Hadoop, a distributed framework for Big Data

Class: CS 237 Distributed Systems Middleware

Instructor: Nalini Venkatasubramanian

Introduction

1. **Introduction: Hadoop's history and advantages**

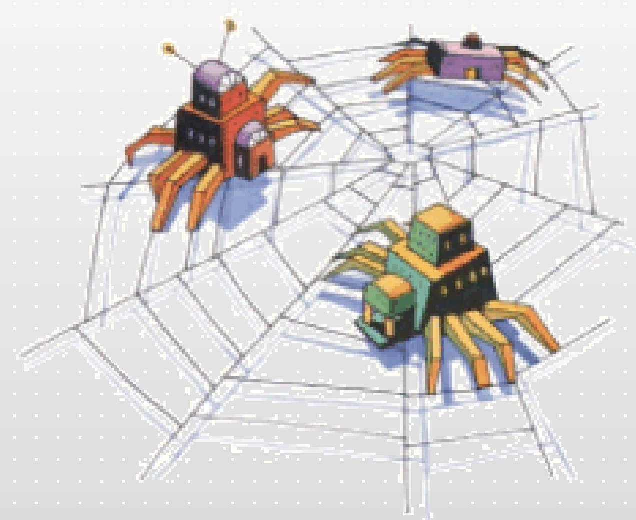
2. **Architecture in detail**

3. **Hadoop in industry**

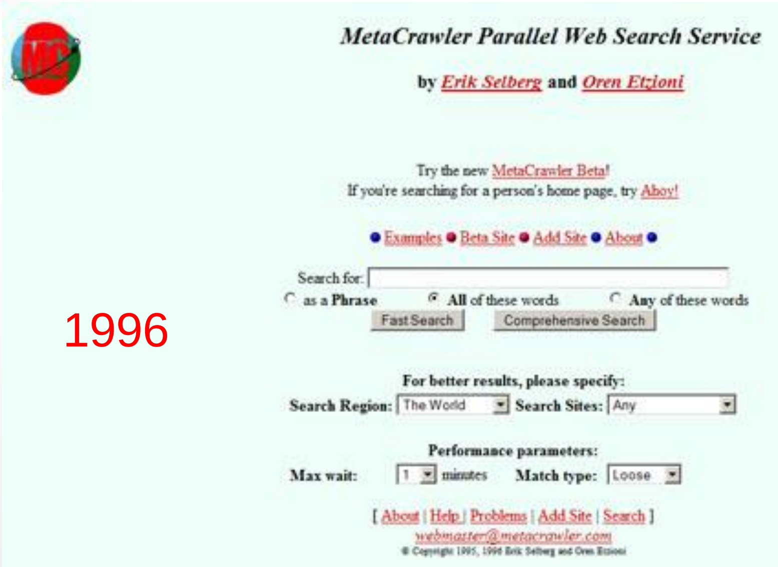
- Apache top level project, open-source implementation of frameworks for reliable, scalable, distributed computing and data storage.
- It is a flexible and highly-available architecture for large scale computation and data processing on a network of commodity hardware.

Brief History of Hadoop

- Designed to answer the question: **“How to process big data with reasonable cost and time?”**



Search engines in 1990s



1996

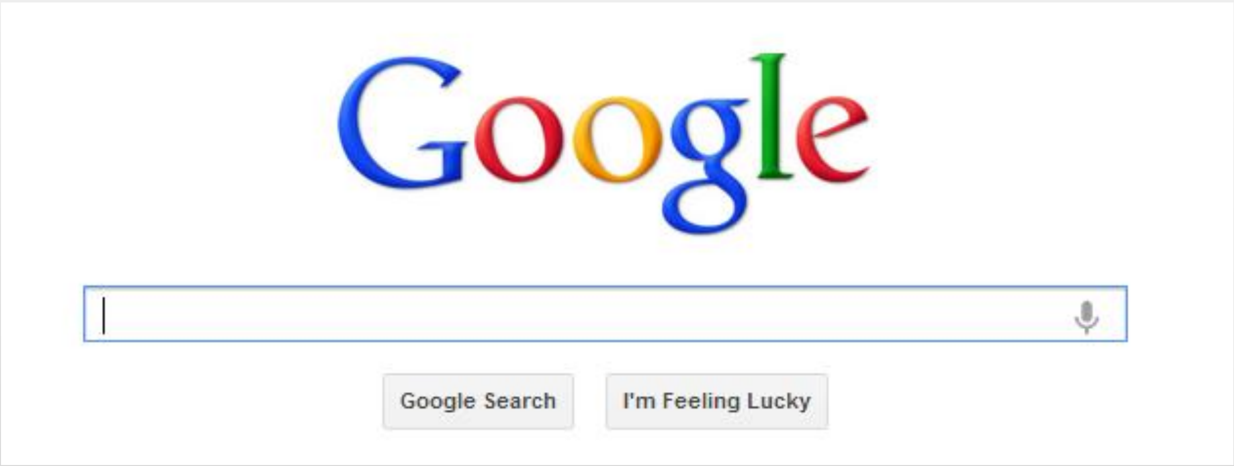
1996

1996

1997

Google search engines

1998



2013

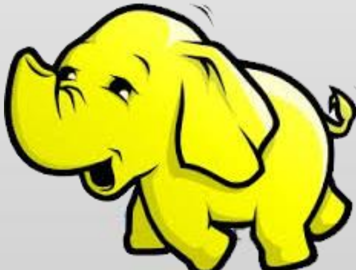
Hadoop's Developers

Doug Cutting

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.



Google Origins

2003

The Google File System

Sanjay Ghemawat, Howard Gobioff, and Shun-Tak Leung

Google*

2004

MapReduce: Simplified Data Processing on Large Clusters

Jeffrey Dean and Sanjay Ghemawat

jeff@google.com, sanjay@google.com

Google, Inc.

2006

Bigtable: A Distributed Storage System for Structured Data

Fay Chang, Jeffrey Dean, Sanjay Ghemawat, Wilson C. Hsieh, Deborah A. Wallach
Mike Burrows, Tushar Chandra, Andrew Fikes, Robert E. Gruber

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

Google, Inc.

Abstract

gtable is a distributed storage system for managing tured data that is designed to scale to a very large petabytes of data across thousands of commodity rs. Many projects at Google store data in Bigtable, ding web indexing, Google Earth, and Google Fi- e. These applications place very different demands igtable, both in terms of data size (from URLs to

achieved scalability and high performance, but Big provides a different interface than such systems. Big does not support a full relational data model; inste provides clients with a simple data model that sup dynamic control over data layout and format, an lows clients to reason about the locality properties o data represented in the underlying storage. Data i dexed using row and column names that can be arb strings. Bigtable also treats data as uninterpreted str

Some Hadoop Milestones

- **2008 - Hadoop Wins Terabyte Sort Benchmark (**sorted 1 terabyte of data in 209 seconds, compared to previous record of 297 seconds)

- 2009 - Avro and Chukwa became new members of Hadoop Framework family

- 2010 - Hadoop's Hbase, Hive and Pig subprojects completed, adding more computational power to Hadoop framework

- **2011 - ZooKeeper Completed**

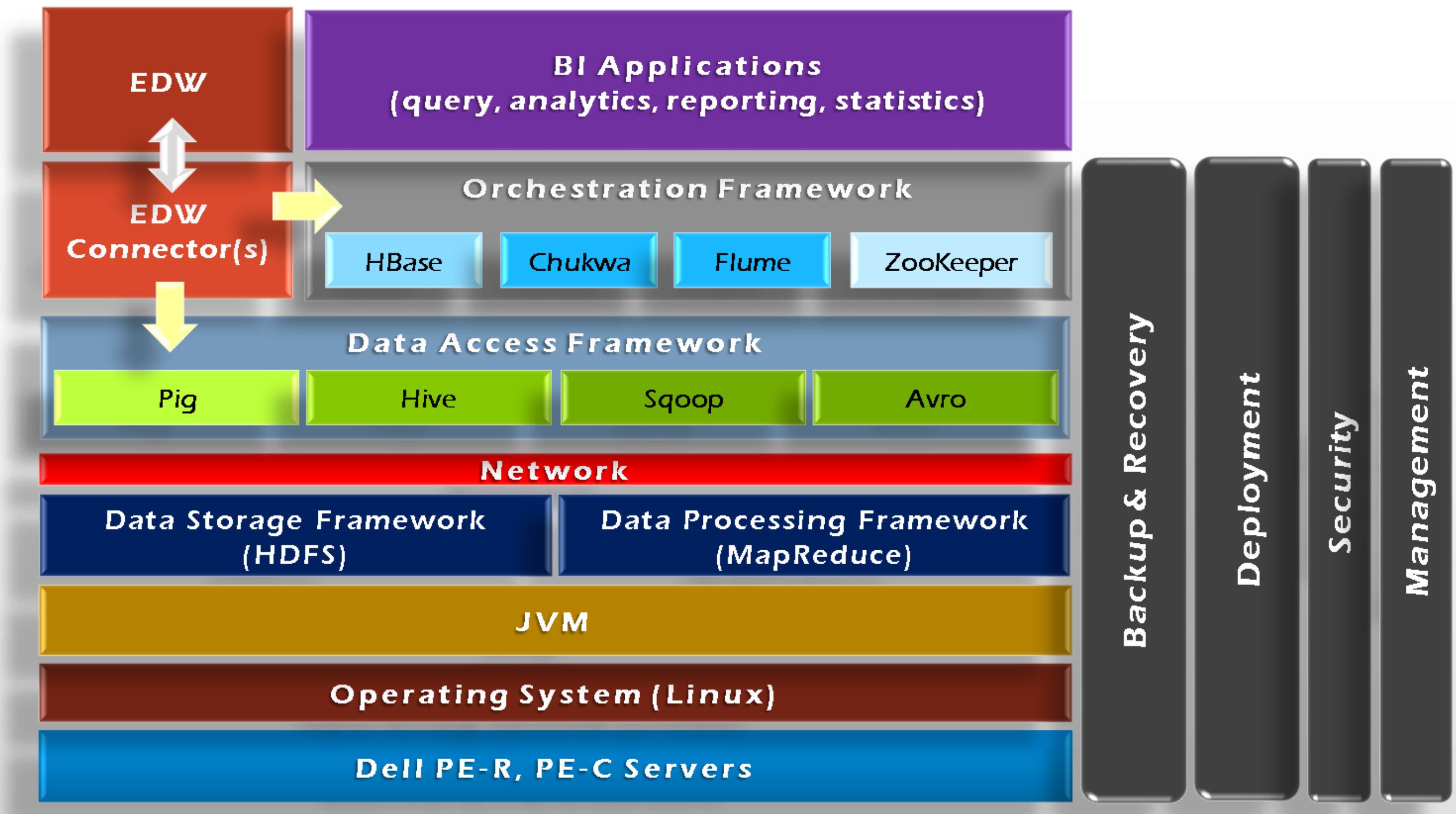
- **2013 - Hadoop 1.1.2 and Hadoop 2.0.3 alpha.**

  - Ambari, Cassandra, Mahout have been added

What is Hadoop?

- **Hadoop:**
  - an open-source software framework that supports data-intensive distributed applications, licensed under the Apache v2 license.
- **Goals / Requirements:**
  - 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

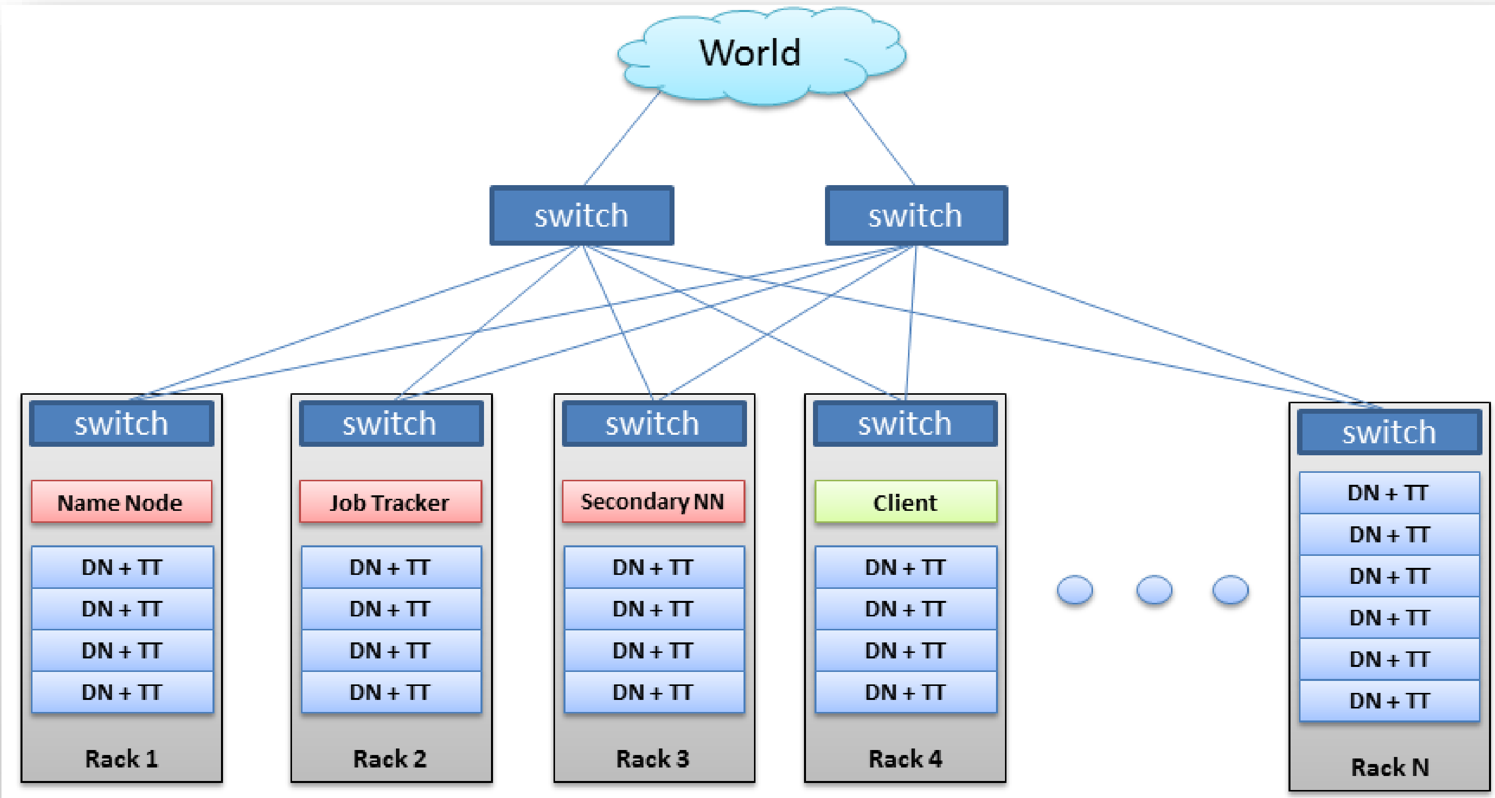
Hadoop Framework Tools



Hadoop’s Architecture

- Distributed, with some centralization
- Main nodes of cluster are where most of the computational power and storage of the system lies
- Main nodes run TaskTracker to accept and reply to MapReduce tasks, and also DataNode to store needed blocks closely as possible
- Central control node runs NameNode to keep track of HDFS directories & files, and JobTracker to dispatch compute tasks to TaskTracker
- Written in Java, also supports Python and Ruby

Hadoop's Architecture



Hadoop's Architecture

- Hadoop Distributed Filesystem
- Tailored to needs of MapReduce
- Targeted towards many reads of filestreams
- Writes are more costly
- High degree of data replication (3x by default)
- No need for RAID on normal nodes
- Large blocksize (64MB)
- Location awareness of DataNodes in network

Hadoop's Architecture

NameNode:

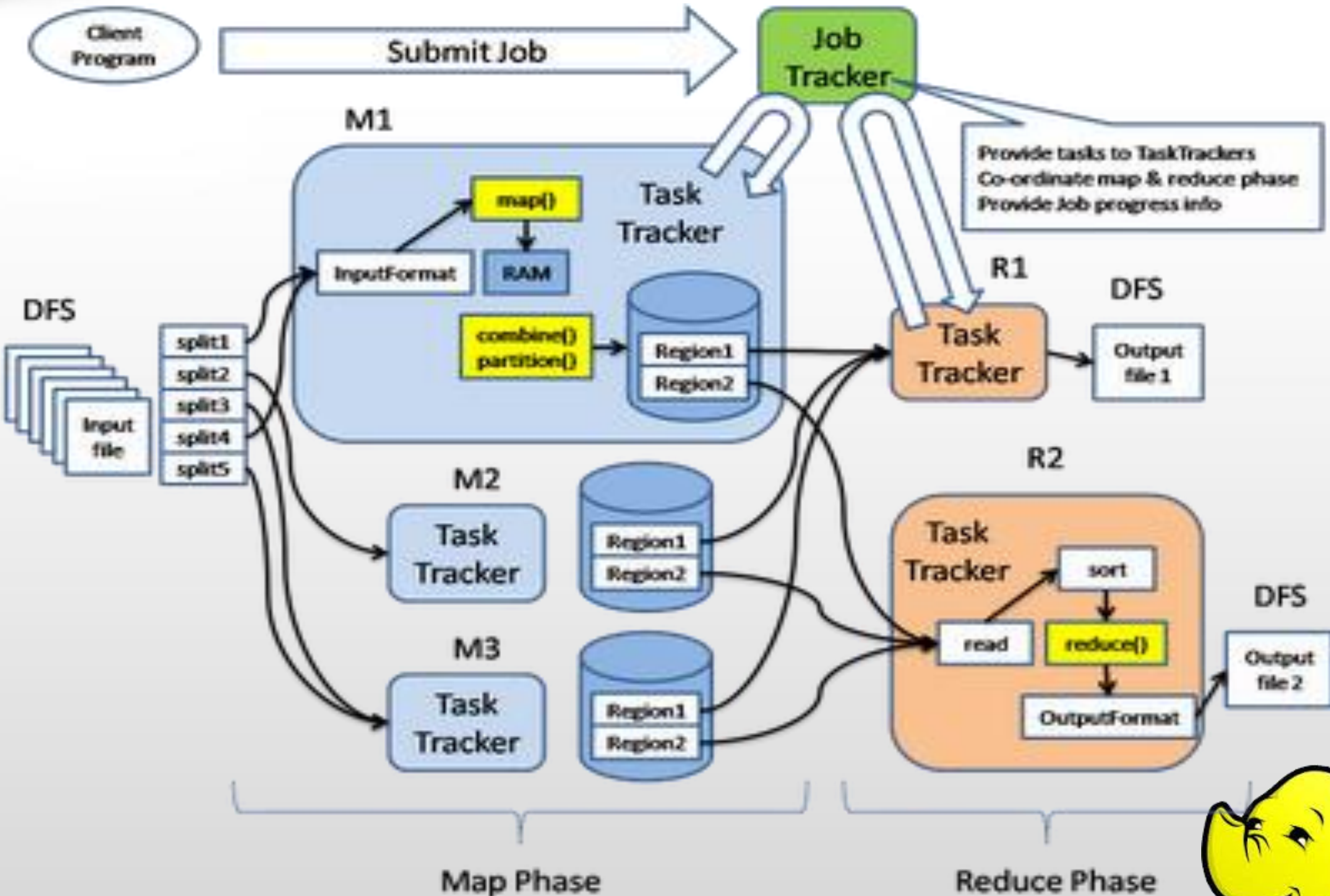
- Stores metadata for the files, like the directory structure of a typical FS.
- The server holding the NameNode instance is quite crucial, as there is only one.
- Transaction log for file deletes/adds, etc. Does not use transactions for whole blocks or file-streams, only metadata.
- Handles creation of more replica blocks when necessary after a DataNode failure

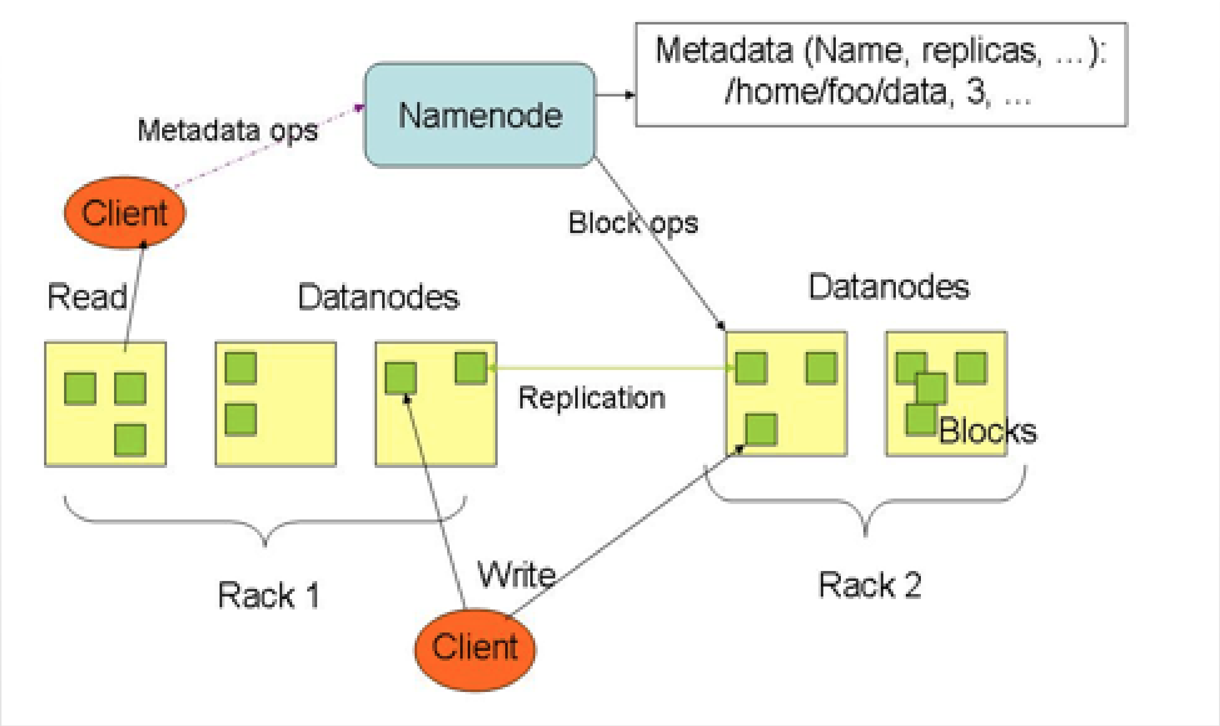
Hadoop’s Architecture

DataNode:

- Stores the actual data in HDFS
- Can run on any underlying filesystem (ext3/4, NTFS, etc)
- Notifies NameNode of what blocks it has
- NameNode replicates blocks 2x in local rack, 1x elsewhere

Hadoop's Architecture: MapReduce Engine




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

Hadoop’s Architecture

MapReduce Engine:

- JobTracker & TaskTracker
- JobTracker splits up data into smaller tasks(“Map”) and sends it to the TaskTracker process in each node
- TaskTracker reports back to the JobTracker node and reports on job progress, sends data (“Reduce”) or requests new jobs

Hadoop's Architecture

- None of these components are necessarily limited to using HDFS
- Many other distributed file-systems with quite different architectures work
- Many other software packages besides Hadoop's MapReduce platform make use of HDFS

Hadoop in the Wild

- Hadoop is in use at most organizations that handle big data:
  - Yahoo!
  - Facebook
  - Amazon
  - Netflix
  - Etc…
- Some examples of scale:
  - Yahoo!'s Search Webmap runs on 10,000 core Linux cluster and powers Yahoo! Web search
  - FB's Hadoop cluster hosts 100+ PB of data (July, 2012) & growing at ½ PB/day (Nov, 2012)

Hadoop in the Wild

Three main applications of Hadoop:

- Advertisement (Mining user behavior to generate recommendations)
- Searches (group related documents)
- Security (search for uncommon patterns)

Hadoop in the Wild

- Non-realtime large dataset computing:
  - NY Times was dynamically generating PDFs of articles from 1851-1922
  - Wanted to pre-generate & statically serve articles to improve performance
  - Using Hadoop + MapReduce running on EC2 / S3, converted 4TB of TIFFs into 11 million PDF articles in 24 hrs

Hadoop in the Wild: Facebook Messages

- Design requirements:
  - Integrate display of email, SMS and chat messages between pairs and groups of users
  - Strong control over who users receive messages from
  - Suited for production use between 500 million people immediately after launch
  - Stringent latency & uptime requirements

Hadoop in the Wild

- System requirements
  - High write throughput
  - Cheap, elastic storage
  - Low latency
  - High consistency (within a single data center good enough)
  - Disk-efficient sequential and random read performance

Hadoop in the Wild

- Classic alternatives
    - These requirements typically met using large MySQL cluster & caching tiers using Memcached
    - Content on HDFS could be loaded into MySQL or Memcached if needed by web tier
- Problems with previous solutions
    - MySQL has low random write throughput… BIG problem for messaging!
    - Difficult to scale MySQL clusters rapidly while maintaining performance
    - MySQL clusters have high management overhead, require more expensive hardware

Hadoop in the Wild

- Facebook's solution
  - Hadoop + HBase as foundations
  - Improve & adapt HDFS and HBase to scale to FB's workload and operational considerations
    - Major concern was availability: NameNode is SPOF & failover times are at least 20 minutes
    - Proprietary "AvatarNode": eliminates SPOF, makes HDFS safe to deploy even with 24/7 uptime requirement
    - Performance improvements for realtime workload: RPC timeout. Rather fail fast and try a different DataNode

```
<?php
/**
 * @package WordPress
 * @subpackage Default_Theme
 */
?>
<!DOCTYPE html PUBLIC "-//W3C
<html xmlns="http://www.w3.

<head profile="http://
<meta http-equiv="Co

<title><?php wp

<link rel="
<link rel

<sty

<
```

- Distributed File System
- Fault Tolerance
- Open Data Format
- Flexible Schema
- Queryable Database

- Need to process Multi Petabyte Datasets
- Data may not have strict schema
- Expensive to build reliability in each application
- Nodes fails everyday
- Need common infrastructure
- Very Large Distributed File System
- Assumes Commodity Hardware
- Optimized for Batch Processing
- Runs on heterogeneous OS

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

- Replication 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

- 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

- 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

- MapReduce programming model
  - Framework for distributed processing of large data sets
  - Pluggable user code runs in generic framework
- Common design pattern in data processing
  - cat * | grep | sort | uniq -c | cat > file
  - input | **map** | shuffle | **reduce** | output

- Log processing
- Web search indexing
- Ad-hoc queries

- MapReduce Component
  - JobClient
  - JobTracker
  - TaskTracker
  - Child
- Job Creation/Execution Process

- 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

- Protocol
  - JobClient <---------------> JobTracker
    JobSubmissionProtocol
  - TaskTracker <------------> JobTracker
    InterTrackerProtocol
  - TaskTracker <--------------> Child
    TaskUmbilicalProtocol
- JobTracker impliments both protocol and works as server in both IPC
- TaskTracker implements the TaskUmbilicalProtocol; Child gets task information and reports task status through it.

- Check input and output, e.g. check if the output directory is already existing
  - job.getInputFormat().validateInput(job);
  - job.getOutputFormat().checkOutputSpecs(fs, job);
- Get InputSplits, sort, and write output to HDFS
  - InputSplit[] splits = job.getInputFormat().
    getSplits(job, job.getNumMapTasks());
  - writeSplitsFile(splits, out); // out is $SYSTEMDIR/$JOBID/job.split

- The jar file and configuration file will be uploaded to HDFS system directory
  - job.write(out); // out is $SYSTEMDIR/$JOBID/job.xml
- JobStatus status = jobSubmitClient.submitJob(jobId);
  - This is an RPC invocation, jobSubmitClient is a proxy created in the initialization

- JobTracker.submitJob(jobID) <-- receive RPC invocation request
- JobInProgress job = new JobInProgress(jobId, this, this.conf)
- Add the job into Job Queue
  - jobs.put(job.getProfile().getJobId(), job);
  - jobsByPriority.add(job);
  - jobInitQueue.add(job);

- Sort by priority
  - resortPriority();
  - compare the JobPrioity first, then compare the JobSubmissionTime
- Wake JobInitThread
  - jobInitQueue.notifyall();
  - job = jobInitQueue.remove(0);
  - job.initTasks();

- JobInProgress(String jobid, JobTracker jobtracker, JobConf default_conf);
- JobInProgress.initTasks()
  - DataInputStream splitFile = fs.open(new Path(conf.get(“mapred.job.split.file”)));

    // mapred.job.split.file --> $SYSTEMDIR/$JOBID/job.split

- splits = JobClient.readSplitFile(splitFile);
- numMapTasks = splits.length;
- maps[i] = new TaskInProgress(jobId, jobFile, splits[i], jobtracker, conf, this, i);
- reduces[i] = new TaskInProgress(jobId, jobFile, splits[i], jobtracker, conf, this, i);
- JobStatus --> JobStatus.RUNNING

- Task getNewTaskForTaskTracker(String taskTracker)
- Compute the maximum tasks that can be running on taskTracker
  – int maxCurrentMap Tasks = tts.getMaxMapTasks();
  – int maxMapLoad = Math.min(maxCurrentMapTasks, (int)Math.ceil(double) remainingMapLoad/numTaskTrackers));

- int numMaps = tts.countMapTasks(); // running tasks number
- If numMaps < maxMapLoad, then more tasks can be allocated, then based on priority, pick the first job from the jobsByPriority Queue, create a task, and return to TaskTracker
  - Task t = job.obtainNewMapTask(tts, numTaskTrackers);

- initialize()
  - Remove original local directory
  - RPC initialization
    - TaskReportServer = RPC.getServer(this, bindAddress, tmpPort, max, false, this, fConf);
    - InterTrackerProtocol jobClient = (InterTrackerProtocol) RPC.waitForProxy(InterTrackerProtocol.class, InterTrackerProtocol.versionID, jobTrackAddr, this.fConf);

- run();
- offerService();
- TaskTracker talks to JobTracker with HeartBeat message periodically
  - HeatbeatResponse heartbeatResponse = transmitHeartBeat();

- TaskTracker.localizeJob(TaskInProgress tip);
- launchTasksForJob(tip, new JobConf(rjob.jobFile));
  - tip.launchTask(); // TaskTracker.TaskInProgress
  - tip.localizeTask(task); // create folder, symbol link
  - runner = task.createRunner(TaskTracker.this);
  - runner.start(); // start TaskRunner thread

- TaskRunner.run();
  - Configure child process' jvm parameters, i.e. classpath, taskid, taskReportServer's address & port
  - Start Child Process
    - runChild(wrappedCommand, workDir, taskid);

- Create RPC Proxy, and execute RPC invocation
  - TaskUmbilicalProtocol umbilical = (TaskUmbilicalProtocol) RPC.getProxy(TaskUmbilicalProtocol.class, TaskUmbilicalProtocol.versionID, address, defaultConf);
  - Task task = umbilical.getTask(taskid);
- task.run(); // mapTask / reduceTask.run

- Child
  - task.done(umilical);
    - RPC call: umbilical.done(taskId, shouldBePromoted)
- TaskTracker
  - done(taskId, shouldPromote)
    - TaskInProgress tip = tasks.get(taskid);
    - tip.reportDone(shouldPromote);
      - taskStatus.setRunState(TaskStatus.State.SUCCEEDED)

- JobTracker
  - TaskStatus report: status.getTaskReports();
  - TaskInProgress tip = taskidToTIPMap.get(taskId);
  - JobInProgress update JobStatus
    - tip.getJob().updateTaskStatus(tip, report, myMetrics);
      - One task of current job is finished
      - completedTask(tip, taskStatus, metrics);
      - If (this.status.getRunState() == JobStatus.RUNNING && allDone) {this.status.setRunState(JobStatus.SUCCEEDED)}

- Word Count
  - hadoop jar hadoop-0.20.2-examples.jar wordcount <input dir> <output dir>
- Hive
  - hive -f pagerank.hive