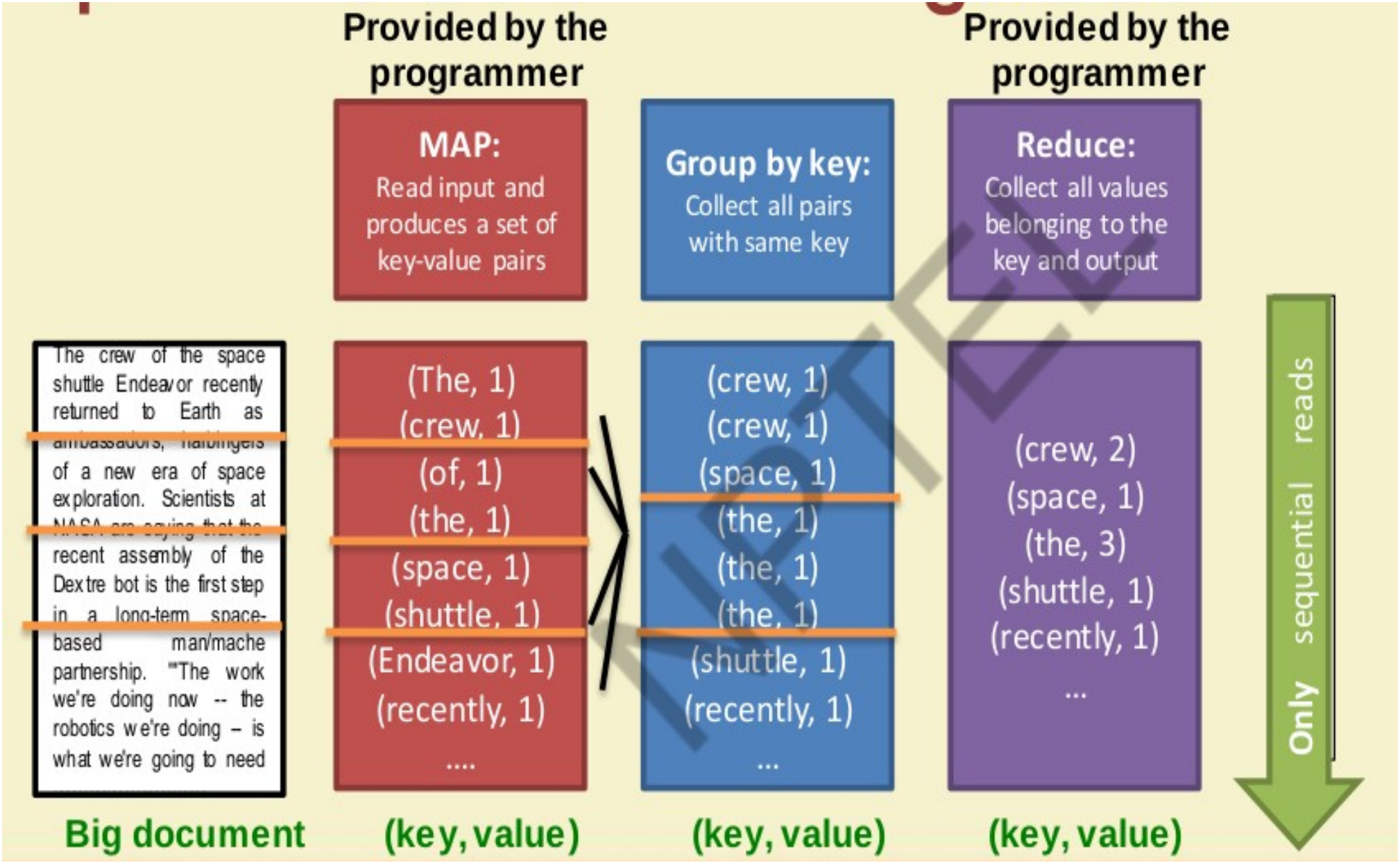
# MapReduce: The Reduce Step



# More Specifically

- **Input:** a set of key-value pairs
- Programmer specifies two methods:
  - Map(k, v) → <k', v'>*
    - Takes a key-value pair and outputs a set of key-value pairs
      - E.g., key is the filename, value is a single line in the file
    - There is one Map call for every (k,v) pair
  - Reduce(k', <v'>*) → <k', v''>*
    - **All values v' with same key k' are reduced together and processed in v' order**
    - There is one Reduce function call per unique key k'

# MapReduce: Word Counting



# Word Count Using MapReduce

- map(key, value):
  - // key: document name; value: text of the document

```
for each word w in value:
    emit(w, 1)
```

- reduce(key, values):
  - // key: a word; value: an iterator over counts

```
result = 0
for each count v in values:
    result += v
emit(key, result)
```

# Map Phase

- User writes the mapper method.
- Input is an unstructured record:
  - E.g. A row of RDBMS table,
  - A line of a text file, etc
- Output is a set of records of the form: <key, value>
  - Both key and value can be anything, e.g. text, number, etc.
  - E.g. for row of RDBMS table: <column id, value>
  - Line of text file: <word, count>

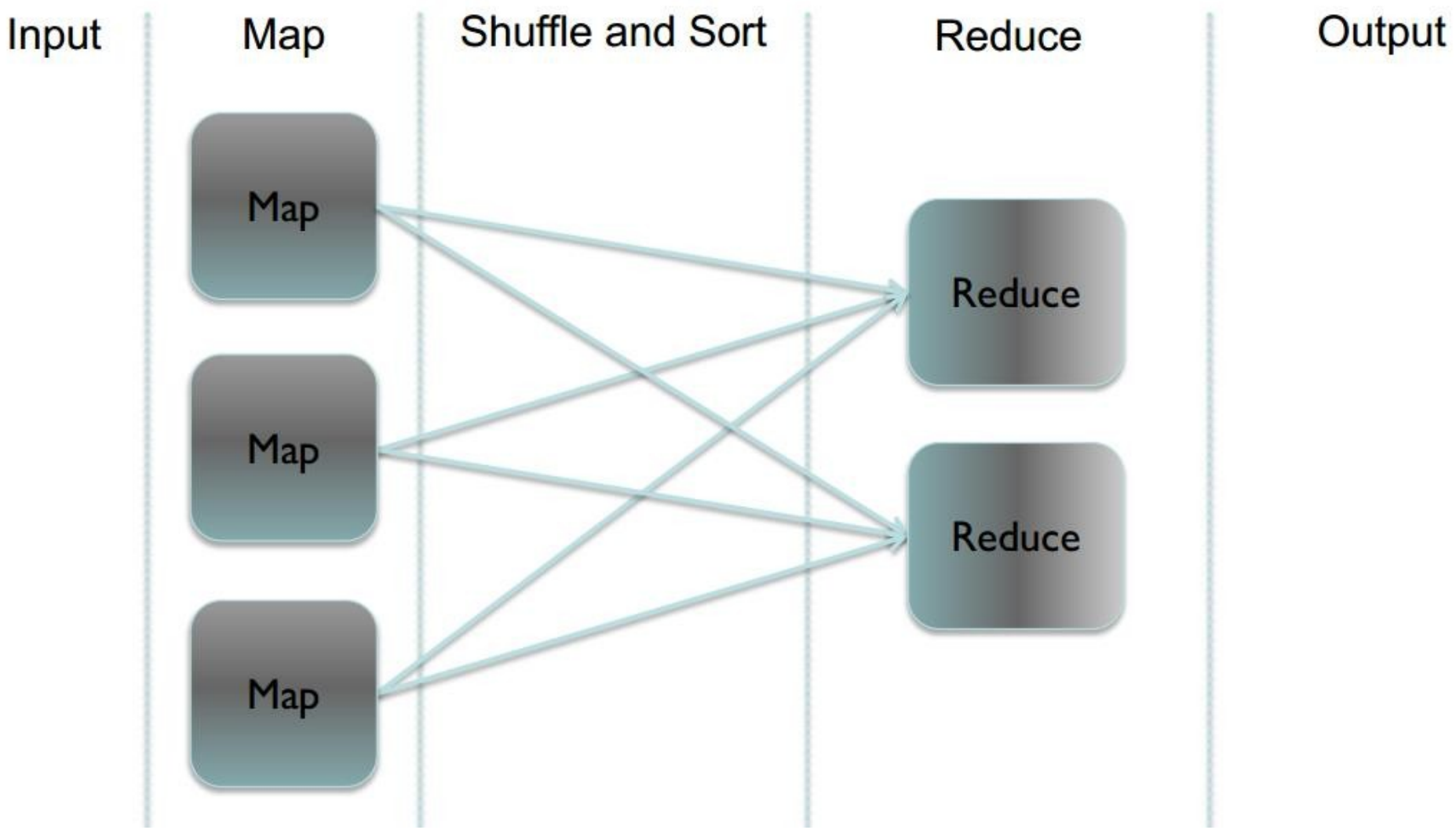
# Shuffle/Sort phase

- Shuffle phase ensures that all the mapper output records with the same key value, goes to the same reducer.
- Sort ensures that among the records received at each reducer, records with same key arrives together.

# Reduce phase

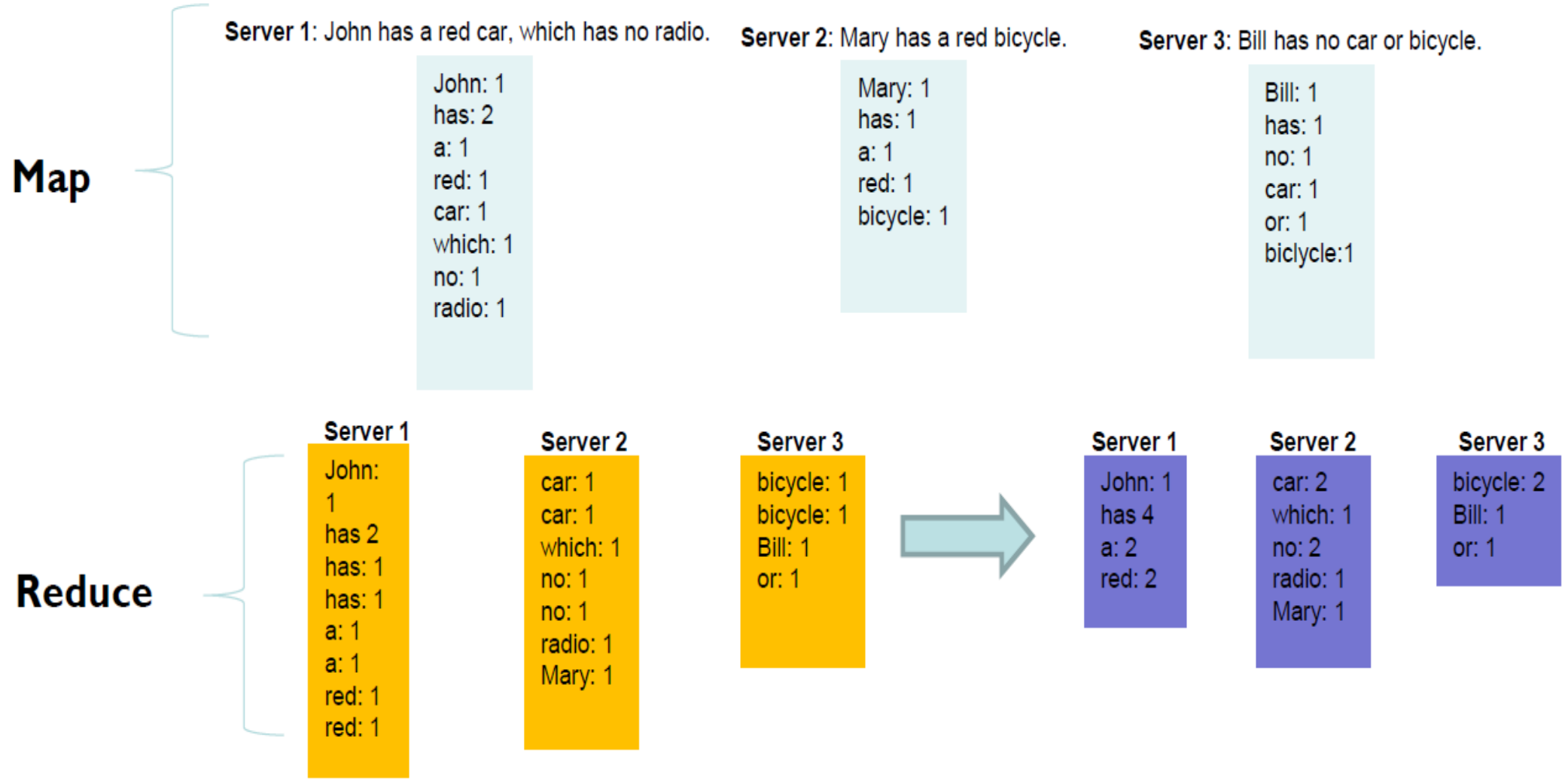
- Reducer is a user defined function which processes mapper output records with some of the keys output by mapper.
- Input is of the form <key, value>
  - All records having same key arrive together.
- Output is a set of records of the form <key, value>
  - Key is not important

# Parallel picture

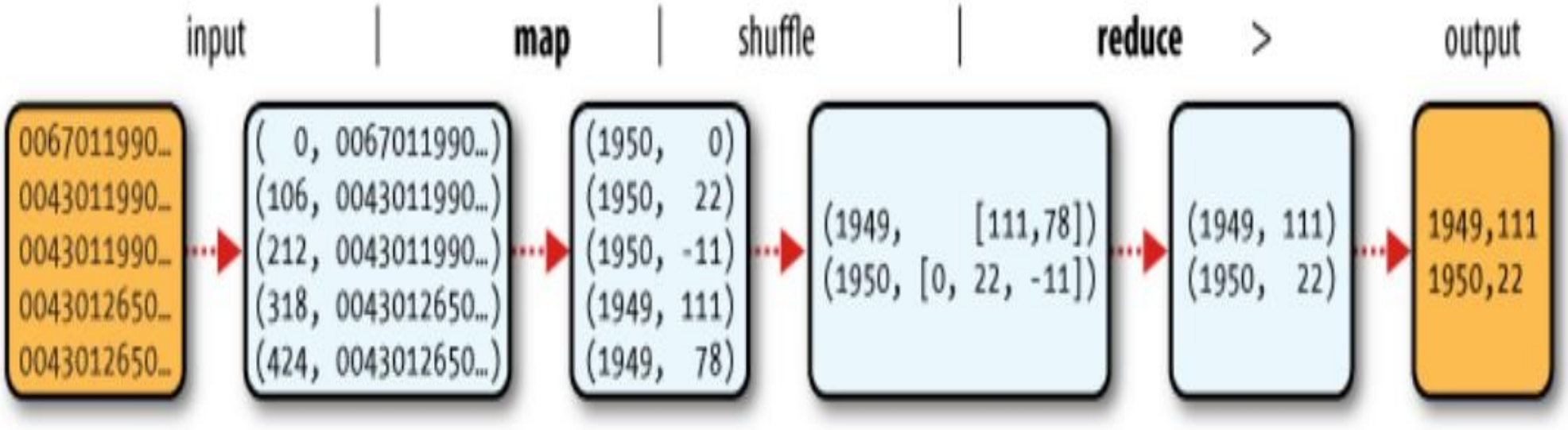


# Example

- Word Count: Count the total no. of occurrences of each word



# Map Reduce - Example




**What was the max/min temperature for the last century ?**

# Hadoop Map Reduce

**Provides:**

- Automatic parallelization and Distribution
- Fault Tolerance
- Methods for interfacing with HDFS for colocation of computation and storage of output.
- Status and Monitoring tools
- API in Java
- Ability to define the mapper and reducer in many languages through Hadoop streaming.

# What is Hadoop ?

- A scalable fault-tolerant distributed system for data storage and processing.
- Core Hadoop:
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  - Hadoop Map Reduce: Framework for distributed data processing.
- Open Source system with large community support.
  - https://hadoop.apache.org/

# What’s HDFS

- HDFS is a distributed file system that is fault tolerant, scalable and extremely easy to expand.
- HDFS is the primary distributed storage for Hadoop applications.
- HDFS provides interfaces for applications to move themselves closer to data.
- HDFS is designed to ‘just work’, however a working knowledge helps in diagnostics and improvements.

# HDFS

- Design Assumptions
  - Hardware failure is the norm.
  - Streaming data access.
  - Write once, read many times.
  - High throughput, not low latency.
  - Large datasets.
- Characteristics:
  - Performs best with modest number of large files
  - Optimized for streaming reads
  - Layer on top of native file system.

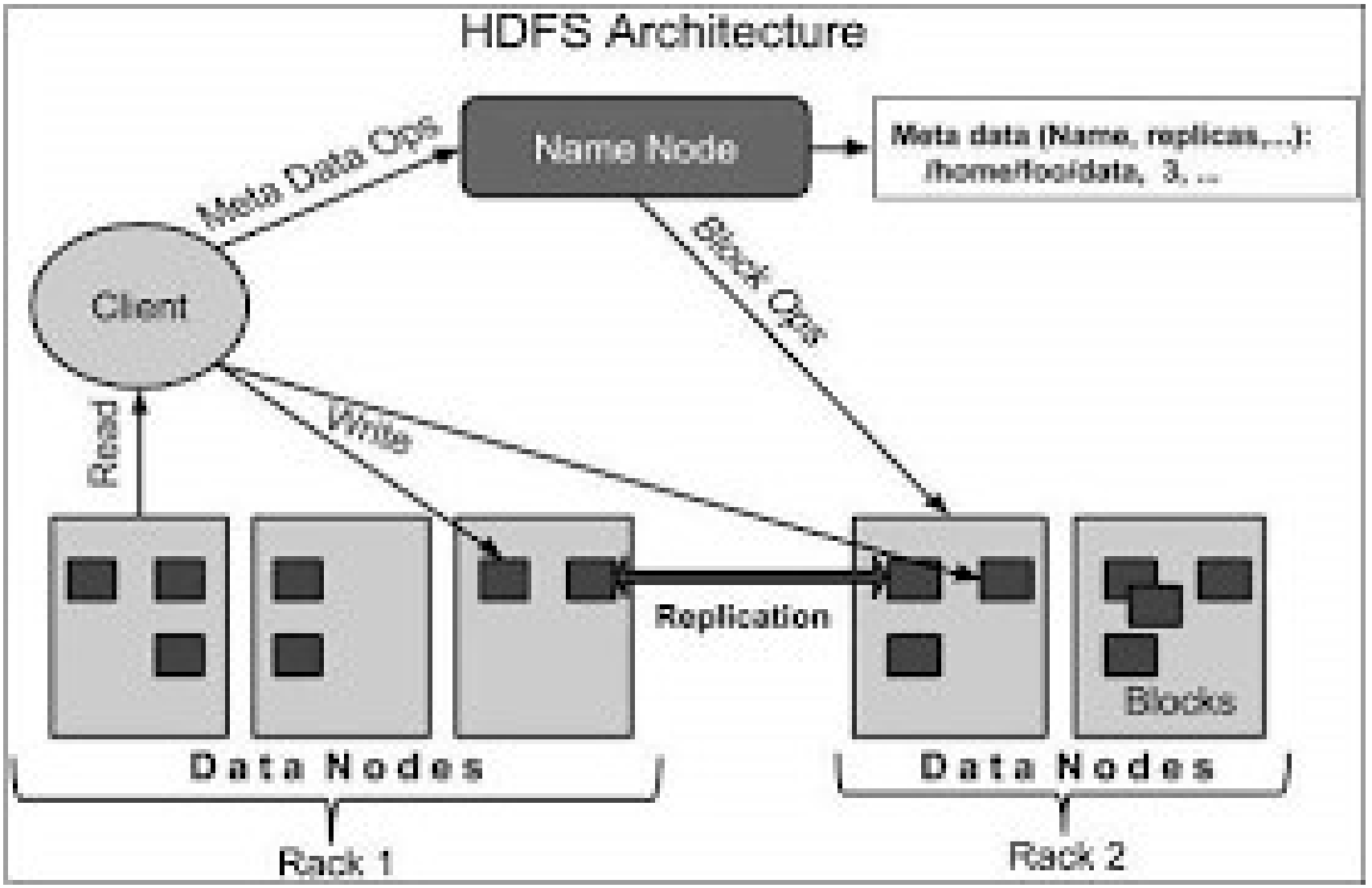
# HDFS

- Data is organized into file and directories.
- Files are divided into blocks and distributed to nodes.
- Block placement is known at the time of read
  - Computation moved to same node.
- Replication is used for:
  - Speed
  - Fault tolerance
  - Self healing.

# Components of HDFS

- There are two (and a half) types of machines in a HDFS cluster
  - **NameNode :–** is the heart of an HDFS filesystem, it maintains and manages the file system metadata. E.g; what blocks make up a file, and on which datanodes those blocks are stored.
  - **DataNode :-** where HDFS stores the actual data, there are usually quite a few of these.

# HDFS Architecture



# Goals of HDFS

- Very Large Distributed File System
  - 10K nodes, 100 million files, 10 PB
- Assumes Commodity Hardware
  - Files are replicated to handle hardware failure
  - Detect failures and recovers from them
- Optimized for Batch Processing
  - Data locations exposed so that computations can move to where data resides
  - Provides very high aggregate bandwidth User Space, runs on heterogeneous OS

# Distributed File System

- Single Namespace for entire cluster
- Data Coherency
  - Write-once-read-many access model
  - Client can only append to existing files
- Files are broken up into blocks
  - Typically 128 MB block size
  - Each block replicated on multiple DataNodes
- Intelligent Client
  - Client can find location of blocks
  - Client accesses data directly from DataNode

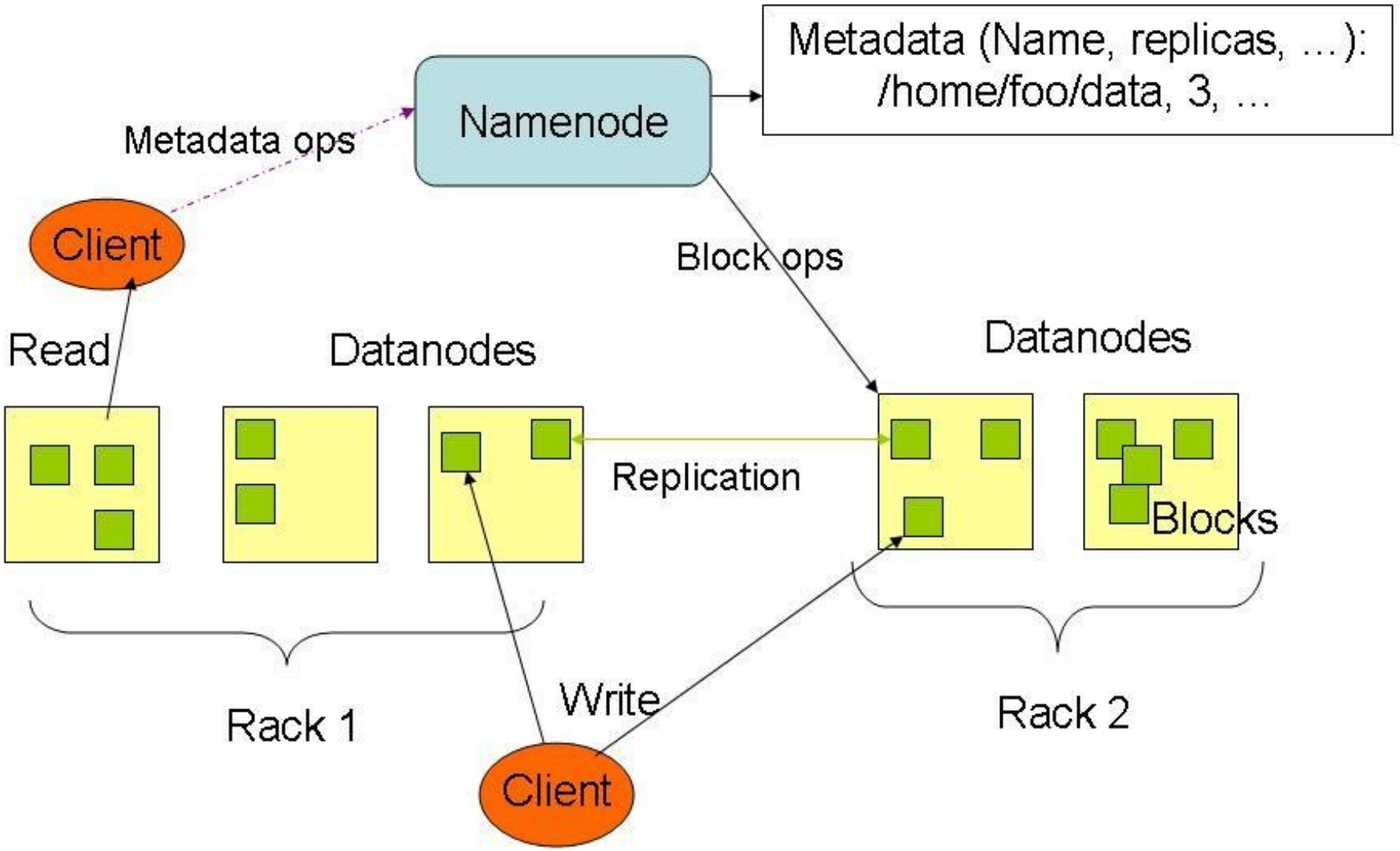
# NameNode Metadata

- Meta-data in Memory
  - The entire metadata is in main memory
  - No demand paging of meta-data
- Types of Metadata
  - List of files
  - List of Blocks for each file
  - List of DataNodes for each block
  - File attributes, e.g creation time, replication factor
- A Transaction Log
  - Records file creations, file deletions. etc

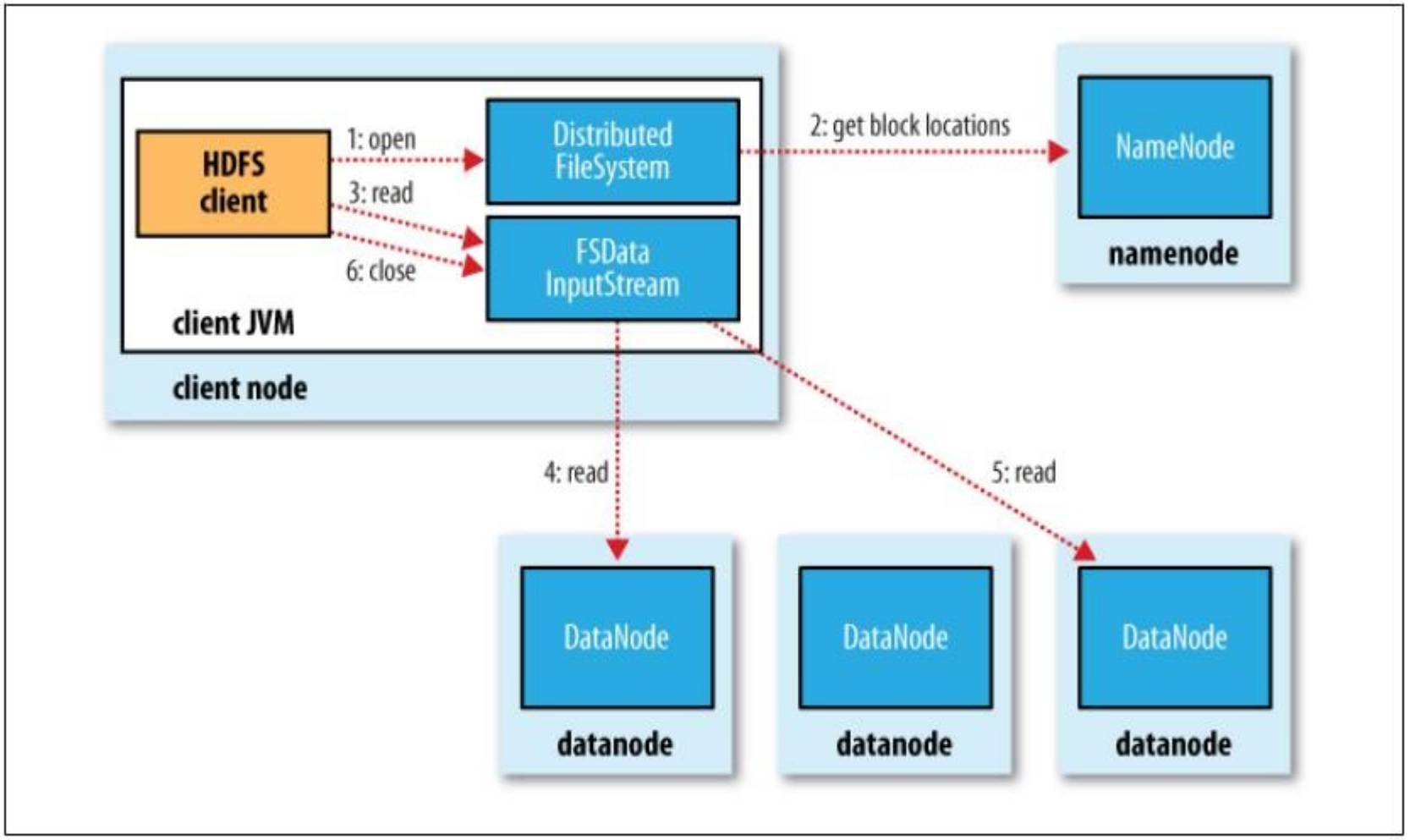
# DataNode

- A Block Server
  - Stores data in the local file system (e.g. ext3)
  - Stores meta-data of a block (e.g. CRC)
  - Serves data and meta-data to Clients
- Block Report
  - Periodically sends a report of all existing blocks to the NameNode
- Facilitates Pipelining of Data
  - Forwards data to other specified DataNodes

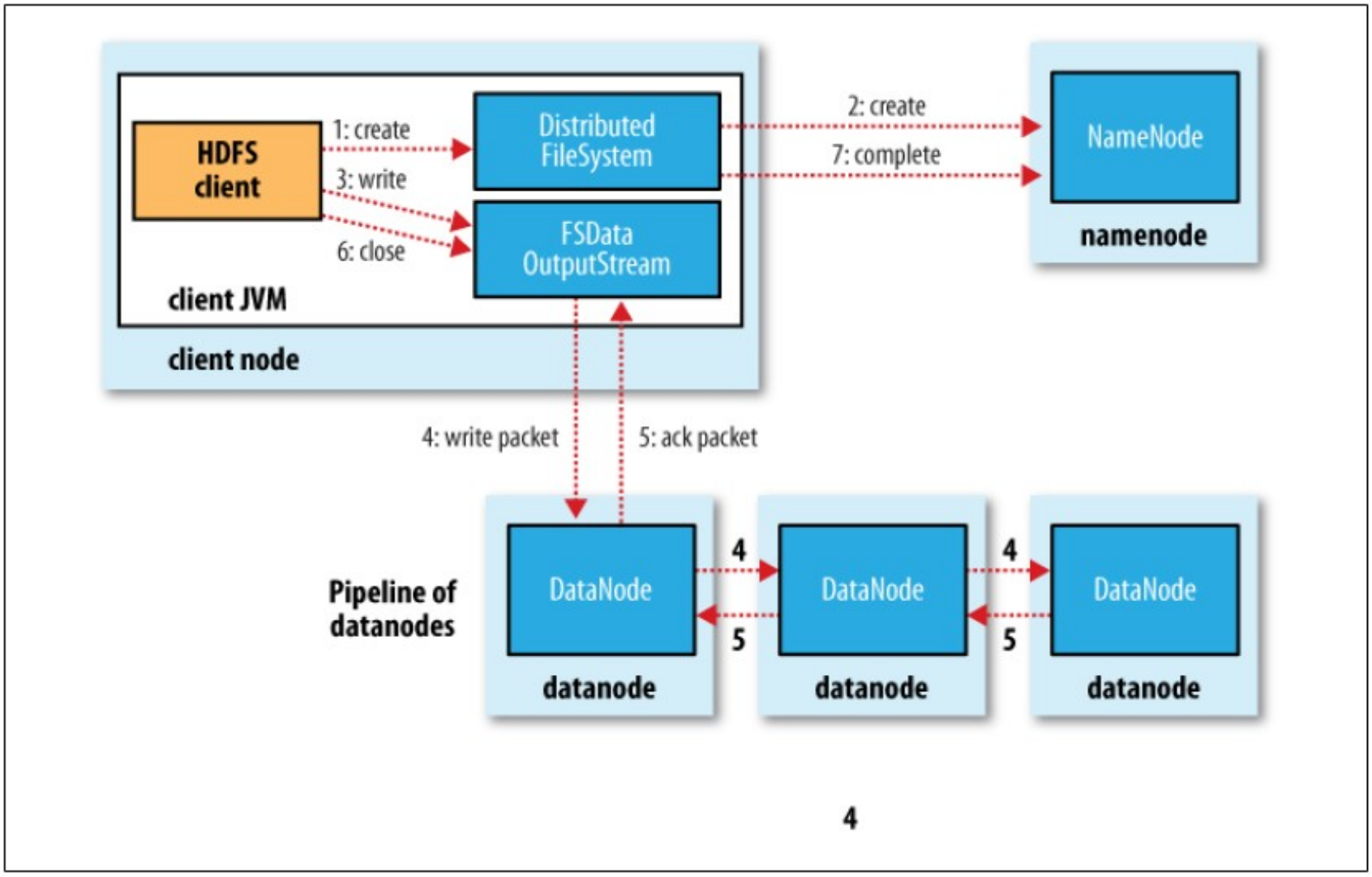
# HDFS Architecture



# HDFS read client



# HDFS write Client



# Block Placement

- Current Strategy
  - One replica on local node
  - Second replica on a remote rack
  - Third replica on same remote rack
  - Additional replicas are randomly placed
- Clients read from nearest replica
- Would like to make this policy pluggable

# NameNode Failure

- A single point of failure
- Transaction Log stored in multiple directories
  - A directory on the local file system
  - A directory on a remote file system (NFS/CIFS)
- Need to develop a real HA solution

# Data Pipelining

- Client retrieves a list of DataNodes on which to place replicas of a block
- Client writes block to the first DataNode
- The first DataNode forwards the data to the next DataNode in the Pipeline
- When all replicas are written, the Client moves on to write the next block in file

# Conclusion:

- We have seen:
  - The structure of HDFS.
  - The architecture of HDFS system.
  - Internal functioning of HDFS.