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Hadoop Operations

Managing Petabytes with Open Source

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My Background

Thanks for Asking

- **hammer@cloudera.com**
- Studied Mathematics at Harvard
- Worked as a Quant on Wall Street
- Conceived, built, and led Data team at Facebook
  - Nearly 30 amazing engineers and data scientists
  - Several open source projects and research papers
- Founder of Cloudera
  - Building cost-effective data management tools for the world

Presentation Outline

Exceedingly Unlikely to Be Completed

- Hadoop overview and sample use cases
- Cloudera and Hadoop
- Hadoop project mechanics
- Cluster facilities, hardware, and system software
- Installation and configuration
- HDFS **(main focus with limited time)**
- MapReduce
- Cluster lifecycle and maintenance
- Questions and discussion

Presentation Sources

For Further Reading

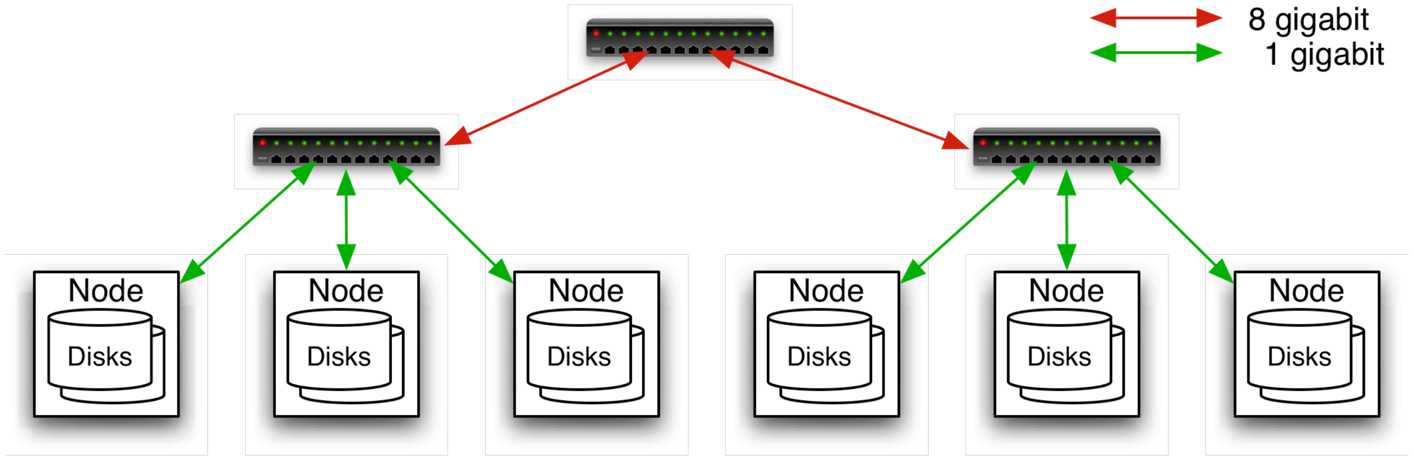
- “Hadoop: The Definitive Guide”
  - Tom White’s book from O’Reilly
  - Many figures in this presentation taken from the book
- “Hadoop Cluster Management”
  - Marco Nicosia’s USENIX 2009 presentation
- Cloudera blog and Get Satisfaction page
- Hadoop documentation
- MarkMail mailing list archives
- Hadoop wiki

What is Hadoop?

- Apache Software Foundation project, mostly written in Java
- Inspired by Google infrastructure
- Software for programming warehouse-scale computers (WSCs)
- Hundreds of production deployments
- Project structure
  - Hadoop Distributed File System (HDFS)
  - Hadoop MapReduce
  - Hadoop Common (formerly “Hadoop Core”)
  - Other subprojects
    - Avro, HBase, Hive, Pig, Zookeeper

Anatomy of a Hadoop Cluster

- Commodity servers
  - 1 RU, 2 x 4 core CPU, 8 GB RAM, 4 x 1 TB SATA, 2 x 1 gE NIC
- Typically arranged in 2 level architecture
  - 40 nodes per rack
- Inexpensive to acquire and maintain

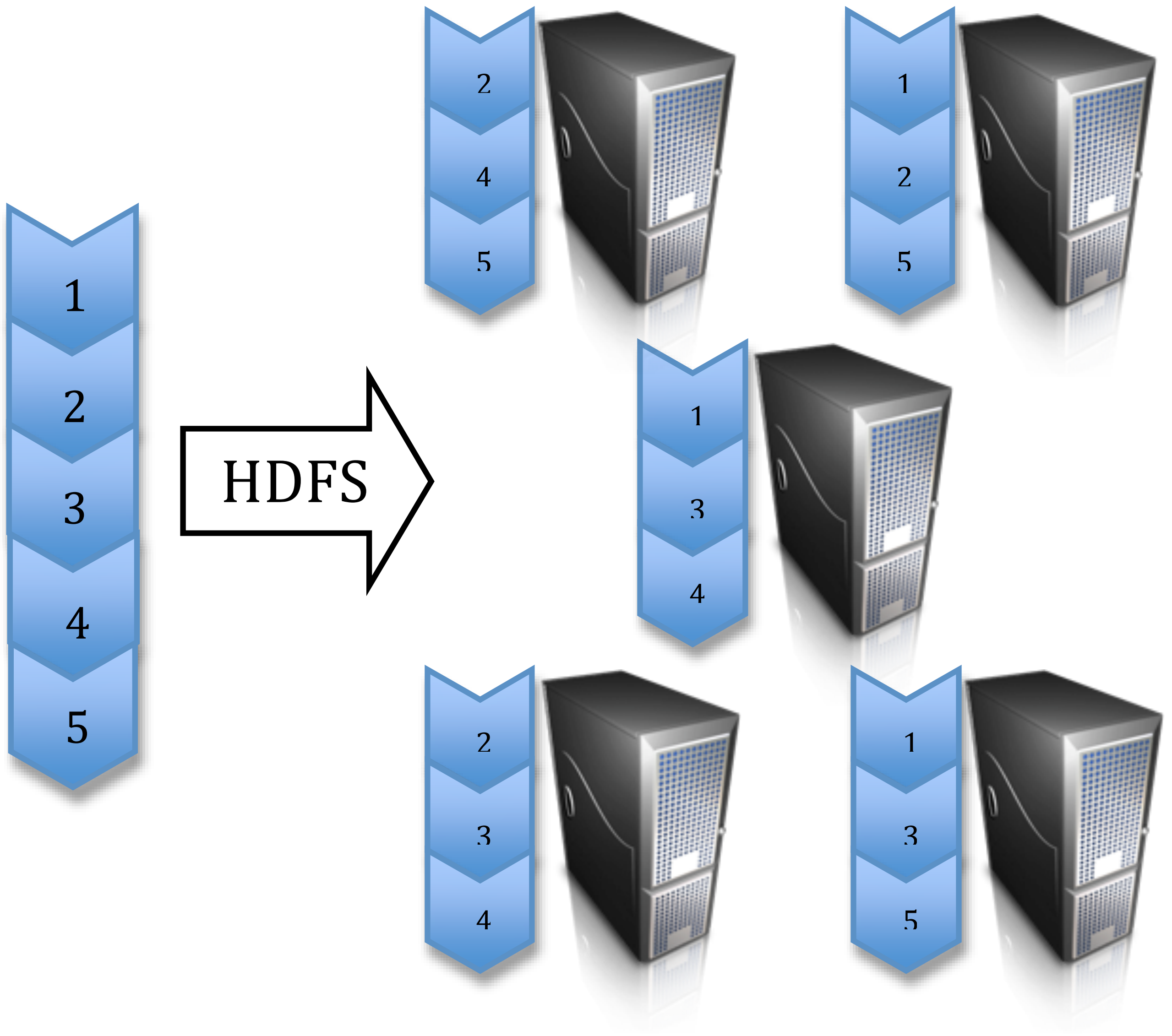


HDFS

- Pool commodity servers into a single hierarchical namespace
- Break files into 128 MB blocks and replicate blocks
- Designed for large files written once but read many times
- Two major daemons: NameNode and DataNode
  - NameNode manages file system metadata
  - DataNode manages data using local filesystem
- HDFS manages checksumming, replication, and compression
- Throughput scales nearly linearly with node cluster size
- Access from Java, C, command line, FUSE, WebDAV, or Thrift
  - Generally not mounted like a usual file system

HDFS

HDFS distributes file blocks among servers

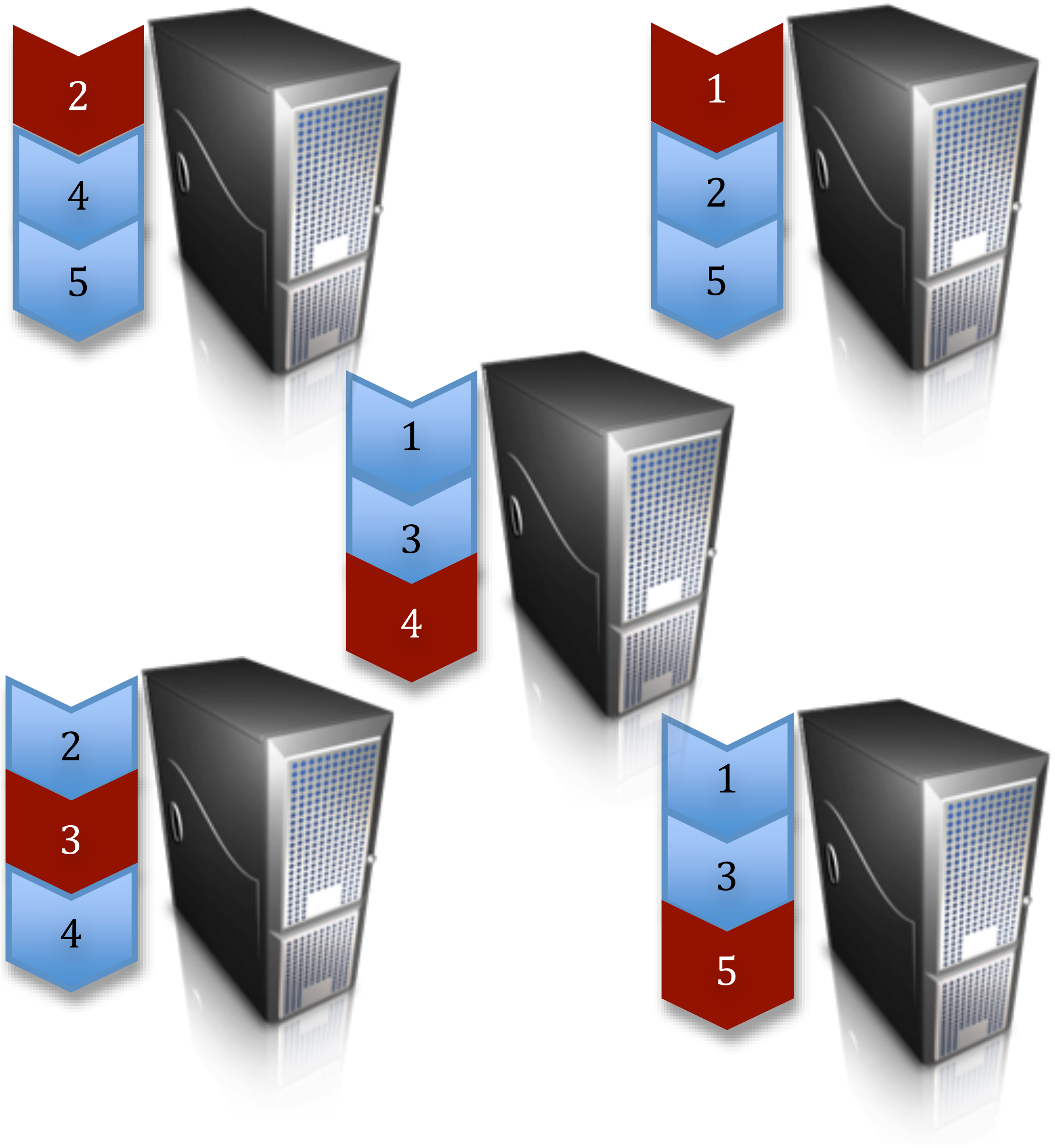


Hadoop MapReduce

- Fault tolerant execution layer and API for parallel data processing
- Can target multiple storage systems
- Key/value data model
- Two major daemons: JobTracker and TaskTracker
- Many client interfaces
  - Java
  - C++
  - Streaming
  - Pig
  - SQL (Hive)

MapReduce

MapReduce pushes work out to the data

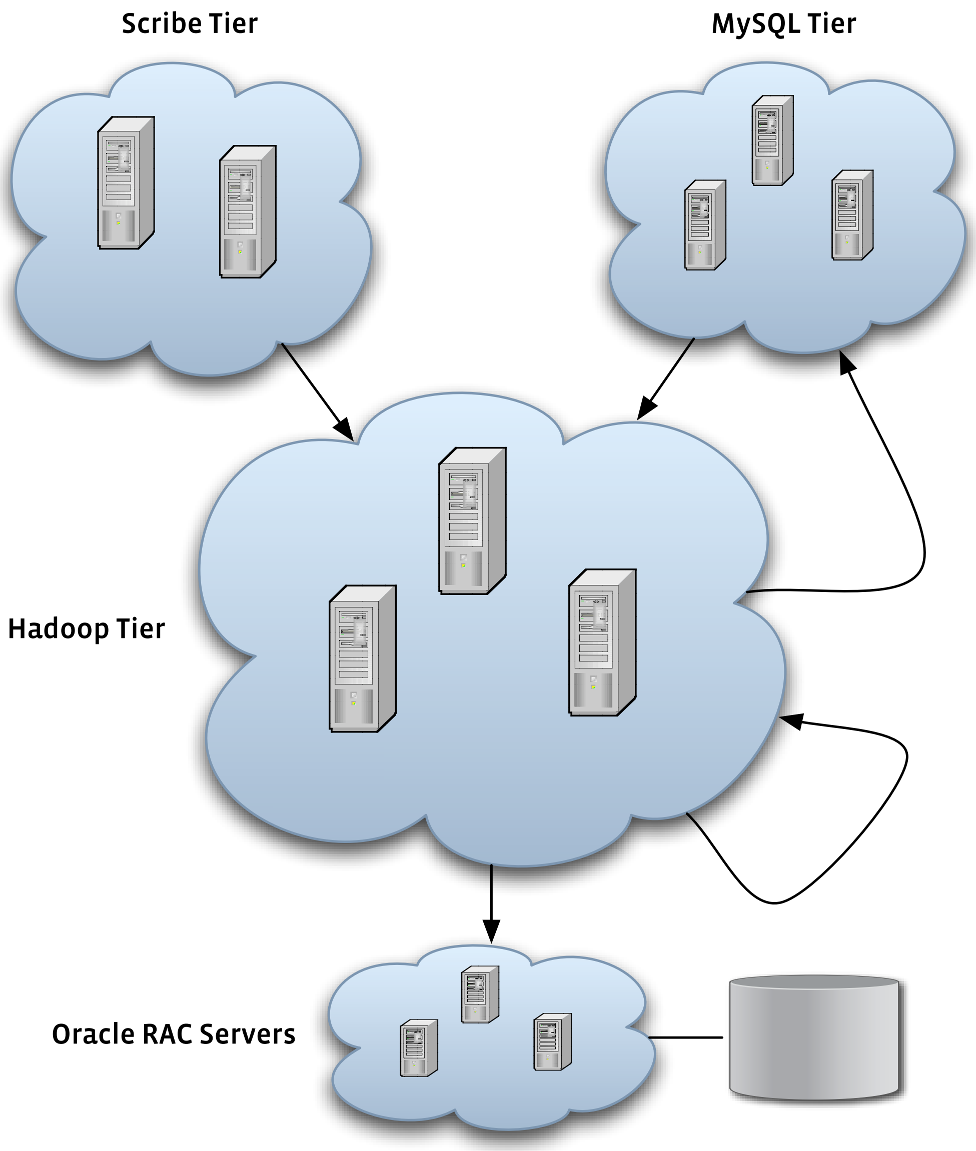


Hadoop Subprojects

- Avro
  - Cross-language serialization for RPC and persistent storage
- HBase
  - Table storage on top of HDFS, modeled after Google's BigTable
- Hive
  - SQL interface to structured data stored in HDFS
- Pig
  - Language for dataflow programming
- Zookeeper
  - Coordination service for distributed systems

Facebook Data Infrastructure

2008



Hadoop at Yahoo!

- Jan 2006: Hired Doug Cutting
- Apr 2006: Sorted 1.9 TB on 188 nodes in 47 hours
- Apr 2008: Sorted 1 TB on 910 nodes in 209 seconds
- Aug 2008: Deployed 4,000 node Hadoop cluster
- May 2009: Sorted 1 TB on 1,460 nodes in 62 seconds
- Data Points
  - Over 25,000 nodes running Hadoop
  - Hundreds of thousands of jobs per day
  - Typical HDFS cluster: 1,400 nodes, 2 PB capacity
  - Sorted 1 PB on 3,658 nodes in 16.25 hours

Hadoop at Your Company

- Sample projects
  - Log or message warehouse
  - Database archival store
  - ETL into an existing data warehouse
  - Search team projects, e.g. autocomplete
  - Targeted web crawls
- Sample clusters
  - Retired database servers
  - Unused desktops
  - Amazon EC2

The Hadoop Community

- Over 750 (paid!) attendees at Hadoop Summit two weeks ago
  - Hadoop Summit East in New York in October
- Books from O’Reilly, Apress, and Manning
- Training videos free online
- Very active mailing lists and IRC channel
- Regular user group meetings in cities around the world
- University courses, also around the world
- Growing consultant and systems integrator expertise
- Commercial training, certification, and support from Cloudera

Cloudera and Hadoop

- Training: online, certification, and on site
- Support: yearly contract to get the most out of Hadoop
- Cloudera’s Distribution for Hadoop (Apache 2.0 licensed)
  - Simplifies upgrades and installation
  - Foundation and glue for Hadoop ecosystem
  - Dozens of supported clusters with thousands of nodes
  - Hundreds of unsupported clusters
- Exposure to a wide range of enterprise workloads
  - Computer vision, financial services, high-energy physics, telecom, bioinformatics, retail, media, and web

Hadoop Project Mechanics

- Trademark owned by Apache Software Foundation
- Apache 2.0 license used for code
- Related tools
  - Subversion for version control
  - JIRA for issue tracking
  - Ant for builds
  - Ivy for dependency tracking
  - JUnit for testing
  - Hudson for continuous integration
  - Javadoc and Forrest for documentation

Hadoop Project Mechanics

- Four classes of people in the Hadoop community
  - Hadoop PMC
  - Subproject committers
  - Subproject contributors
  - The unwashed masses
- Major organizations committing code
  - Yahoo!: Pig, Capacity Scheduler, Avro, etc.
  - Facebook: Hive, Fair Share scheduler, etc.
  - Cloudera: MRUnit, Sqoop, PyZK, Avro C bindings, etc.
  - You: http://wiki.apache.org/hadoop/HowToContribute

Hadoop Project Mechanics

- Release cycle of 3 months (-ish)
  - Last release: 0.20 on April 22, 2009
  - Subprojects on different release cycles
- Voting for a release
  - Feature freeze votes before release date
  - Releases put to a vote according to Apache guidelines
- Cutting an Apache release
  - Releases made available as tarballs on Apache and mirrors
  - Release notes at http://tinyurl.com/hadoop-releasenotes

Cluster Facilities and Hardware

- Data center: run Hadoop in a single data center, please
- Servers
  - Clusters are often either capacity bound or CPU bound
  - The 1U configuration specified previously is mostly standard
  - Many organizations now testing 2U, 12 drive configurations
  - Use ECC RAM and cheap hard drives: 7200 RPM SATA
  - Start with standard 64-bit box for masters and workers
- Network
  - Gigabit ethernet, 2 level tree, 5:1 oversubscription to core
  - May want redundancy at top of rack and core

System Software

- Operating system: Linux, CentOS mildly preferred
- Local file system
  - ext3 versus xfs
  - Mount with `noatime` for performance improvements
- RAID configuration: RAID0 versus JBOD
- Java 6, update 14 or later (compressed ordinary object pointers)
- Useful unix utilities
  - sar, iostat, iftop, vmstat, nfsstat, strace, dmesg, and friends
- Useful java utilities
  - jps, jstack, jconsole

Installation and Configuration

- Installation: http://www.cloudera.com/hadoop
  - Get Hadoop as RPM, Debs, AMI, or tarballs
  - Will put configuration in /etc, logs in /var/log
  - Registers services with /etc/init.d
  - Matches versions across subprojects
  - Backported bug fixes and extra Cloudera features
- Configuration: http://my.cloudera.com
  - Need to decide if JT and NN live on same machine
  - Will have to manually specify toplogy
  - Can save your configuration for updating later

Installation

Hadoop Modes

- Standalone mode
  - Run all mappers and single reducer inside one JVM
- Pseudo-distributed mode
  - Run all daemons on single machine and use sockets for IPC
- Distributed mode
  - For production deployments
  - Can run master daemons on same box or separate boxes

Configuration

- `org.apache.hadoop.conf` package has `Configuration` class
- Configurations read their properties from resources
- Properties in later resources override those defined earlier
  - `final` keyword will prevent a property from being overwritten
- Site files contain site-specific configuration
  - `core-site.xml`
  - `hdfs-site.xml`
  - `mapred-site.xml`
- Default configurations in `.template` site files

Installation and Configuration

Operator Utilities

- Distributed shell
  - Nice to have something like dsh
- Configuration management
  - cfengine, Puppet, bcfg2, Chef, etc.
- Hadoop utilities
  - hadoop-env.sh
  - [start|stop]-dfs.sh
  - [start|stop]-mapred.sh

Installation and Configuration

Common Problems

- Todd Lipcon: “the problem is almost always DNS”
- Open the necessary ports in your firewall
- Distribute ssh keys
- Make sure you have permission to write directories
- Use all of your disks
- Don’t share an NFS mount for large clusters
- Set JAVA_HOME appropriately

HDFS

NameNode

- `VERSION` specifies layoutVersion, among other information
- Two major data structures
  - filesystem image
  - edit log
- Secondary NameNode
  - Checkpoints filesystem image and truncates edit log
  - In 0.21, renamed to “checkpoint node”
  - Also in 0.21, “backup node” added
    - Replaces need to write data structures to NFS mount for durability

HDFS

DataNode

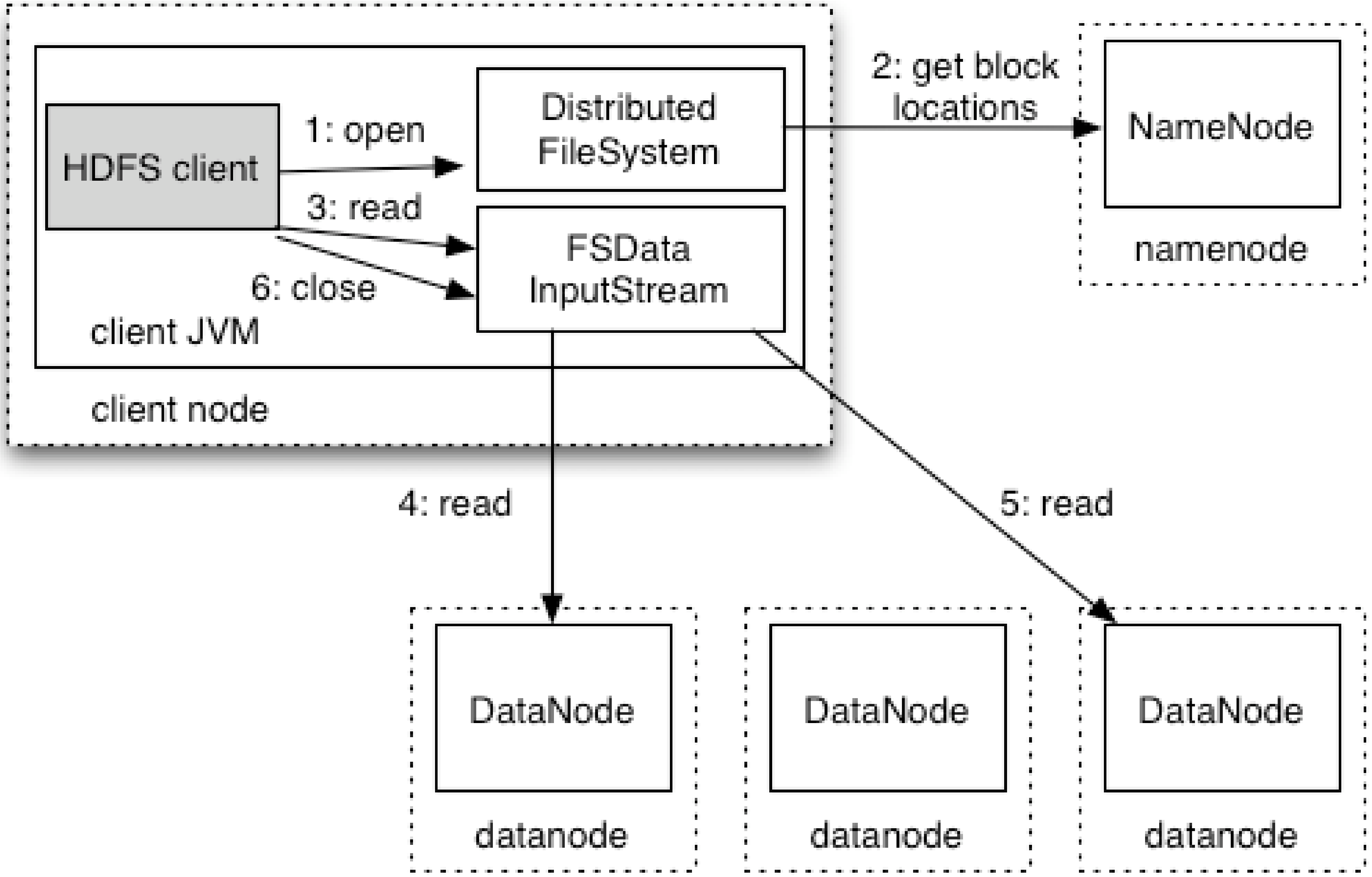
- Also has a VERSION file with layoutVersion information
- Stores data in local filesystem under `${dfs.data.dir}`/current
  - Data stored in blk_<id> files
  - Metadata (checksums) stored in blk_<id>.meta files
  - New subdirectory created for every `dfs.data.numblocks`
  - Round-robin blocks across directories
- `dfs.hosts[.exclude]` specifies allowed/removed DataNodes
- Serves data to client using a socket, not Hadoop RPC

HDFS

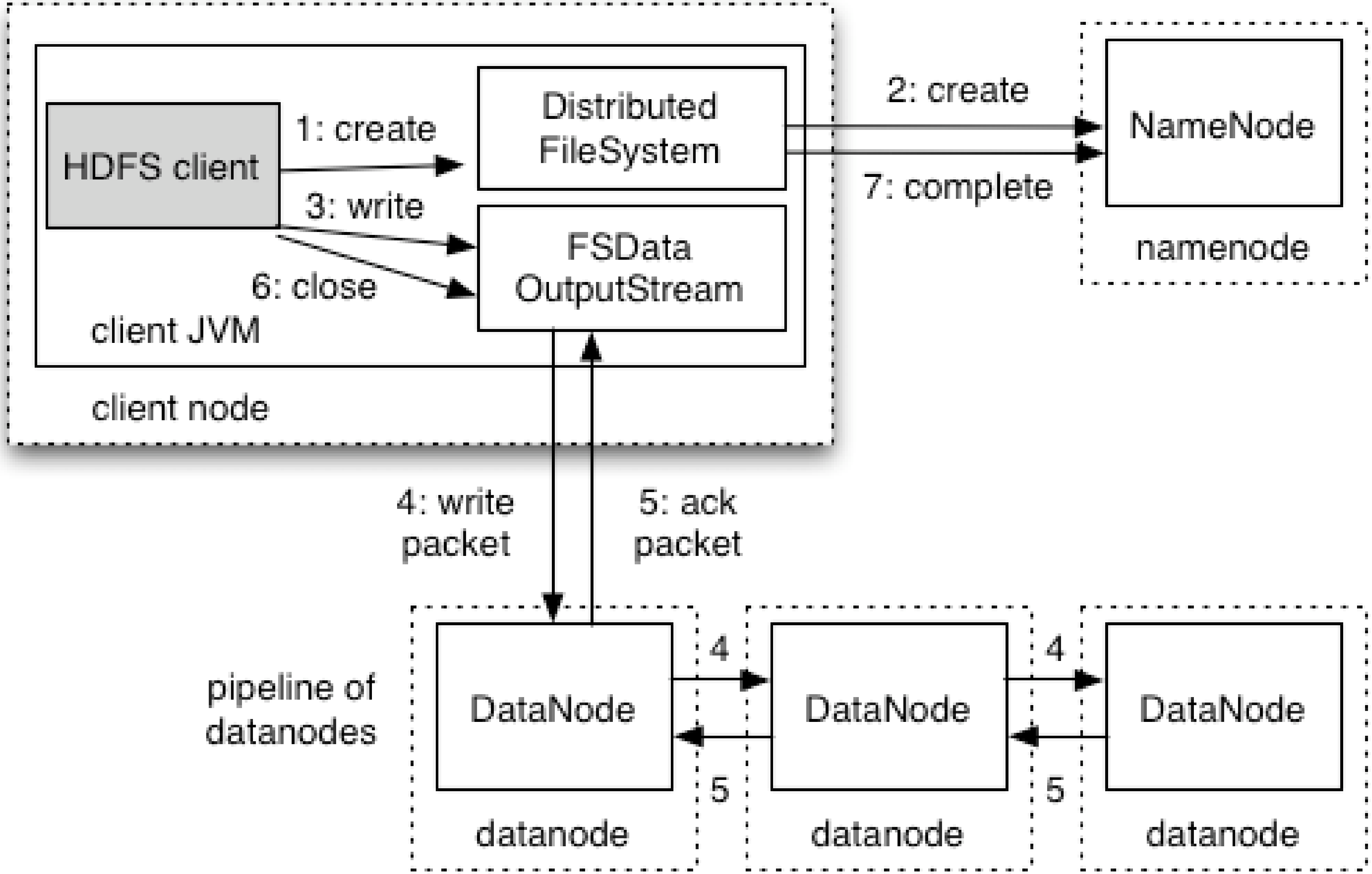
Client

- Can use Java libraries or command line for access
  - `libhdfs` has been behind the Java interface in last few releases
  - FUSE interface is unstable, so filesystem is not mounted
- Client only contacts NameNode for metadata
- Read path
  - Client keeps a list of block locations ranked by distance
- Write path
  - Client maintains two queues: data queue and ack queue

HDFS Read Path



HDFS Write Path



HDFS

Operator Utilities

- Safe mode
- Filesystem check (fsck)
- dfsadmin
- Block scanner
- balancer
- archive
- distcp
- quotas: name space and disk space

HDFS

More Operator Utilities

- Users, groups, and permissions
- Audit logs
- Topology
- Web UIs
- Trash
- HDFS Proxy and Thriftfs
- Benchmarks and load testing

HDFS

Safe Mode

- NameNode automatically enters “safe mode” at startup
  - Loads the image file and applies edits from the edit log
  - Only metadata reads will work during safe mode
  - DataNodes send block lists to NameNode
  - Once 99.9% of blocks have reported, exit safe mode
- Configuration parameters
  - `dfs.replication.min`
  - `dfs.safemode.threshold.pct`
  - `dfs.safemode.extension`

HDFS

Filesystem Check

- Run with hadoop `fsck`
  - Speaks to NameNode and only examines metadata
- Evaluate health of file system
  - Minimally, over-, under-, and misreplicated blocks
  - Corrupt blocks
  - Missing replicas
- Can also be used to determine blocks for a file
  - `hadoop fsck /path/to/file -files -blocks`

HDFS
`dfsadmin`

- Tool used to perform most administrative operations
- Run via `hadoop dfsadmin`
  - Run with no arguments to see options
  - Most operations require superuser
  - Administer quotas
  - Commission or decommission DataNodes
  - Checkpoint the filesystem image
  - Check upgrade progress or finalize an upgrade

HDFS

DataBlockScanner

- Each DataNode runs its own block scanner
- Periodically verifies the checksum for each block
  - Reports corrupt blocks to NameNode for correction
- Built-in throttling to conserve bandwidth
- Runs every three weeks by default
  - Frequency controlled by `dfs.datanode.scan.period.hours`
- Web interface to block scanner
  - http://datanode:50075/blockScannerReport

HDFS

Balancer

- Examines ratio of used space to total capacity
  - Looks at this ratio for each node and the entire cluster
  - Tries to bring all nodes within a configurable threshold of mean
- Run as background process
  - `start-balancer.sh`
  - Only one balancer can be run against a single cluster
- Tries to throttle bandwidth used to 1 MB/s
  - Controlled via `dfs.balance.bandwidthPerSec`

HDFS

Archive Tool

- HAR files are Hadoop Archives and use the `.tar` extension
  - Conceptually similar to a `.tar` file
- Used to conserve namespace utilization
- Run via `hadoop archive -archiveName my.har /file1 ...`
  - Will generate two index files and a number of part files
  - Many files are concatenated into a small number of part files
  - Index files enable lookup of individual files in the part files
- HAR files don’t support compression and are immutable

HDFS

`distcp`

- Distributed copy utility to move large amounts of data in parallel
- Can be controlled with some granularity
  - `-overwrite` and `-update` options
  - Preserve attributes, ignore failures, throttle space used
  - File globbing and filtering also supported
- Implemented as a MapReduce job with no reducers
- Use cases
  - Transfer data between clusters
  - Bulk load data into a cluster

HDFS
Quotas

- Used to prevent runaway resource consumption
- Quotas apply to directories, not users or groups
- Quotas must be manually applied; no default quotas
- Namespace quotas
  - `hadoop dfsadmin -[set|clr]Quota`
- Disk space quotas
  - `hadoop dfsadmin -[set|clr]SpaceQuota`

HDFS

Users, Groups, and Permissions

- Enabled by default; control via `dfs.permissions`
- Every file and directory has an owner, group, and a mode
- Three types of permissions: read (r), write (w), execute (x)
    - Must have write permission on a directory to create/delete files
    - Must have execute permission to access children of directory
- The super-user is the identity of the NameNode process
- Client is assigned user and group of local process
    - Easy to spoof, so limit access to "gateway" cluster

HDFS

Audit Logs

- Not configured by default
- Particularly useful given the current state of security
- Can turn on by editing `log4j.properties`
  - Should also have it write to a separate file
  - See http://wiki.apache.org/hadoop/HowToConfigure

HDFS

Topology

- Replica placement dictated by rack topology
- Distance calculated in multiple levels
  - node, rack, core switch
- Topology normally specified using `ScriptBasedMapping`
  - Control via `topology.script.file.name`
  - Recent work on inferring topology from IP

HDFS

Web UIs

- Simple jsp user interfaces
- Can make edits from web UI
  - Runs with user and group set by `dfs.web.ugi`
- Web interfaces (port numbers)
  - NameNode: 50070, `dfs.http.address`
    - Also /metrics, /logLevel, /stacks
  - DataNode: 50075, `dfs.datanode.http.address`
  - Secondary NameNode: 50090, `dfs.secondary.http.address`

HDFS

HDFS Proxy and Thriftfs

- HDFS Proxy
  - HTTP server that allows access by non-HDFS clients
- Thriftfs
  - Thrift server that allows access by non-HDFS clients

HDFS

Trash

- Each user has a .Trash directory in their home directory
- Files will remain in the trash for `fs.trash.interval` minutes
  - Set to zero to disable the trash
  - Trash is disabled by default
- Enable the trash to prevent mistaken deletions
- Programmatic access
  - moveToTrash() and expunge()

HDFS

Benchmarks and Load Testing

- TestDFSIO
  - Use a MapReduce job to read and write files in parallel
  - Run without arguments to get options
    - Can run read and write benchmarks
  - Files are written under /benchmarks/TestDFSIO by default
    - Control with `test.build.data`
- NNBench
  - Load test the NameNode before deployment

HDFS

Common Problems

- Disk capacity!
  - Especially due to log file sizes
  - Crank up `dfs.datanode.du.reserved`
- Slow, but not dead, disks
- Checkpointing and backing up metadata
- Losing a write pipeline for long-lived writes
- Upgrades
- Many small files

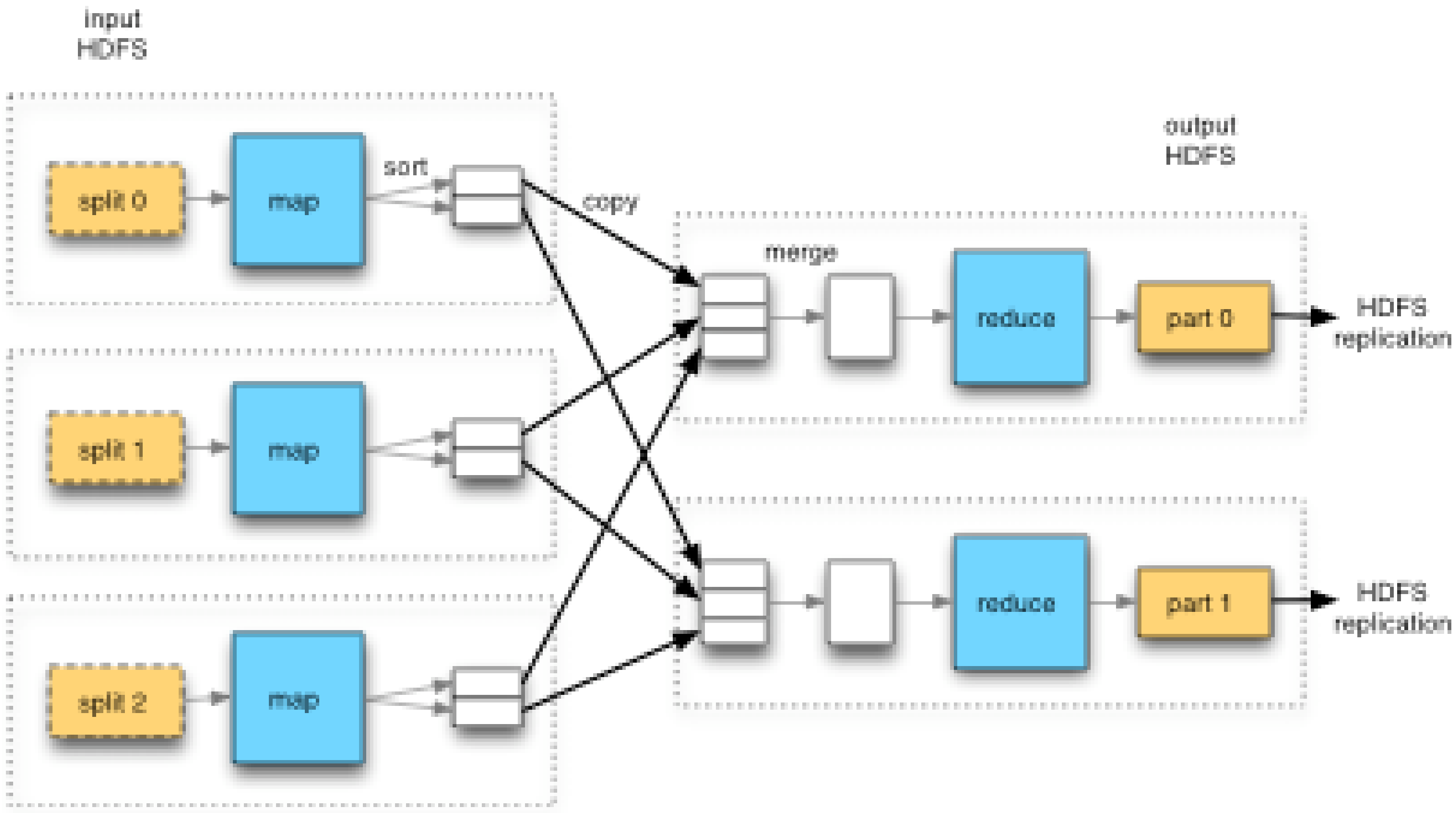
Hadoop MapReduce

Overview

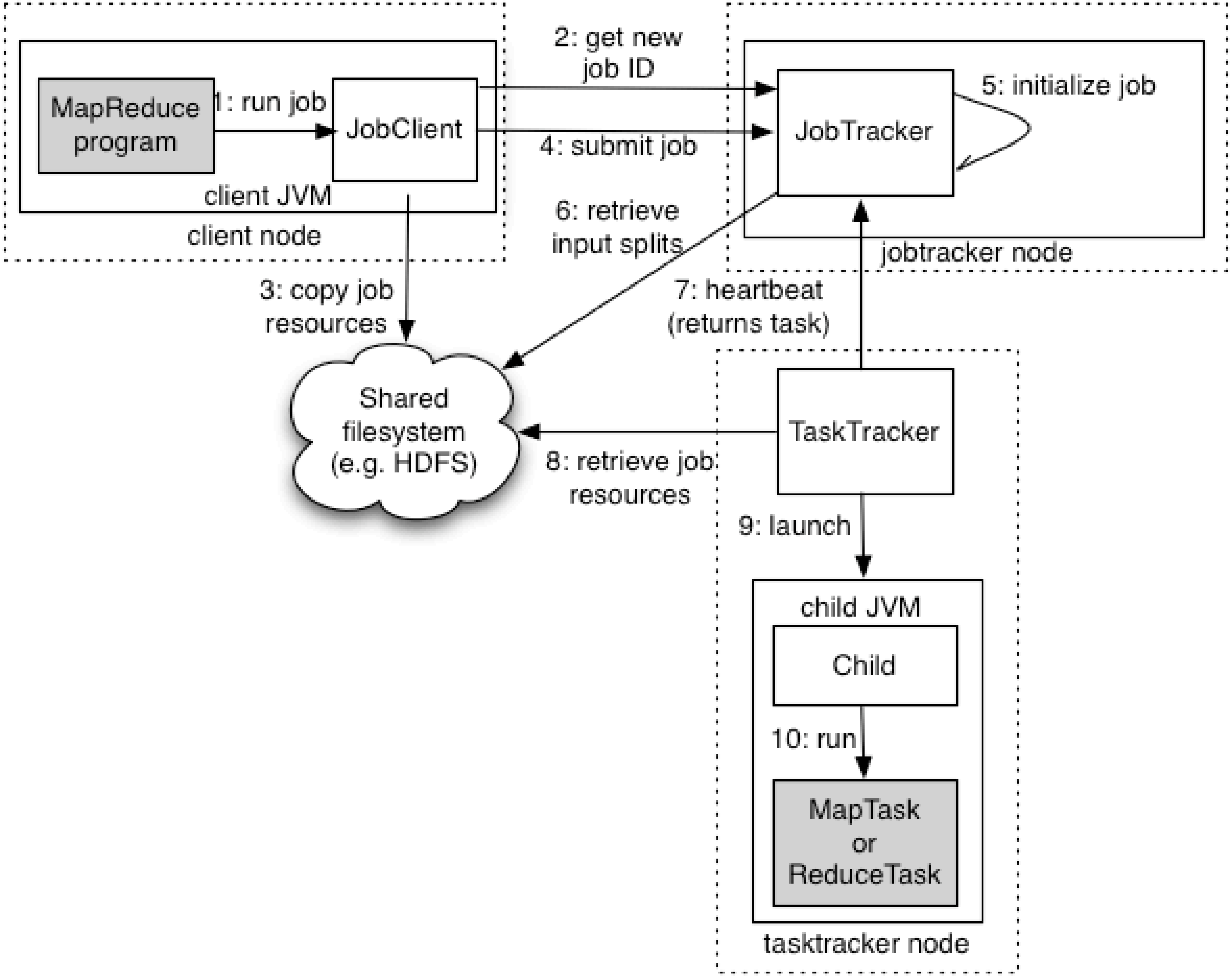
- JobTracker
  - Long-lived master daemon which distributes tasks
  - Maintains a job history of job execution statistics
- TaskTrackers
  - Long-lived client daemon which executes Map and Reduce tasks
- Client
  - Submits processing logic and necessary libraries to JobTracker
  - Performs input split calculation and waits for job success

Hadoop MapReduce Data Flow

Map, Shuffle, Reduce



Hadoop MapReduce Process Communication



Hadoop MapReduce

Operator Utilities

- Tool interface
- Fair Share and Capacity schedulers
- Distributed Cache
- MRUnit
- IsolationRunner
- JobControl
- Web UIs
- Sqoop

Hadoop MapReduce

More Operator Utilities

- Counters
- Metrics
- Profiling tasks with HPROF
- Job History
- Benchmarks and load testing: Sort, MRBench, Gridmix
- Recover running jobs after restart
- JVM reuse

Hadoop MapReduce

Common Problems

- Debugging and testing large jobs
- Memory utilization of tasks
- Large jobs holding a cluster hostage
- Multi-stage MapReduce
- Overall cluster utilization
- JobTracker stability and memory utilization
- Distributing shared libraries
- Access to distributed logfiles

Cluster Lifecyle and Maintenance

Metrics and Monitoring

- Ganglia, jconsole, Nagios
- Metrics belong to a context
  - dfs, mapred, rpc, and jvm are current contexts
  - Metrics are aggregated at worker and at master daemons
  - Configured via conf/hadoop-metrics.properties
- Canary jobs
- Should also monitor some system properties
  - Ensure disks are writable and NICs remain configured correctly

Cluster Lifecycle and Maintenance

Upgrades

- Prepare for the upgrade
  - Clear out the temp directory
  - Run fsck to make sure the filesystem is healthy
  - Finalize the previous upgrade
  - Shut down MapReduce and kill any orphaned processes
  - Shut down HDFS and backup the NameNode directories
- Install the new version of HDFS and MapReduce on the cluster
- Start HDFS with the -upgrade option
- Sanity check and finalize the upgrade

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