Hadoop distributed file system (HDFS)

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Overview of HDFS

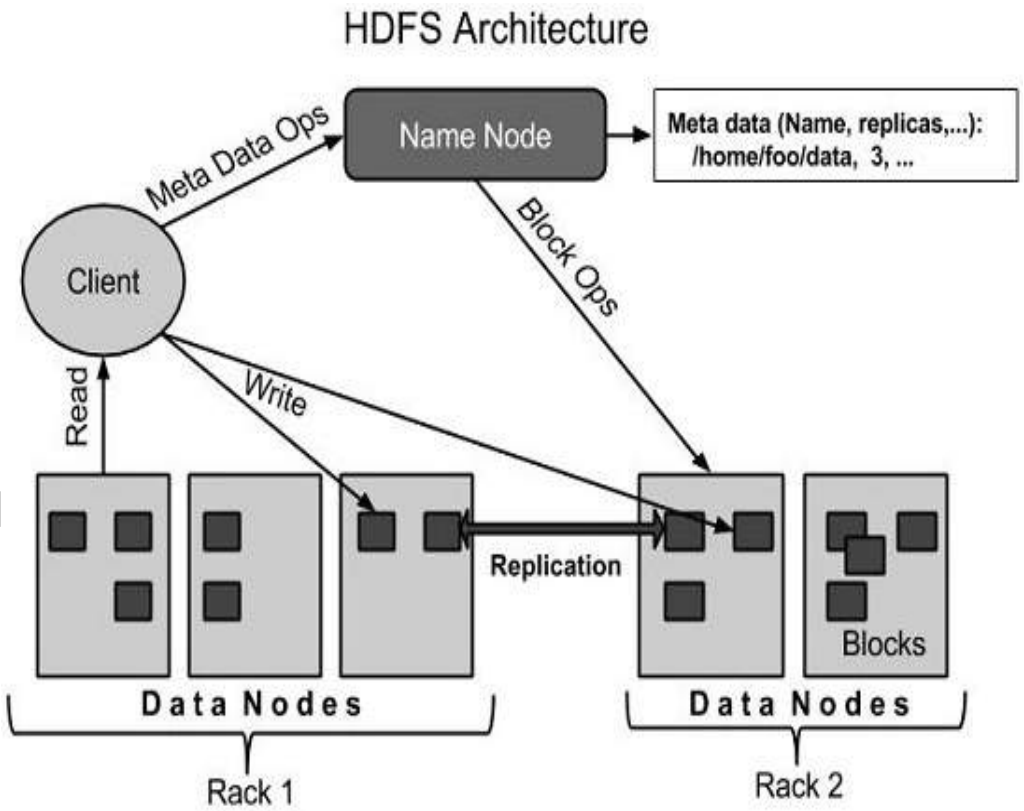
- Provides inexpensive and reliable storage for massive amounts of data
- Designed for
  - Big files (100 MB to several TBs file sizes)
  - Write once, read many times (Appending only)
  - Running on commodity hardware
- Hierarchical UNIX style file systems
  - (e.g., /hust/soict/hello.txt)
  - UNIX style file ownership and permissions

HDFS main design principles

- I/O pattern
  - Append only → reduce synchronization
- Data distribution
  - File is splitted in big chunks (64 MB)
  - → reduce metadata size
  - → reduce network communication
- Data replication
  - Each chunk is usually replicated in 3 different nodes
- Fault tolerance
  - Data node: re-replication
  - Name node
    - Secondary Namenode
    - Standby, Active Namenodes

HDFS Architecture

- Master/slave architecture
- HDFS master: Namenode
  - Manage namespace and metadata
  - Monitor Datanode
- HDFS slaves: Datanodes
  - Handle read/write the actual data {chunks}
  - Chunks are local files in the local file systems



Functions of a Namenode

- Manages File System Namespace
  - Maps a file name to a set of blocks
  - Maps a block to the Datanodes where it resides
- Cluster Configuration Management
- Replication Engine for Blocks

Namenode metadata

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

Datanode

- A Block Server
  - Stores data in the local file system (e.g. ext3)
  - Stores metadata of a block (e.g. CRC)
  - Serves data and metadata to Clients
- Block Report
  - Periodically sends a report of all existing blocks to the Namenode
- Facilitates Pipelining of Data
  - Forwards data to other specified Datanodes
- Heartbeat
  - Datanodes send heartbeat to the Namenode
    - Once every 3 seconds
  - Namenode uses heartbeats to detect Datanode failure

Data replication

- Chunk placement
  - Current Strategy
    - One replica on local node
    - Second replica on a remote rack
    - Third replica on same remote rack
    - Additional replicas are randomly placed
  - Clients read from nearest replicas
- Namenode detects Datanode failures
  - Chooses new Datanodes for new replicas
  - Balances disk usage
  - Balances communication traffic to Datanodes

Data rebalance

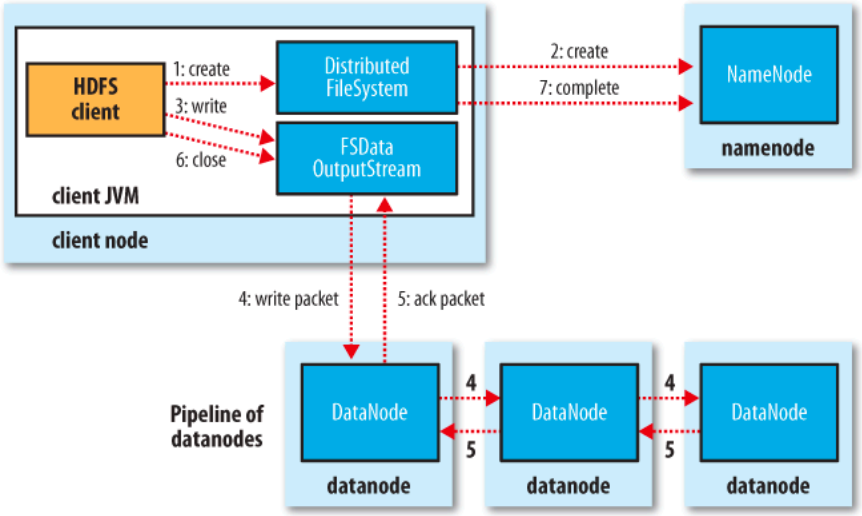
- Goal: % disk full on Datanodes should be similar
  - Usually run when new Datanodes are added
  - Cluster is online when Rebalancer is active
  - Rebalancer is throttled to avoid network congestion
  - Command line tool

Data correctness

- Use Checksums to validate data
  - Use CRC32
- File Creation
  - Client computes checksum per 512 bytes
  - Datanode stores the checksum
- File access
  - Client retrieves the data and checksum from Datanode
  - If Validation fails, Client tries other replicas

Data pipelining

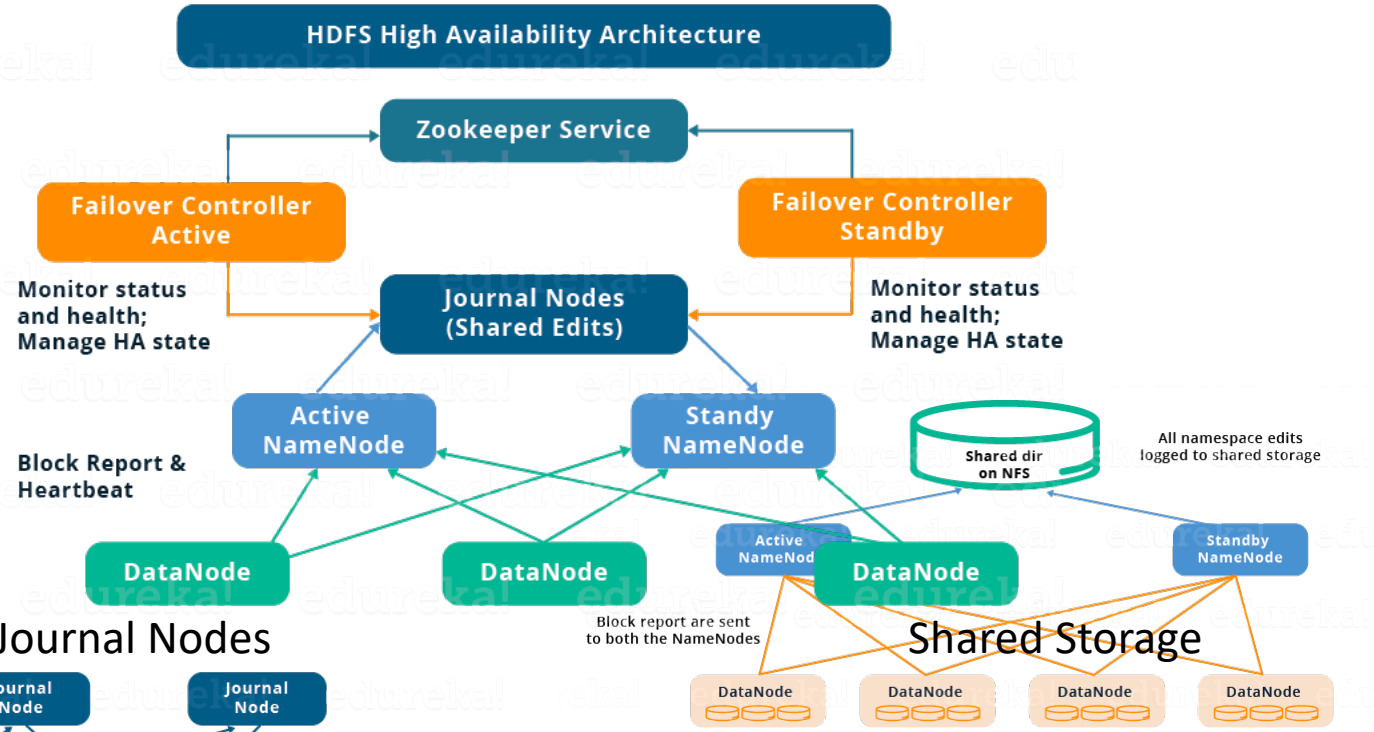
- Client retrieves a list of Datanodes on which to place replicas of a block
- Client writes block to the first Datanode
- The first Datanode forwards the data to the next node in the Pipeline
- When all replicas are written, the Client moves on to write the next block in file

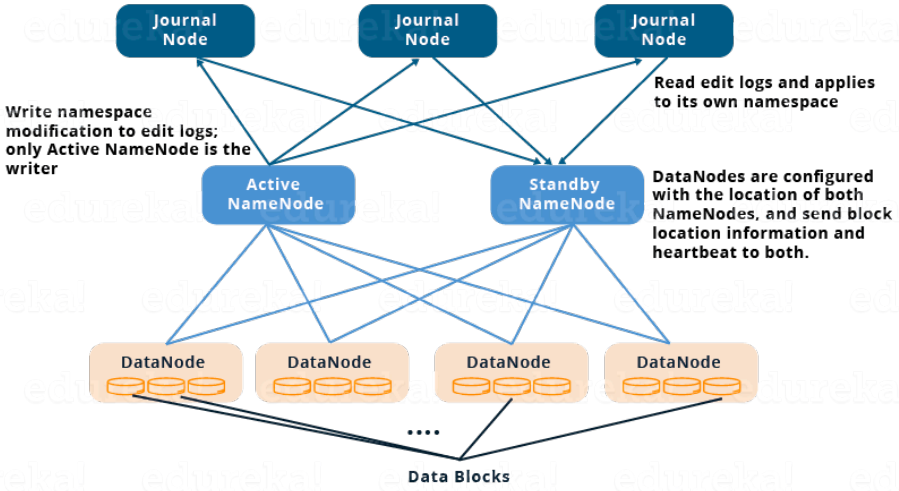


Secondary Name node

- Namenode is a single point of failure
- Secondary Namenode
  - Checkpointing latest copy of the FsImage and the Transaction Log files.
    - Copies FsImage and Transaction Log from Namenode to a temporary directory
- When Namenode restarted
  - Merges FSImage and Transaction Log into a new FSImage in temporary directory
  - Uploads new FSImage to the Namenode
    - Transaction Log on Namenode is purged

Namenode high availability (HA)





HDFS command-line interface

List Files	
hdfs dfs -ls /	List all the files/directories for the given hdfs destination path.
hdfs dfs -ls -d /hadoop	Directories are listed as plain files. In this case, this command will list the details of hadoop folder.
hdfs dfs -ls -h /data	Format file sizes in a human-readable fashion (eg 64.0m instead of 67108864).
hdfs dfs -ls -R /hadoop	Recursively list all files in hadoop directory and all subdirectories in hadoop directory.
hdfs dfs -ls /hadoop/dat*	List all the files matching the pattern. In this case, it will list all the files inside hadoop directory which starts with 'dat'.

Read/Write Files	
hdfs dfs -text /hadoop/derby.log	HDFS Command that takes a source file and outputs the file in text format on the terminal. The allowed formats are zip and TextRecordInputStream.
hdfs dfs -cat /hadoop/test	This command will display the content of the HDFS file test on your stdout .
hdfs dfs -appendToFile /home/ubuntu/test1 /hadoop/text2	Appends the content of a local file test1 to a hdfs file test2.

Upload, download files

Upload/Download Files	
hdfs dfs -put /home/ubuntu/sample /hadoop	Copies the file from local file system to HDFS.
hdfs dfs -put -f /home/ubuntu/sample /hadoop	Copies the file from local file system to HDFS, and in case the local already exits in the given destination path, using -f option with put command will overwrite it.
hdfs dfs -put -l /home/ubuntu/sample /hadoop	Copies the file from local file system to HDFS. Allow DataNode to lazily persist the file to disk. Forces replication factor of 1.
hdfs dfs -put -p /home/ubuntu/sample /hadoop	Copies the file from local file system to HDFS. Passing -p preserves access and modification times, ownership and the mode.
hdfs dfs -get /newfile /home/ubuntu/	Copies the file from HDFS to local file system.
hdfs dfs -get -p /newfile /home/ubuntu/	Copies the file from HDFS to local file system. Passing -p preserves access and modification times, ownership and the mode.
hdfs dfs -get /hadoop/*.txt /home/ubuntu/	Copies all the files matching the pattern from local file system to HDFS.
hdfs dfs -copyFromLocal /home/ubuntu/sample /hadoop	Works similarly to the put command, except that the source is restricted to a local file reference.
hdfs dfs -copyToLocal /newfile /home/ubuntu/	Works similarly to the put command, except that the destination is restricted to a local file reference.
hdfs dfs -moveFromLocal /home/ubuntu/sample /hadoop	Works similarly to the put command, except that the source is deleted after it's copied.

File management

File Management	
hdfs dfs -cp /hadoop/file1 /hadoop1	Copies file from source to destination on HDFS. In this case, copying file1 from hadoop directory to hadoop1 directory.
hdfs dfs -cp -p /hadoop/file1 /hadoop1	Copies file from source to destination on HDFS. Passing -p preserves access and modification times, ownership and the mode.
hdfs dfs -cp -f /hadoop/file1 /hadoop1	Copies file from source to destination on HDFS. Passing -f overwrites the destination if it already exists.
hdfs dfs -mv /hadoop/file1 /hadoop1	Move files that match the specified file pattern <src> to a destination <dst>. When moving multiple files, the destination must be a directory.
hdfs dfs -rm /hadoop/file1	Deletes the file (sends it to the trash).
hdfs dfs -rm -r /hadoop hdfs dfs -rm -R /hadoop hdfs dfs -rmr /hadoop	Deletes the directory and any content under it recursively.
hdfs dfs -rm -skipTrash /hadoop	The -skipTrash option will bypass trash, if enabled, and delete the specified file(s) immediately.
hdfs dfs -rm -f /hadoop	If the file does not exist, do not display a diagnostic message or modify the exit status to reflect an error.
hdfs dfs -rmdir /hadoop1	Delete a directory.
hdfs dfs -mkdir /hadoop2	Create a directory in specified HDFS location.
hdfs dfs -mkdir -f /hadoop2	Create a directory in specified HDFS location. This command does not fail even if the directory already exists.
hdfs dfs -touchz /hadoop3	Creates a file of zero length at <path> with current time as the timestamp of that <path>.

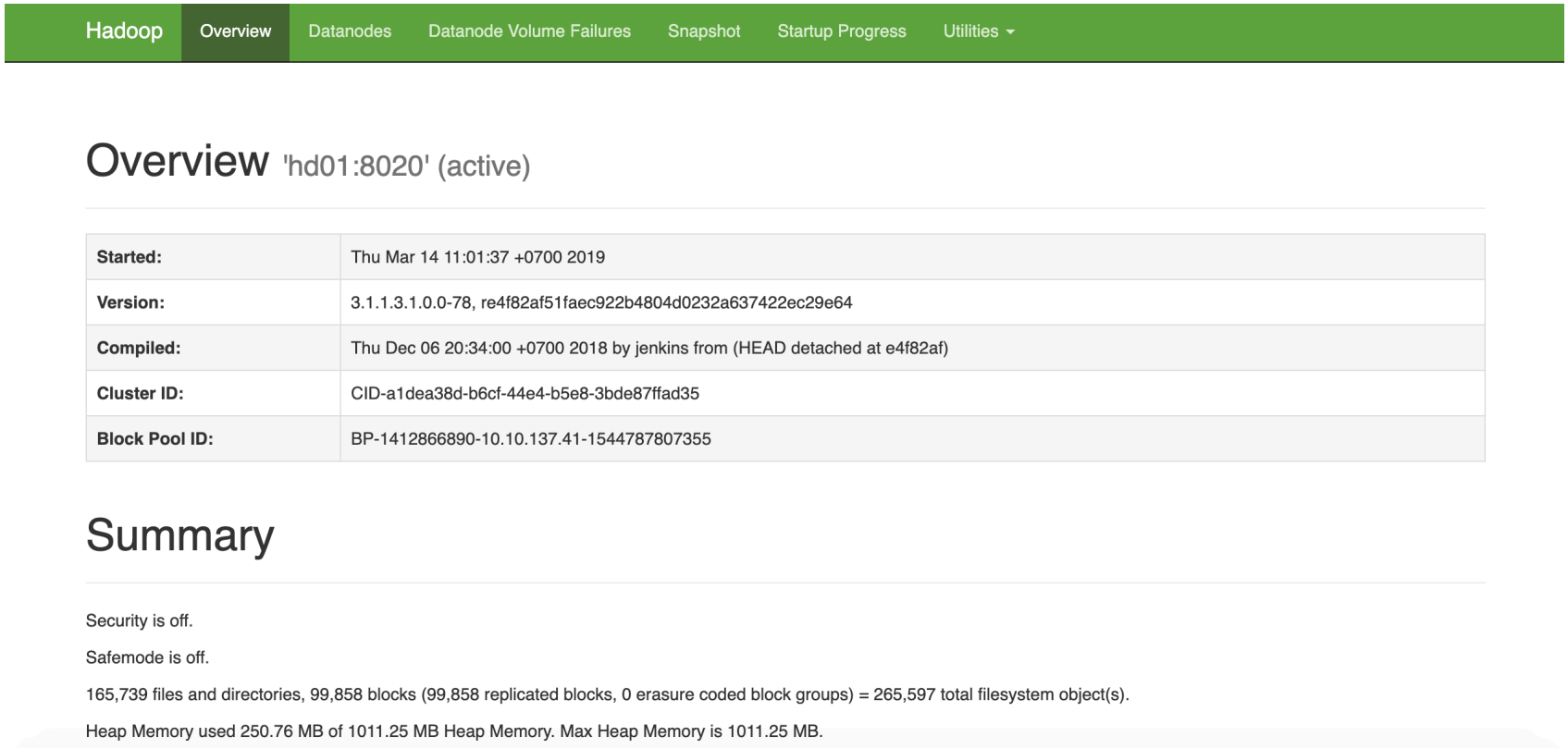
Ownership and validation

Ownership and Validation	
hdfs dfs -checksum /hadoop/file1	Dump checksum information for files that match the file pattern <src> to stdout.
hdfs dfs -chmod 755 /hadoop/file1	Changes permissions of the file.
hdfs dfs -chmod -R 755 /hadoop	Changes permissions of the files recursively.
hdfs dfs -chown ubuntu:ubuntu /hadoop	Changes owner of the file. 1st ubuntu in the command is owner and 2nd one is group.
hdfs dfs -chown -R ubuntu:ubuntu /hadoop	Changes owner of the files recursively.
hdfs dfs -chgrp ubuntu /hadoop	Changes group association of the file.
hdfs dfs -chgrp -R ubuntu /hadoop	Changes group association of the files recursively.
Filesystem	
hdfs dfs -df /hadoop	Shows the capacity, free and used space of the filesystem.
hdfs dfs -df -h /hadoop	Shows the capacity, free and used space of the filesystem. -h parameter Formats the sizes of files in a human-readable fashion.
hdfs dfs -du /hadoop/file	Show the amount of space, in bytes, used by the files that match the specified file pattern.
hdfs dfs -du -s /hadoop/file	Rather than showing the size of each individual file that matches the pattern, shows the total (summary) size.
hdfs dfs -du -h /hadoop/file	Show the amount of space, in bytes, used by the files that match the specified file pattern. Formats the sizes of files in a human-readable fashion.

Administration

Administration	
hdfs balancer -threshold 30	Runs a cluster balancing utility. Percentage of disk capacity. This overwrites the default threshold.
hadoop version	To check the vesrion of Hadoop.
hdfs fsck /	It checks the health of the Hadoop file system.
hdfs dfsadmin -safemode leave	The command to turn off the safemode of NameNode.
hdfs dfsadmin -refreshNodes	Re-read the hosts and exclude files to update the set of Datanodes that are allowed to connect to the Namenode and those that should be decommissioned or recommissioned.
hdfs namenode -format	Formats the NameNode.

HDFS Name node UI



HDFS Name node UI (2)

In operation

Show 25 entries Search:

Node	Http Address	Last contact	Last Block Report	Capacity	Blocks	Block pool used	Version
✔hd01:50010 (10.10.137.41:50010)	http://hd01:50075	1s	251m	296.83 GB	99858	166.56 GB (56.11%)	3.1.1.3.1.0.0-78
✔hd02:50010 (10.10.137.42:50010)	http://hd02:50075	0s	57m	296.83 GB	99858	166.57 GB (56.12%)	3.1.1.3.1.0.0-78
✔hd03:50010 (10.10.137.43:50010)	http://hd03:50075	2s	197m	296.83 GB	99858	166.57 GB (56.12%)	3.1.1.3.1.0.0-78

Showing 1 to 3 of 3 entries Previous 1 Next

Hadoop Overview Datanodes Datanode Volume Failures Snapshot Startup Progress Utilities

Browse Directory

/ Go!

Show 25 entries Search:

Permission	Owner	Group	Size	Last Modified	Replication	Block Size	Name
drwxrwxrwt	yarn	hadoop	0 B	Jun 01 17:52	0	0 B	app-logs
drwxr-xr-x	hdfs	hdfs	0 B	Dec 18 2018	0	0 B	apps
drwxr-xr-x	yarn	hadoop	0 B	Dec 14 2018	0	0 B	ats
drwxr-xr-x	hdfs	hdfs	0 B	Dec 14 2018	0	0 B	atsv2

Other HDFS interfaces

- Java API
- Thrift API
- Fuse
- WebDAV

HDFS data format

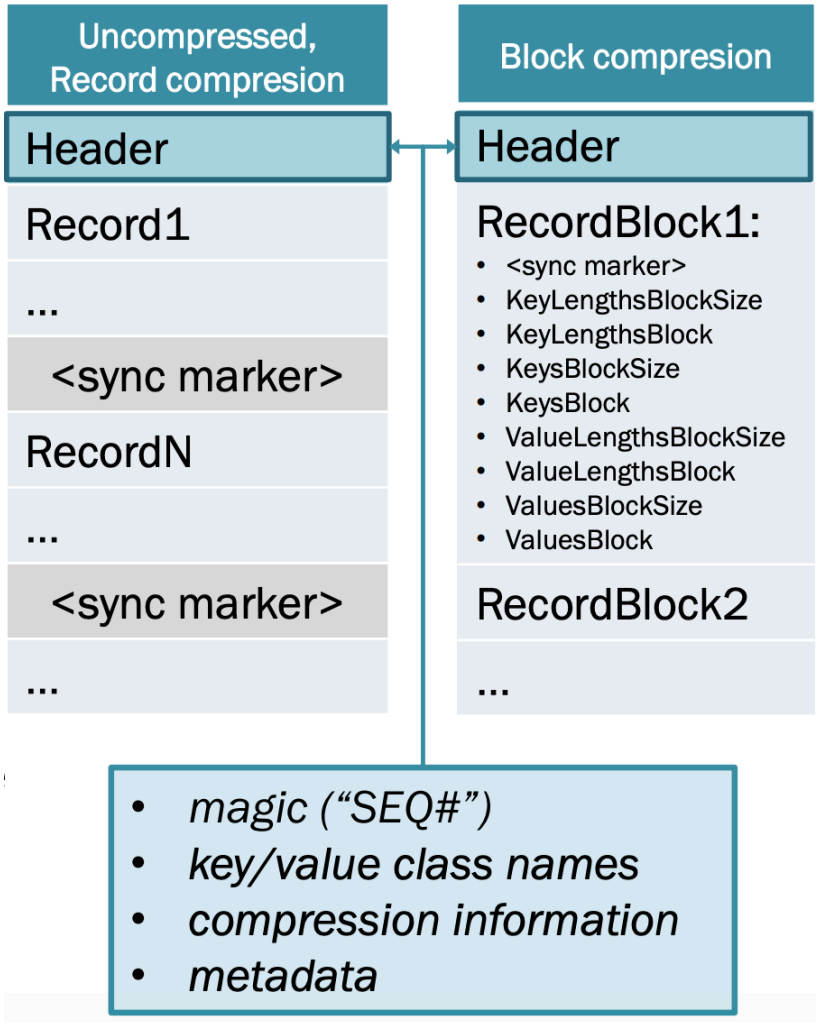
Text
Sequence file
Avro
Parquet
Optimized Row Columnar (ORC)

Text file

- CSV, TSV, Json records
- Convenient format to use to exchange between applications or scripts
- Human readable and parsable
- Do not support block compression
- Not as efficient to query
- Good for the beginning, but not good enough for real life.

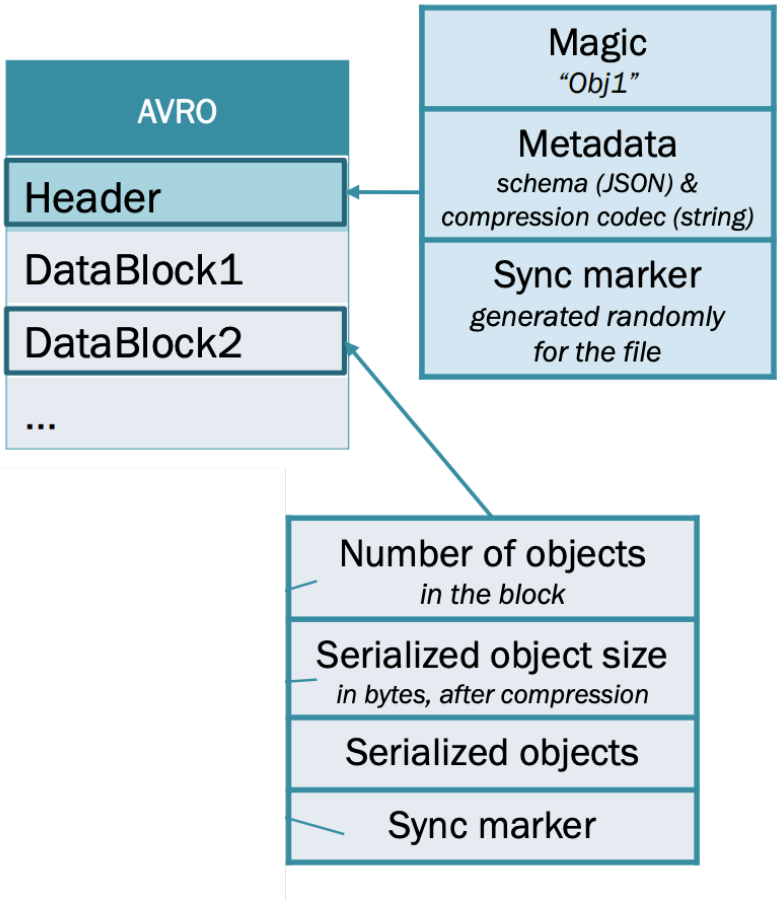
Sequence file

- Provides a persistent data structure for binary key-value pairs
- Commonly used to transfer data between Map Reduce jobs
- Can be used as an archive to pack small files in Hadoop
- Row-based
- Compression
- Splittable
  - Support splitting even when the data is compressed



Avro

- Row based
- Supports (object) compression and splitting
- Flexible data scheme
  - Schema (JSON) included to the file
- Data types
  - primitive: null, boolean, int, long, ...
  - complex: records, arrays, maps, ...
- Binary and JSON data serialization
- Data corruption detection

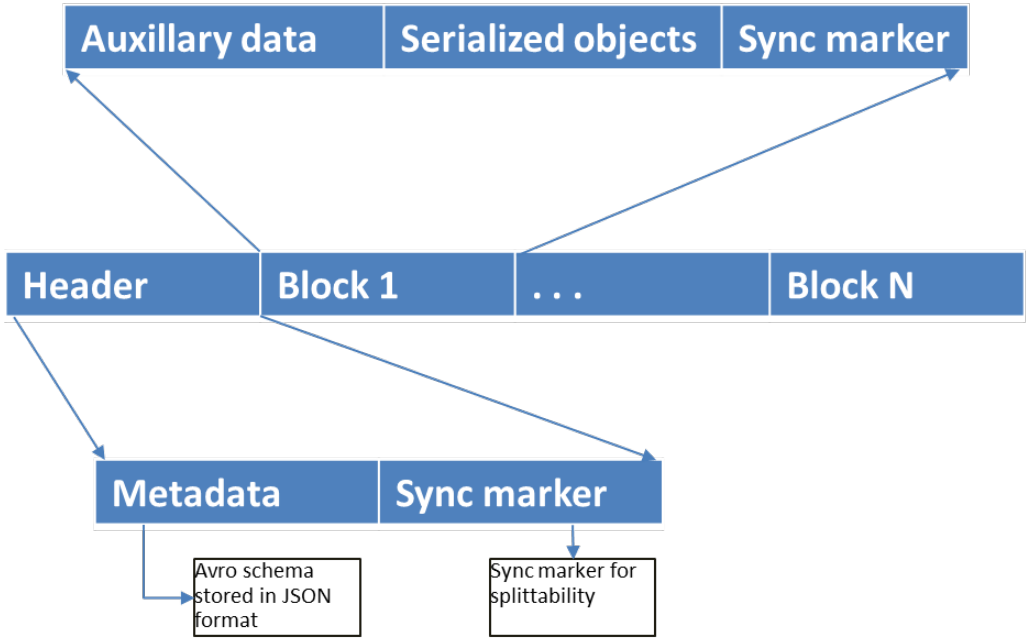


Avro – File structure and example

Sample AVRO schema in JSON format

```
{
  "type" : "record",
  "name" : "tweets",
  "fields" : [ {
    "name" : "username",
    "type" : "string",
}, {
    "name" : "tweet",
    "type" : "string",
}, {
    "name" : "timestamp",
    "type" : "long",
} ],
  "doc:" : “schema for storing tweets"
}
```

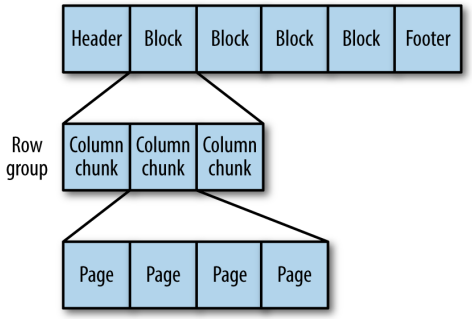
Avro file structure



Parquet

- Column-oriented binary file format
- Efficient in terms of disk I/O when specific columns need to be queried
- Supports (page) compression and splitting
- Supports nested columns (Dremel encoding)

Internal structure of parquet file



Nested schema

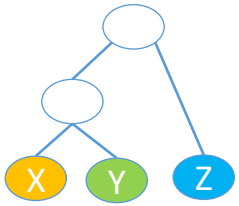
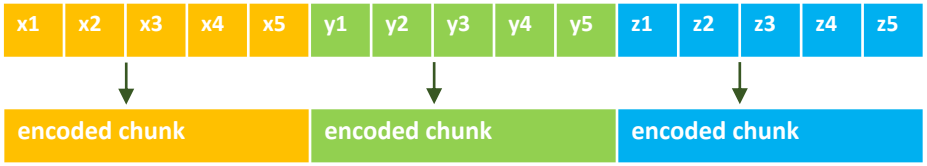


Table representation

X	Y	Z
x1	y1	z1
x2	y2	z2
x3	y3	z3
x4	y4	z4
x5	Y5	z5

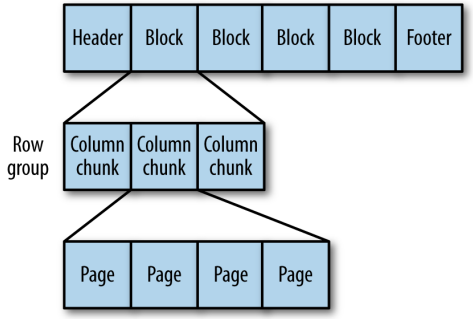
Row format

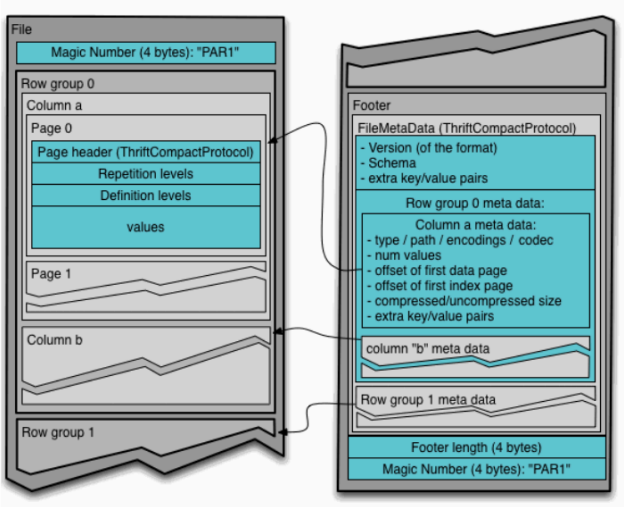
Columnar format



Parquet file structure & configuration

Internal structure of parquet file





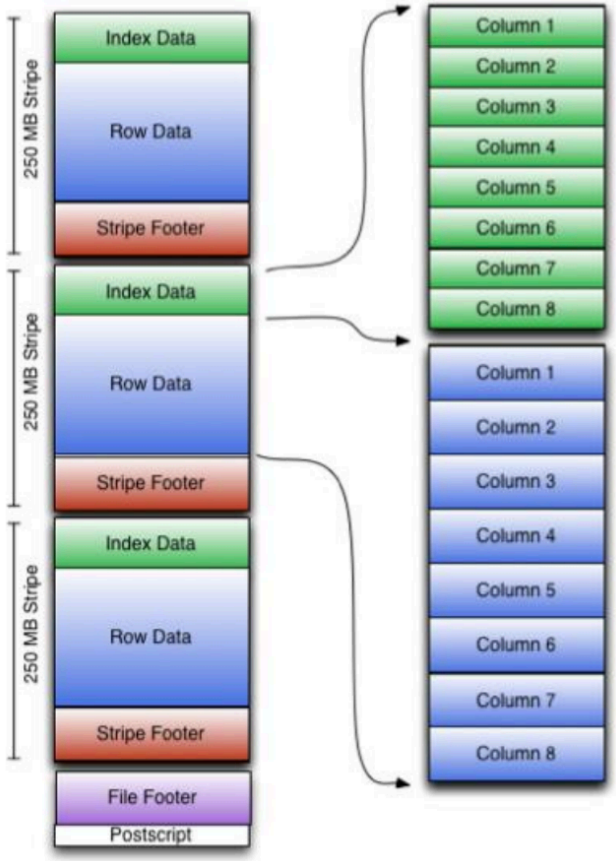
Configurable parquet parameters

Property name	Default value	Description
parquet.block.size	128 MB	The size in bytes of a block (row group).
parquet.page.size	1MB	The size in bytes of a page.
parquet.dictionary.page.size	1MB	The maximum allowed size in bytes of a dictionary before falling back to plain encoding for a page.
parquet.enable.dictionary	true	Whether to use dictionary encoding.
parquet.compression	UNCOMPRESSED	The type of compression: UNCOMPRESSED, SNAPPY, GZIP & LZO

Parquet is optimized for high compression and high scan efficiency

Optimized row columnar (ORC)

- RCFile
  - Every column is compressed individually within the row group
- ORC File
  - Block-mode compression
  - Data type support
  - Ordered data store (within one stripe)
- Stores collections of rows and within the collection the row data is stored in columnar format
- Introduces a lightweight indexing that enables skipping of irrelevant blocks of rows
- Splittable: allows parallel processing of row collections
- Indices with column-level aggregated values (min, max, sum and count)



Thank you for your attention!

Q&A