CSE 4/587
Data Intensive Computing

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Introduction To Hadoop

What is Big data ?

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What is Big data ?

- According to Wikipedia : Big data is a collection of data sets that are so large and complex to be dealt with by traditional data-processing application software.

Different versions of Big data ?

- Volume : Data is being generated at an accelerated speed
- Variety : Different kinds of data is being generated from various sources
- Velocity: Data is being generated at a high speed
- Veracity : uncertainty and inconsistencies in the data

Problems with Big data ?

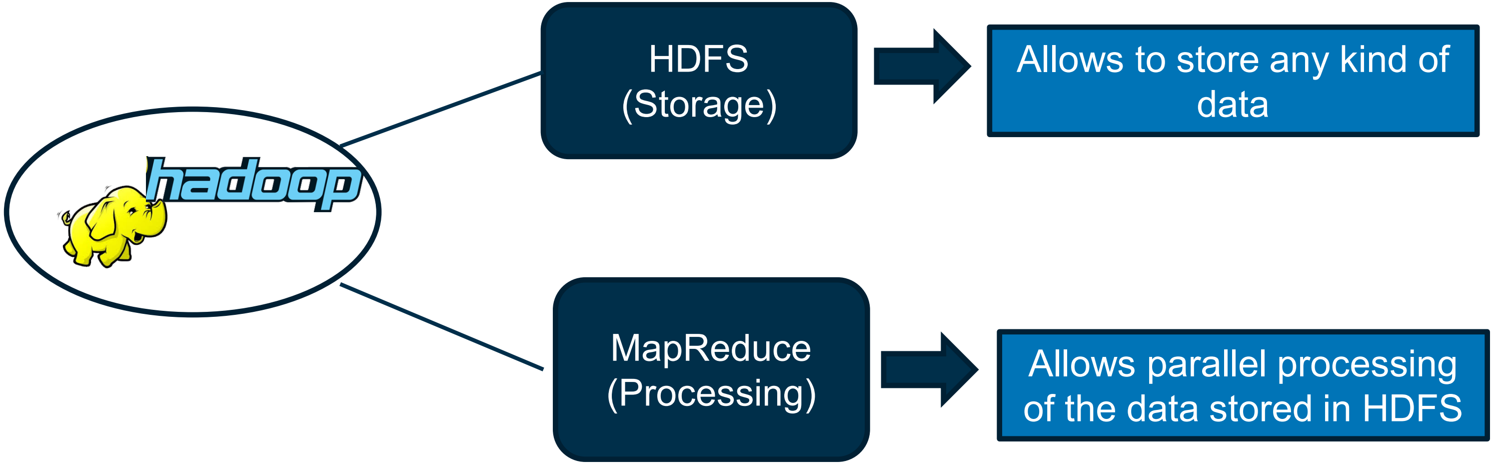
- Storing Huge and Exponentially growing datasets
- Processing different types of data are having complex structure (structured, semi-structured, un-structured)
- Processing huge amount of data to the computation unit becomes a bottleneck .

What is Hadoop?

- Hadoop is a framework that allows us to store and process large data sets in parallel and distributed fashion.

- Designed to answer the question: **"How to process big data with reasonable cost and time?"**
- The internet introduced a new challenge with web logs
  - Large scale (petascale)
  - Unique characteristic: "Write Once, Read Many" (WORM)
- Google exploited this characteristic in its Google File System (GFS)
- Hadoop is the open source version of GFS
  - Distributed file system
  - Started as part of project Nutch and Lucene (focused on search)
  - Found to have wide application outside of search
  - Now its own Apache project

What is Hadoop?



How Hadoop overcome the problems

- Storing Exponentially growing huge datasets

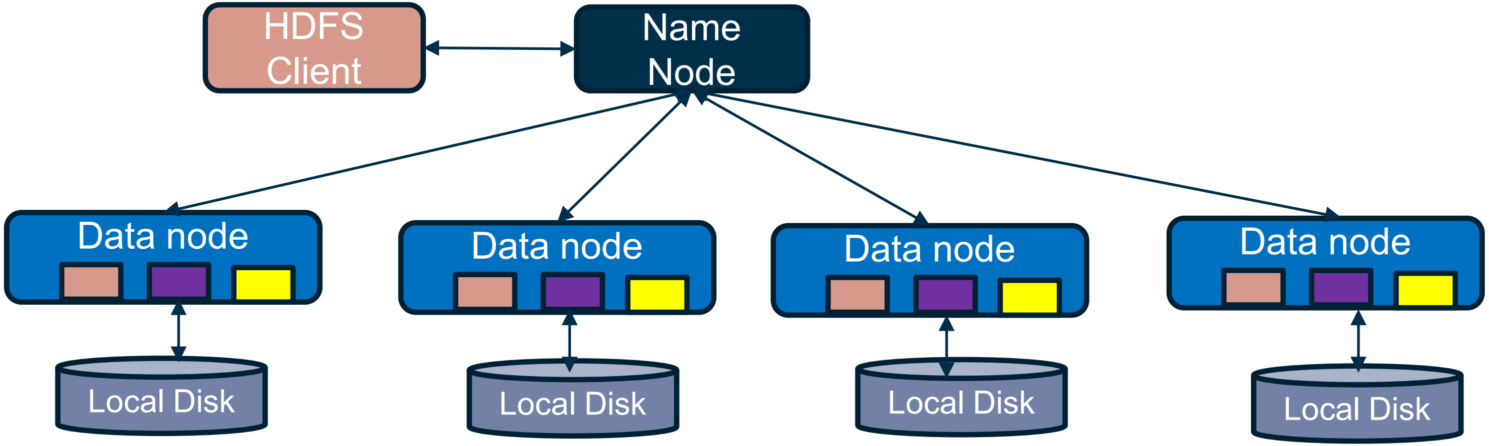
HDFS, storage unit of Hadoop is a distributed file system

- Storing different types of data

HDFS allows to store any kind of data

- Processing Data Faster

HDFS allows to store any kind of data



Hadoop Features

- Highly fault-tolerant
- High throughput
- Handles large data sets effectively
- Streaming access to file system data
- Can be built from commodity hardware
- Files browsable with any HTTP browser
- Initially provided a Java API — but now supports most programming languages

Key Aspects

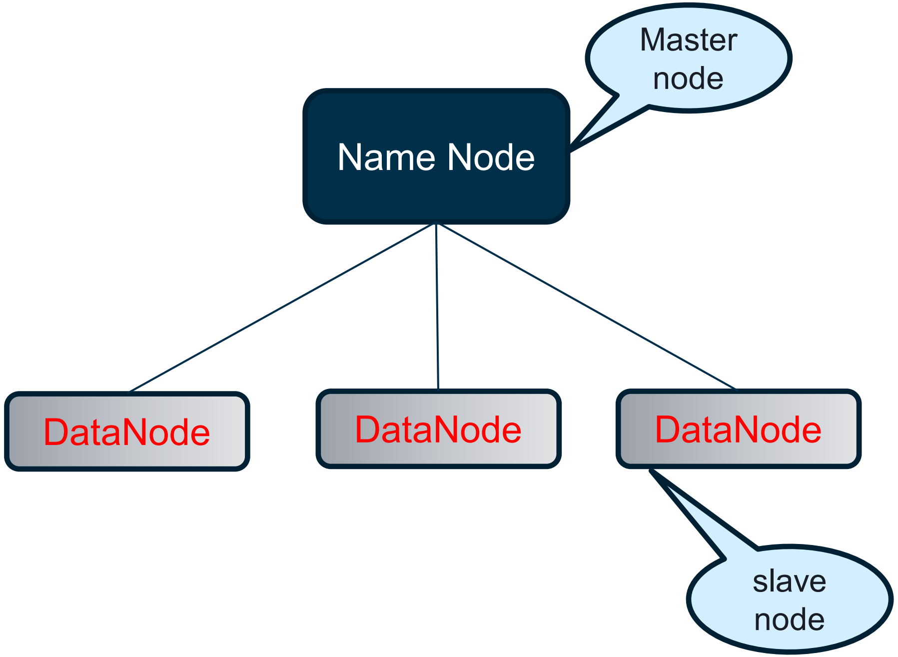
- The key aspects of Hadoop we will be discussed are:
  - Architecture
  - Protocol - rules for operation
  - Data Organization
  - Robustness
  - API to access services
  - Software (MapReduce)

Architecture

Architecture: HDFS

HDFS

- Storage unit of Hadoop
- Distributed file System
- Divide files into smaller chunks and stores across the cluster
- Store any kind of data
- No schema validation is required while inserting data



Architecture: NameNode and DataNodes

- HDFS clusters consist of a single **NameNode** and multiple **DataNodes**

NameNode

A master server that manages the filesystem namespace, tracks metadata, and regulates client access to files.

DataNodes

Usually one per node in a cluster.

Manages storage attached to their node.

Serves read/write requests, file creation/deletion, and replication.

Architecture: Files

- HDFS exposes a filesystem namespace, and allows user data to be stored in files.
- A file is split into one or more blocks, and sets of blocks are stored in the DataNodes
  - All blocks in a file are the same size (except the last)
  - These blocks may be replicated and/or migrated

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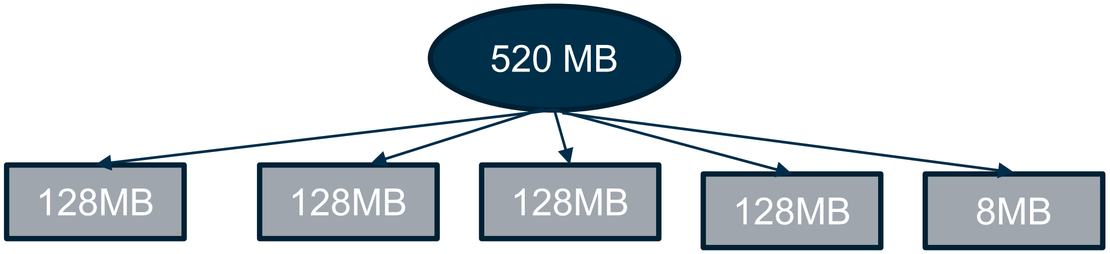
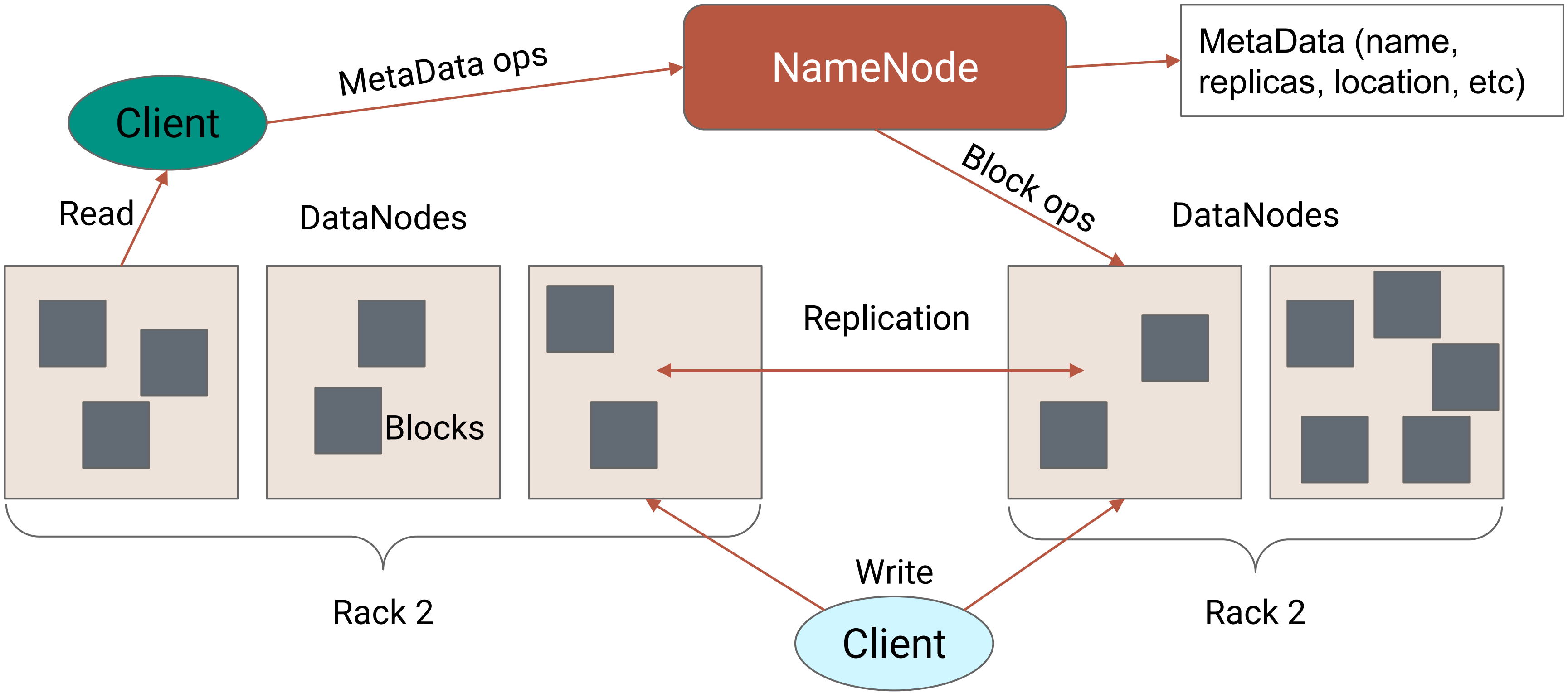
  - Example:



Architecture



File System

- Hierarchical file system with directories and files
  - Create, remove, move, rename, etc
- NameNode maintains the file system
- Any metadata changes to the file system recorded by the NameNode
- The replication factor for each file is also stored by the NameNode

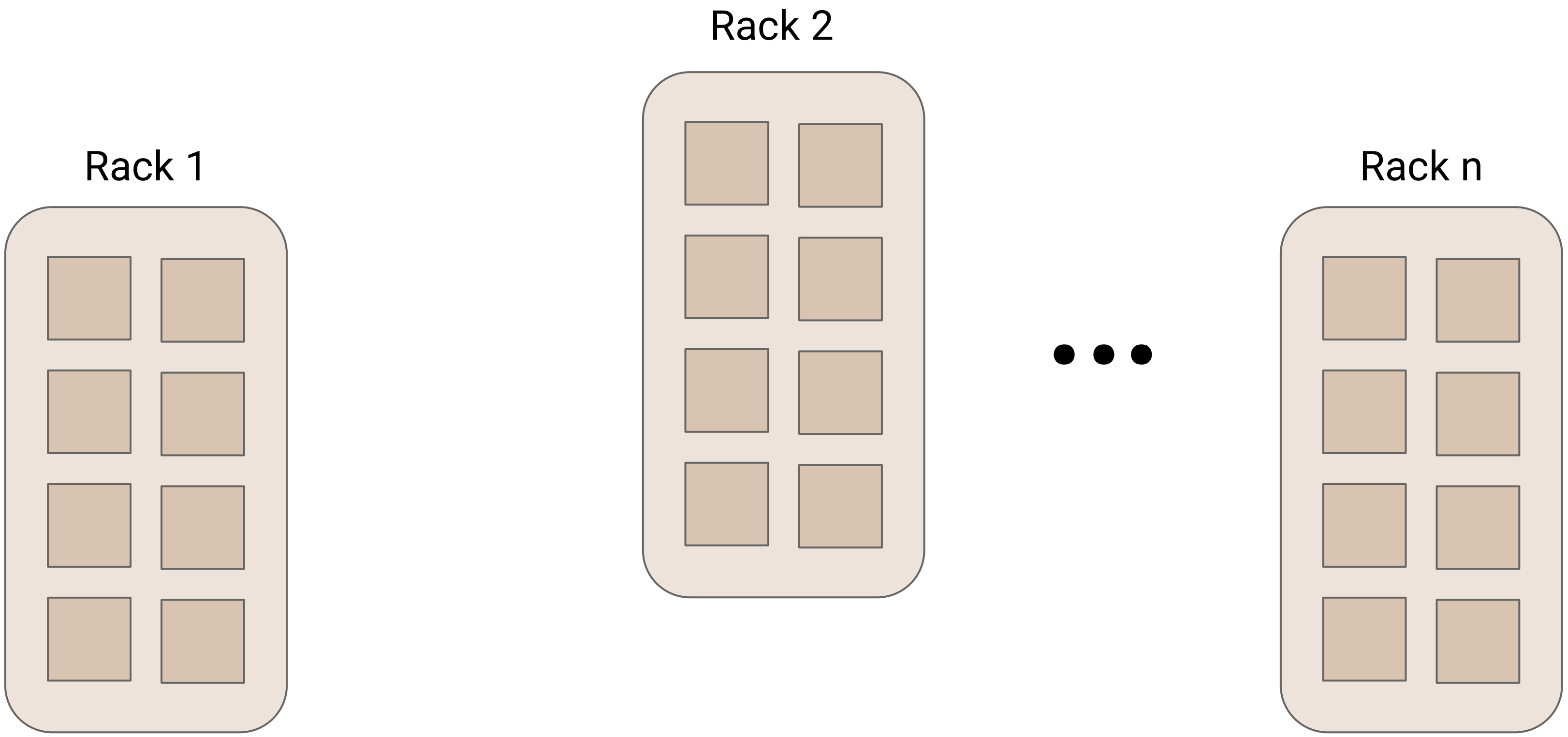
Data Replication

- HDFS is designed to store very large files across machines in a cluster
- Each file is a sequence of blocks
  - All blocks in a file are the same size (except the last block)
  - Blocks are replicated for fault tolerance
  - Block size and replica are configurable per file
- The NameNode receives a **heartbeat** and **BlockReport** from each DataNode
  - This report contains information about all the blocks on the DataNode

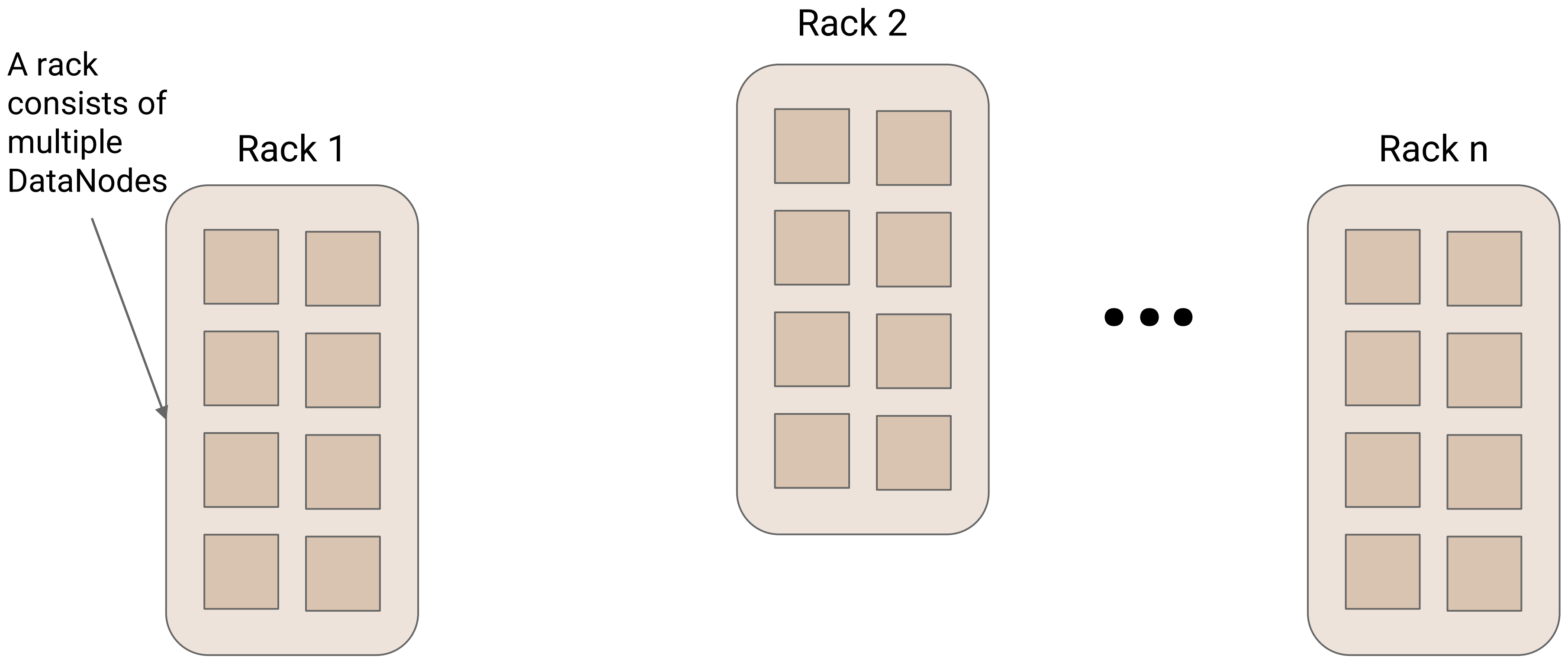
Replica Placement

- Replica placement is critical to reliability and performance
- Optimizing replica placement is what distinguishes HDFS from other distributed file systems
- First, what does a typical cluster look like…

Replica Placement



Replica Placement



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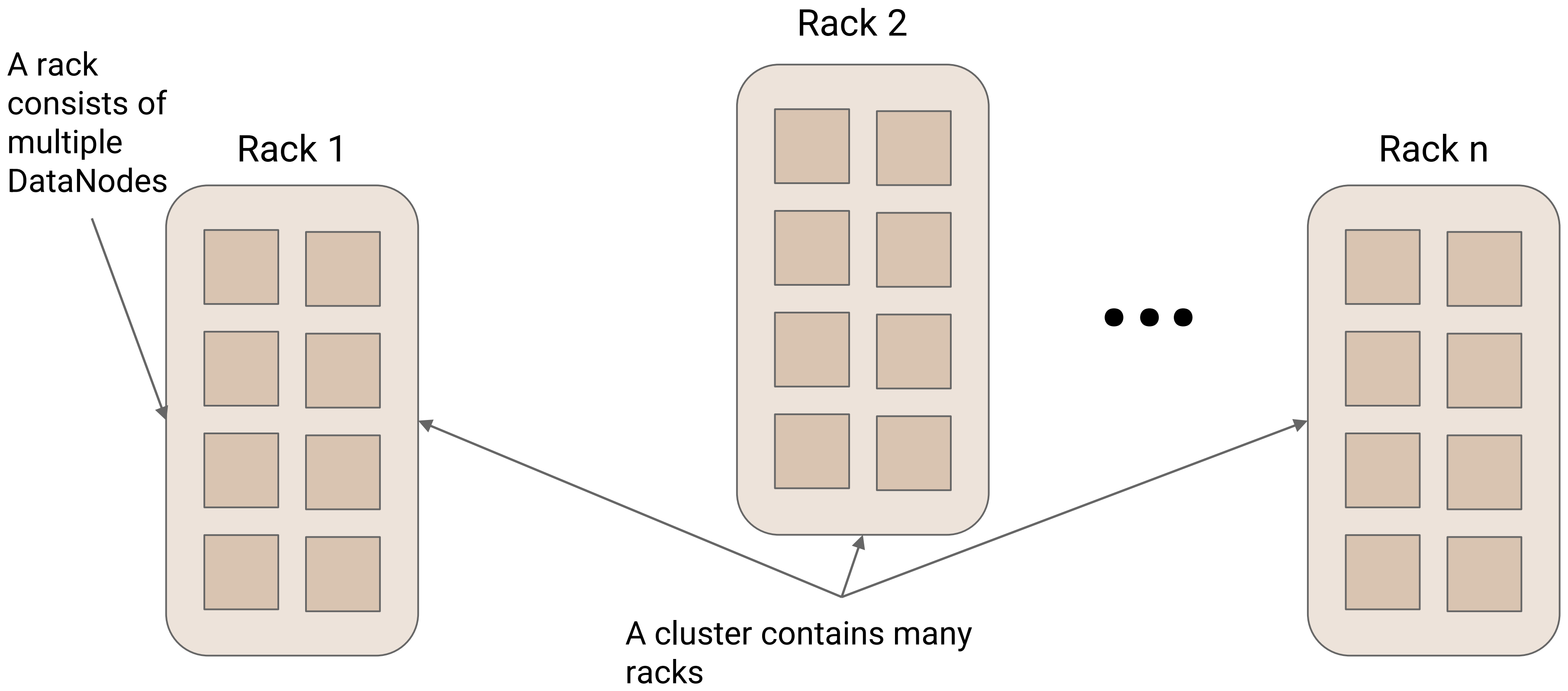

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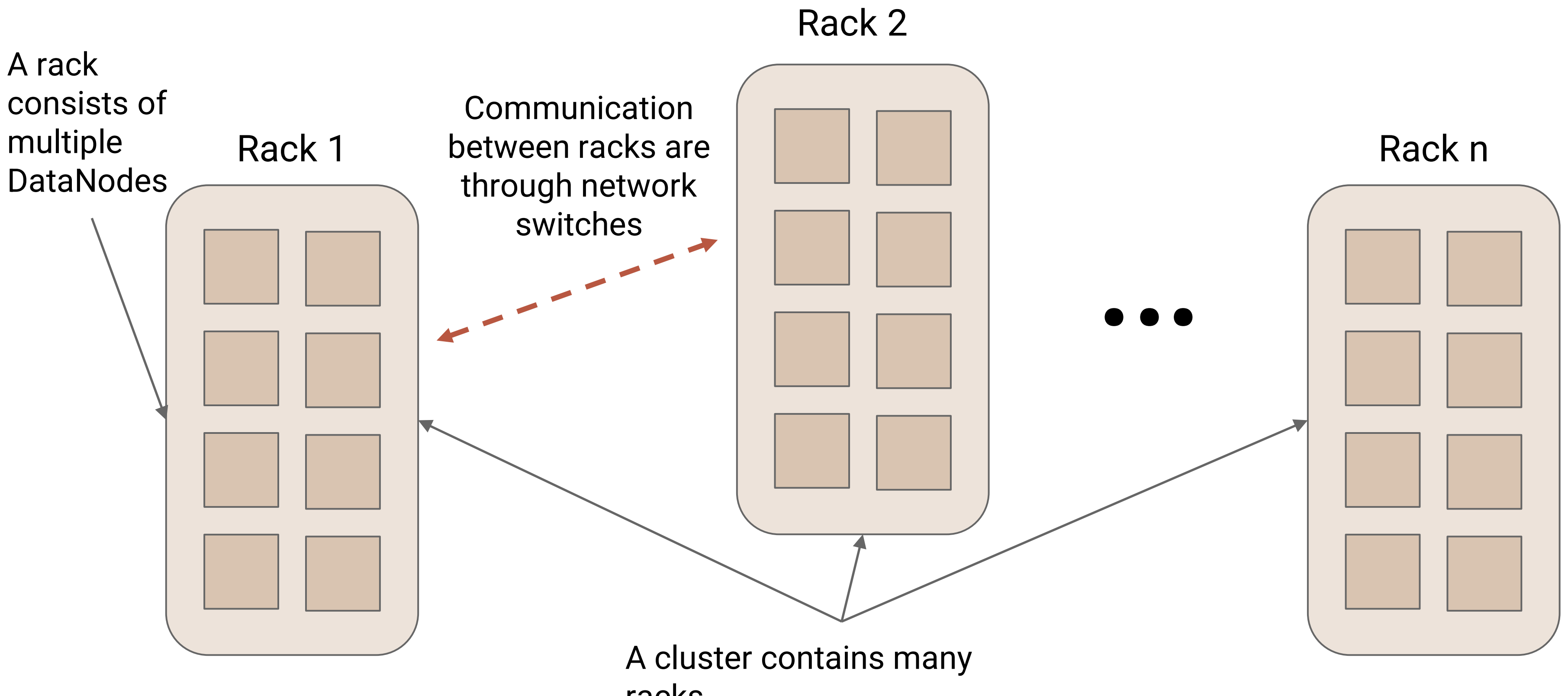
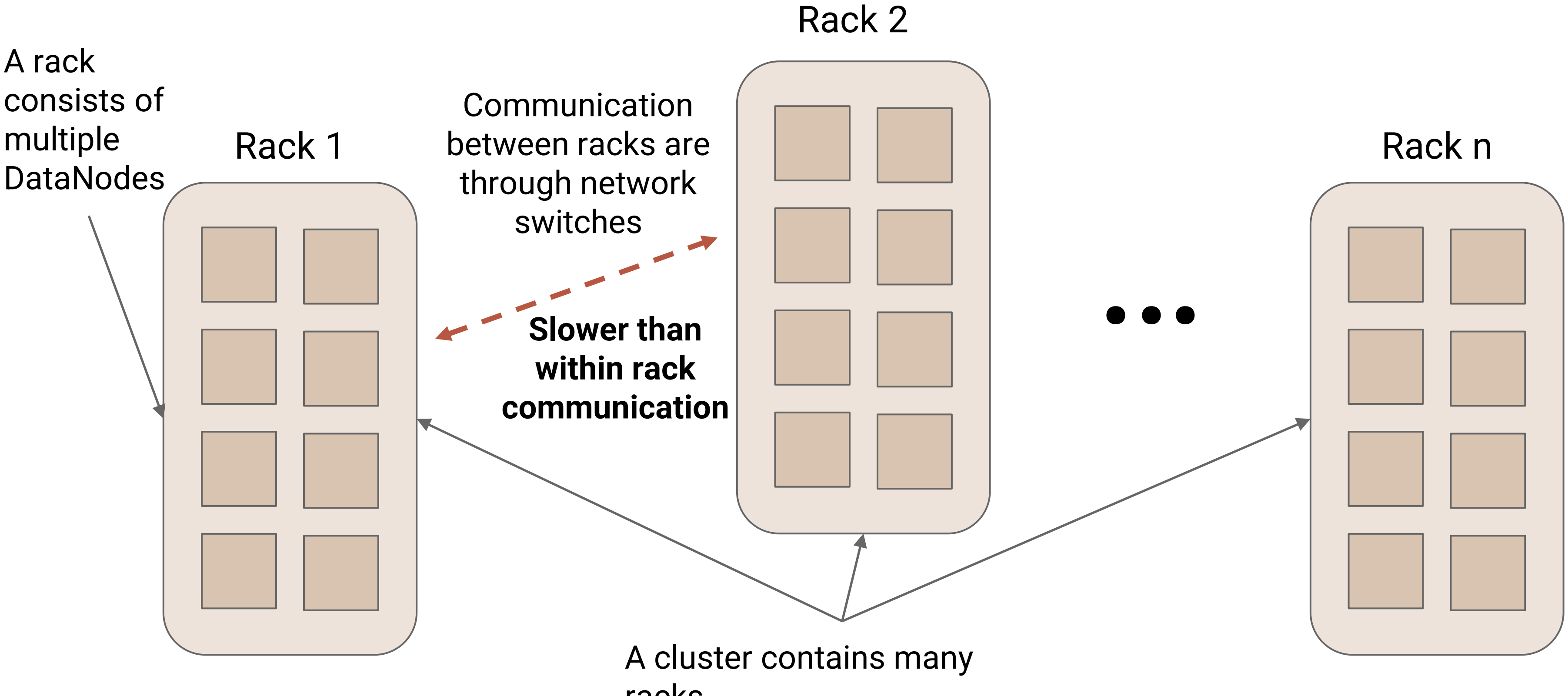
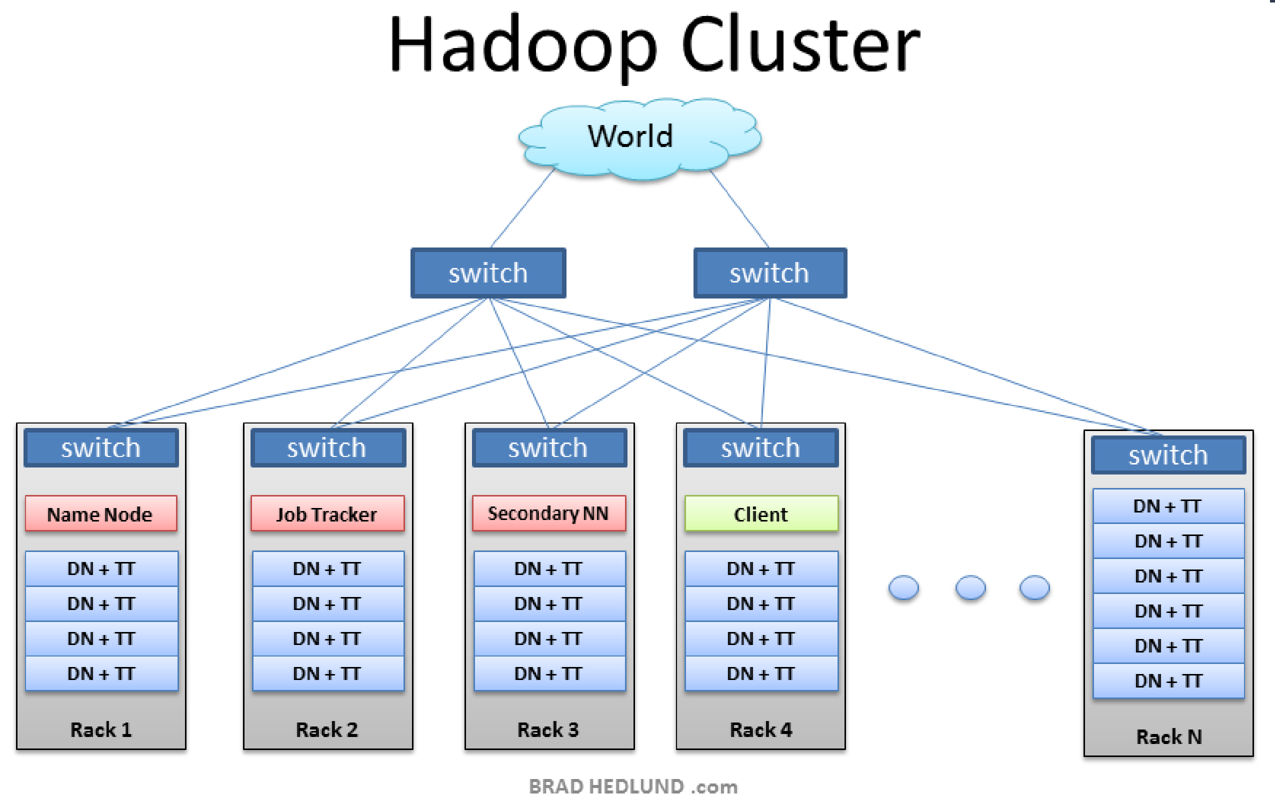


Replica Placement



From Brad Hedlund: a very nice picture



Replica Placement

Rack Aware Placement

- Goal: Improve reliability, availability, and network bandwidth utilization
- NameNode determines the rack id for each DataNode
- Replicas are typically placed on unique racks
  - Simple scheme but non-optimal
  - Writes are expensive
  - Typical replication factor is 3

Replica Placement

Rack Aware Placement

- Goal: Improve reliability, availability, and network bandwidth utilization
- NameNode determines the rack id for each DataNode
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  - Simple scheme but non-optimal
  - Writes are expensive
  - Typical replication factor is 3
- **Improvement:** Place one on a node in the local rack, one on a node in a remote rack, and another on a different node in that same remote rack.
- For a file this means ⅓ of the replicas on one node, ⅔ on one rack, and the other ⅓ distributed across all other racks.

Replica Selection

- When a client attempts to perform a read, HDFS tries to minimize bandwidth consumption and latency.
  - If there is a replica on the reader's node, then that is preferred
  - Otherwise try for the same rack
  - An HDFS cluster may span multiple data centers, a replica in the local data center is preferred over a remote data center

Startup (Safemode)

- On initial startup of a NameNode, the system enters a safe mode
  - During safe mode no replication occurs
- Each DataNode checks in with a heartbeat and a BlockReport
- Each Block in the BlockReport has a minimum number of replicas to be considered "safely replicated"
- The NameNode waits for a certain percentage of blocks to reach the threshold for safely replicated before leaving safe mode and replicating any blocks which are lacking

File System MetaData

- The HDFS namespace is stored by NameNode
- There are two files associated with the metadata:
- **EditLog** : It contains all the recent modifications made to the files system MetaData
  - Creating a new file
  - Changing the replication factor
  - Deletion
- EditLog is stored in the NameNode's local file system
- **FSImage:** It contains the complete state of the file system namespace since the start of the namespace .Entire namespace including block mapping is stored in FsImage file in the NameNodes local filesystem.

DataNode

- A DataNode stores data in files in its local file system
- DataNode has no knowledge about the HDFS file system
- It stores each block in a separate file
- It does not create all files in the same directory
  - It uses heuristics to determine the optimal number of files per directory
- Upon starting, it generates a list of all blocks and send the report to the NameNode

Robustness

Possible Failures

- The primary objective of HDFS is to store data reliably in the presence of failures
- Three common failures that it must handle are:
  - DataNode failure
  - Network partition
  - NameNode failure

DataNode Failure and Heartbeat

- A crashed DataNode or a network partition can cause a subset of DataNodes to lose connectivity with the NameNode
- NameNode detects this by the absence of a heartbeat
    - NameNode marks these DataNodes, and does not send requests to them
    - Data registered to the failed DataNode is not available to the HDFS
    - Death of a DataNode may cause some blocks to require more replication

Re-Replication

- Sometimes Blocks in the system may fall below the required replication factor
- This can occur for a number of reasons
  - A DataNode has become unavailable
  - A replica may become corrupted
  - A hard disk on a DataNode may fail
  - The replication factor may have been increased

Data Integrity

- What if a block of data fetched from a DataNode arrives corrupted
    - Fault in a storage device
    - Network faults
    - Buggy software
- An HDFS client creates a checksum for every block of its file and stores it in the HDFS namespace
- When the client retrieves the contents of a file it verifies that they match…if not it must retrieve the block from another replica

MetaData Disk Failure

- FsImage and EditLog are central data structures of HDFS
  - Corruption of these files can cause an entire HDFS instance to become non-functional.
- A NameNode can be configured to maintain multiple copies of these files
  - These copies are updated synchronously
  - MetaData is not data intensive
- The NameNode is a potential single point of failure
  - This currently requires manual intervention

Cluster Rebalancing

- HDFS architecture is compatible with data rebalancing schemes
- A scheme may more data from one DataNode to another if the free space on a DataNode is falling below a certain threshold
- A scheme may dynamically create and place additional replicas and rebalance other data if there is sudden high demand for a particular file
- These types of rebalancing are not yet implemented

Data Organization

Data Block

- HDFS support write-once-read-many with reads at streaming speeds.
- A typical block size is 64MB (or even 128 MB).
- A file is chopped into 64MB chunks and stored.

Staging

- A client request to create a file does not reach Namenode immediately.
- HDFS client caches the data into a temporary file. When the data reached a HDFS block size the client contacts the Namenode.
- Namenode inserts the filename into its hierarchy and allocates a data block for it.
- The Namenode responds to the client with the identity of the Datanode and the destination of the replicas (Datanodes) for the block.
- Then the client flushes it from its local memory.

Staging (Cont.)

- The client sends a message that the file is closed.
- Namenode proceeds to commit the file for creation operation into the persistent store.
- If the Namenode dies before file is closed, the file is lost.
- This client side caching is required to avoid network congestion; also it has precedence is AFS (Andrew file system).

API

FS Shell, Admin, and Browser Interface

- HDFS organizes its data in files and directories
- Command line interface called the FS shell
  - Syntax similar to bash and csh
  - ie: /bin/hadoop dfs -mkdir /foo
- There is also a DFSAdmin interface
- A browser can be used to view the namespace

Space Reclamation

- When a file is deleted, HDFS moves it to a trash directory for a configurable amount of time
- A client can request for the file to be recovered during this time
- After the specified time the file is deleted along with replicas, and all space is reclaimed
- This will also occur automatically if the replication factor is reduced