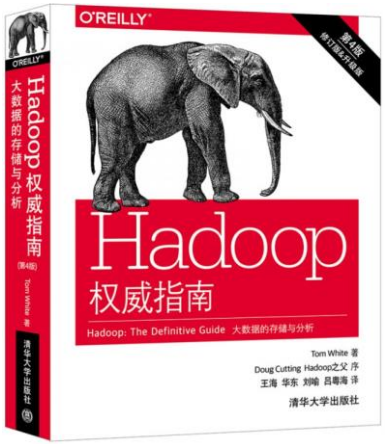
# 分布式计算框架Hadoop

– 典型的分布式系统




https://www.oreilly.com/library/view/hadoop-the-definitive/9781491901687/

Some slides from:
Nalini Venkatasubramanian @ UIC Irvine
https://www.ics.uci.edu/~cs237/
林子雨 厦门大学
http://dblab.xmu.edu.cn/post/linziyu

# Outline

1. Basics
2. MapReduce
3. YARN
4. HDFS
5. ZooKeeper

# Hadoop

- Apache top level project
- Open-source implementation of frameworks
- For reliable, scalable, distributed computing and data storage
- A flexible and highly-available architecture for large scale computation and data processing on a network of commodity hardware.


https://hadoop.apache.org/

# Motivation


1998

**The Google File System**

2003

Sanjay Ghemawat, Howard Gobioff, and Shun-Tak Leung

Google*

**MapReduce: Simplified Data Processing on Large Clusters**

2004

Jeffrey Dean and Sanjay Ghemawat

jeff@google.com, sanjay@google.com

*Google, Inc.*

**Bigtable: A Distributed Storage System for Structured Data**

2006

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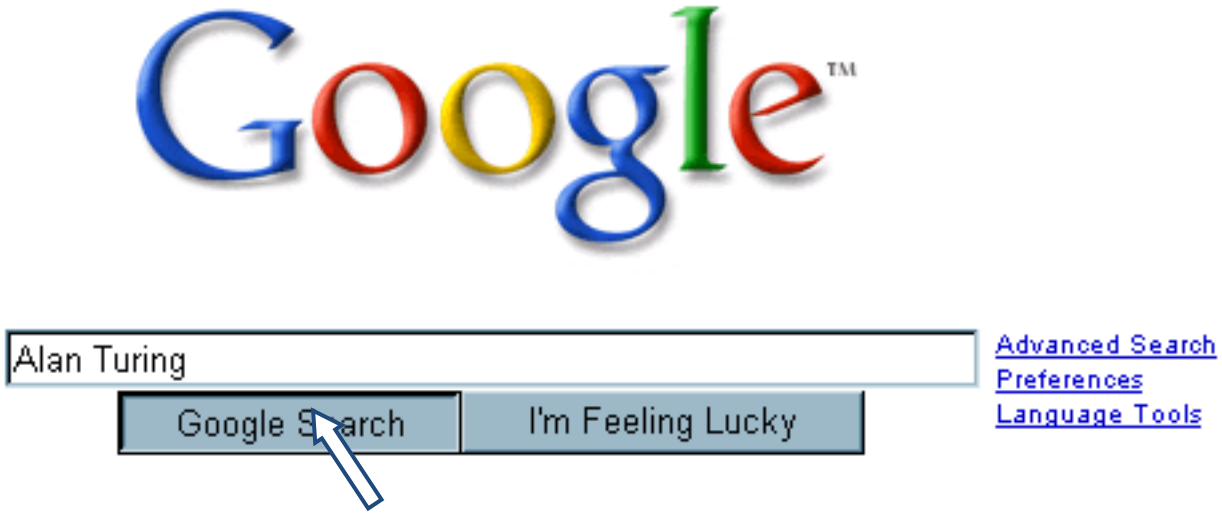
{fay,jeff,sanjay,wilsonh,kerr,m3b,tushar,fikes,gruber}@google.com

*Google, Inc.*


2013

# Motivation




- 200+ processors
- 200+ terabyte database
- $10^{10}$ total clock cycles
- 0.1 second response time
- 5¢ average advertising revenue

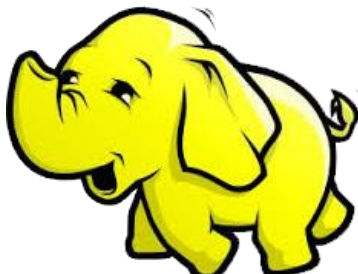
# Motivation

- For large scale data processing
- Want to process lots of data ( > 1 TB)
- Want to parallelize across hundreds/thousands of CPUs
- … Want to make this easy

"Google Earth uses **70.5 TB**: 70 TB for the raw imagery and 500 GB for the index data.“-2016

# Goals of Hadoop

- Abstract and facilitate the storage and processing of large and/or rapidly growing data sets
  - Structured and non-structured data
  - Simple programming models
- High scalability and availability
- Use commodity (cheap!) hardware with little redundancy
- Fault-tolerance
- Move computation rather than data



# Hadoop's Developers

**2005**: Doug Cutting and  Michael J. Cafarella developed Hadoop to support distribution for the Nutch search engine project.

The project was funded by Yahoo!

**2006**: Yahoo gave the project to Apache Software Foundation.


Doug Cutting

# Motivated by Google

2003

**The Google File System**

Sanjay Ghemawat, Howard Gobioff, and Shun-Tak Leung
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2004

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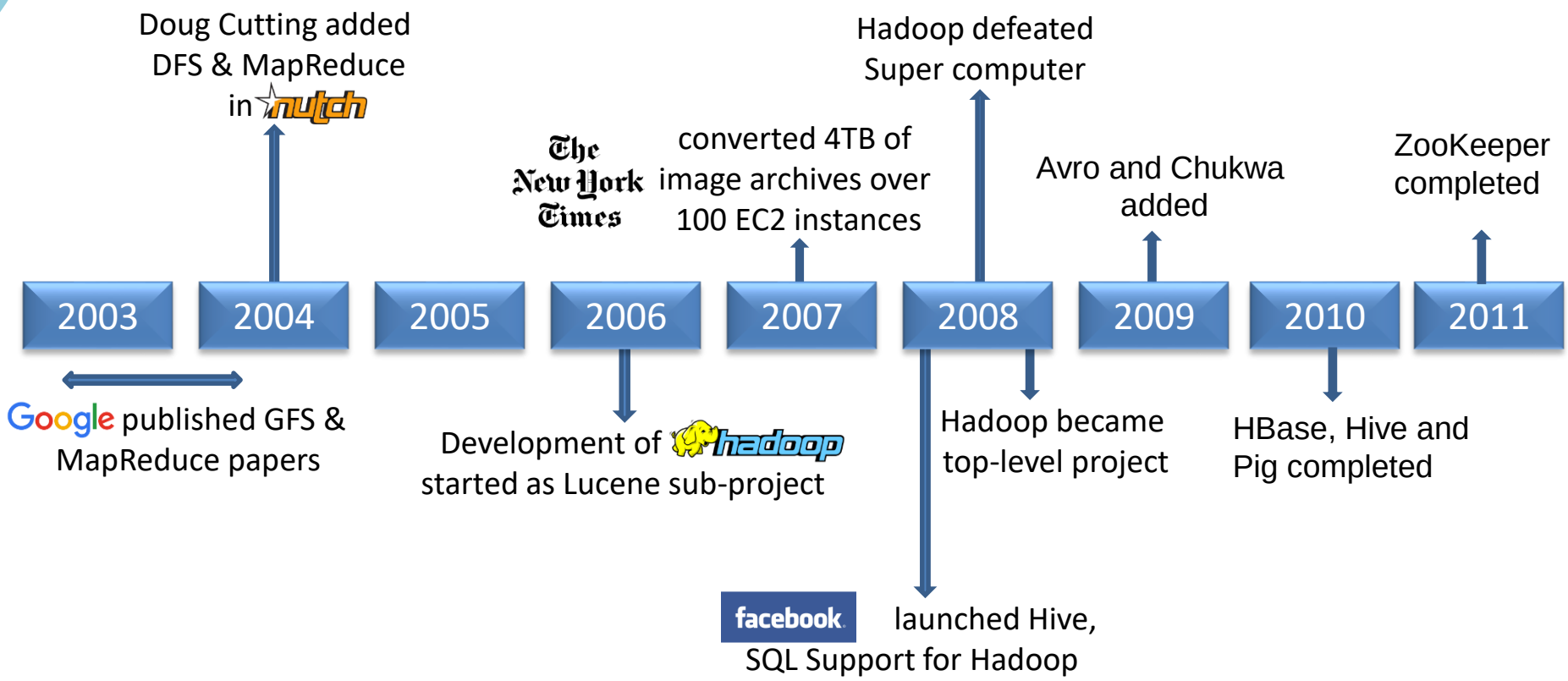
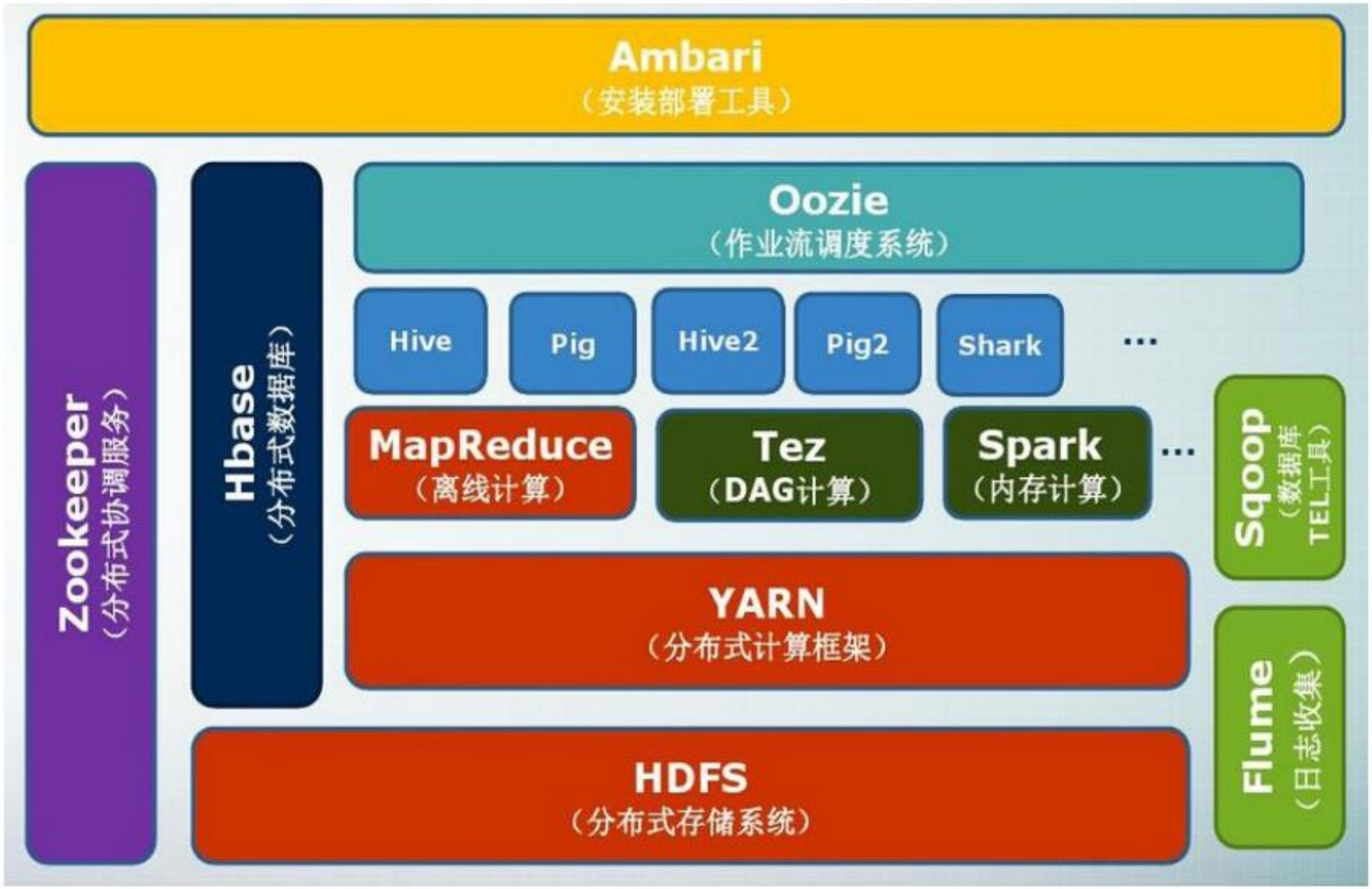
# Development of Hadoop



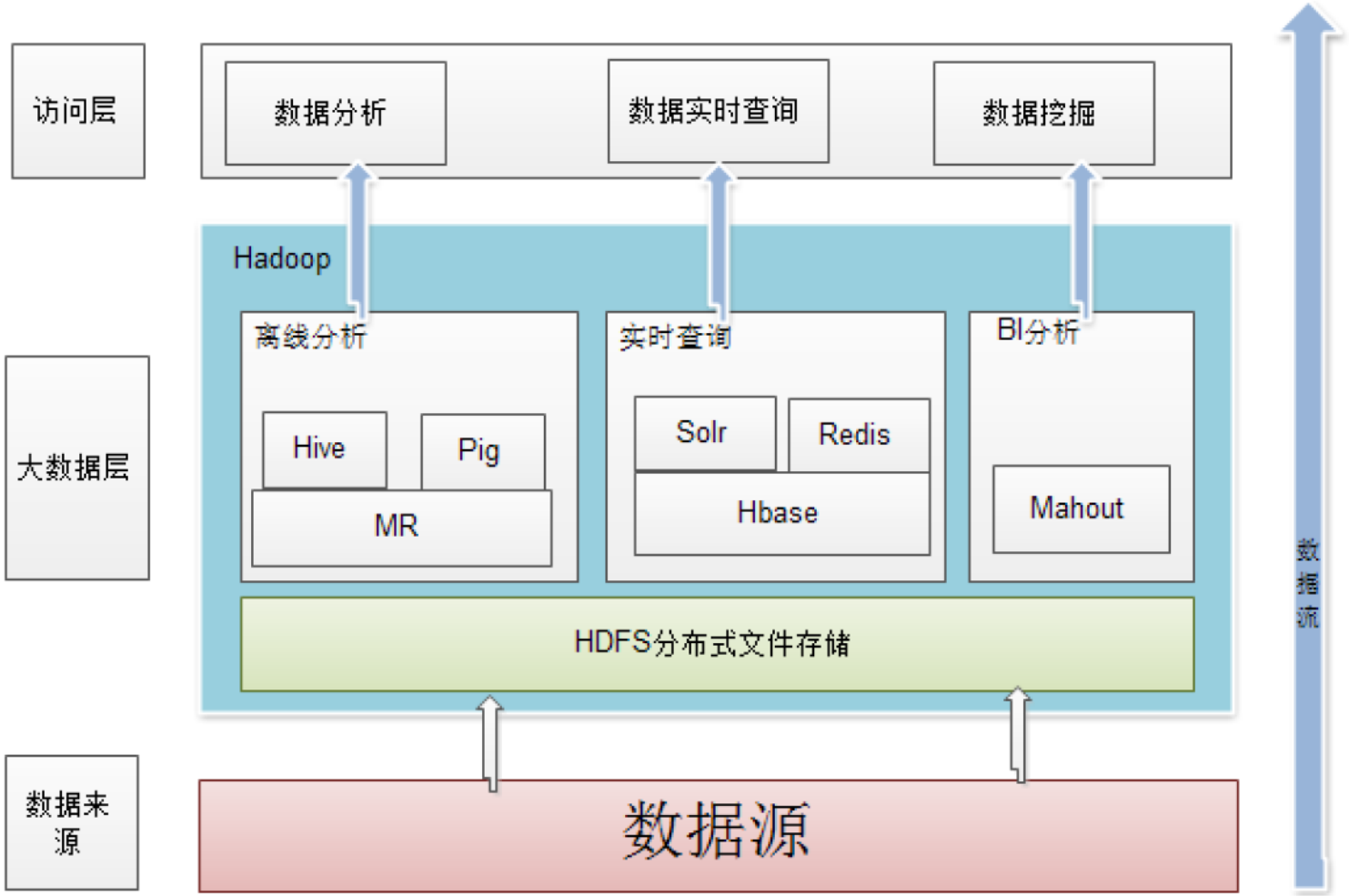
# Hadoop Ecosystem



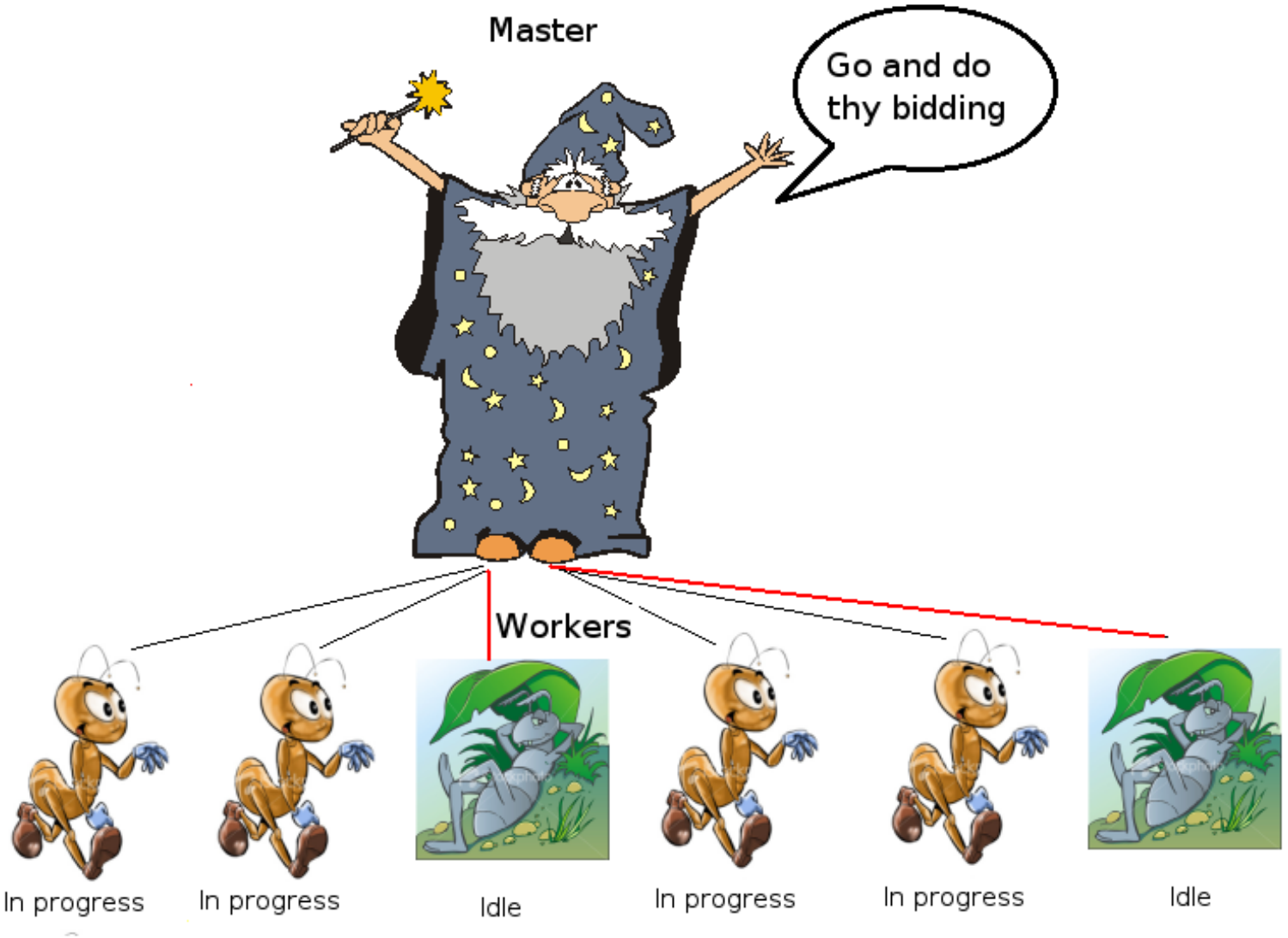
# Hadoop Ecosystem

| 组件 | 功能 |
| --- | --- |
| HDFS | 分布式文件系统 |
| MapReduce | 分布式并行编程模型 |
| YARN | 资源管理和调度器 |
| Tez | 运行在YARN之上的下一代Hadoop查询处理框架 |
| Hive | Hadoop上的数据仓库 |
| HBase | Hadoop上的非关系型的分布式数据库 |
| Pig | 一个基于Hadoop的大规模数据分析平台，提供类似SQL的查询语言Pig Latin |
| Sqoop | 用于在Hadoop与传统数据库之间进行数据传递 |
| Oozie | Hadoop上的工作流管理系统 |
| Zookeeper | 提供分布式协调一致性服务 |
| Storm | 流计算框架 |
| Flume | 一个高可用的，高可靠的，分布式的海量日志采集、聚合和传输的系统 |
| Ambari | Hadoop快速部署工具，支持Apache Hadoop集群的供应、管理和监控 |
| Kafka | 一种高吞吐量的分布式发布订阅消息系统，可以处理消费者规模的网站中的所有动作流数据 |
| Spark | 类似于Hadoop MapReduce的通用并行框架 |

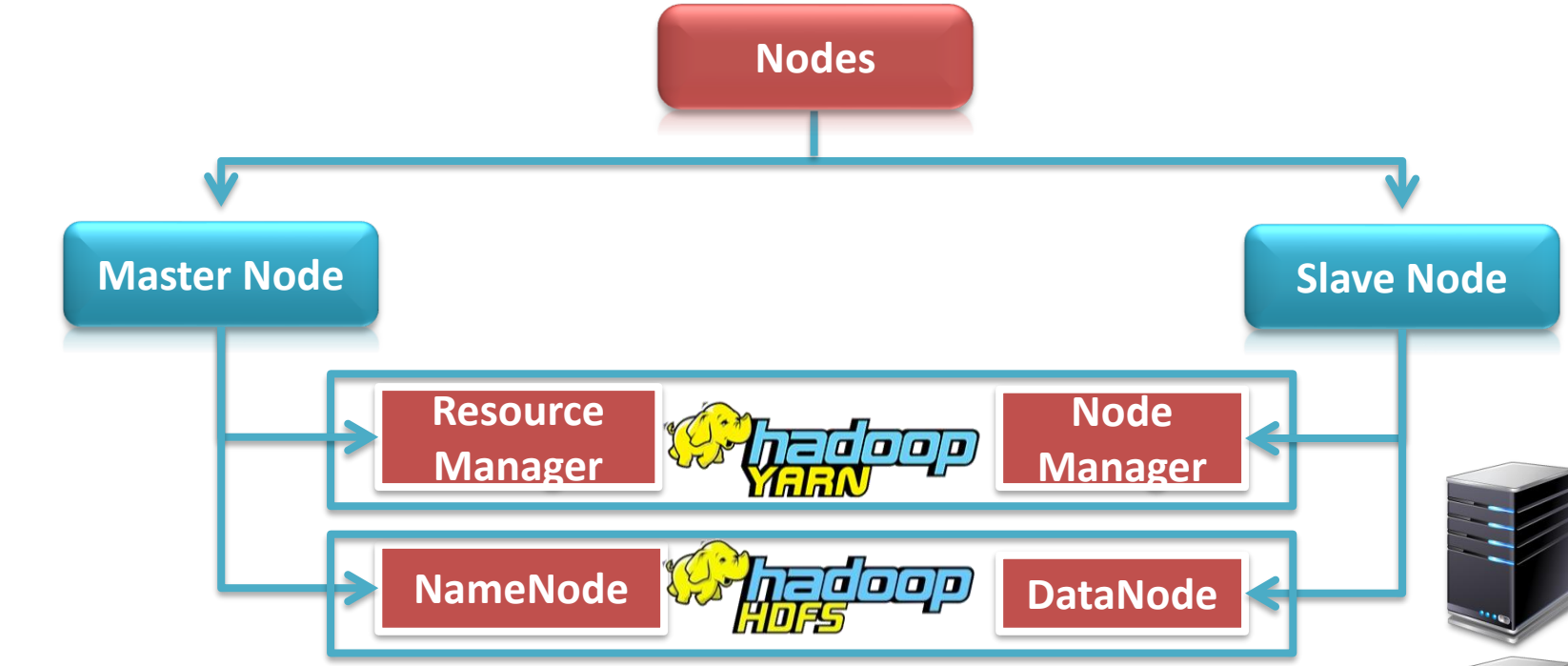
# Application of Hadoop



# Hadoop Architecture



# Hadoop Architecture



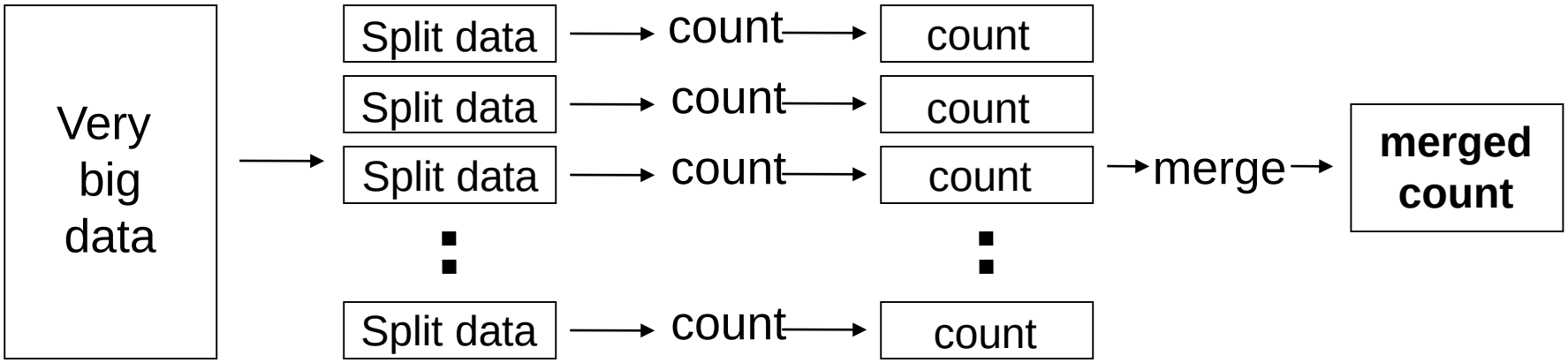
# Outline

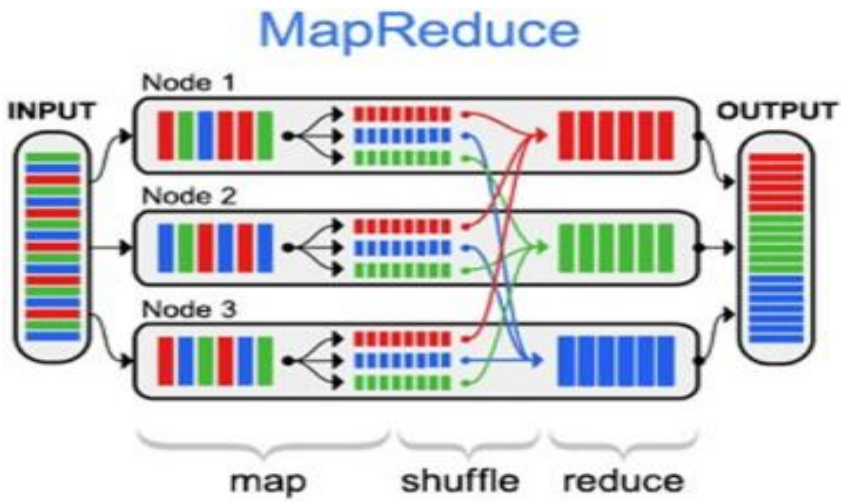
1. Basics
2. MapReduce
3. YARN
4. HDFS
5. ZooKeeper

# MapReduce

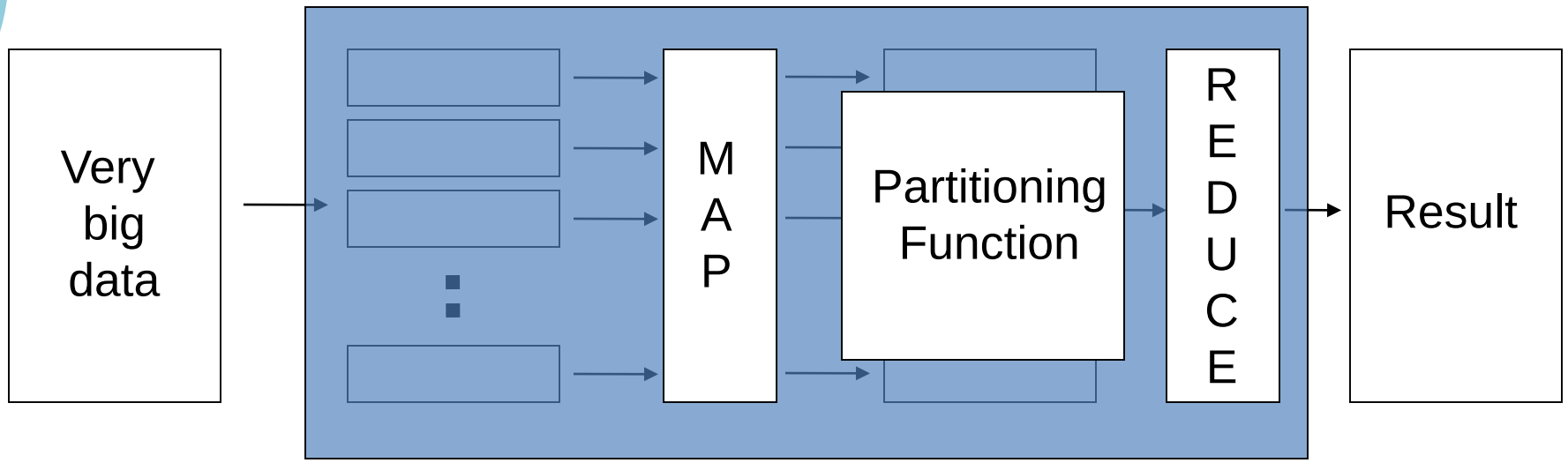
- A programming model (& its associated implementation)
- For processing large data set
- Exploits large set of commodity computers
- Executes process in distributed manner
- Offers high degree of transparencies

# Distributed Word Count



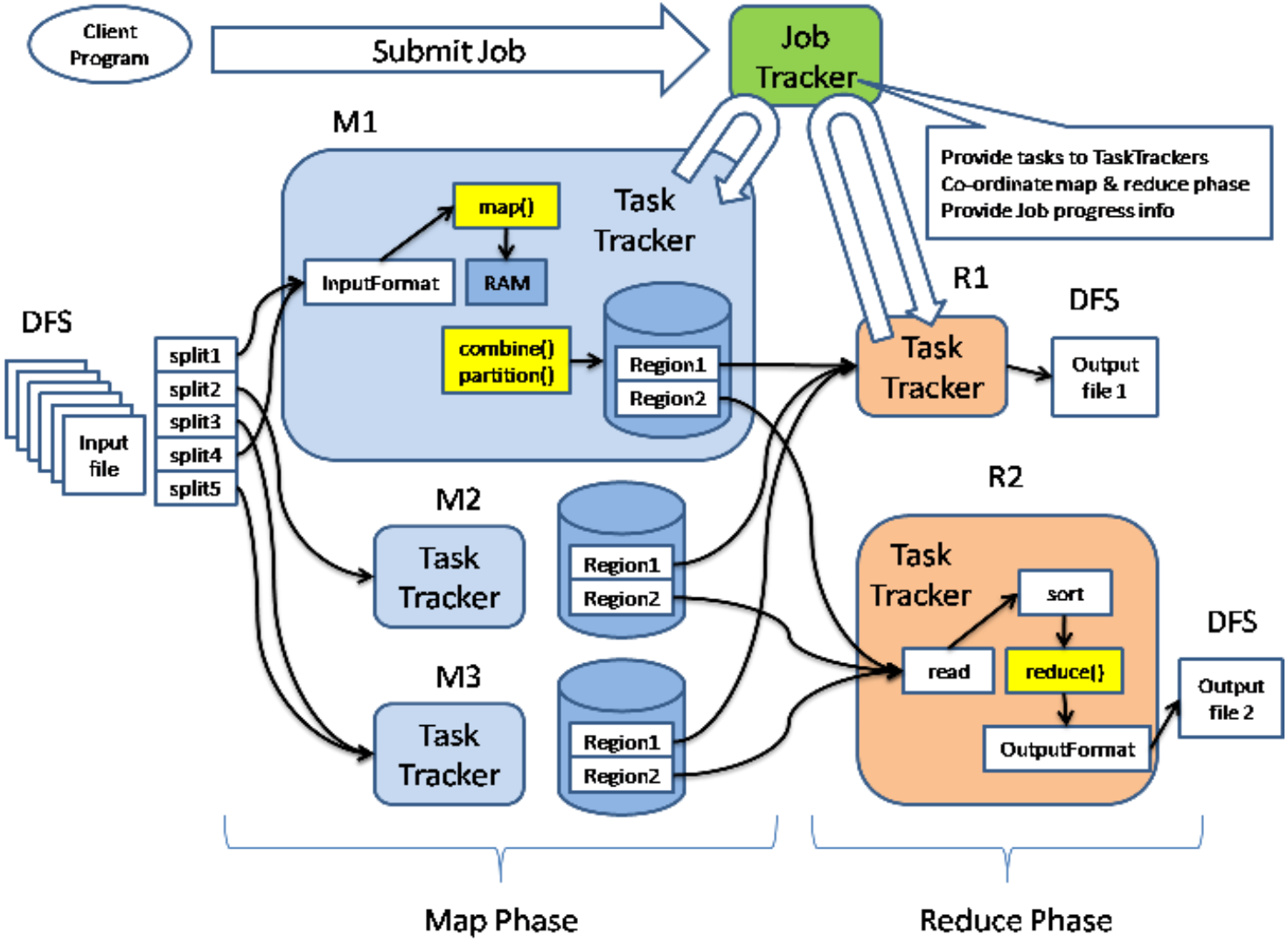



# MapReduce Procedure




- Map:
  - Accepts *input* key/value pair
  - Emits *intermediate* key/value pair
- Reduce :
  - Accepts *intermediate* key/value* pair
  - Emits *output* key/value pair

# MapReduce Framework



# MapReduce Process (org.apache.hadoop.mapred)

- JobClient
  - Submit job
- JobTracker
  - Manage and schedule job, split job into tasks
- TaskTracker
  - Start and monitor the task execution
- Child
  - The process that really execute the task

# Inter Process Communication IPC/RPC (org.apache.hadoop.ipc)

- Protocol

| Client Role | | Server Role |
|---|---|---|
| JobClient | <------JobSubmissionProtocol-------> | JobTracker |
| TaskTracker | <------ InterTrackerProtocol ------> | JobTracker |
| TaskTracker | <-------TaskUmbilicalProtocol ------> | Child |

# Mapper

- Records from the data source
  - lines out of files, rows of a database, etc.
  - key*value pairs: e.g., (filename, line)
- map() produces one or more *intermediate* values along with an output key from the input.

# Mapper

- 每一个Mapper类的实例生成了一个Java进程
  - 在某一个InputSplit上执行

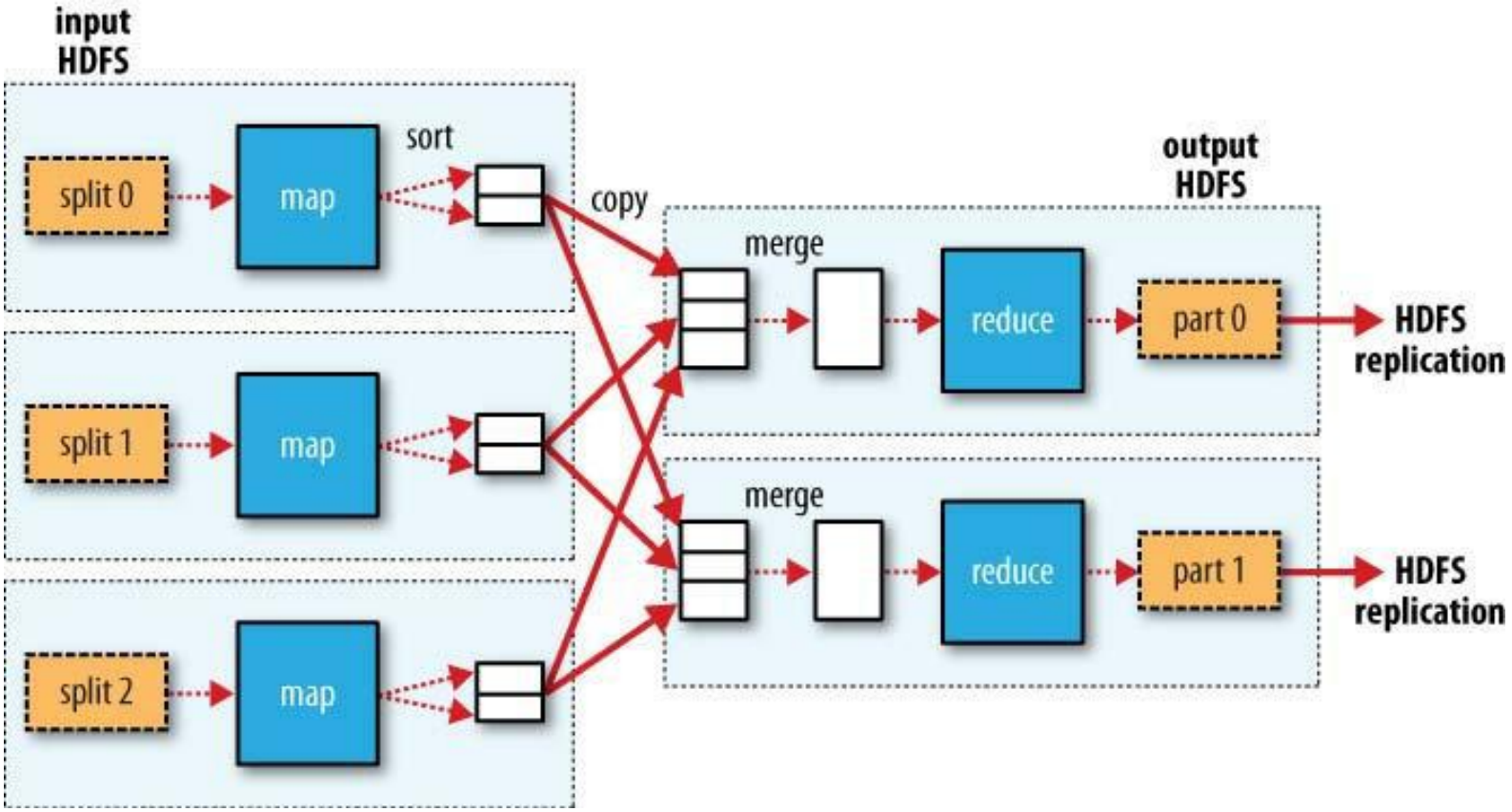
- 有两个额外的参数OutputCollector以及Reporter
  - 前者用来收集中间结果
  - 后者用来获得环境参数以及设置当前执行的状态。

# Reducer

- After the map phase is over, all the intermediate values for a given output key are combined together into a list
- reduce() combines those intermediate values into one or more *final values* for that same output key

(in practice, usually only one final value per key)

# MapReduce Data Flow



# Partition&Shuffle

- 在Map工作完成之后，每一个 Map函数会将结果传到对应的Reducer所在的节点
- 用户可以提供一个Partitioner类，用来决定一个给定的<key,value>对传输的具体位置

# Sort

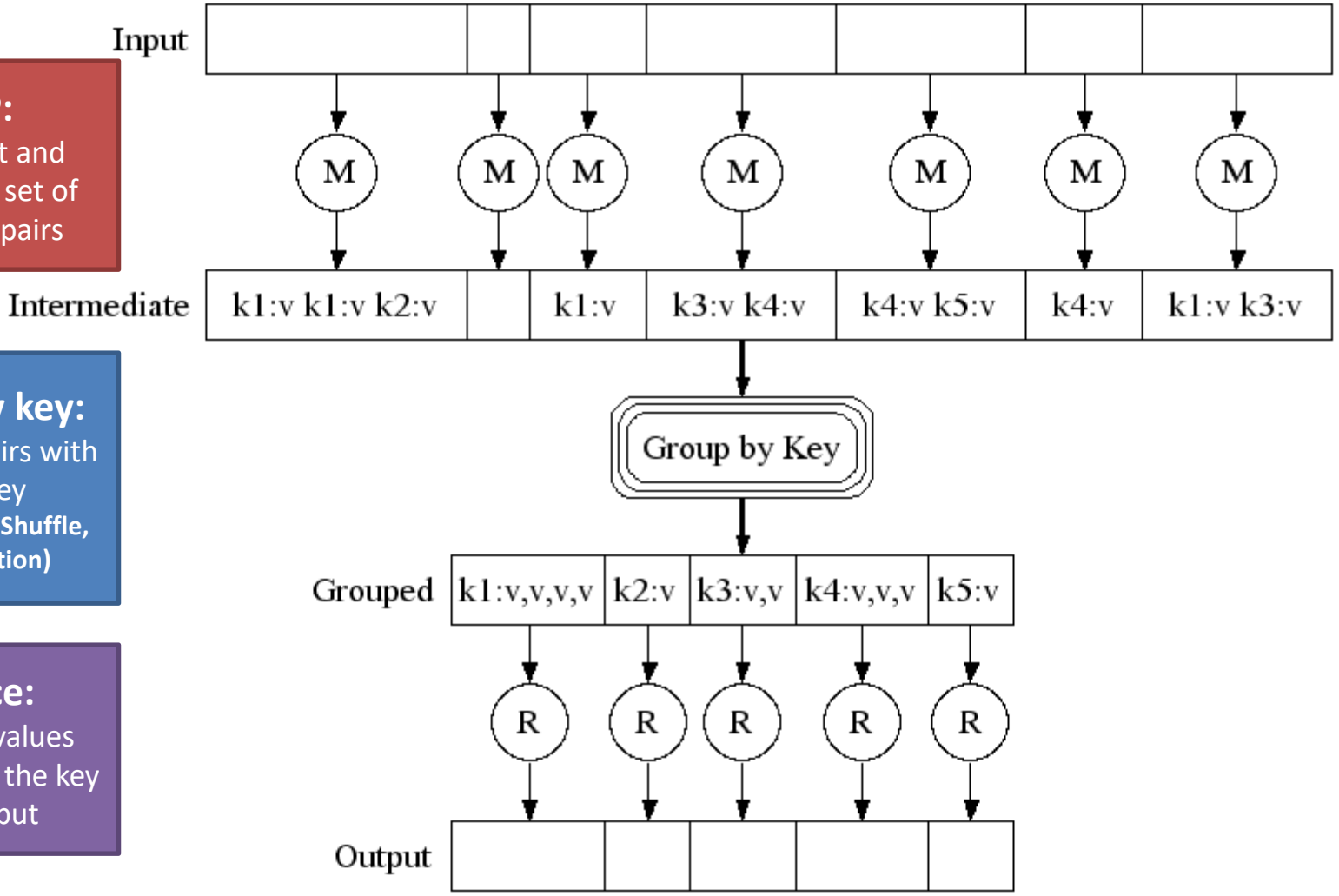
- 传输到每一个节点上的所有的Reduce函数接收到的<key,value>对会被Hadoop自动排序
  - 即Map生成的结果传送到一个节点时，会被自动排序
- Default : `hash(key) mod R`
- Guarantee:
  - Relatively well-balanced partitions
  - Ordering guarantee within partition

# Partitioning Function

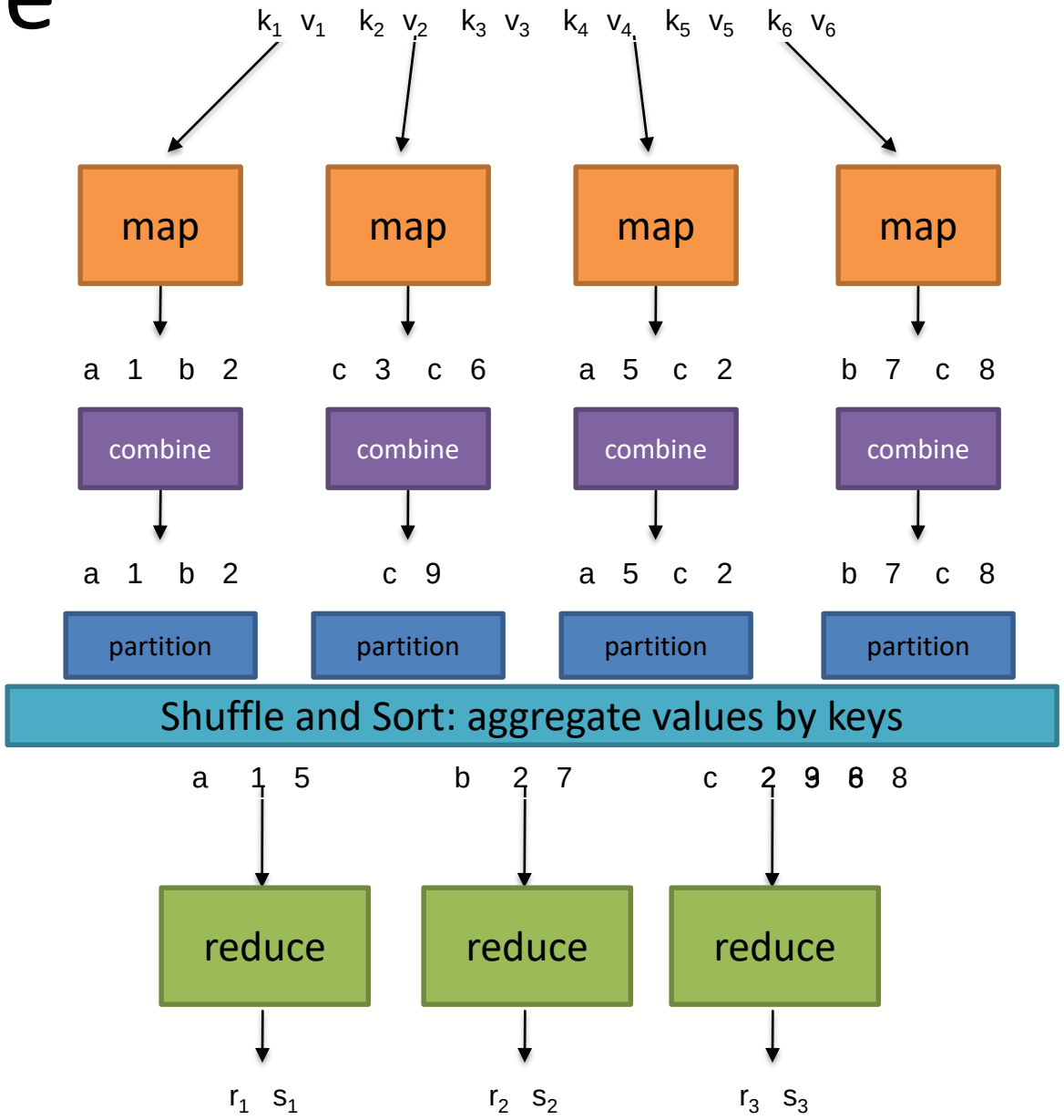
**MAP:**
Read input and produces a set of key-value pairs

**Group by key:**
Collect all pairs with same key
**(Hash merge, Shuffle, Sort, Partition)**

**Reduce:**
Collect all values belonging to the key and output



# Example


k1 v1 k2 v2 k3 v3 k4 v4 k5 v5 k6 v6
map
map
map
map
a 1 b 2
c 3 c 6
a 5 c 2
b 7 c 8
combine
combine
combine
combine
a 1 b 2
c 9
a 5 c 2
b 7 c 8
partition
partition
partition
partition
Shuffle and Sort: aggregate values by keys
a 1 5
b 2 7
c 2 9 8
reduce
reduce
reduce
r1 s1
r2 s2
r3 s3

# MapReduce

```
Class MapReduce{
    Class Mapper …{
        Map code;
    }
    Class Reduer …{
        Reduce code;
    }
    Main(){
        JobConf  Conf=new JobConf(“MR.Class”);
        Other code;
    }
}
```

# MapReduce Transparencies

Plus Google Distributed File System :

- Parallelization
- Fault-tolerance
- Locality optimization
- Load balancing

# Example Word Count: Map

```
public static class MapClass extends MapReduceBase
implements Mapper {
  private final static IntWritable one= new IntWritable(1);
  private Text word = new Text();

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

# Example Word Count: Reduce

```
public static class Reduce extends MapReduceBase
implements Reducer {
  public void reduce(WritableComparable key, Iterator
  values, OutputCollector output, Reporter reporter)
  throws IOException {
    int sum = 0;
    while (values.hasNext()) {
      sum += ((IntWritable) values.next()).get();
    }
    output.collect(key, new IntWritable(sum));
  }
}
```

# Example Word Count: Main

```
public static void main(String[] args) throws IOException
{
  //checking goes here
  JobConf conf = new JobConf();

  conf.setOutputKeyClass(Text.class);
  conf.setOutputValueClass(IntWritable.class);

  conf.setMapperClass(MapClass.class);
  conf.setCombinerClass(Reduce.class);
  conf.setReducerClass(Reduce.class);

  conf.setInputPath(new Path(args[0]));
  conf.setOutputPath(new Path(args[1]));

  JobClient.runJob(conf);
}
```

# Example

- Page 1: the weather is good
- Page 2: today is good
- Page 3: good weather is good.

# 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 Input

- Worker 1:
  - (the 1)
- Worker 2:
  - (is 1), (is 1), (is 1)
- Worker 3:
  - (weather 1), (weather 1)
- Worker 4:
  - (today 1)
- Worker 5:
  - (good 1), (good 1), (good 1), (good 1)

# Reduce Output

- Worker 1:
  - (the 1)
- Worker 2:
  - (is 3)
- Worker 3:
  - (weather 2)
- Worker 4:
  - (today 1)
- Worker 5:
  - (good 4)

# Outline

1. Basics
2. MapReduce
3. YARN
4. HDFS
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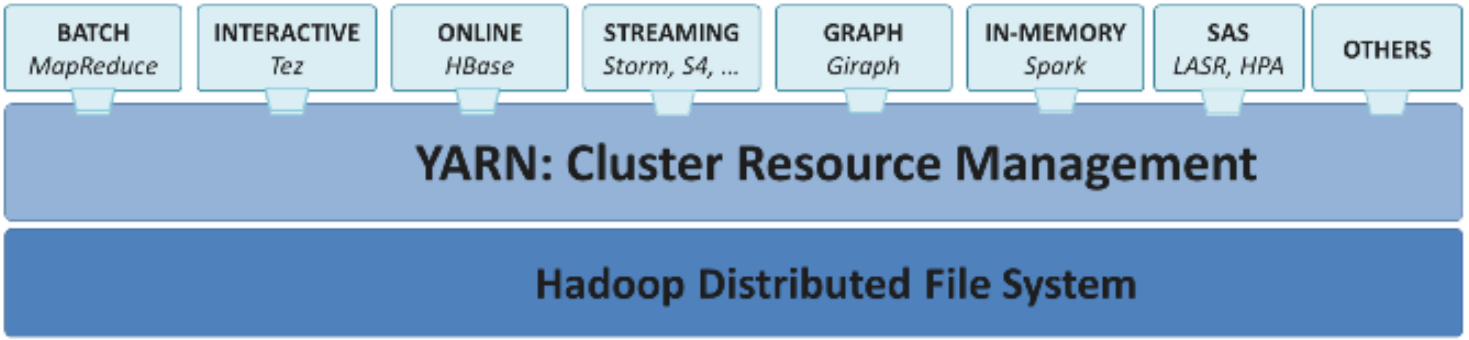
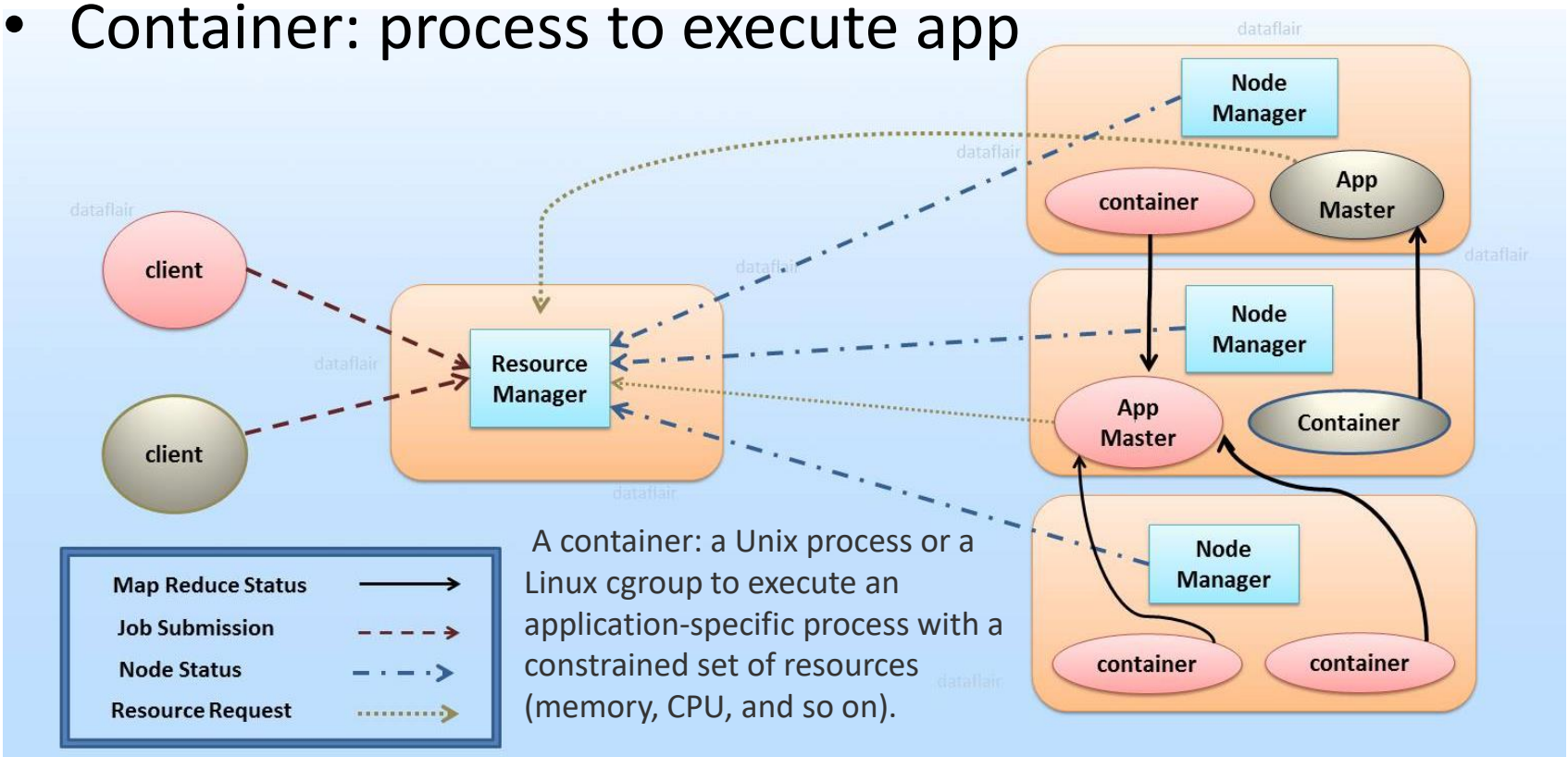
# YARN

- **Y**et **A**nother **R**esource **N**egotiator
- The resource management layer of Hadoop
- The job scheduler of Hadoop
- Introduced in Hadoop 2.x

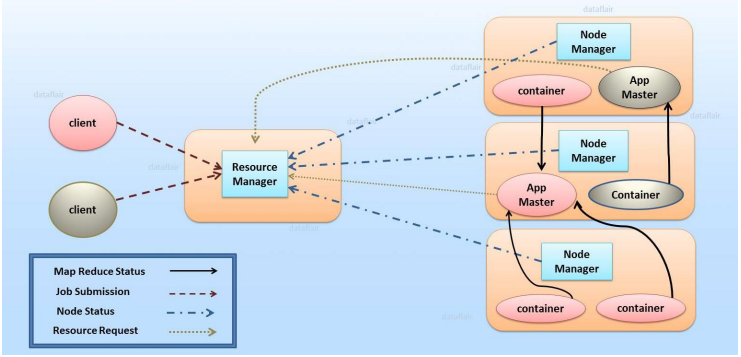


# YARN Architecture

- Resource Manager: a master daemon
- Node Manager: slave daemon, one per salve node
- Application Master: one per application
- Container: process to execute app

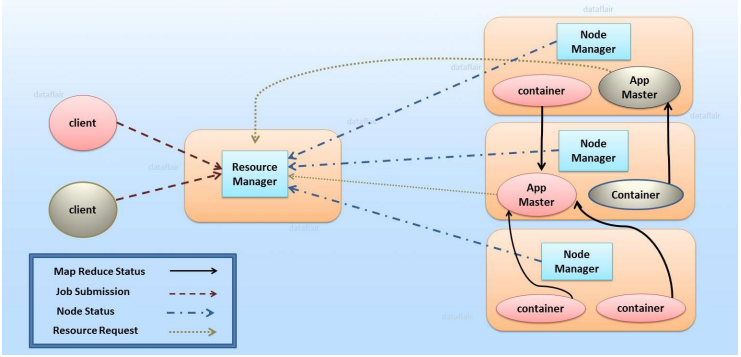


# Resource Manager




- Two main components
- Scheduler
  - responsible for allocating the resources to the running application
  - pure scheduler
    - no monitoring no tracking for the application
    - doesn't guarantees about restarting failed tasks either due to application failure or hardware failures
- Applications Manager
  - manages running Application Masters in the cluster
  - responsible for starting application masters
  - responsible for monitoring and restarting them upon failures

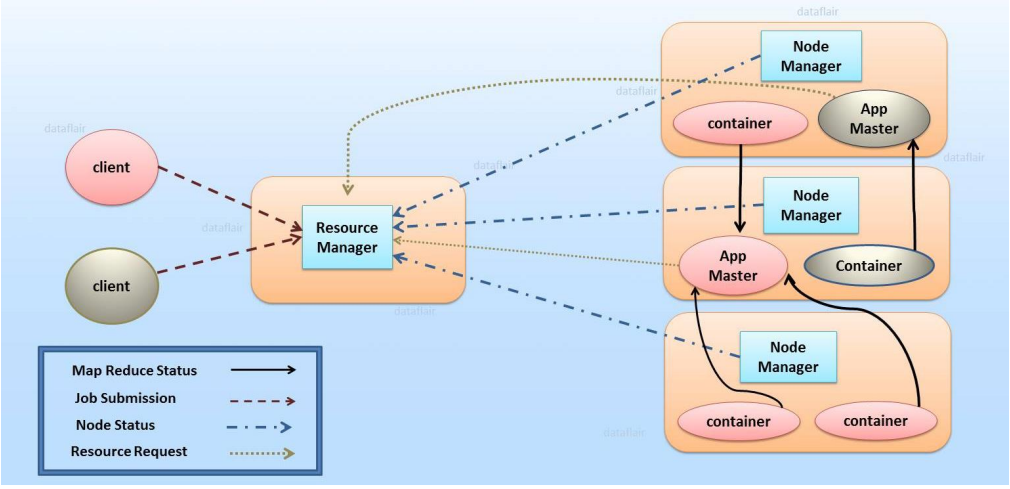
# Node Manager



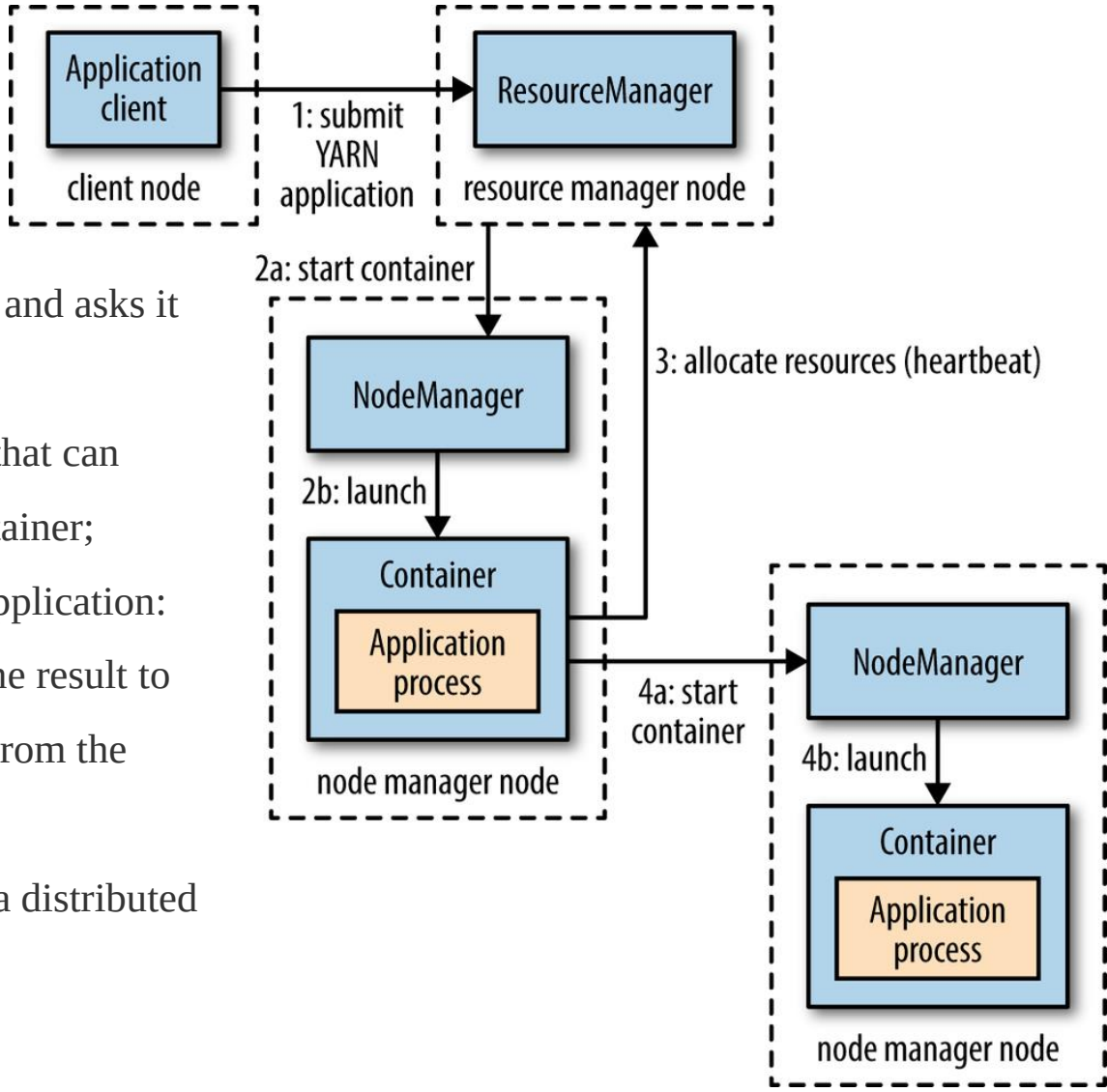

- The slave daemon of YARN
- Responsible for monitoring resource usage and containers and reporting the info. to RM
- Manage the user process on that node
- Track the health of the machine node
- Allows plugging long-running auxiliary services
  - these are application-specific services
  - specified as part of the configurations and loaded during startup
  - A shuffle is a typical auxiliary service by the NMs for MapReduce applications

# Application Master

- One application master runs per application
- Negotiate resources from the resource manager
- Manage the application life cycle
- Major operations:
  - Acquires containers from the RM's Scheduler, then
  - Contacts the corresponding NMs to start the application's individual tasks



# YARN Application Run




1. A client contacts the resource manager and asks it to run an *application master* process;

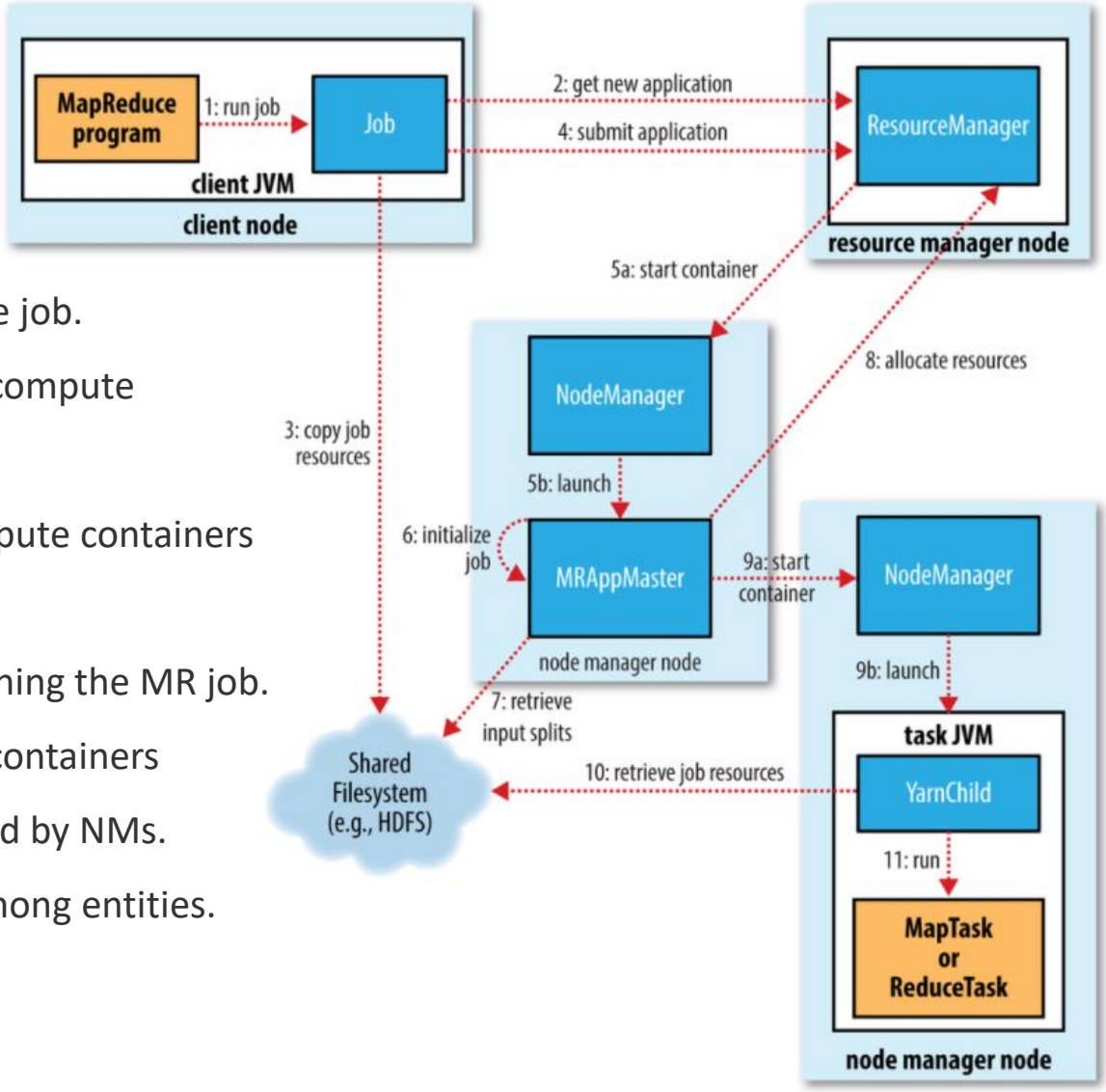
2ab. The RM then finds a node manager that can launch the application master in a container;

3. AM does operations specified by the application: simply run a computation and return the result to the client, or request more containers from the resource managers;

4ab. AM uses containers obtained to run a distributed computation (e.g., a MapReduce job).

# MapReduce Job Run

- The client submits the MapReduce job.
- RM coordinates the allocation of compute resources on the cluster.
- NMs launch and monitor the compute containers on machines in the cluster.
- The AM coordinates the tasks running the MR job.
- The AM and the MR tasks run in containers scheduled by the RM and managed by NMs.
- DFS is used for sharing job files among entities.



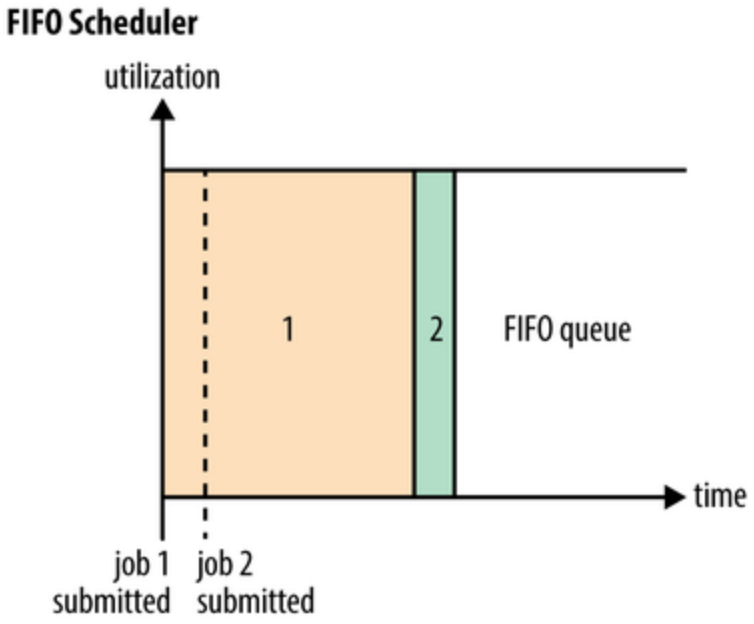
# Resource Requests

- YARN has a flexible model for making resource requests.
- A request for a set of containers
  - Required resources for each container
- Allow locality constraint
  - to request a container on a specific node or rack, or anywhere on the cluster (off-rack).
  - If not met: either no allocation made or, constraint loosened
  - critical in reduce comm. cost, e.g., MR task run at DataNode
- Allow dynamic request during application execution
  - resource requests at any time while app is running
  - MR jobs: mapper requested up front, reducer requested later; if tasks fail, additional containers will be requested

# Scheduling in YARN

- Three schedulers are available in YARN
- FIFO Scheduler
- Capacity Scheduler
- Fair Scheduler

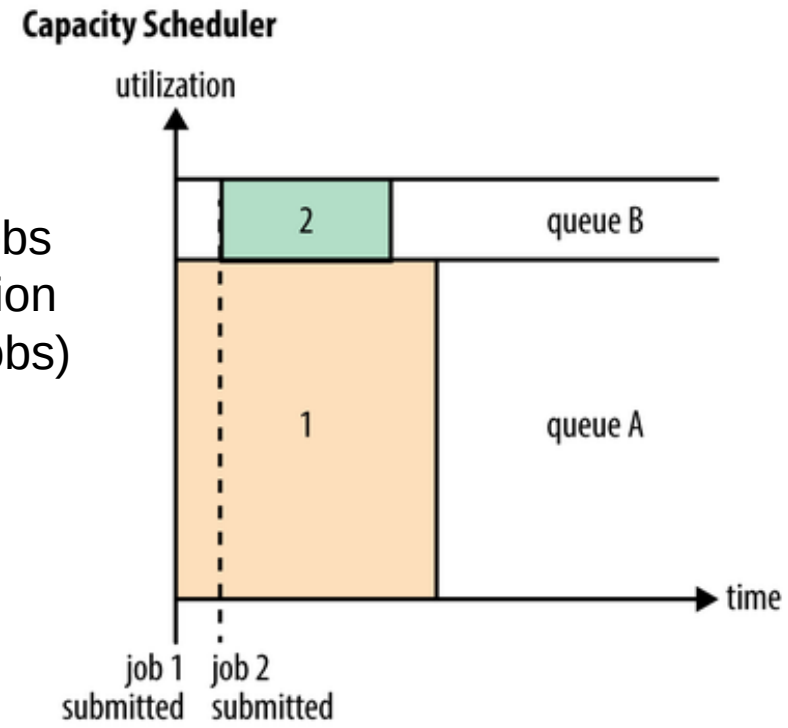
Pro: simple
Con: small jobs suffer



# Capacity Scheduler

- Short job first policy
- A separate dedicated queue for small job to start as soon as submitted

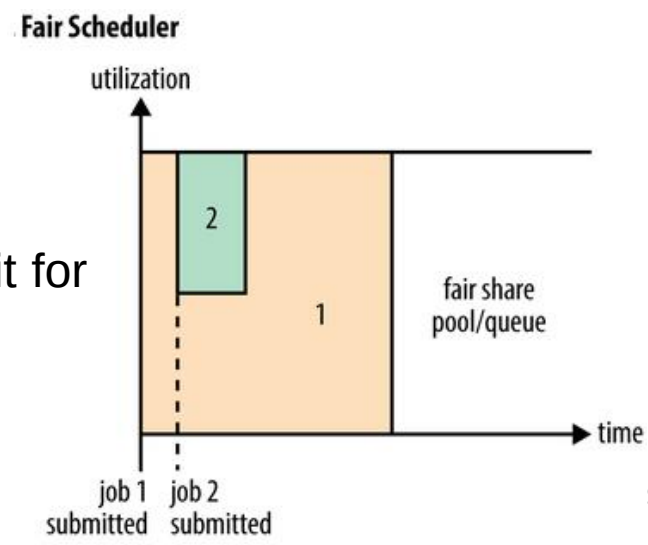
Pro: reduce waiting time of shot jobs
Con: cost of overall cluster utilization
(resources reserved for small jobs)

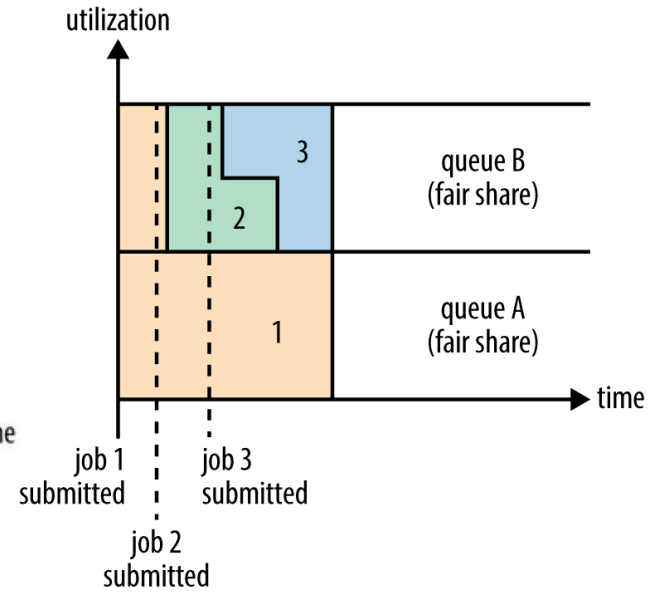


# Fair Scheduler

- Dynamic resource split from large/long jobs
  - No need to reserve capacity
- An example:
  - When small job starts, it is allocated half of resources
- Can be queue based
  - Intra, inter

Pro: resource efficiency
Con: small jobs need to wait for resource release



# Delay Scheduling

- Upon locality not met
  - Loosen it, or wait for resource becoming available
- Delay scheduling
  - waiting a short time (no more than a few seconds) can dramatically increase the chances of meeting locality
  - supported by Capacity scheduler and Fair scheduler
- NM periodically sends heartbeat request to RM
  - by default, one per second
  - carry info. about the running containers and available resources (each heartbeat is a “scheduling opportunity”)
- Scheduler waits for a given number of opportunities before loosening the locality

# Dominant Resource Fairness (DRF)

- Dominant resource of a user: the resource that user has the biggest share of.
  - Total resources: <8CPU; 5GB>
  - User 1 allocation: <2CPU; 1GB>, 2/8 = 25%CPU and 1/5 = 20%RAM
  - Dominant resource of User 1 is CPU (25% > 20%)

- Dominant share of a user: the fraction of the dominant resource she is allocated.
  - User 1 dominant share is 25%.

# Dominant Resource Fairness (DRF)

- Apply max-min fairness to dominant shares: give every user an equal share of her dominant resource.
- Equalize the dominant share of the users.
  - Total resources: <9CPU; 18GB>
  - User 1 wants <1CPU; 4GB>; Dominant resource: RAM 1/9 < 4/18
  - User 2 wants <3CPU; 1GB>; Dominant resource: CPU 3/9 > 1/18

- $\max(x, y)$

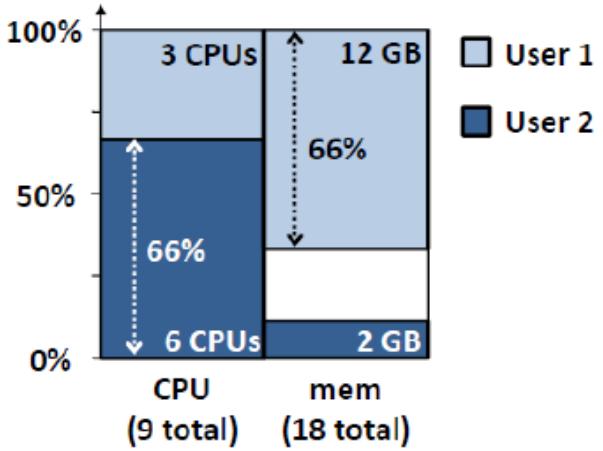
$$x + 3y \leq 9$$

$$4x + y \leq 18$$

$$\frac{4x}{18} = \frac{3y}{9}$$

User 1: $x = 3$: $\langle 33\%CPU, 66\%GB \rangle$

User 2: $y = 2$: $\langle 66\%CPU, 16\%GB \rangle$

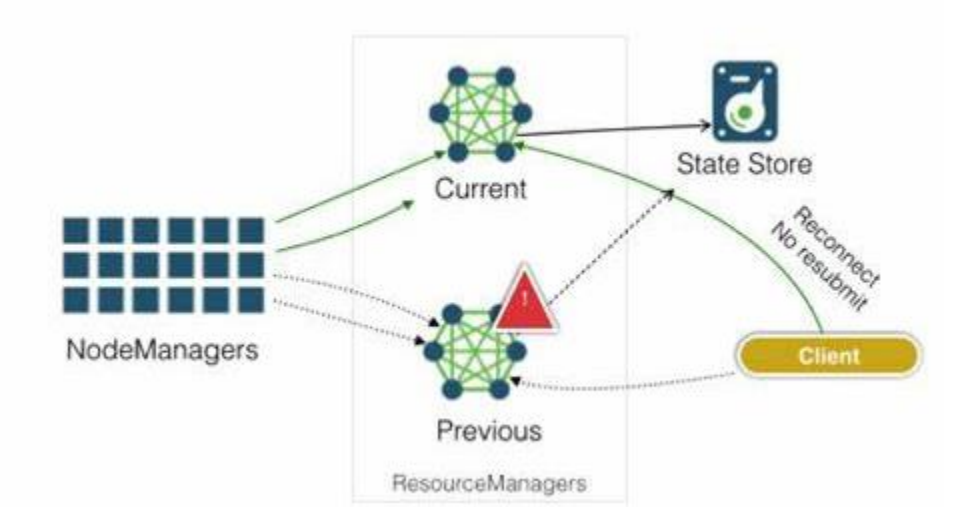


# Resource Manager High Availability

- RM is SPOF before to Hadoop v2.4
- Backup pair: Active-Standby
- Transition-to-active
  - By the admin or the failover-controller based automatic failover
- Automatic failover
  - The master has an option to embed the Zookeeper based ActiveStandbyElector to decide which RM should be Active

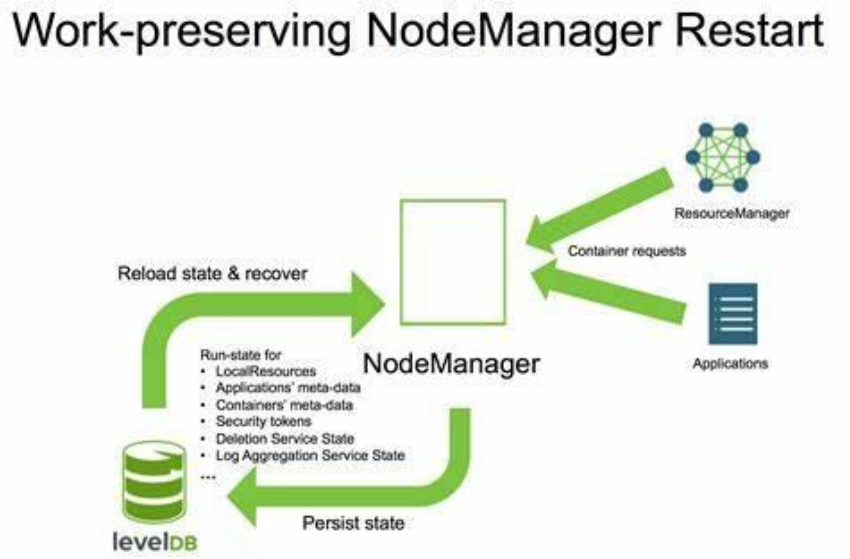
# Resource Manager Restart

- Enhance RM with a pluggable state-store to persist application/attempt state and other credentials information .
- RM will reload this information from state-store upon restart and re-kick the previously running applications.
- Users are not required to re-submit the applications.



# Node Manager Restart

- The NM stores any necessary state to a local state-store as it processes container-management requests.
- Upon restarting, NM recovers by
  - first loading state for various subsystems and
  - then letting those subsystems perform recovery using the loaded state.

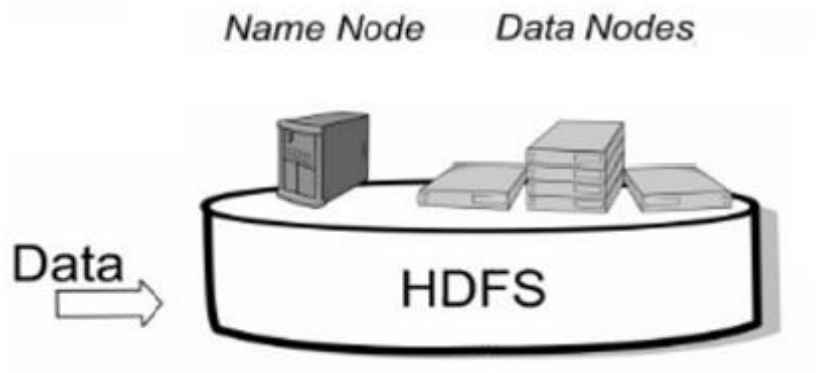


# Outline

1. Basics
2. MapReduce
3. YARN
4. HDFS
5. ZooKeeper

# HDFS

- Google GFS的开源实现
- 容量大：terabytes or petabytes
  - 将数据保存到大量的节点当中
  - 支持很大单个文件
- 高可靠性、快速访问、高可扩展
  - 按块存储、并行读取、效率高
  - 大量的数据复制
- HDFS是针对MapReduce设计
  - 尽可能本地局部性进行访问



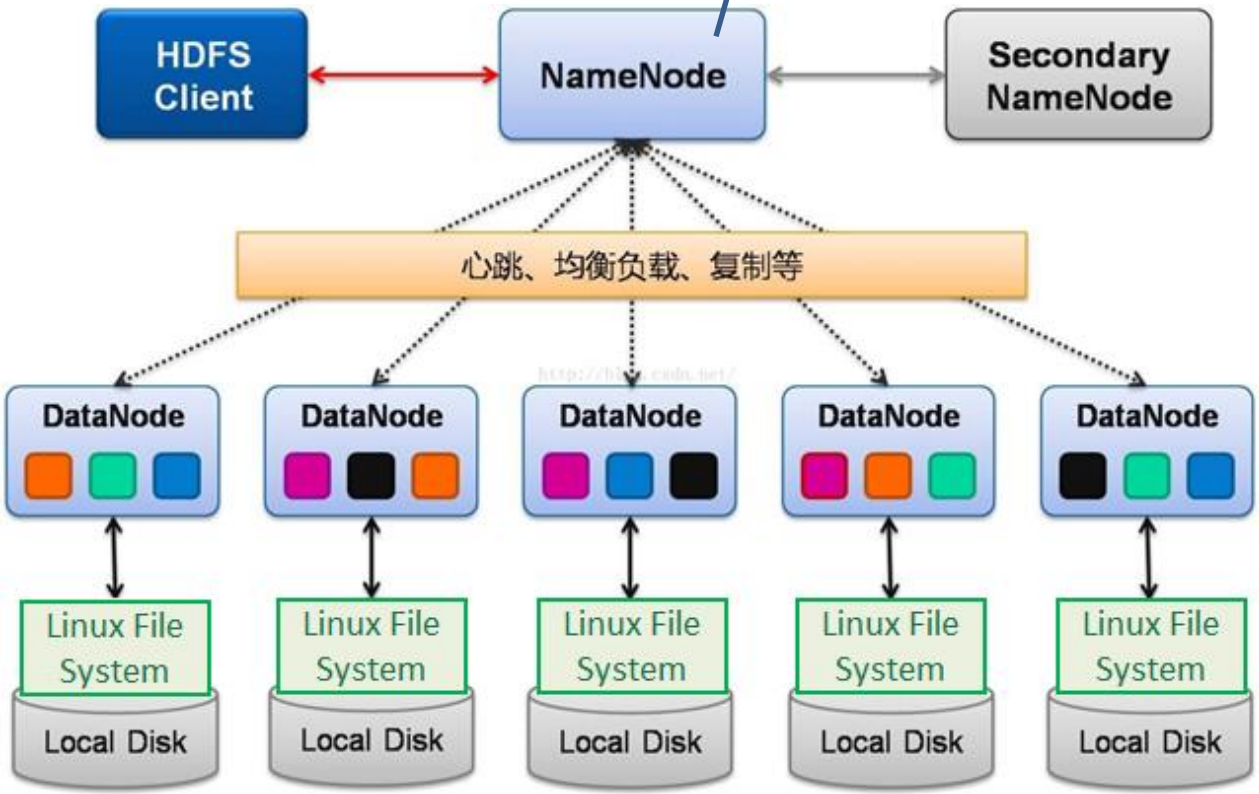
# HDFS适用场景

- 大量地从文件中顺序读
  - HDFS对顺序读进行了优化
  - 随机的访问负载较高
- 数据支持一次写入，多次读取
  - 不支持数据更新（但可以直接进行文件替换）
- 数据不进行本地缓存
  - 文件很大，且顺序读

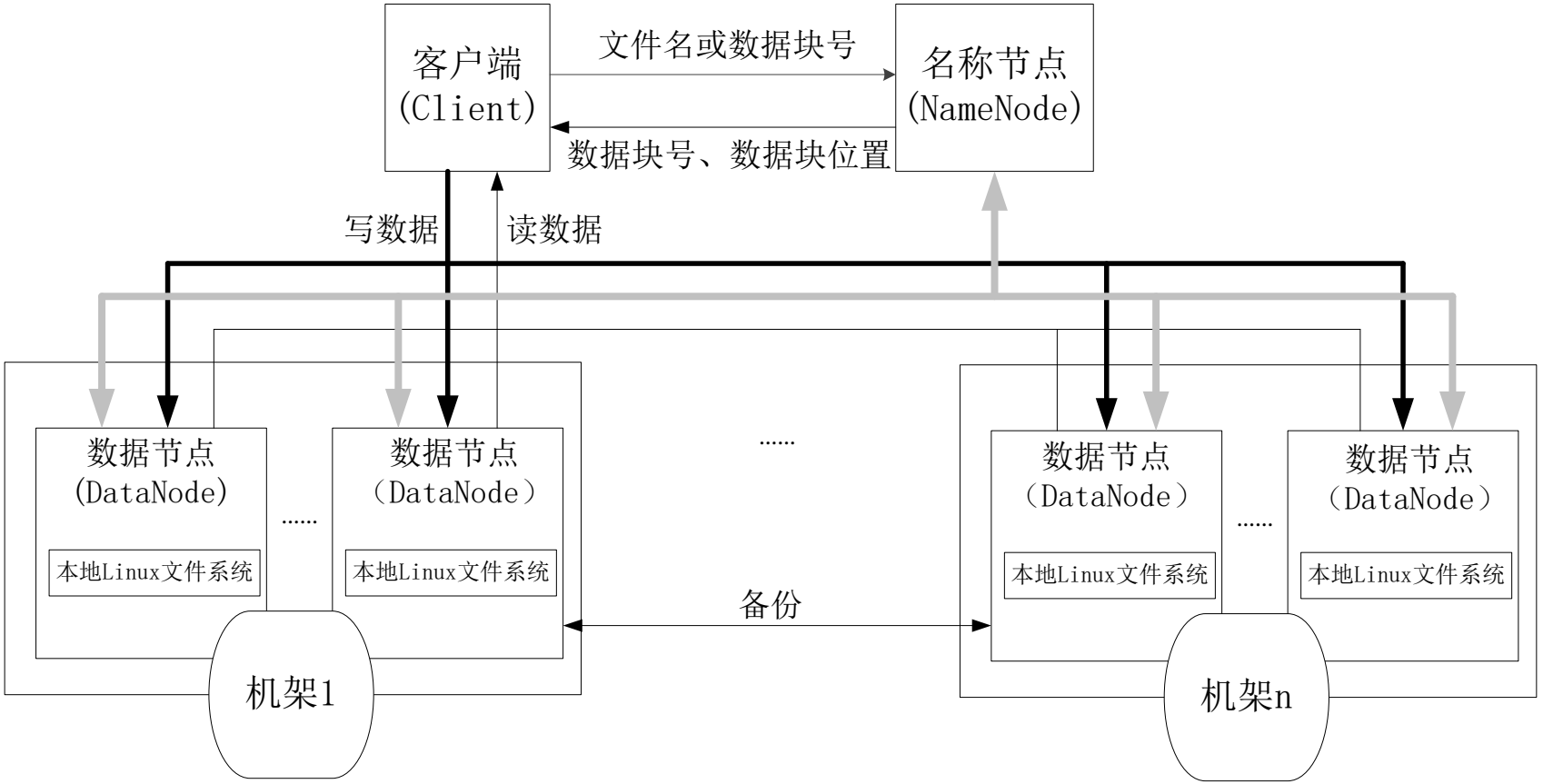
# HDFS系统架构

- Master-Slave架构
- 节点的本地OS具体管理本地资源
- HDFS处于中间件层次，整合集群存储

支持联邦模式：
多个NameNode各自负责命名空间的一部分，如“/user”



# HDFS系统架构


客户端
(Client)
文件名或数据块号
名称节点
(NameNode)
数据块号、数据块位置
写数据
读数据
数据节点
(DataNode)
本地Linux文件系统
数据节点
(DataNode)
本地Linux文件系统
.....
.....
数据节点
(DataNode)
本地Linux文件系统
数据节点
(DataNode)
本地Linux文件系统
.....
备份
机架1
机架n

# HDFS的基本设计

- 基于块的文件存储
- 使用传统的分级文件命名体系
  - 命名空间包含目录、文件和块
- 数据块有复制放置
  - 副本的默认数目是3
  - Erasure coding in Hadoop 3.0
- 默认的块的大小是128MB
  - 减少元数据的量
  - 有利于顺序读写

  （在磁盘上数据顺序存放）

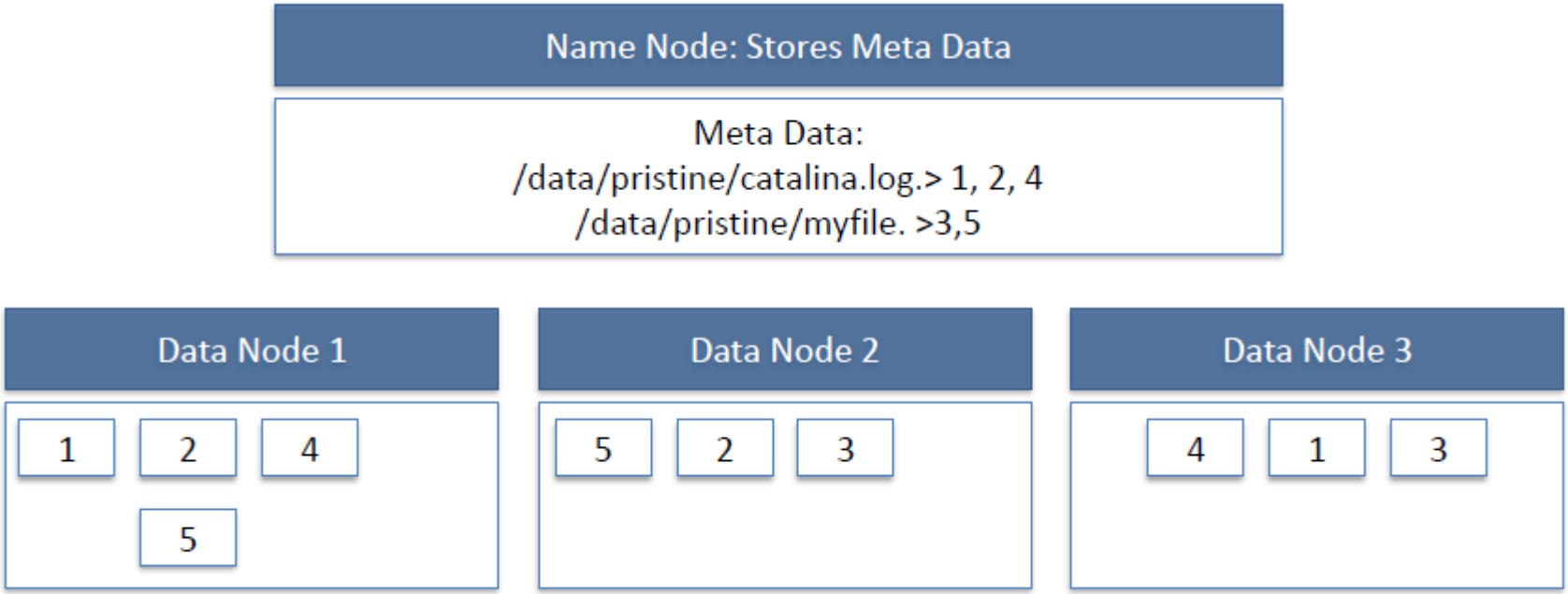
# HDFS节点通信

- 所有HDFS通信协议都是基于TCP/IP协议
- Client-NameNode：
  - 通过一个可配置的端口向NameNode主动发起TCP连接；
  - 使用客户端协议与NameNode进行交互。
- NameNode-DataNode:
  - 使用数据节点协议进行交互
- Client-DataNode:
  - 通过RPC通信
- 名称节点不会主动发起RPC，而是响应来自客户端和数据节点的RPC请求

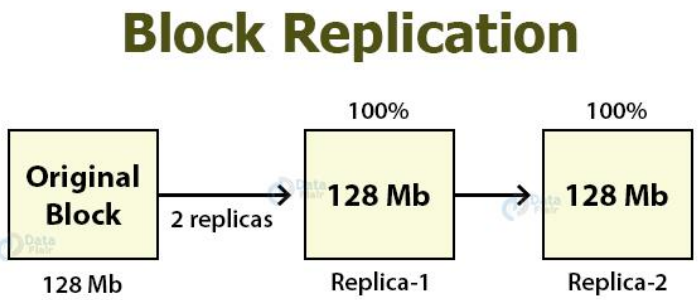
# HDFS数据

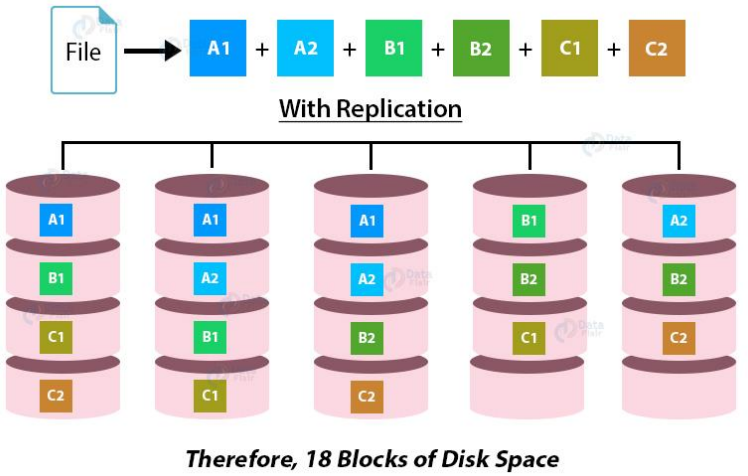
| NameNode |
| --- |
| • 存储元数据 |
| •元数据保存在内存中 |
| • 保存文件,block， datanode 之间的映射关系 |

| DataNode |
| --- |
| • 存储文件内容 |
| •文件内容保存在磁盘 |
| •维护了block id到datanode本地文件的映射关系 |

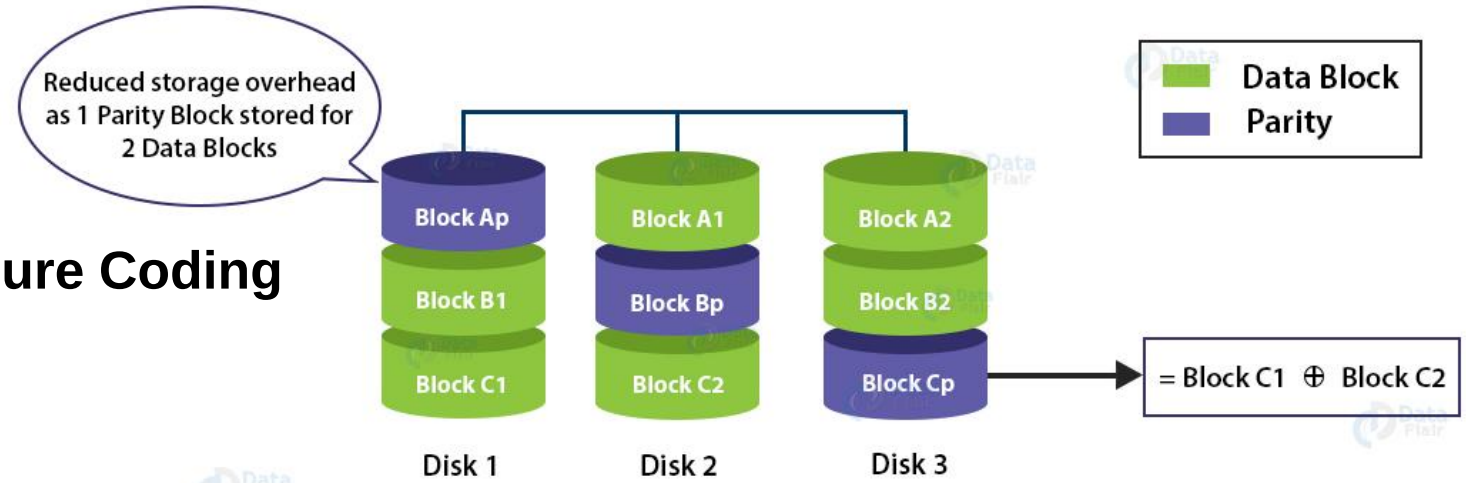


# HDFS数据



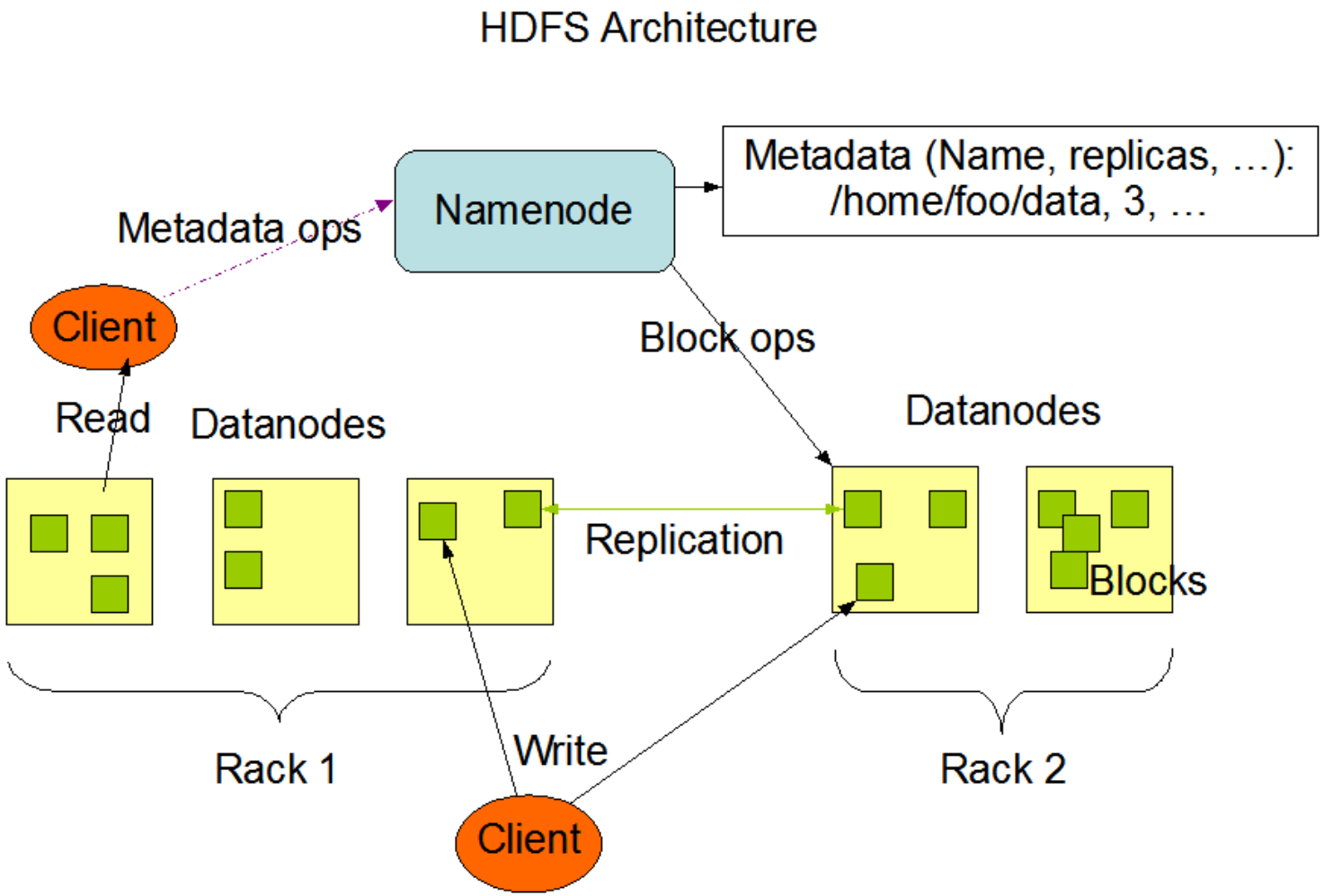

## Erasure Coding




Limitations

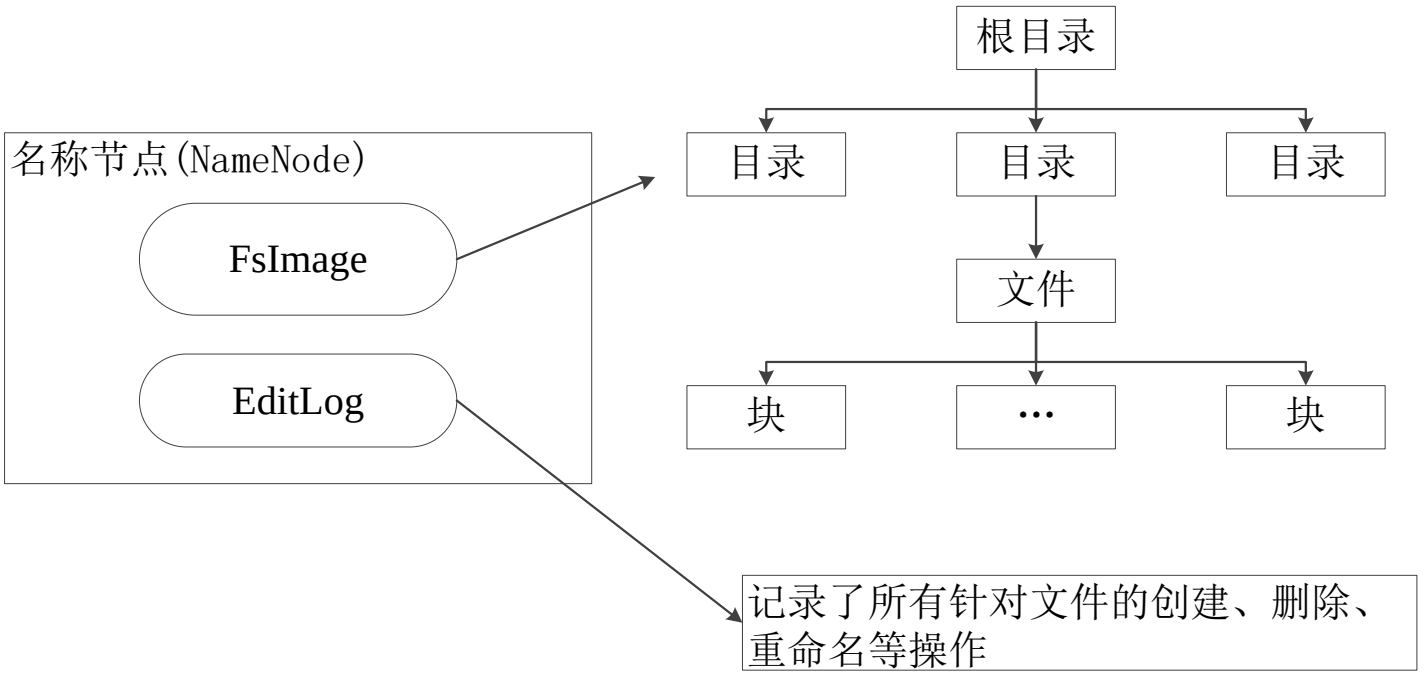
- Do not support certain file writes like hflush, hsync, and append.
- Need additional processing/computing
- Additional overhead in data reconstruction due to remote reads.

# HDFS读写


HDFS Architecture
Namenode
Metadata (Name, replicas, …):
/home/foo/data, 3, …
Metadata ops
Client
Block ops
Read
Datanodes
Datanodes
Replication
Blocks
Rack 1
Write
Rack 2
Client

# NameNode数据结构

- 两个关键数据结构：
  - FsImage：维护文件目录树及文件和目录的元数据
  - EditLog：记录文件的创建、删除、重命名等操作



# NameNode

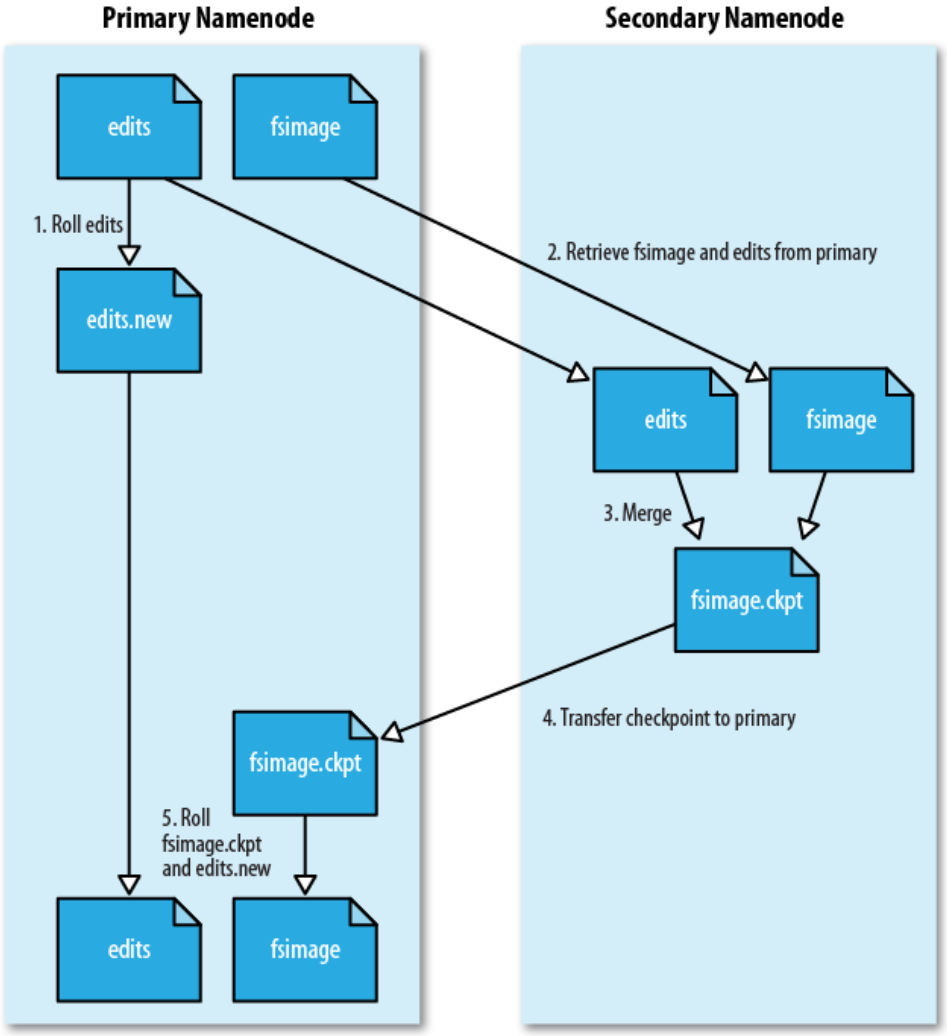
- 名称节点启动：
  - 先将FsImage文件加载到内存
  - 然后执行EditLog文件中的各项操作
  - 创建一个新的FsImage文件和一个空的EditLog文件
- 元数据更新：
  - NameNode启动后，更新操作写到EditLog文件
    - 因为FsImage文件一般很大（GB级别），直接更新太慢
    - 往EditLog文件里面写就会很快：EditLog 要小很多
  - 每次执行写操作之后，且在向客户端发送成功代码之前，edits文件都需要同步更新

# Secondary NameNode

- 保存元数据备份
- 协助执行操作日志
  - 加速NameNode启动

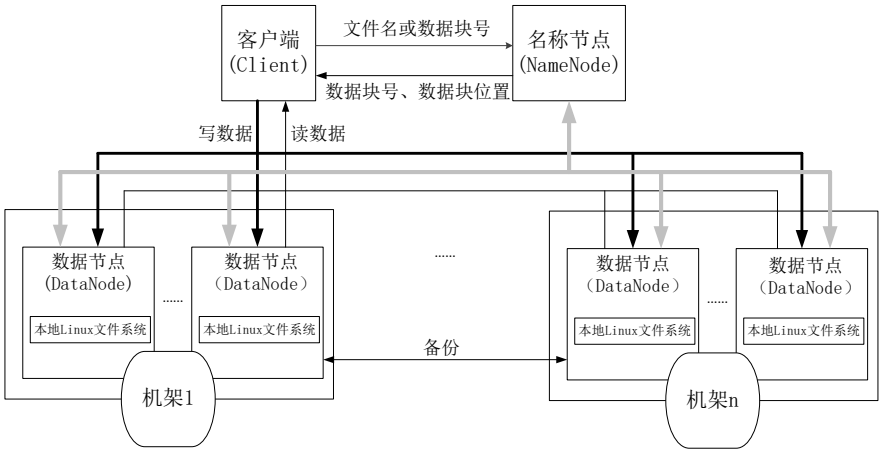
**工作流程：**

1) 请求：定期与NameNode通信，请求其停止使用EditLog文件，暂时将新的写操作写到一个新的文件edit.new中；
(瞬间完成，上层写日志的函数完全感觉不到)
1) 下载：通过HTTP GET从NameNode下载FsImage和EditLog文件；
2) 执行：将FsImage载入内存，逐条执行EditLog中的操作，更新FsImage，即EditLog和FsImage文件合并；
3) 推送：通过post方式将新的FsImage文件发送到NameNode节点。
4) 替换：NameNode将用新的FsImage替换旧的FsImage文件，用edit.new替换EditLog文件。



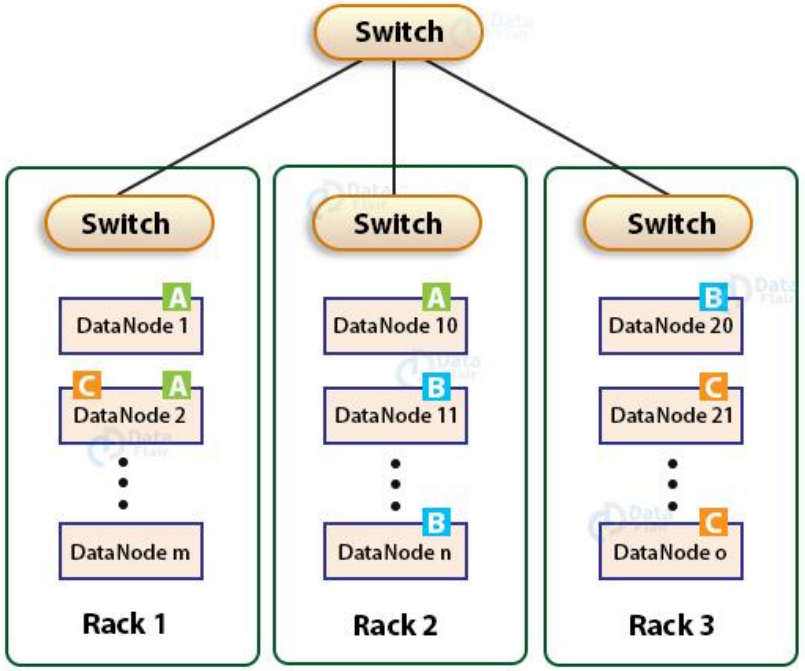
# DataNode

- A Block Sever
  - Stores data in local file system
  - Stores meta-data of a block: checksum
  - Serves data to clients
- Block Report
  - Periodically sends reports of existing blocks to NameNode
- Facilitate Pipelining of Data
  - Forwards data to other specified DataNodes



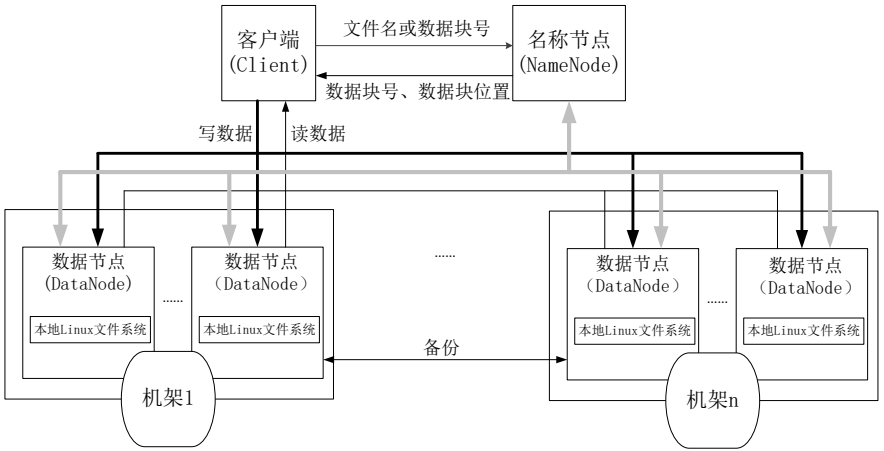
# Block Placement

- Replication Strategy
  - One replica on local node
  - Second/third replica the same remote rack
  - Additional replicas are randomly placed
- Clients read from nearest replica
  - Based on rack id, …
- Block Cache
  - A block may be cached by at most one DataNode



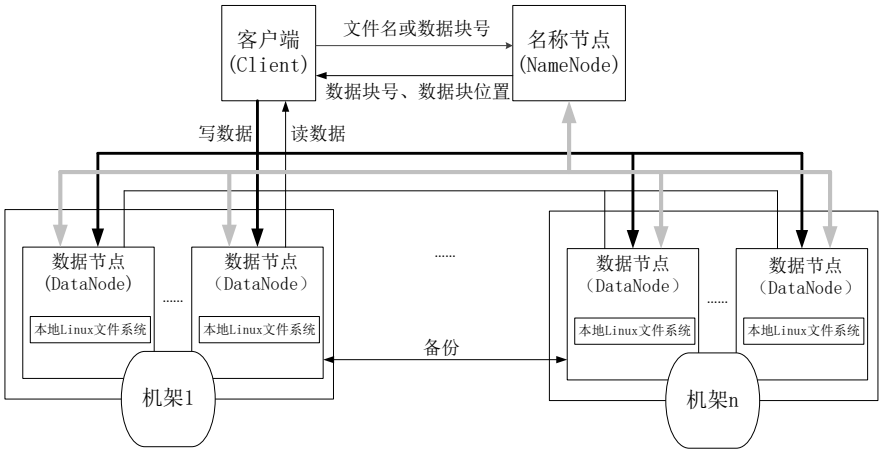
# Data Correctness

- Use Checksums to validate data – CRC32
- File Creation
  - Client computes checksum per 512 byte
  - DataNode stores the checksum
- File Access
  - Client retrieves the data and checksum from DataNode
  - If validation fails, client tries other replicas



# 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



# HDFS FT and HA

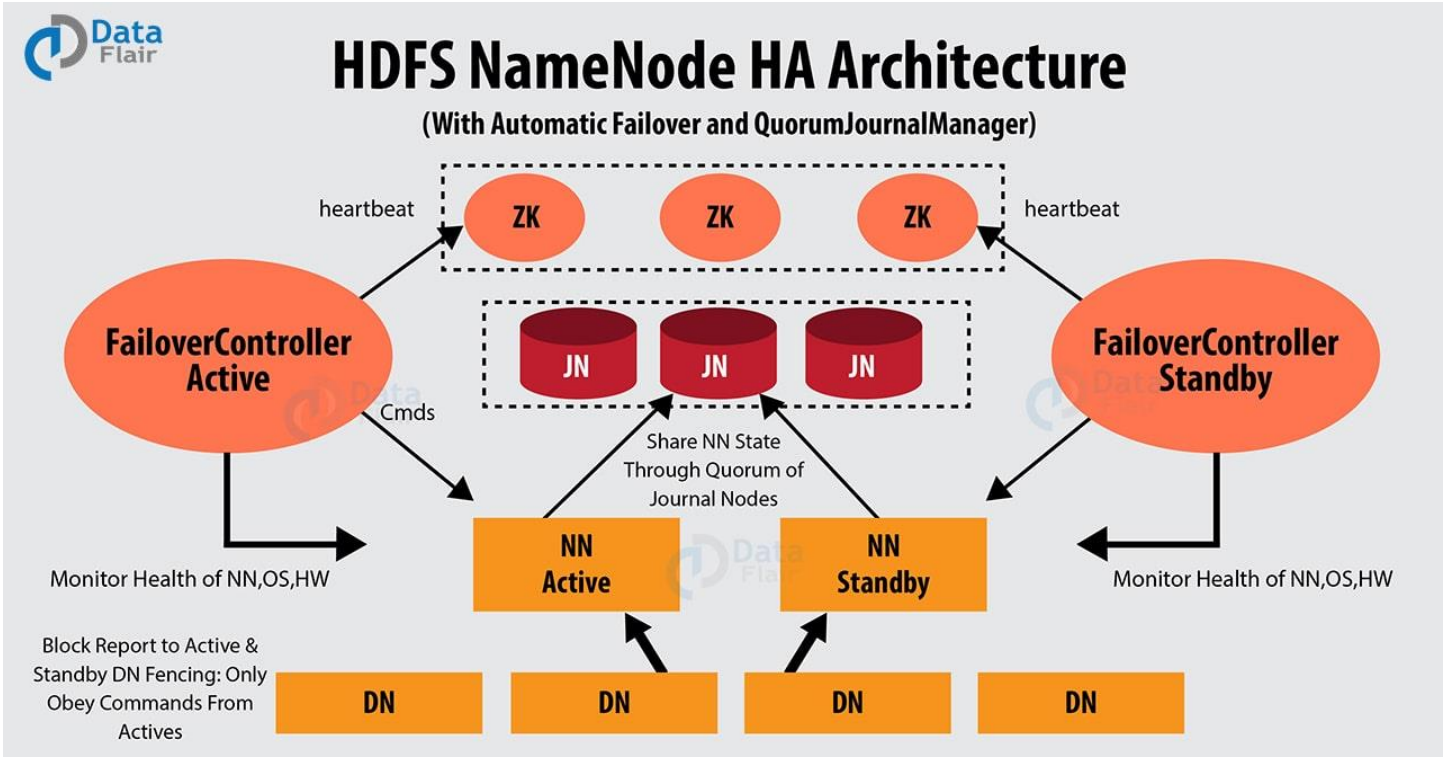
- DataNode Failure：
  - Replication, heartbeat
- Data Integrity:
  - Checksum
- Metadata Failure:
  - Multiple FsImage and EditLog, Checkpoint
- NameNode failure?

# NameNode HA

- Introduced in Hadoop 2.0
- Secondary NameNode: active-standby
- Quorum journal manager (QJM)
  - A group of nodes for sharing edit logs between NameNodes
  - At least 3
  - Can tolerate N/2 failures
- Normal operations
  - Active logs its modification operations to all QJM nodes
  - Standby reads the edits from the journal nodes and applies to its own namespace in a constant manner
  - Datanodes send block reports and heartbeat to both

# NameNode HA

- Failover controller
  - Daemon at each NameNode
  - Trigger switch upon failure
  - Help from Zookeeper to guarantee at most one “active”



# Fencing of NameNode

- Unreliable failure detection (Paxos, ZooKeeper)
  - Too slow speed or network partition
  - Two “living” Namenodes?
- Fencing (规避):
  - To guarantee only one NameNode can write
  - Journal nodes allowing only one namenode to be the writer at a time.
  - The standby namenode takes the responsibility of writing to the journal nodes and prohibit any other namenode to remain active.

Can this really “solve” the problem?

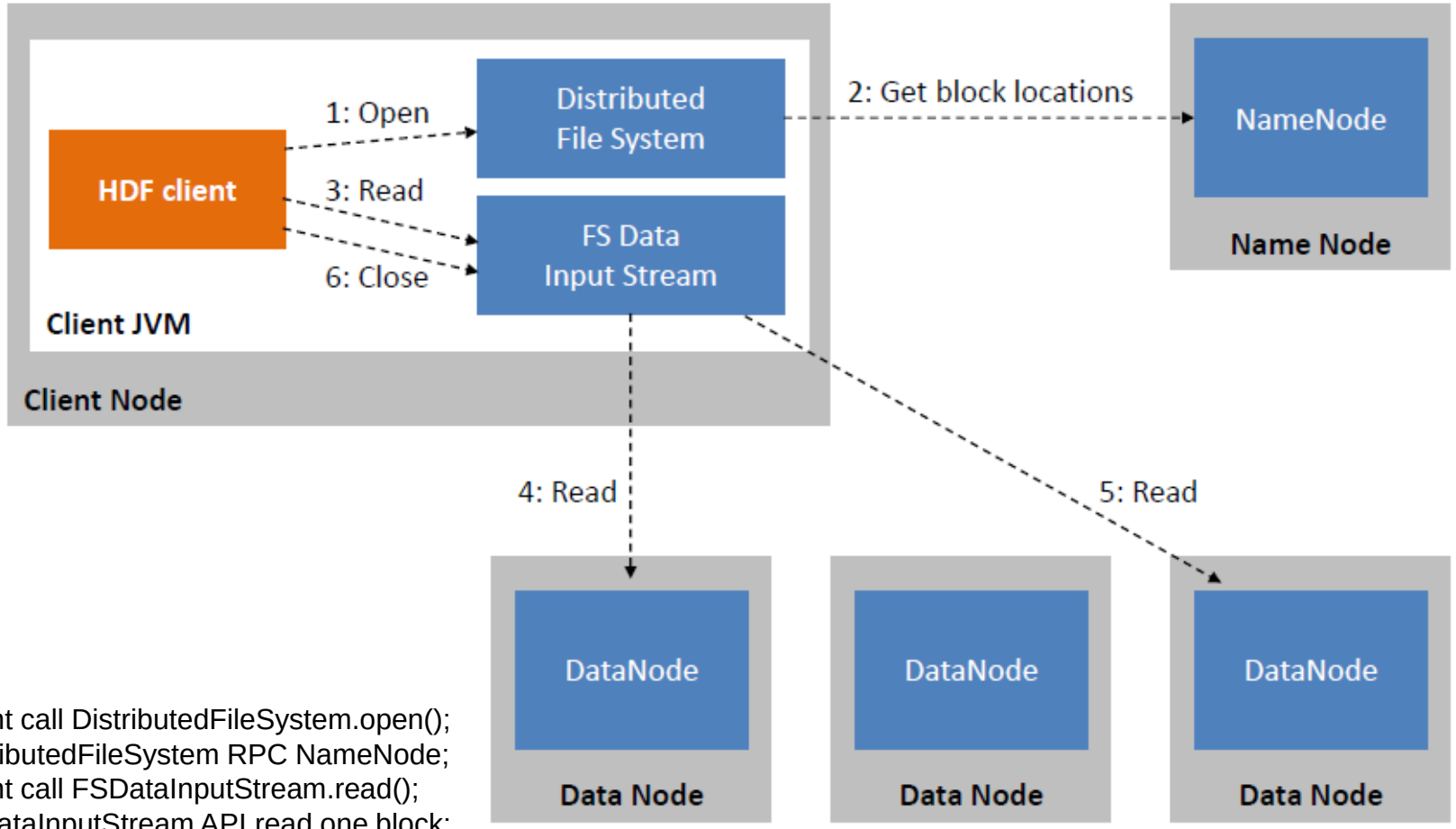
# HDFS权限控制与安全特性

- 类似于POSIX的安全特性
  - 不完全，主要预防操作失误
  - 三类权限：只读、写入、执行
  - Owner、group、mode
- 用户：
  - 当前登录的用户名，即使用Linux自身设定的用户与组的概念
- 安全性弱：不能保证操作的完全安全性

# 负载均衡

- 加入一个新节点的步骤
  - 配置新节点上的hadoop程序
  - 在Master的slaves文件中加入新的slave节点
  - 启动slave节点上的DataNode，会自动去联系NameNode，加入到集群中
- Balancer类用来做负载均衡
  - 默认的均衡参数是10%范围内
  - bin/start-balancer.sh –threshold 5

# Workflow of Reading

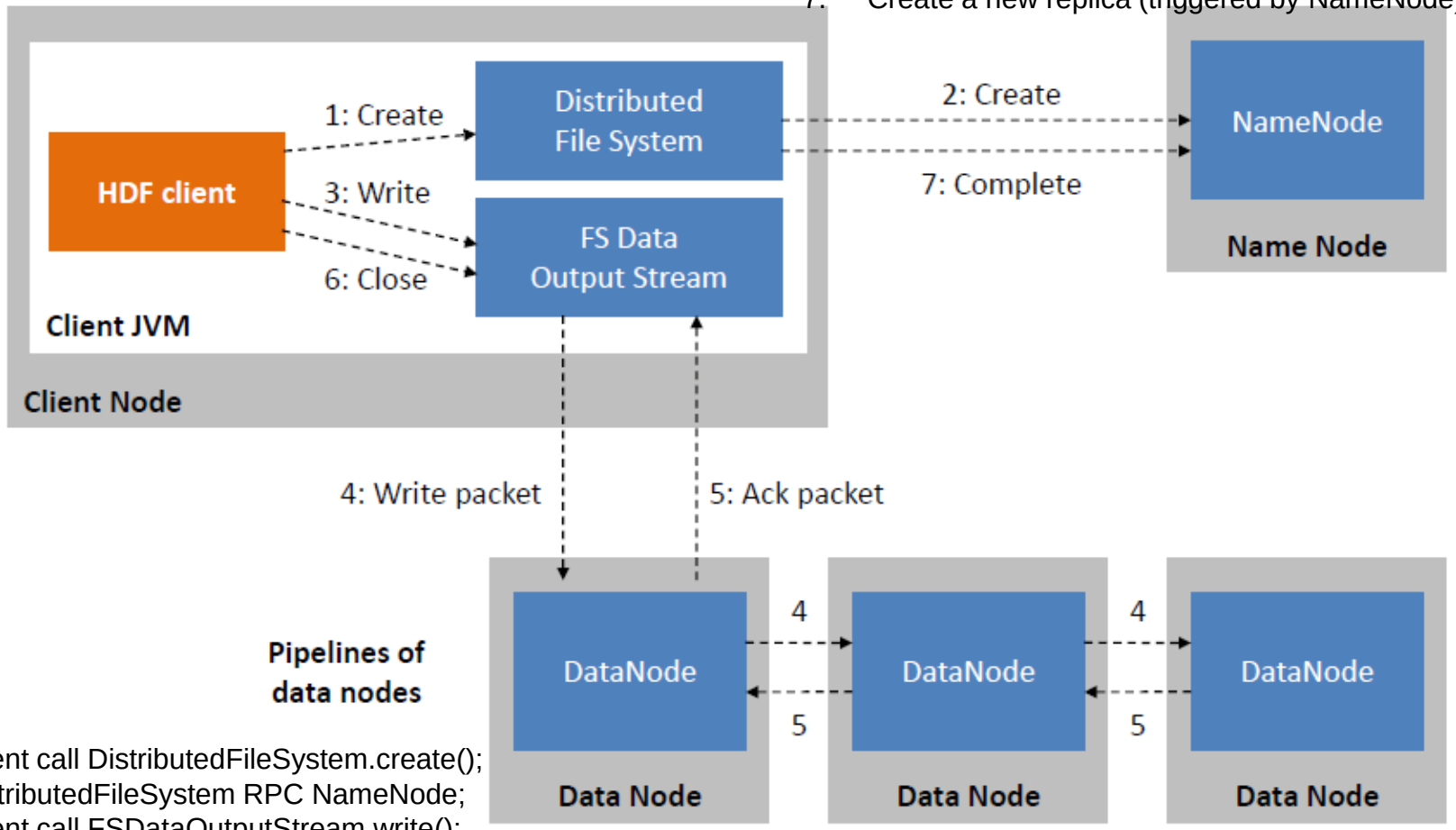



1. Client call DistributedFileSystem.open();
2. DistributedFileSystem RPC NameNode;
3. Client call FSDataInputStream.read();
4. FSDataInputStream API read one block;
5. FSDataInputStream API read another block;
6. Client call DistributedFileSystem.close();

# Workflow of Writing

Upon failure at DataNode during writing:

1. Close the pipleline;
2. Add packets back to queue;
3. Inform NameNode about failed block;
4. Delete failed DataNode from pipeline;
5. Construct new pipleline for the two correct DataNodes;
6. Write rest blocks to correct nodes;
7. Create a new replica (triggered by NameNode).




1. Client call DistributedFileSystem.create();
2. DistributedFileSystem RPC NameNode;
3. Client call FSDataOutputStream.write();
   FSDataOutputStream split data into packets and write to data queue;
4. DataStreamer select DataNodes, request blocks from NameNode, and write via Pipeline;
5. DataNodes send Ack, FSDataOutputStream collects all Ack of the Pipeline;
6. Client call FSDataOutputStream.close();
7. DistributedFileSystem RPC NameNode to complete.

# Outline

1. Basics
2. MapReduce
3. YARN
4. HDFS
5. ZooKeeper

# ZooKeeper

- A highly-available service for distributed coordination and agreement
  - **designed** to relieve developers from writing coordination logic code
  - Coordination problems:
    - leader election, mutual exclusion,
    - group membership, barriers, etc.
- Developed at Yahoo! Research
- Started as sub-project of Hadoop
- Now a top-level Apache project


http://zookeeper.apache.org/

# Design Principles

- API is wait-free
  - No blocking primitives in ZooKeeper
  - Blocking can be implemented by a client
  - No deadlocks
- Guarantees
  - Client requests are processed in FIFO order
  - Writes to ZooKeeper are linearizable
- Clients receive notifications of changes before the changed data becomes visible

# High Performance and Reliability

- Server replication
  - Typically 5 nodes
- Client side cache
  - E.g., caching ID of the current leader to avoid probing every time
- New leader elected?
  - Naive solution: polling (not optimal)
  - Watch mechanism: clients can watch for anupdate of a given data object

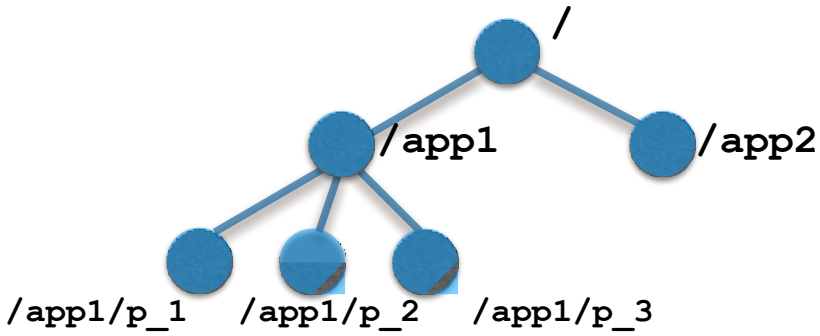
ZooKeeper is optimised for read-dominant operations!

# ZooKeeper Terminology

- **Client**: user of the ZooKeeper service
- **Server**: process providing the ZooKeeper service
- **znode**: **in-memory** data node in ZooKeeper
- **Update/Write**: any operation which modifies the state of znodes
- Clients establish a **session** when connecting to ZooKeeper

# Data Model

- znodes organised in a hierarchical namespace, i.e., a data tree
- It is a filesystem
  - znodes are referred to by UNIX style file system paths
  - Manipulated by clients through API



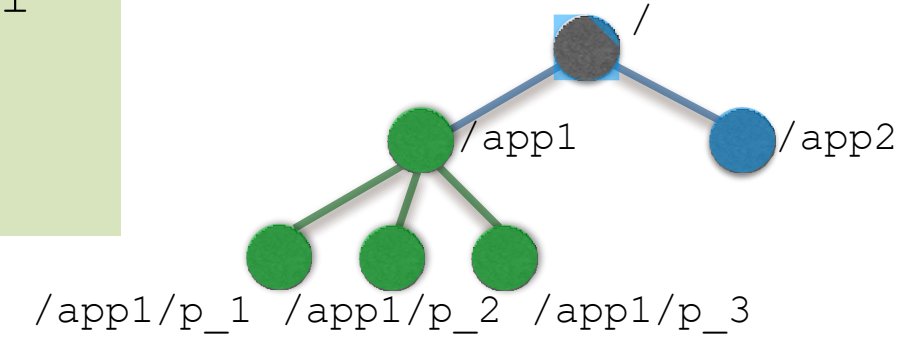

All znodes store **data (file like)** & can have **children (directory like)**.

# znode

- znode is not designed for general data storage (usually require storage in the order of kilobytes)
- znodes map to abstractions of the client application
- Clients manipulate znodes by creating and deleting them

**Group membership protocol:**

Client process `pi` creates znode `p_i` under `/app1`.
`/app1` persists as long as the process is running.

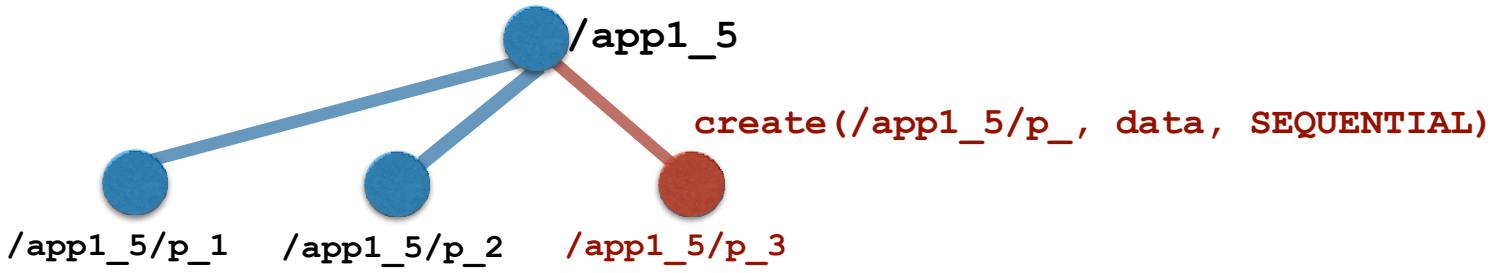


# APIs

- **`String create(path, data, flags)`**
  - creates a znode with path name path, stores data in it and sets flags (ephemeral, sequential)
- **`void delete(path, version)`**
  - deletes the anode if it is at the expected version
- **`Stat exists(path, watch)`**
  - watch flag enables the client to set a watch on the znode
- **`(data, Stat) getData(path, watch)`**
  - returns the data and meta-data of the znode
- **`Stat setData(path, data, version)`**
  - writes data if the version number is the current version of the znode
- **`String[] getChildren(path, watch)`**

# znode Flags

- **EPHEMERAL** flag:
  - znode will be deleted at the end of the client's session
- **SEQUENTIAL** flag:
  - monotonically increasing counter appended to a znode's path
  - counter value of a new znode under a parent is always larger than value of existing children



# znode Watch Flag

- Clients can issue read operations on znodes with a watch flag (true or false)
- Server **notifies** the client when the information on the znode has changed
- Watches are **one-time** triggers associated with a session (unregistered once triggered or session closes)
- Watch notification indicates the change, not new data

```
getData(/app1/lock1,true)
```

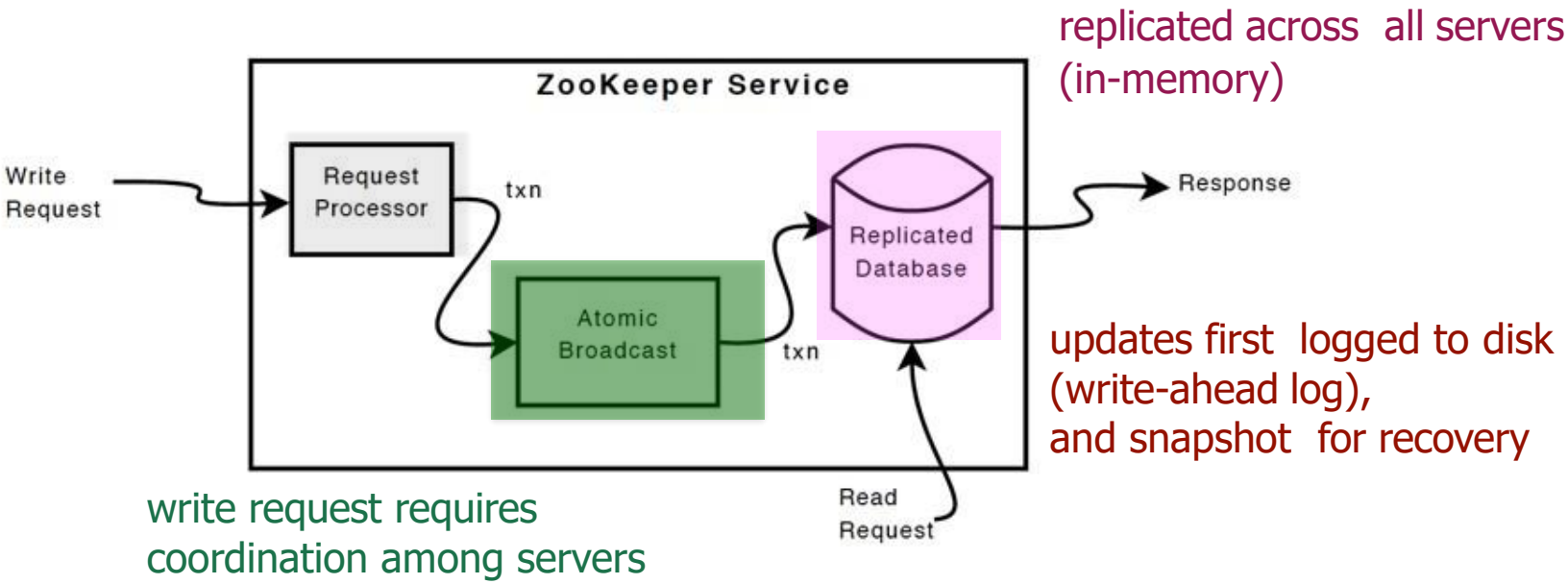
# Session Operations

- Initiation:
  - A client connects to ZooKeeper and initiates a session
- Timeout:
  - session has an associated **timeout**
  - ZooKeeper considers a client faulty if nothing received from its session upon timeout
- End:
  - faulty client or explicitly ended by client

# Major Operations

- Clients connect to exactly one server to submit requests
- read requests served from the local replica
- write requests are processed by an consensus protocol

  (leader initiates processing of the write request)

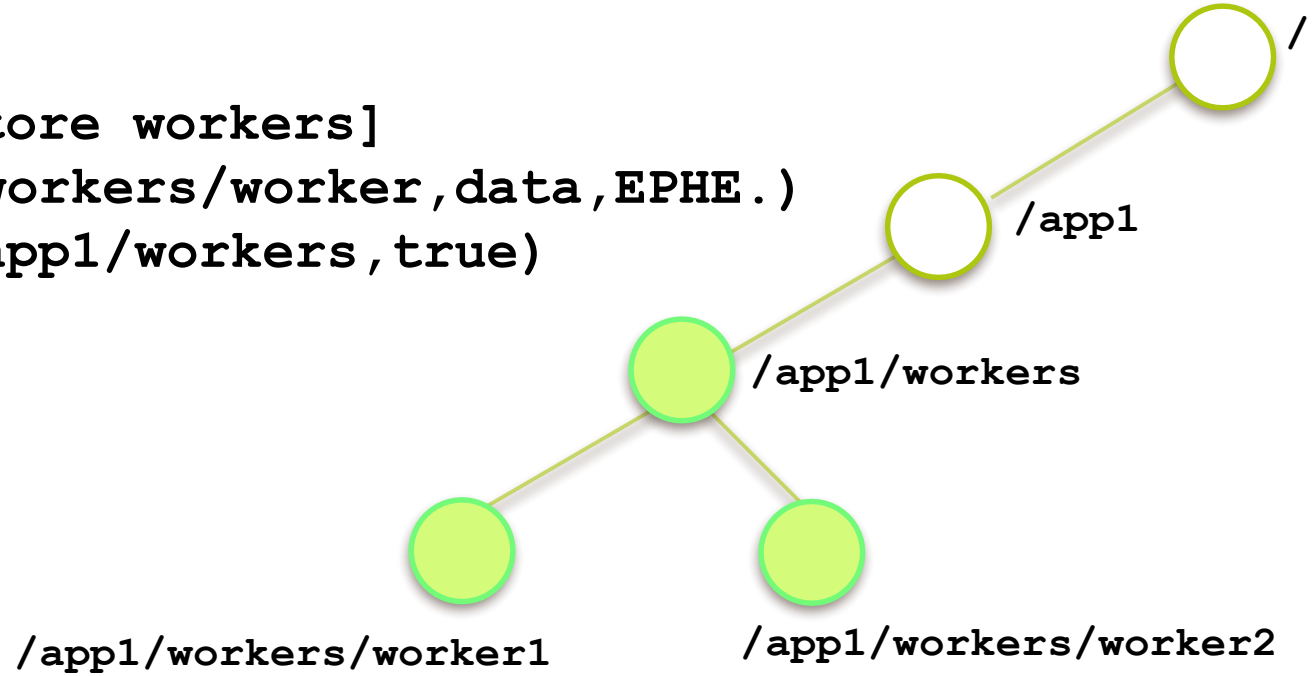


# Example: group membership

**Questions:**
1. How can all workers (slaves) of an application **register themselves** on ZK?
2. How can a process find out about all **active** workers of an application?

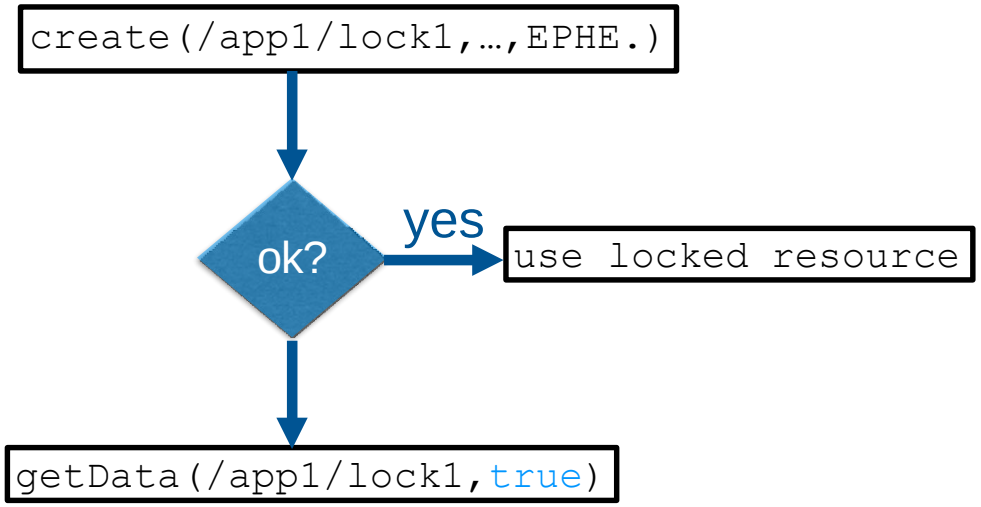
- `String create(path, data, flags)`
- `void delete(path, version)`
- `Stat exists(path, watch)`
- `(data, Stat) getData(path, watch)`
- `Stat setData(path, data, version)`
- `String[] getChildren(path, watch)`

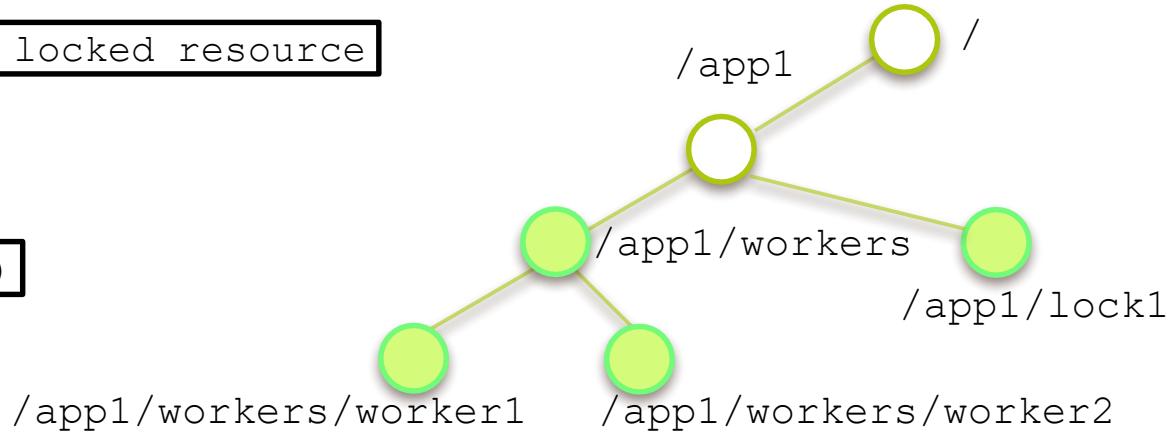
**[a znode to store workers]**
**create(/app1/workers/worker,data,EPHE.)**
**getChildren(/app1/workers,true)**



# Example: simple lock

**Question:**
How can all workers of an application use a single resource through a lock?

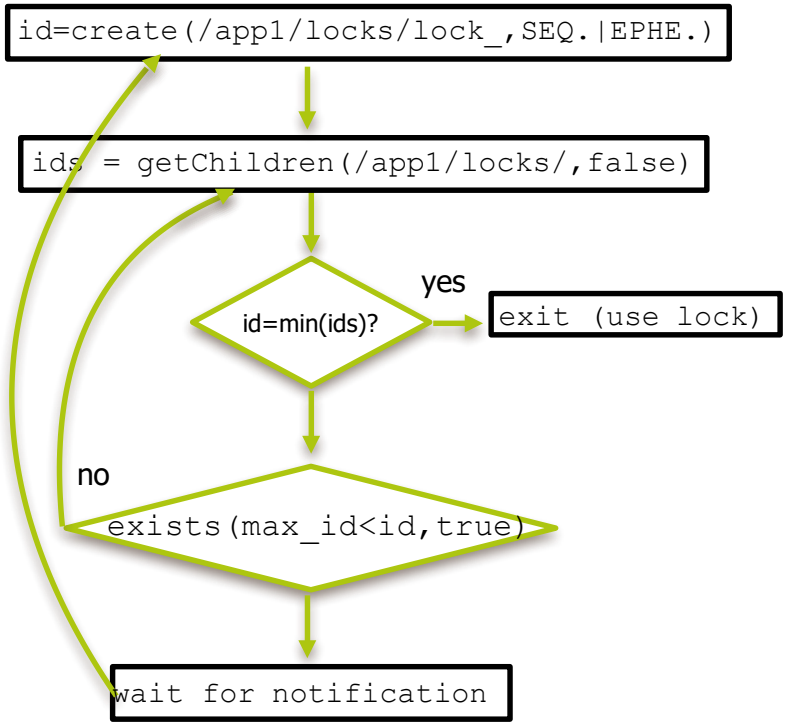


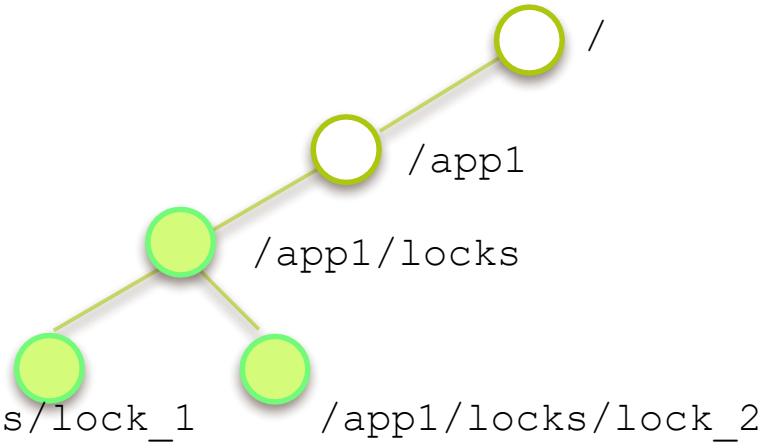




all processes compete at all times for the lock

# Example: locking without herd effect

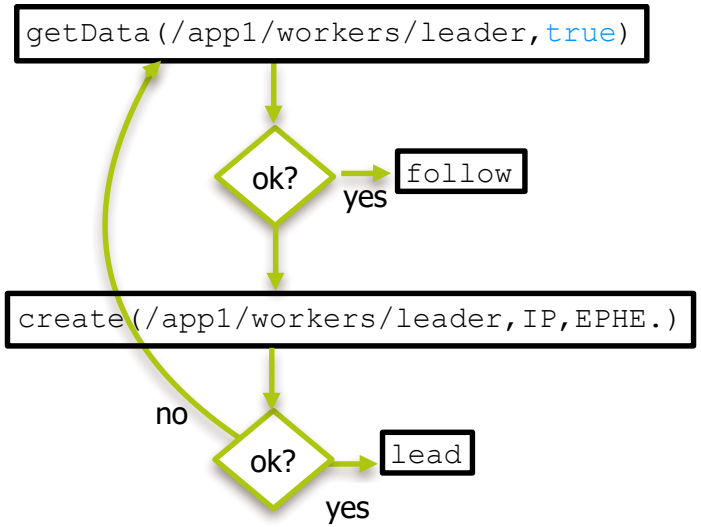
**Question:**
1. How can all workers of an application use a single resource through a lock with queuing?

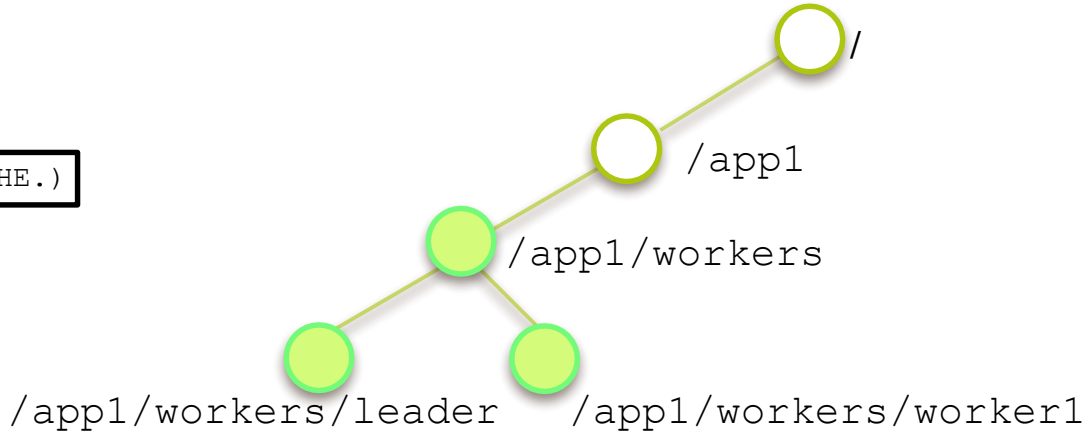


# Example: leader election

**Question:**
**How can all workers of an application elect a leader among themselves?**

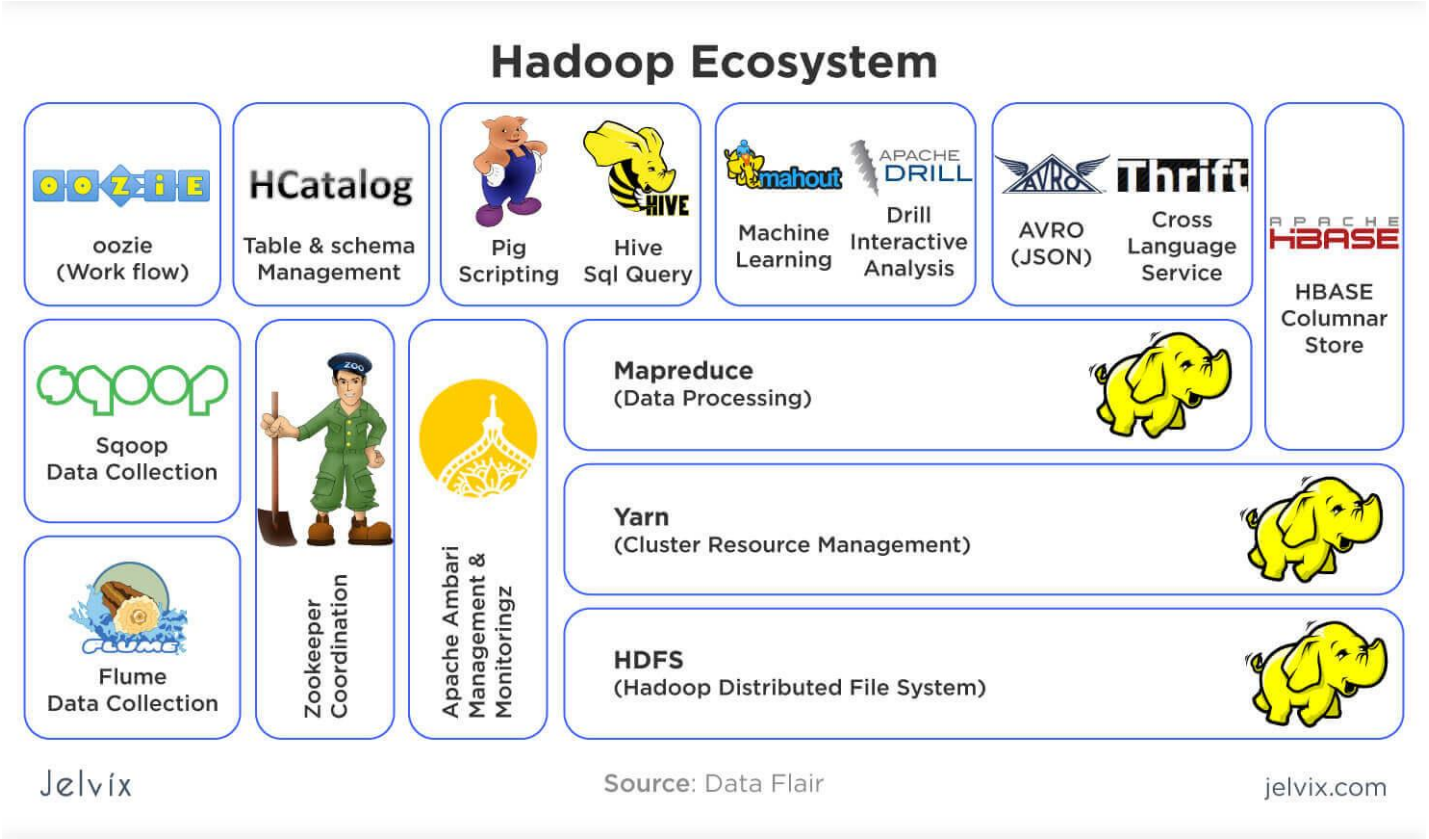



if the leader dies, elect again (“herd effect”)

# A Summary

- Hadoop is a great distributed system
- Well developed and still developing
- MapReduce, YARN, HDFS, ZooKeeper, etc.



# 谢谢！