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Advanced Database Systems

MapReduce

Strategic project of TBU in Zlín, reg. no. CZ.02.2.69/0.0/0.0/16_015/0002204

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Distributed data processing

- **MapReduce** - the basic principle for parallel distributed processing of Big Data
- **Programming model** – introduced by Google in 2004

Definition:

MapReduce is "a simple and powerful interface that enables the automatic distribution and parallelization of computations over large-scale data, and the corresponding implementation of this interface that allows achieving high performance using a large cluster of commonly available computers" (Dean, 2008).

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Dean, J., & Ghemawat, S. (2008). MapReduce: simplified data processing on large clusters. *Communications of the ACM, 51*(1), 107-113.

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Distributed data processing

⇒ the implementation is called the **MapReduce framework**

- Hadoop (Apache) - the best known and most widespread, it follows on from it
  - Hive - data warehouses
  - Mahout - data mining
  - ZooKeeper - distributed coordination of services
  - Spark - a unified analytical tool for large-scale data processing
- It also occurs as a direct part of NoSQL databases
  - MongoDB
  - CouchDB
  - Riak

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Ghazi, M. R., & Gangodkar, D. (2015). Hadoop, MapReduce and HDFS: a developers perspective. *Procedia Computer Science, 48*, 45-50.

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The basic principle of MapReduce

- MapReduce is a programming model that sits on top of the Distributed File System (DFS)
  - Originally: no data model - data stored directly in files
- A distributed computing task contains **three phases**:
  1. **Mapping phase**: data transformation
  2. **Grouping phase**
     - It is done automatically by the MapReduce Framework
  3. **Reduction phase**: merging data

- The user only needs to define the mapping and reduction functions

Chang, F., Dean, J., Ghemawat, S., Hsieh, W. C., Wallach, D. A., Burrows, M., . . . Gruber, R. E. (2006). *A distributed storage system for structured data.* Paper presented at the Proceedings OSDI.

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Mapping phase - Map

- **Map** is used to process each object from a set of input data, and its output is pairs (key, value)
  - **Input**: one data item (e.g. a line of text) from a data file
  - **Output**: zero or more pairs (key, value) - multiple pairs can be created with the same key (non-unique)

- The mapping phase applies the Map function to all items

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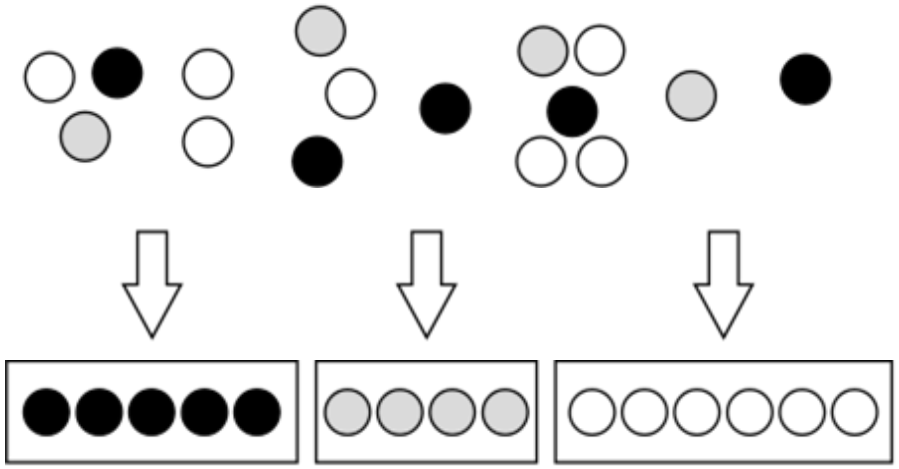
Shuffling phase

- **Grouping** (Shuffling): The key value **outputs** from the mapping phase **are grouped by key**
  - Values sharing the same key are sent to the same reducer
  - These values are consolidated into a single list (key, list of values)



intermediate step – mapping output

shuffle phase

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Reduction phase - Reduce

- **Reduce** combines the **values for each key**
  - To achieve the final result of the computational task
- **Input**: (key, list of values)
  - The list of values contains all values generated for a given key in the Map phase
- **Output**: (key, reduced list of values)

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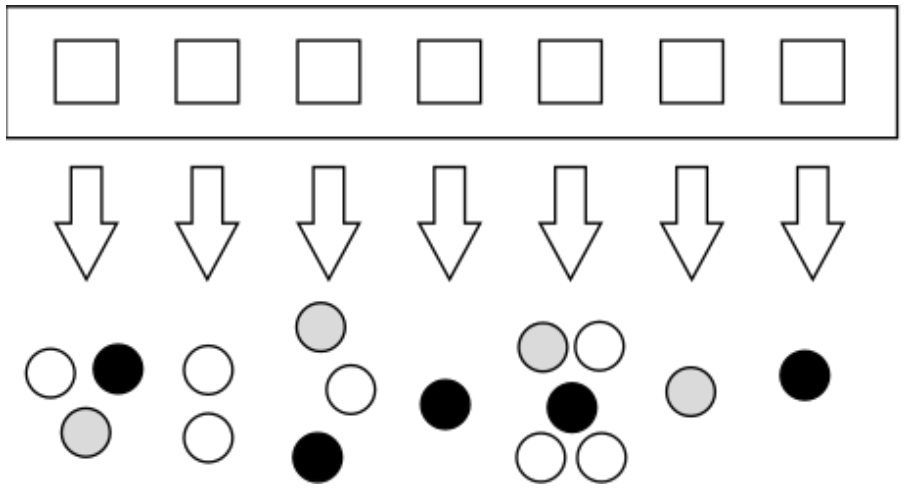
Example: Sum of words

Task: Find the number of words occurrences in a given set of documents

```
Map(String key, String value):
   // key: the document name
   // value: the document content(words)
 foreach word in value:
     return(word, 1);
```



input data (words)

Map function

output data (*colour indicates key*)

The Map function loops through individual document words and returns for each of them pair (word,1)

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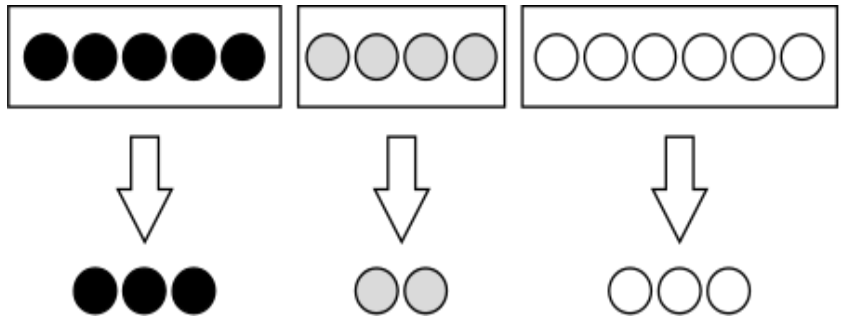
Example: Sum of words

```
Reduce(String key, Iterator values):
   // key: word
   // values: list of occurrences
int result = 0;
foreach v in values:
    result += v;
return(key, result);
```

The Reduce function sums the occurrence values of words in documents



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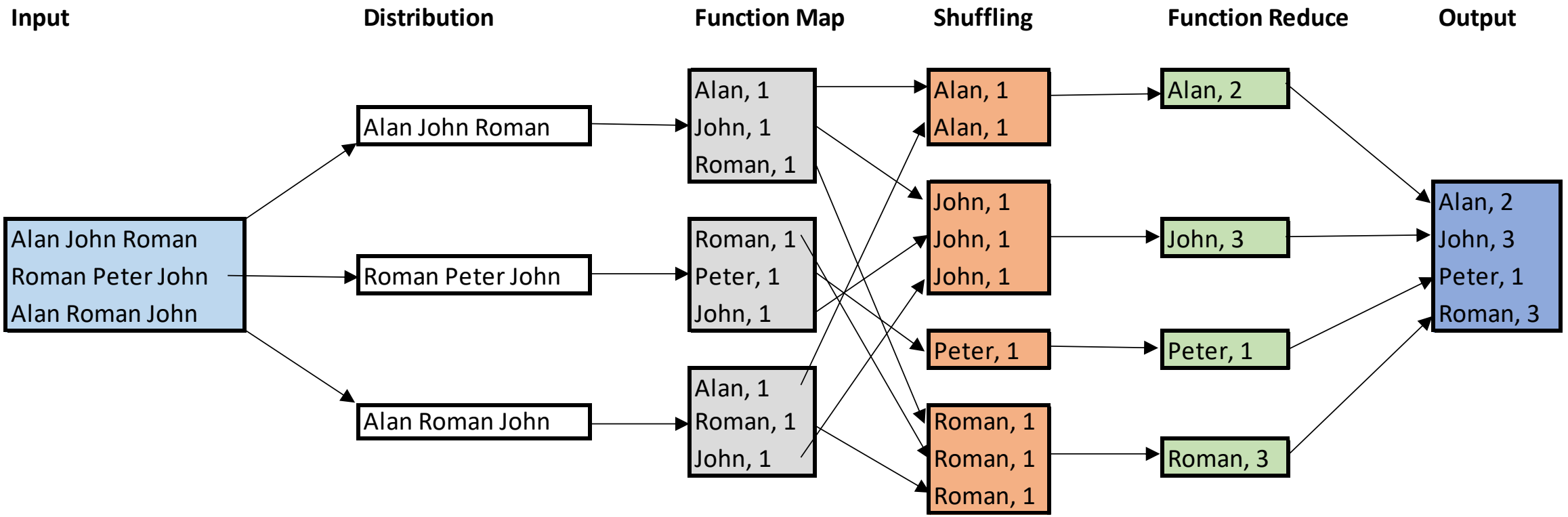
Example: Sum of names



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Holubová, I., Kosek, J., Minařík, K., & Novák, D. (2015). *Big Data a NoSQL databáze*: Grada.

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MapReduce Framework

- MapReduce framework takes care of:
  - Distribution and parallelization of calculation
  - Monitoring the entire distributed task
  - Grouping phase (compilation of interim results)
  - Recovery from all failures

- The user **only needs to define** the Map and Reduce functions
  - Defines the number of parts to process the Map functions - the M parameter
  - Defines the number of parts to process the Reduce functions - the R parameter
  - The parameters M and R may not exactly correspond to the number of nodes in the cluster (they tend to be higher)

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MapReduce Framework - work phase

1. **Input Read** (function)
   - Defines how to read data from storage
2. **Map** (stage)
   - The master node prepares M parts of data and M Map of tasks (waiting)
   - Passes the individual split parts to the Map function, these tasks run on workers
   - After the task is completed, its interim results are saved
3. **Combinator** (function) - optional
   - Combines local intermediate results from the Map Phase

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MapReduce Framework - work phase

4. **Partition** (function)
   - Specifies the distribution of data to the R part of the disk, corresponding to the R Reduce jobs
5. **Comparator** (function)
   - Sorts and groups the inputs for each reducer
6. **Reduce** (phase)
   - The master node prepares R tasks (waiting) for workers (workers)
   - The Partition function defines a data batch for each reducer
   - Each Reduce job uses a comparator to create (key, value) pairs
7. **Output Write** (Function)
   - Defines how output pairs (key, value) are printed

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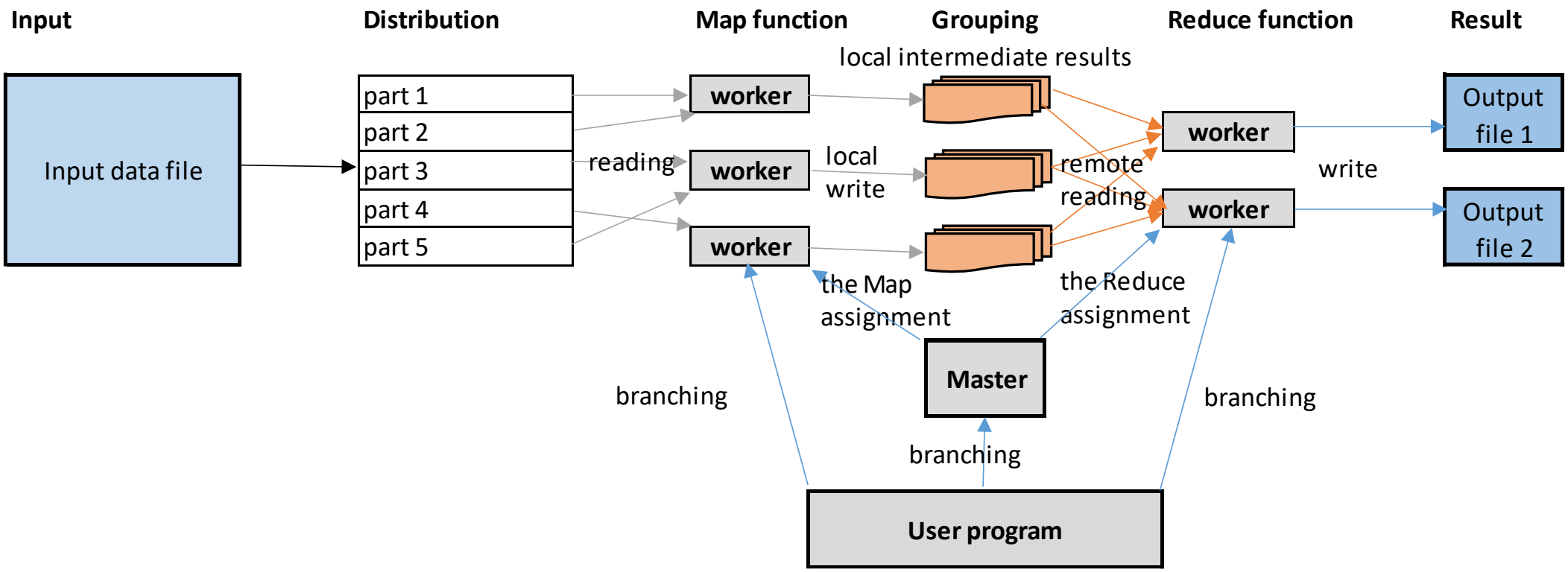
MapReduce Framework



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MapReduce - properties

- MapReduce uses a "**shared nothing**" architecture
  - Nodes work independently, without memory/disk sharing
  - A common feature of many NoSQL databases

- Data is partitioned and replicated across multiple nodes
  - **Advantage**: a large number of read / write operations per second
  - **Disadvantage**: coordination problem - which nodes have my data, and when…

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Apache Hadoop

- **Hadoop modules** and related projects
- **Hadoop Distributed File System** (HDFS)
- **Hadoop MapReduce**

Koitzsch, K. (2016). *Pro Hadoop Data Analytics: Designing and Building Big Data Systems Using the Hadoop Ecosystem*: Apress.

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Apache Hadoop

- Open-source Framework (created as part of the Nutch project - a web search engine)
  - 1st edition 2006
  - Implemented in Java
- The basic ideas are based on the MapReduce framework of Google

- Capable of running applications on large clusters of commodity hardware
  - Petabytes (10^{15}), Exabytes (10^{18}), Zettabytes (10^{21}) …data
  - Thousands of nodes

Apache Hadoop. (2019). Retrieved from http://hadoop.apache.org/

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Hadoop - Core Modules

- Hadoop Common
  - Common support functions for other Hadoop modules
- Hadoop Distributed File System (HDFS)
  - Distributed file system
  - It allows you to load and store large data efficiently
- Hadoop YARN
  - Task scheduling and resource management of the entire cluster
- Hadoop MapReduce
  - Implementation of MapReduce using previous modules

Apache Hadoop. (2019). Retrieved from http://hadoop.apache.org/

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Hadoop Distributed File System (HDFS)

- Open-source, platform independent (Java)
- Highly scalable
- Fault tolerant - able to:
  - Detect errors
  - Recover quickly and automatically
- Low efficiency
  - Optimized for batch processing

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HDFS - data characteristics

- It assumes:
  - Access to streaming data
    - Read files from start to finish
  - Batch processing rather than interactive user access
- Large data sets
- Write-once / read-many
  - The created file does not need to be changed often
- Optimal applications for this model: MapReduce, web crawlers, data warehouses,…

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HDFS – basic elements

- **Master/Slave** architecture
- **NameNode** – Master type node
  - Manages the file system namespace
  - Open / close / rename files and directories
  - Regulates access to files
  - Specifies the mapping of blocks to DataNodes
- **DataNode** – (slave type data nodes) data in local file systems
  - Block read/write/create/delete/replicate
  - Typically, one data node corresponds to one physical node

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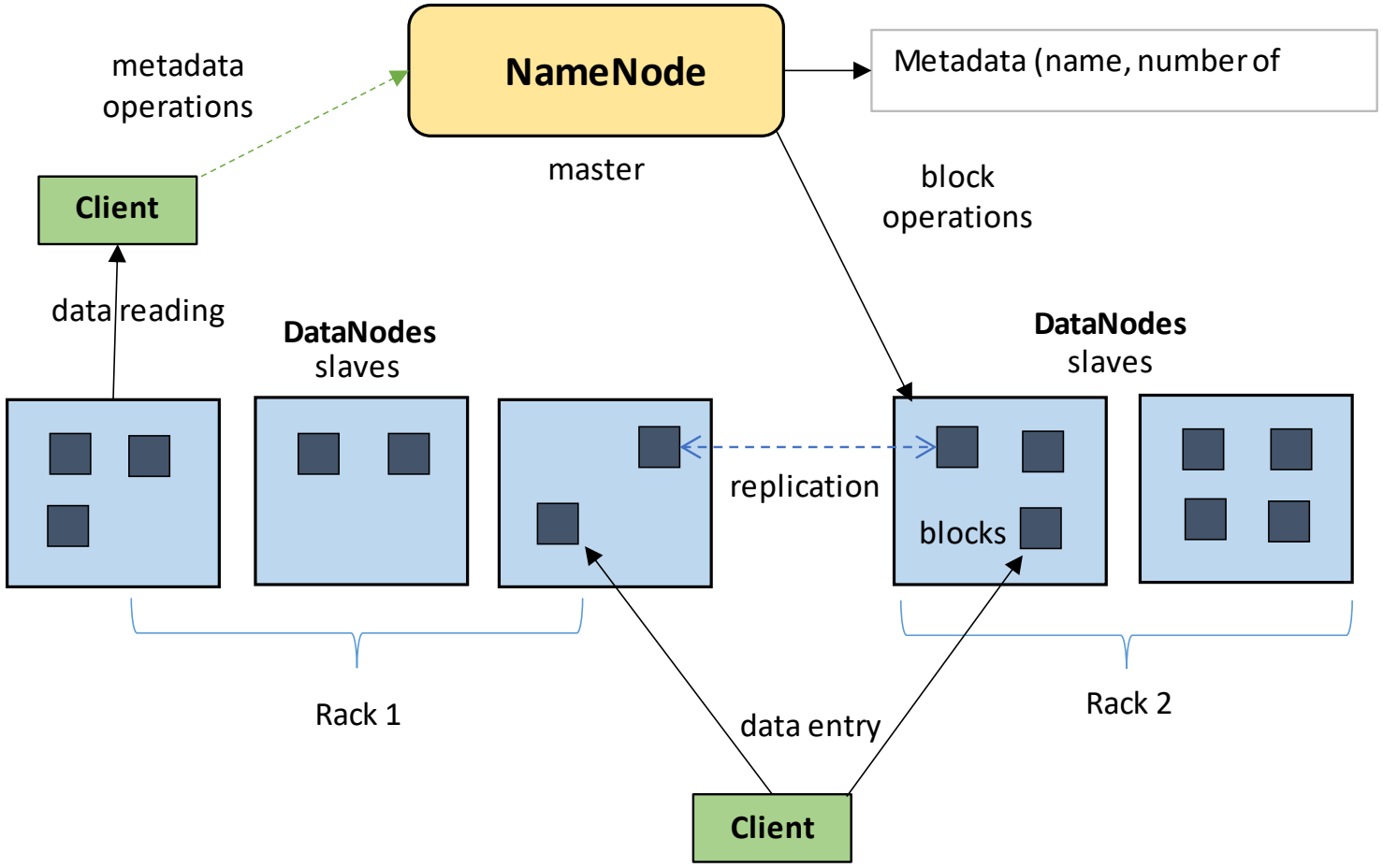
HDFS schema



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Blocks and replication

- HDFS can store very large files across the cluster - each file is a sequence of blocks
  - All blocks in the file are the same size - except for the last one
  - Block size is configurable to one file (default 128 MB)
- **Blocks are replicated** for fault tolerance
  - The number of replicas is configurable for each file (the replication factor is typically set to 3)
- The **NameNode** receives HeartBeat and BlockReport messages from each DataNode
  - HeartBeat – a message about the functionality of the connection (if it does not come, the blocks on the DataNode are marked as non-functional)
  - BlockReport - list of all blocks in the DataNode

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Reliability

- The main goal is to **reliably store data** in case of:
  - NameNode failures
  - DataNode failures
  - Network fragmentation - a subset of DataNodes may lose connection to the NameNode

- In the absence of a HeartBeat message
  - NameNode marks DataNodes without HeartBeat and does not send any I/O requests to them
  - The death of a DataNode usually results in repeated replication

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Hadoop - MapReduce

- **Hadoop MapReduce** needs:
  - Distributed file system (usually HDFS) – for storing data
  - A tool that can distribute, coordinate, track, and aggregate results (usually YARN)
- It contains **two main components**:
  - JobTracker (master) – provides control of the calculation (scheduler)
    - Monitors the entire MapReduce job
    - Communicates with the HDFS NameNode to run a job near the data
  - TaskTracker (slave, worker) - performs calculations - assigned Map or Reduce task (or other operations)
- A separate JVM (Java Virtual Machine) is started for each task

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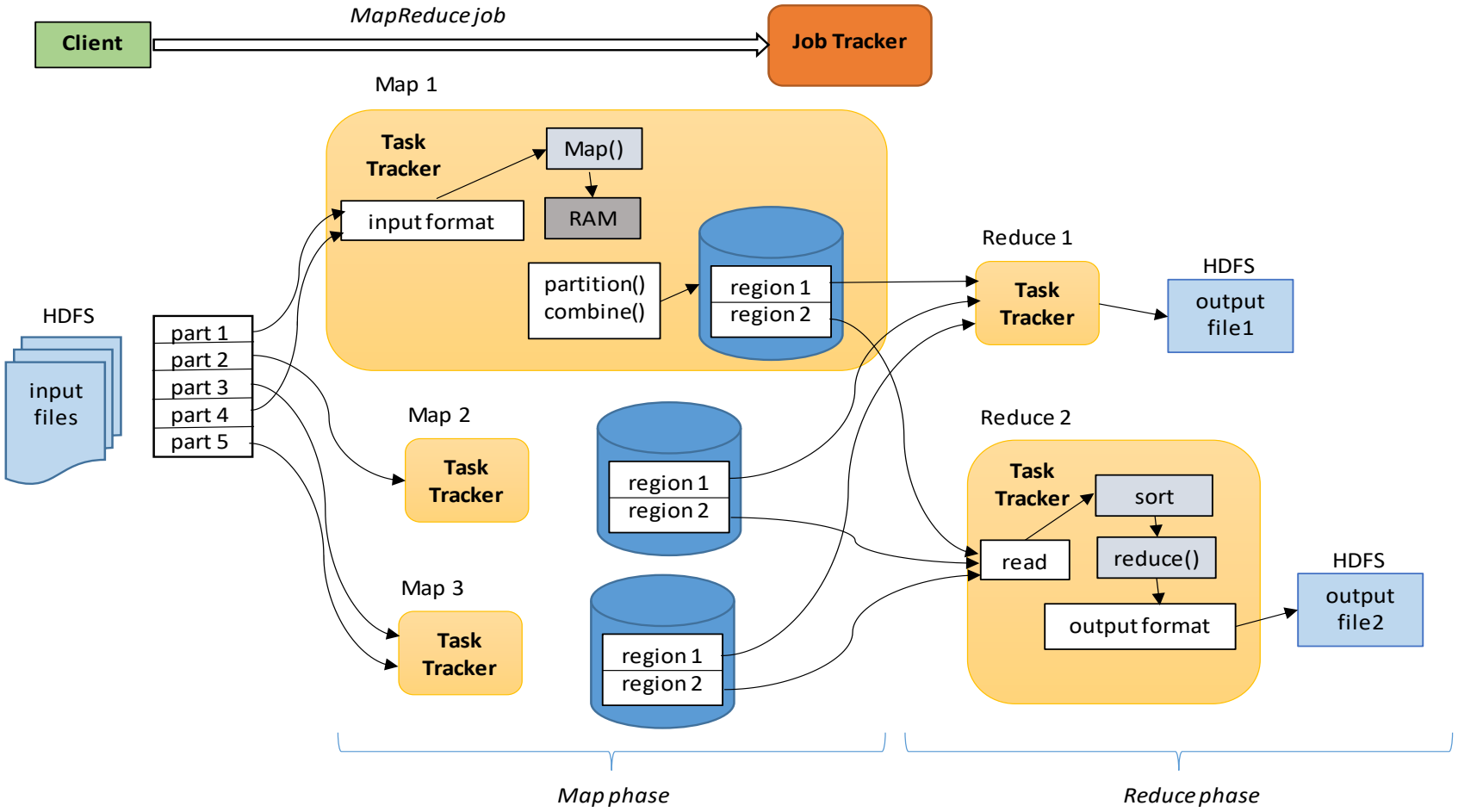
Schema - Hadoop MapReduce



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Hadoop - system superstructures

- Mahout: a scalable library for machine learning and data mining
- Hive: data warehouse - ad hoc querying and summarization of data
- Pig: using MapReduce principles for BigData analysis
- ZooKeeper: a high-performance coordination service for distributed applications

Lakhe, B. (2016). *Practical Hadoop migration : how to integrate your RDBMS with the Hadoop Ecosystem and re-architect relational applications to NoSQL*. Berkeley, California: Apress.

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MapReduce on other systems

- MongoDB - scalable distributed document database
- Cassandra - Scalable distributed columnar database
- Riak - Scalable distributed key-value database
- Spark - a universal distributed computing system for processing large volumes of data
- Amazon Elastic MapReduce - Hadoop-based data processing service

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The negatives of MapReduce

- The MapReduce principle is suitable for a specific set of tasks
- The efficiency of processing tasks using MapReduce tends to be very low
- MapReduce lacks important features that are part of DBS (integrity constraints, indexes, transactions, etc.)
- MapReduce is not compatible with tools that are implemented in DBS (business intelligence, data mining, etc.)
- A new approach - cloud computing

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References

- Dean, J., & Ghemawat, S. (2008). MapReduce: simplified data processing on large clusters. *Communications of the ACM, 51*(1), 107-113.
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Questions?

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