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Big Data Storage and Processing

MSc in Data Analytics

CCT College Dublin

Hadoop Distributed File System (HDFS)

Week 2

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Agenda

- Introduction
- Hadoop Design Goals
- Hadoop Concepts
- Hadoop Dataflow
- Hadoop Proximity
- Hadoop Replication

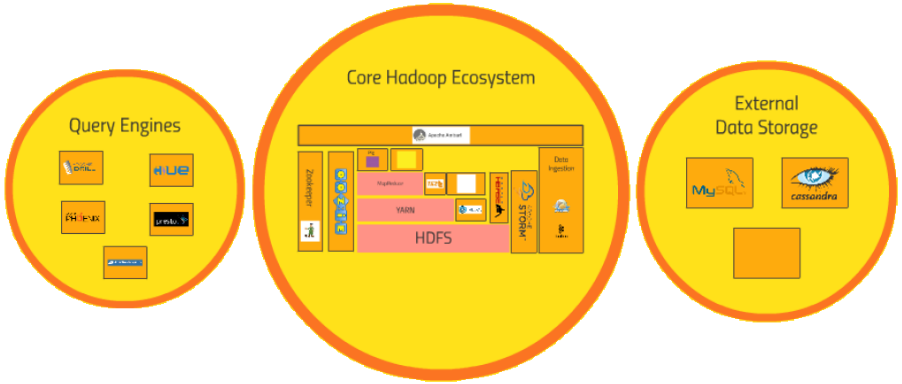
Introduction

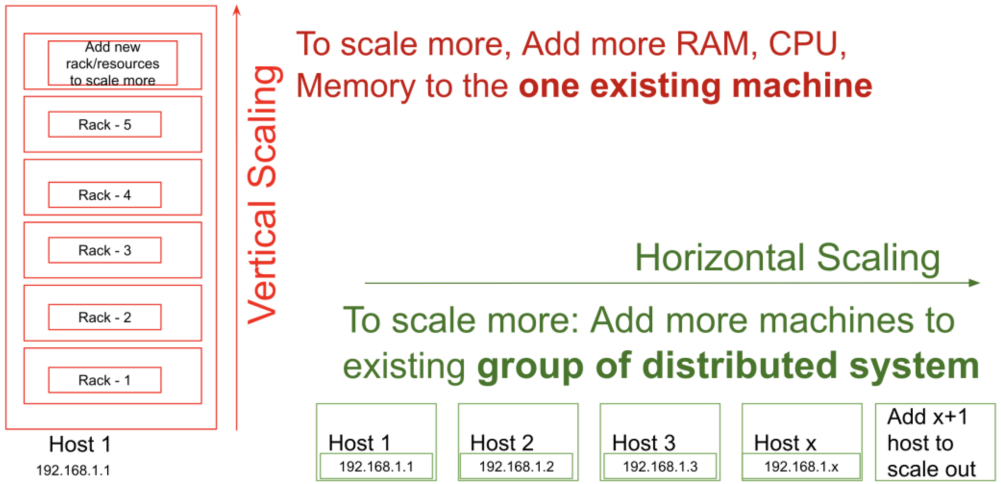
- **What is Hadoop?**
- An open source software platform for distributed storage and distributed processing of very large data sets on computer clusters built from commodity hardware. *Hortonworks*
- **Hadoop Distributed File System (HDFS)**
  - When a dataset outgrows the storage capacity of a single physical machine, it becomes necessary to partition it across a number of separate machines.
  - Filesystems that manage the storage across a network of machines are called **distributed filesystems**.
  - Storage requirements necessitate partitioning datasets across a number of machines.

Can we ensure filesystem tolerance to a node failure?

Why Hadoop?

- Data's too darn big - Terabytes per day
- **Vertical scaling** doesn't cut it
  - Disk seek times
  - Hardware failures
  - Processing times
- **Horizontal scaling** is linear.
- **Hadoop:** It's not just for batch processing anymore.
- **HDFS** is horizontally scalable.





Hadoop Design Goals

- **Hadoop distributed file system (HDFS)** is designed
  - to handle very **<u>large datasets</u>**
  - be deployed on **<u>commodity hardware</u>**
  - exhibit a high level of **<u>fault tolerance</u>**
  - enable streaming access to filesystem data

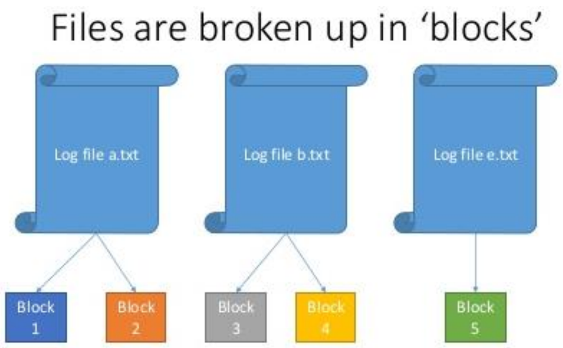
Megabytes – Terabytes - Petabytes

High chance of node failure

In case of node failure

Write-once, read-many pattern – time to read whole file more important than latency in reading the first record

Hadoop Concepts
Blocks



- We are familiar with block I/O at the disk level
- **Filesystems** implement a block size which is typically an integral multiple of the disk block size, e.g.

Disk Block Size	Filesystem Block Size
512 Bytes	4 Kilobytes

- **HDFS** also implements a block size
  - 128MB by default
- **HDFS** files are broken up into block sized chunks which can then be stored as independent units
- **Note:** A **HDFS** file that is smaller than the **HDFS** block will not take up a full block of space – all blocks in a file are the same size except possibly for the last one

Why such large HDFS block sizes?

Hadoop Concepts
Blocks

- HDFS blocks are large to reduce the cost of seek operations

- We would like the time taken to transfer data from the disk to be as close as possible to the disk transfer rate

  - **Reduce the percentage time spent doing seek operations**

If the seek time is approximately 10ms for a disk with a transfer rate of 100MB/s then to make the seek time 1% of the total transfer time, the block should be configured to approximately 100MB.

Hadoop Concepts

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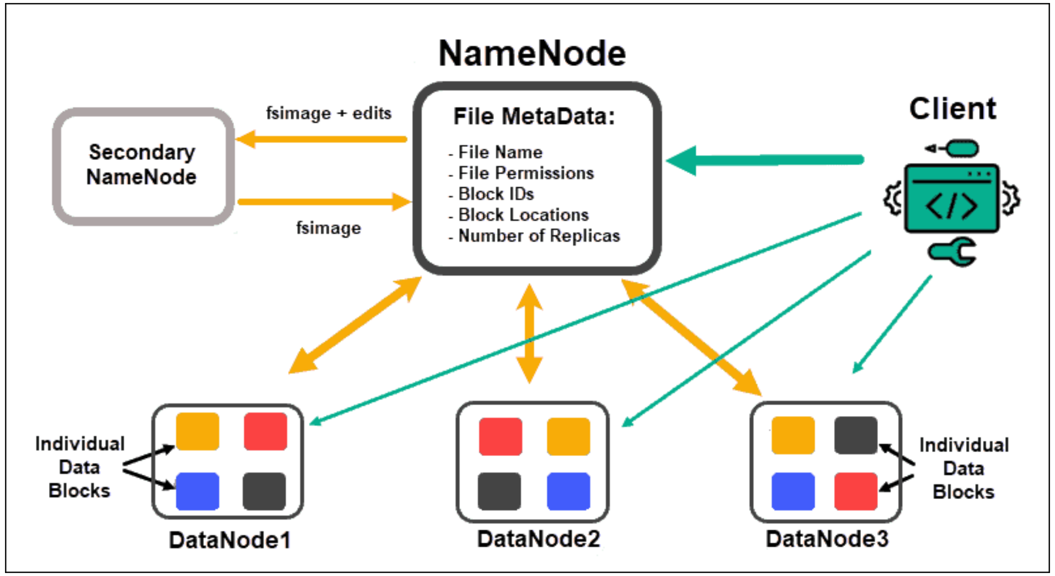
- **Namenodes and Datanodes**
  - **HDFS** has a master/ slave (or master/ worker) architecture
  - A ***namenode*** is the master
  - A set of ***datanodes*** act as the slaves or workers



Source: https://phoenixnap.com/kb/apache-hadoop-architecture-explained

Hadoop Concepts

The Namenode

- Maintains the filesystem tree and the metadata for the files and directories in the tree

  - Stored persistently on disk in the form of two files:

SPOF?

1. **The *namespace image (FSImage file)*** – filesystem namespace, file-block mappings, filesystem properties – 4GB RAM should be plenty for large filesystem

2. **The *edit log (EditLog file)*** – a transaction log

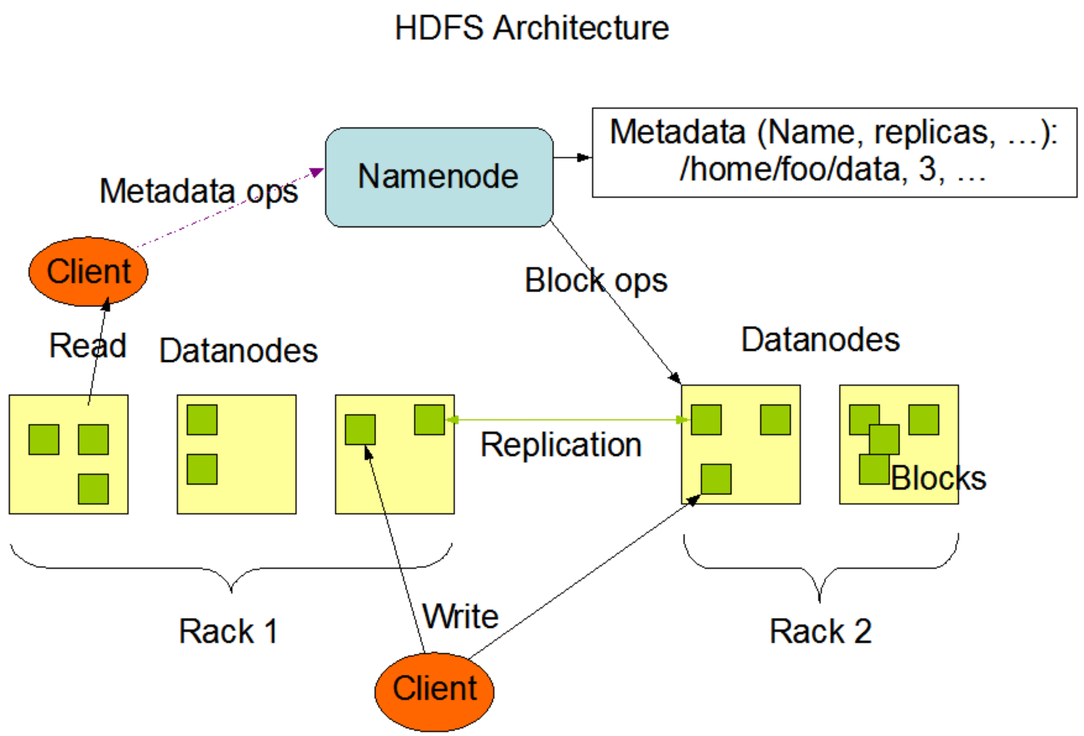
- The **namenode** also knows the **datanodes** on which all the blocks for a given file are located

  - This information is reconstructed from the datanodes when the system starts

Hadoop Concepts
The datanode

- For every node (Commodity hardware/ System) in a cluster, there will be a datanode. These nodes manage the data storage of their system.
- Handle read/ write requests from clients (or the namenode).
- They also perform operations such as block creation, deletion, and replication according to the instructions of the namenode.
- Usually, one datanode per node in the cluster.
- **Note:** User data does not flow through the namenode.

Namenodes and Datanodes

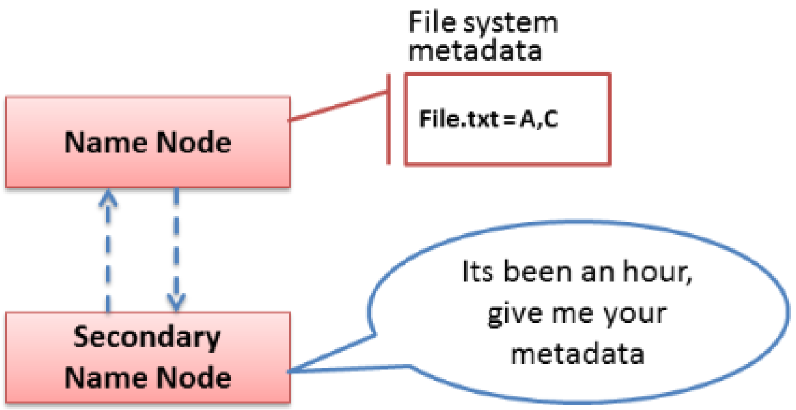


Hadoop Concepts
HDFS High Availability

- **NameNode Failure**
  - Replication of persistent state to remote Network File System (NFS) mount
    - Secondary NameNode (*deprecated)*
    - Checkpoint Node
    - Backup Node
  - Hadoop provides HDFS HA via active-passive standby configuration

SPOF?

- **Active / Standby** – should be machines with equivalent specifications
- **DataNodes** send **heartbeat** and blockreports to both Active and Standby nodes



Hadoop Concepts

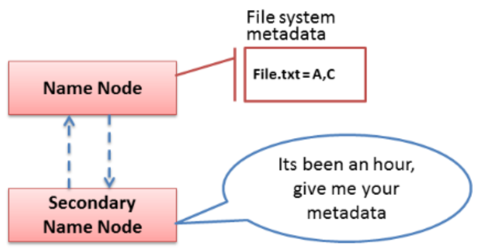
HDFS High Availability

- **Secondary NameNode**

    - Used to periodically merge the namespace image with the edit log file

    - Should run on a separate machine with same memory requirements as the NameNode

    - Keeps copy of the merged namespace image that can be used in the case of failure



Does not provide HA

- Secondary namenode will lag the primary – high probability of data loss!

Hadoop Concepts
HDFS High Availability

- ### Checkpoint Node

Does not provide HA

  - Replaces the role of the Secondary NameNode.
  - Multiple Checkpoint Nodes can be configured as long as there is no Backup Node operational.
  - It performs periodic checkpoints of the namespace and helps to minimize the size of the log stored at the NameNode containing changes to the HDFS.
  - The NameNode allows multiple Checkpoint nodes simultaneously, as long as there are no Backup nodes registered with the system.

Hadoop Concepts

HDFS High Availability

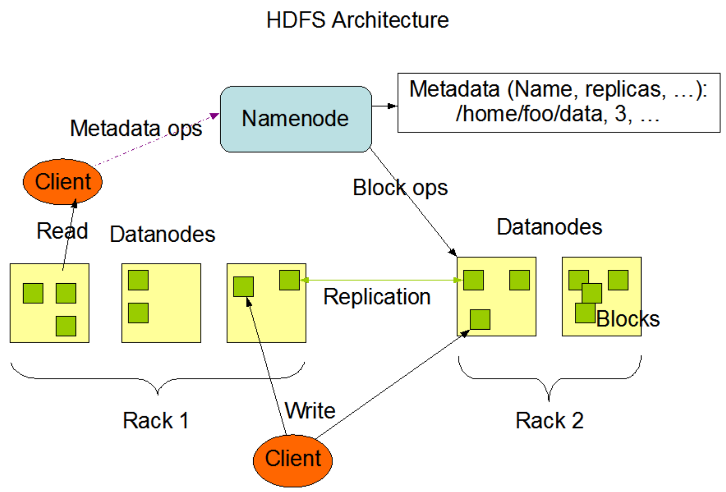
- **Backup Node**

Does not provide HA – facilitates warm standby possibility

  - Performs checkpointing
  - Also receives a stream of edits from the NameNode and maintains its own in-memory copy of the namespace, which is always in sync with the active NameNode namespace state.
  - Only one Backup node may be registered with the NameNode at once.

Hadoop Dataflow

File Read



- **Client** **NameNode** **DataNodes**

- Client calls open( ) on a **`FileSystem` object** (which is an instance of `DistributedFileSystem`)

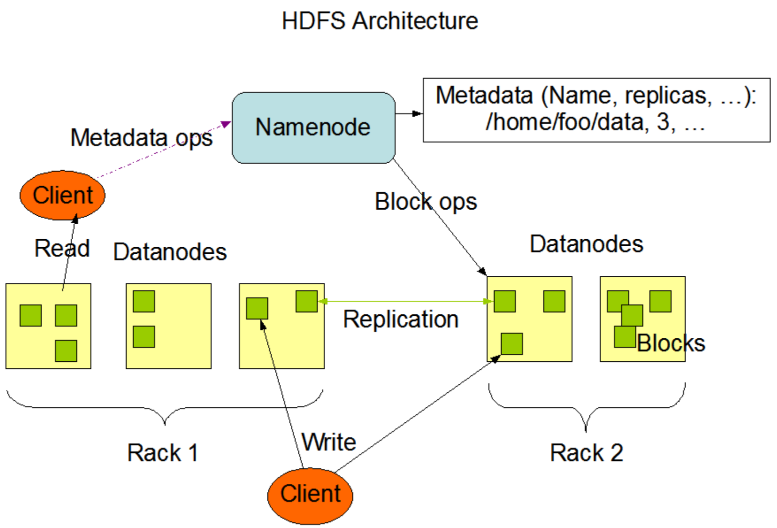
`DistributedFileSystem Object = initialization`

- **`DistributedFileSystem`** calls the namenode via **RPC** to determine locations of first few blocks in the file
- For each block, the namenode returns the addresses of the datanodes that have a copy of that block
- Datanodes are sorted according to proximity of client process
- **`DistributedFileSystem`** returns a **`FSDataInputStream`** to the client
- **`FSDataInputStream`** wraps a **`DFSInputStream`** which manages the namenode and datanode I/O

Hadoop Dataflow

File Read

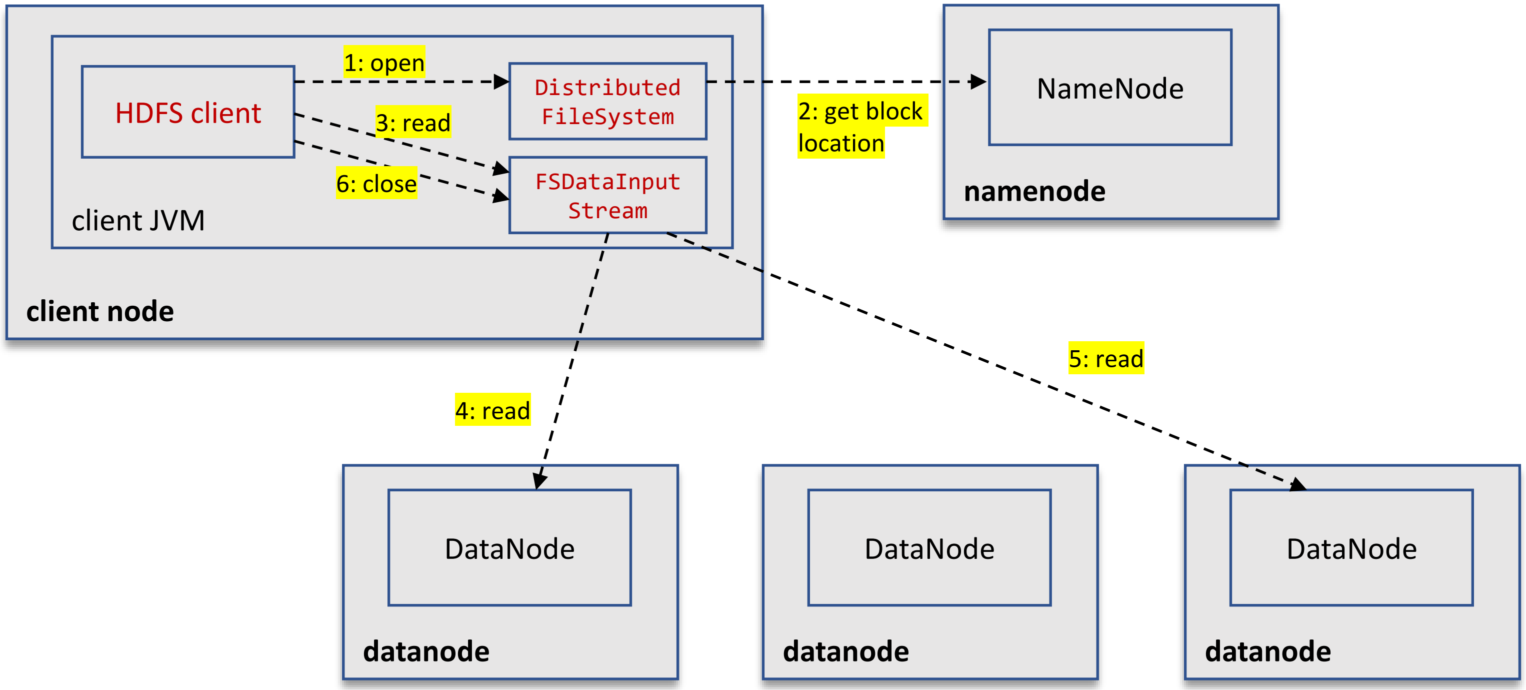
- **Client** **NameNode** **DataNodes**



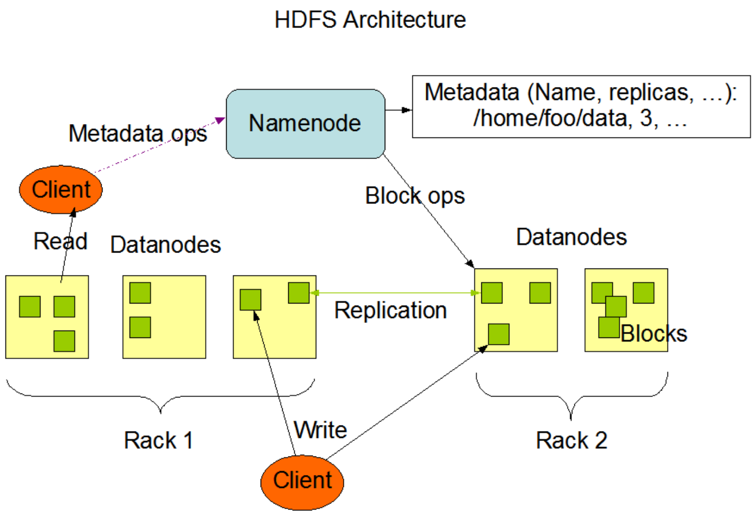
- The client then calls **read()** on the stream
- **`DFSInputStream`** connects to the first datanode for the first block in the file
- The client calls **read()** repeatedly on the stream
- When the end of the block is reached, **`DFSInputStream`** closes the connection to the datanode and then finds the next datanode for the next block
- **`DFSInputStream`** will make calls when necessary to get the datanode locations for subsequent batches of blocks
- When the client has finished reading it calls **`close()`** on the **`FSDataInputStream`**

Hadoop Dataflow

File Read



Hadoop Dataflow
File Write

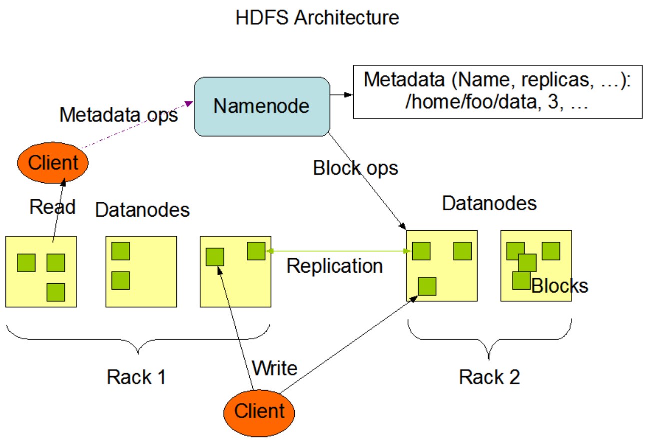


- **Client** **NameNode** **DataNodes**

- Client creates a file by calling **`create()`** on **`DistributedFileSystem`**
- **`DistributedFileSystem`** calls the **namenode** via **RPC** to create a new file in the filesystem's **namespace** (no blocks associated yet)
- **Namenode** performs a series of checks to ensure file does not already exist and that client has required permissions
- If checks pass **namenode** makes a record of the new file
- **`DistributedFileSystem`** returns a **`FSDataOutputStream`** to the client
- **`FSDataInputStream`** wraps a **`DFSOutputStream`** which manages the namenode and datanode I/O

Hadoop Dataflow

File Write



- **Client** **NameNode** **DataNodes**

- As the client writes data **`DFSOutputStream`** splits it into packets which are written to an internal ***data queue***

- The **data queue** is consumed by a **`DataStreamer`** which is responsible for requesting the namenode to allocate new blocks by picking a suitable set of datanodes to store the replicas

- The set of datanodes form a **pipeline (assume 3 datanodes)**

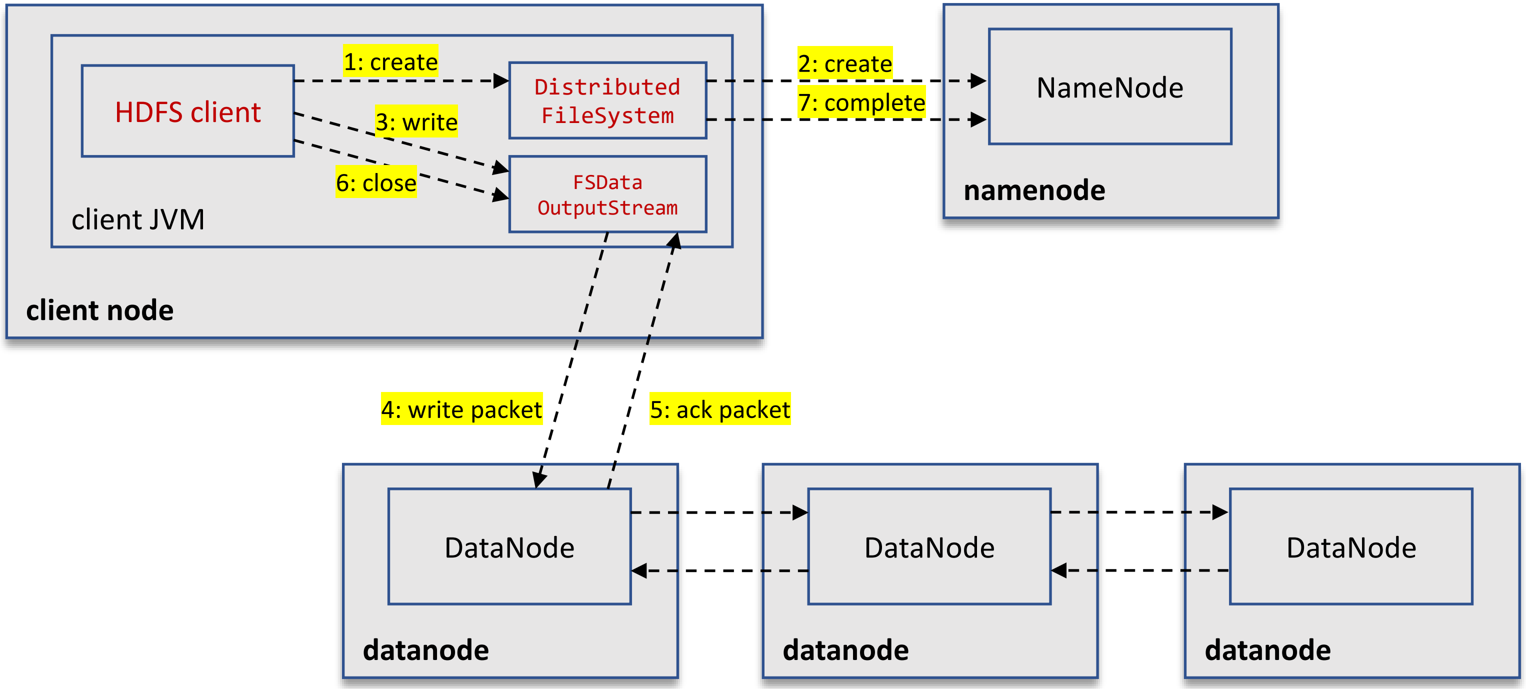
- The **`DataStreamer`** streams the packet to the **<u>first datanode</u>** in the pipeline which stores the packet and forwards it to the **<u>second datanode</u>**

- The **<u>second datanode</u>** stores the packet and forwards it to the **<u>third datanode</u>**

- The **`DFSOutputStream`** also maintains an internal queue of packets that are waiting to be acknowledged by the datanodes – the ***ack queue***

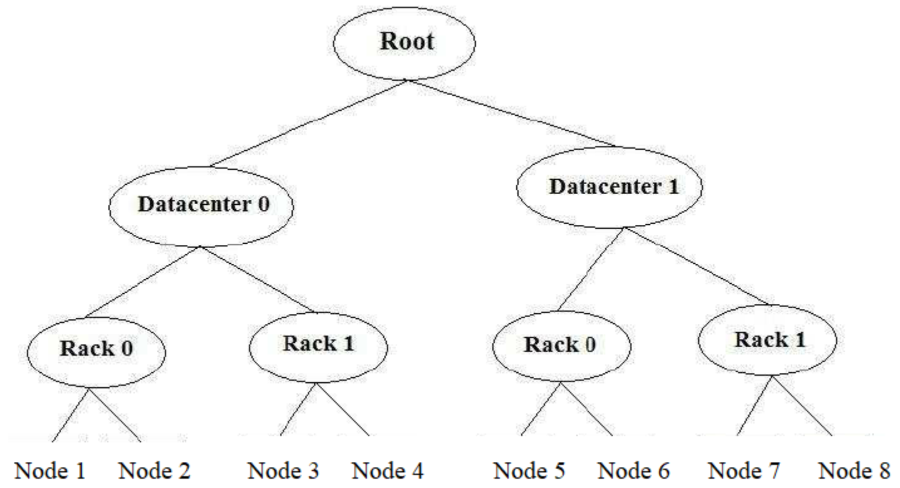
- **A packet is removed from the ack queue only when it has been acknowledged by all the datanodes in the pipeline**

Hadoop Dataflow
File Write



Hadoop Proximity
Network Topology

- Measure of node 'closeness'.
- Use **bandwidth** between nodes as a measure of closeness
- Network represented as a tree.
- Distance between nodes is the sum of their distances to their closest common ancestor.
- Commonly, levels in the tree correspond to the **data-centre**, the **rack**, and the **node** that the processing is running on.



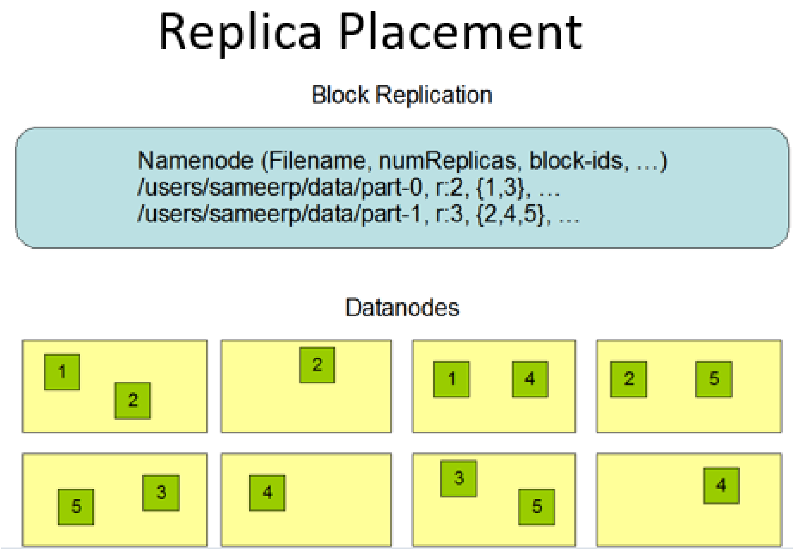
- **Example:**

  Consider a node ***n1*** on rack ***r1*** in data-centre ***d1*** being represented by `/d1/r1/n1`, Then

  - *`distance(/d1/r1/n1, /d1/r1/n1) = 0`*
  - *`distance(/d1/r1/n1, /d1/r1/n2) = 2`*
  - *`distance(/d1/r1/n1, /d1/r2/n3) = 4`*
  - *`distance(/d1/r1/n1, /d2/r3/n4) = 6`*

Hadoop Replication
Replica Placement

- **Blocks** replicated for fault-tolerance
- Application can specify the number of replicas required. **Replication factor** can be specified at create time and changed later
- **Namenode** responsible for decision making with respect to replicas
- **Namenode** will periodically receive a heartbeat from **datanodes** indicating that the **datanode** is functioning correctly
- Replica placement is critical to **HDFS** performance and reliability
- Optimising replica placement is a distinguishing factor of **HDFS** as opposed to other distributed file systems
- Possible research area



Hadoop Replication

Replica Placement

- How does the **namenode** choose **datanodes** on which to store replicas?

- **All replicas on a single node**
  - Lowest write bandwidth penalty since replication pipeline runs on a single node
  - No real redundancy though
  - Read bandwidth high for off-rack reads
- **All replicas in different data-centres**
  - Maximise redundancy
  - High bandwidth cost

Hadoop Replication

Replica Placement

- Default behaviour is to place the first replica on the same node as the client.
- If the client is running from outside the cluster then a datanode is randomly chosen (taking account of which datanodes are busiest and the capacity available on datanodes).
- The second replica is placed ***off-rack*** randomly.
- The third replica is placed on the same rack as the second replica but on a different node chosen at random.
- Further replicas are placed on random nodes in the cluster with an effort not to place too many replicas on the same rack.

Resources/ References

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- https://hadoop.apache.org/docs/stable/hadoop-mapreduce-client/hadoop-mapreduce-client-core/MapReduceTutorial.html
- Some images are used from Google search repository (https://www.google.ie/search) to enhance the level of learning.