Assignment #1

BIG DATA

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Part A: Conceptual

1. Explain in your own words the roles of the following Hadoop components in this scenario:

a) NameNode:

Acts as the master of the Hadoop cluster.
Maintains metadata: file names, block IDs, locations, and replication details.
In this case, it manages metadata for 180 TB of census data split into blocks.

b) Data Node:

Stores actual data blocks (e.g., demographic text files, images, coordinates).
Sends heartbeat and block reports to the NameNode to indicate its status.

c) Secondary NameNode:

Does not replace the NameNode during failures.
Periodically merges the FsImage (snapshot of file system metadata) with edit logs to reduce the size of logs.
Helps keep memory usage of the NameNode within limits (critical since RAM is only 32GB)

d) Rack Awareness:

Ensures data is spread across multiple racks.
Improves fault tolerance and network bandwidth usage.
If a whole rack fails, data can still be retrieved from blocks on other racks.

e) Checkpointing:

Involves creating a new FsImage from edit logs.
Helps the system restart faster and minimizes metadata loss in case of NameNode failure.

2. List five key reasons why HDFS is preferred for such large-scale projects.

Scalability Can scale to handle petabytes of data.
Fault Tolerance Replicates data across nodes; survives node/rack failures.
High Throughput Optimized for large, sequential data reads (batch processing).
Cost-Efficiency Uses commodity hardware, reducing infrastructure cost.
Data Locality Moves computation to where the data resides, reducing latency.

Part B: Analytical Simulation & Numerical Problem Solving

Q1. HDFS Block Planning and Replication

- Demographic text files (100 TB)
- Household images (60 TB)
- Geo-coordinates (20 TB)

a) Number of blocks needed (before replication)

Conversion:
1 TB = 1,024 GB = 1,048,576 MB
Block Size = 256 MB
Demographic Text Files:
100 TB = 100 × 1,048,576 MB = 104,857,600 MB
Number of blocks = 104,857,600 ÷ 256 = 409,600 blocks
Household Images:
60 TB = 62,914,560 MB
Blocks = 62,914,560 ÷ 256 = 245,760 blocks
Geo-coordinates:
20 TB = 20 × 1,048,576 = 20,971,520 MB
Blocks = 20,971,520 ÷ 256 = 81,920 blocks

Total Blocks Before Replication = 409,600 + 245,760 + 81,920 = 737,280 blocks

Dataset	Size (TB)	Convert to MB	Blocks Needed
Demographic	100TB	102,400,00MB	102,400,000/256 = 40,000
Household Images	60TB	61,440,000MB	61,440,000/256= 240,000
Geo-coordinates	20TB	20,480,000MB	20,480,000/256 = 80,000

b) Determine the total number of blocks after replication.

Replication Factor = 3

Total blocks = 737,280 × 3 = 2,211,840 blocks

c) Total Storage Required (With Replication)

Total raw data = 180 TB

With replication = 180 × 3 = 540 TB

Q2. NameNode Metadata Analysis

Given:

Metadata per block = 250 bytes

NameNode RAM = 32 GB = 32 × 1024 MB = 32,768 MB

a) Calculate the memory required by the NameNode to store metadata for all blocks before replication.

737,280 blocks × 250 bytes = 184,320,000 bytes

= 184,320,000 ÷ (1024×1024) **≈ 175.75 MB**

b) Recalculate the memory requirement after replication.

2,211,840 blocks × 250 bytes = 552,960,000 bytes

= 552,960,000 ÷ (1024×1024) **≈ 527.25 MB**

c) Can the current NameNode (32 GB RAM) handle the metadata? If not, suggest a solution.

Required = ~527 MB

Available = 32,768 MB

Yes, the NameNode can easily handle this metadata.

Q3: Cluster Size Planning

Given:

Each DataNode = 4 TB usable

Total required storage = 540 TB (including replication)

a) How many DataNodes are needed to store the entire dataset with replication?

540 TB ÷ 4 TB = 135 DataNodes

b) How many additional DataNodes would be required to tolerate 1 node failure and still meet replication requirements?

Let N be the number of nodes.

To survive 1 failure, $(N - 1) \times 4 \geq 540$

$(N - 1) \times 4 \geq 540 \rightarrow N - 1 \geq 135 \rightarrow N \geq 136$

So, we need at least 136 nodes, but to be safe, 137 nodes

Extra Nodes = 2

c) If 120 TB of IoT data is added (with replication):

Total = 120 × 3 = 360 TB

Additional nodes = 360 ÷ 4 = 90 more DataNodes

Q4: Advanced Scenario Simulation

Given:

5% of DataNodes go offline

Minimum nodes = 135

Replication factor temporarily reduced to 2

a) If you had the minimum number of nodes from Q3, how much data becomes under-replicated?

5% of 135 = 6.75 ≈ 7 nodes offline

Data in those nodes = 7 × 4 = 28 TB

With RF reduced from 3 → 2, data now covered = 180 TB × 2 = 360 TB

Previously = 540 TB

Under-replicated Data = 540 - 360 = 180 TB

b) What strategy will Hadoop follow to restore replication once the nodes are back online?

Heartbeat recovery – Nodes return online and notify NameNode.

Under-replicated blocks identified.

Replication process resumes automatically to meet factor = 3.

Blocks with only 1 replica prioritized.

Replication spread evenly to avoid network bottlenecks.

c) If this outage happens during a MapReduce job that depends on blocks from failed nodes, what challenges will occur, and how does Hadoop mitigate them?

Challenges:

Mapper may fail if its data block is unavailable.

Job execution slows or fails.

Reduced data locality and parallelism.

Hadoop's Mitigation:

Speculative execution: launches duplicate tasks on other nodes.

Task Tracker reschedules failed tasks automatically.

Rack awareness helps find alternate replicas quickly.

Job continues with minimal disruption.