Google File System

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What is the Problem?

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- Crawl the whole web.
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- Process users' searches on one big CPU.

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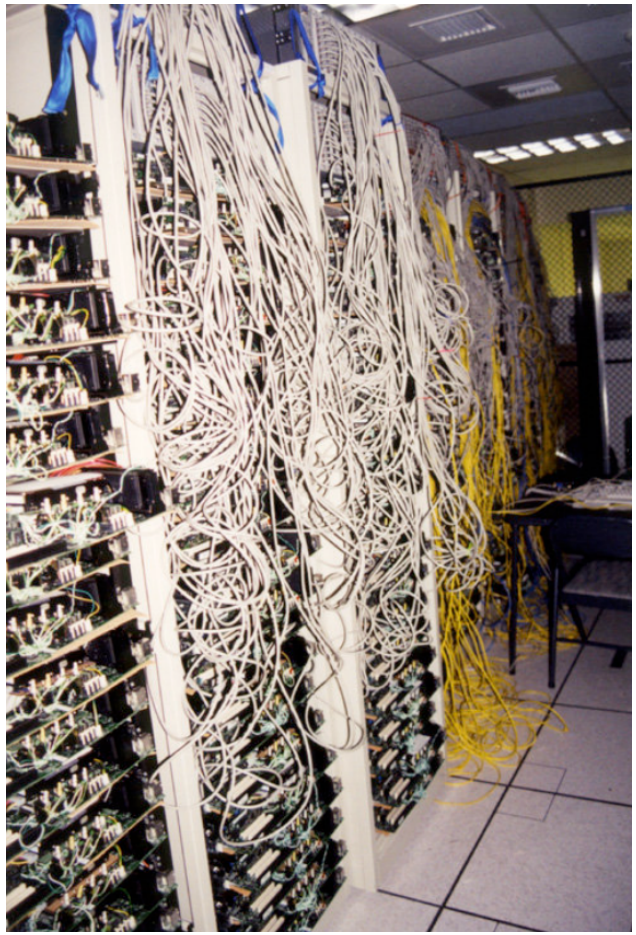
- Crawl the whole web.
- Store it all on one big disk.
- Process users' searches on one big CPU.
- Does not scale.

Motivation and Assumptions (1/3)

- Lots of cheap PCs, each with disk and CPU.
  - How to share data among PCs?

Motivation and Assumptions (2/3)

- 100s to 1000s of PCs in cluster.
  - Failure of each PC.
  - Monitoring, fault tolerance, auto-recovery essential.



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- Append to files rather than overwrite.

Reminder

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- Controls how data is stored in and retrieved from disk.

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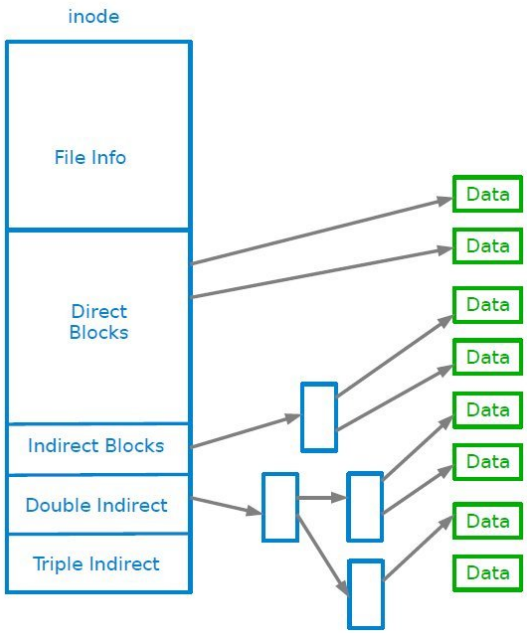
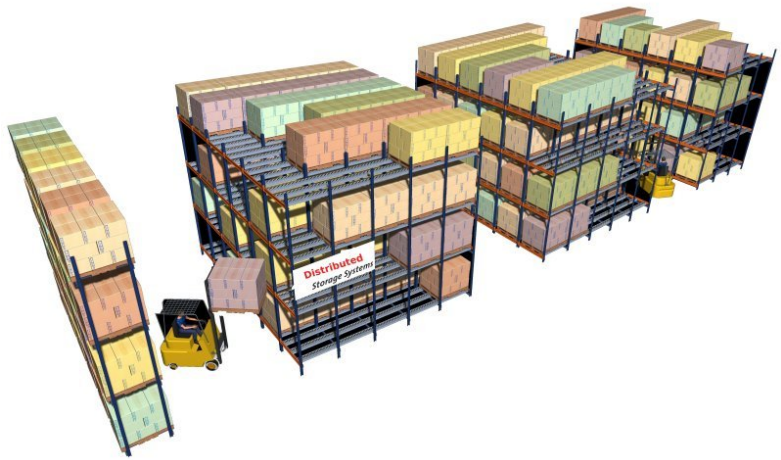


Distributed Filesystems

- When data outgrows the storage capacity of a single machine: partition it across a number of separate machines.
- Distributed filesystems: manage the storage across a network of machines.



Google File System (GFS)

GFS

- Appears as a single disk
- Runs on top of a native filesystem.
- Fault tolerant: can handle disk crashes, machine crashes, ...
- Hadoop Distributed File System (HDFS) is an open source Java product similar to GFS.

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- Storing large files
  - Terabytes, Petabytes, etc...
  - 100MB or more per file.

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- Streaming data access
  - Data is written once and read many times.
  - Optimized for batch reads rather than random reads.
- Cheap commodity hardware
  - No need for super-computers, use less reliable commodity hardware.

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- Low-latency reads
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- Multiple writers
  - Single writer per file.
  - Writes only at the end of file, no-support for arbitrary offset.

Files and Chunks

- Files are split into chunks.
- Chunks
  - Single unit of storage: a contiguous piece of information on a disk.
  - Transparent to user.
  - Chunks are traditionally either 64MB or 128MB: default is 64MB.

GFS Architecture

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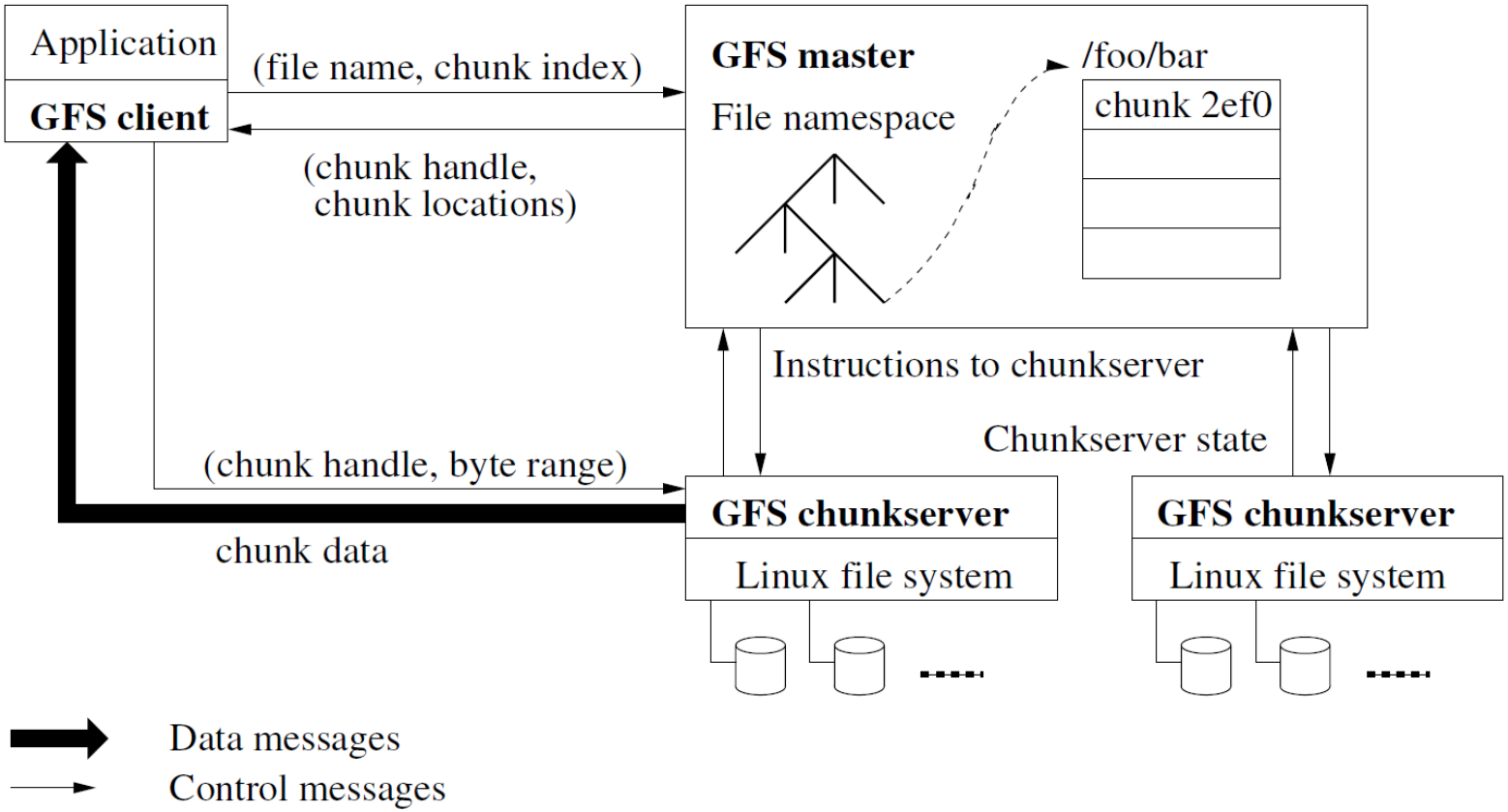
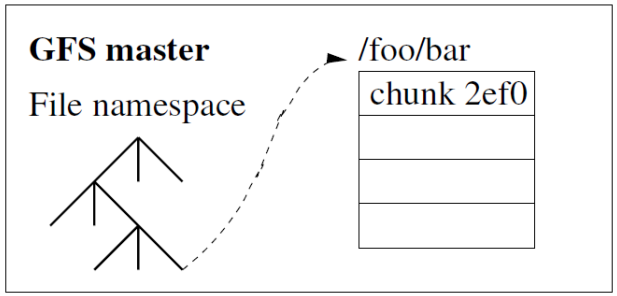


- Main components:
  - GFS master
  - GFS chunk server
  - GFS client

GFS Master

- Manages file namespace operations.



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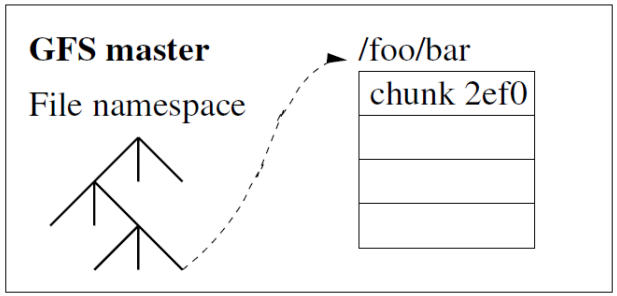
- Manages file metadata (holds all metadata in memory).
  - Access control information
  - Mapping from files to chunks
  - Locations of chunks



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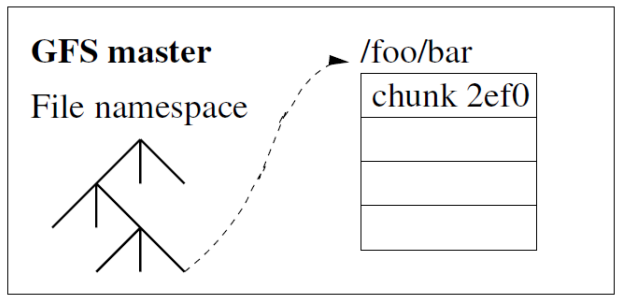
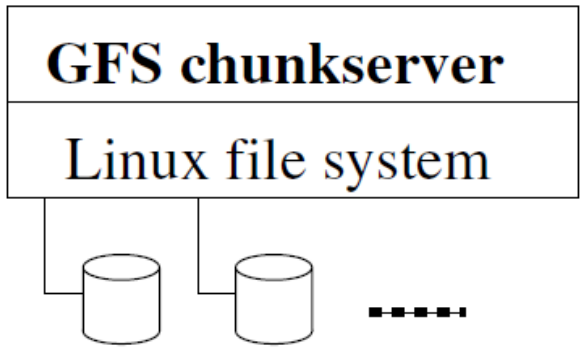
  - Locations of chunks
- Manages chunks in chunk servers.
  - Creation/deletion
  - Placement
  - Load balancing
  - Maintains replication
  - Garbage collection



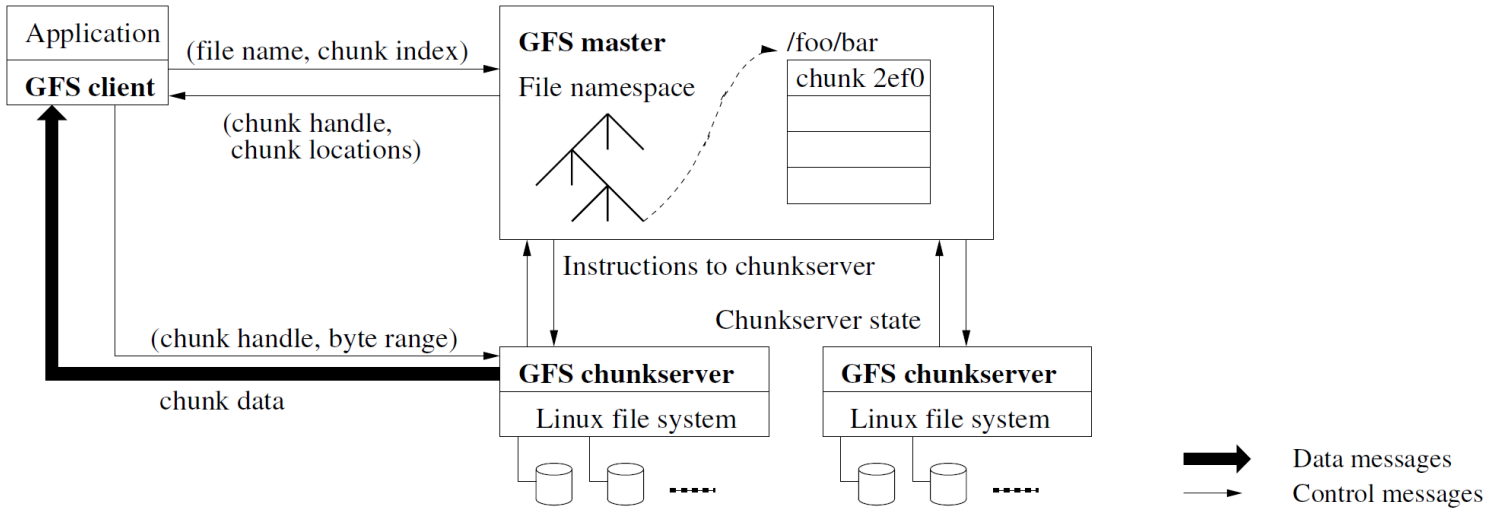
GFS Chunk Server

- Manage chunks.
- Tells master what chunks it has.
- Store chunks as files.
- Maintain data consistency of chunks.



GFS Client

- Issues control (metadata) requests to master server.
- Issues data requests directly to chunk servers.
- Caches metadata.
- Does not cache data.



The Master Operations

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- Namespace management and locking
- Replica placement
- Creating, re-replicating and re-balancing replicas
- Garbage collection
- Stale replica detection

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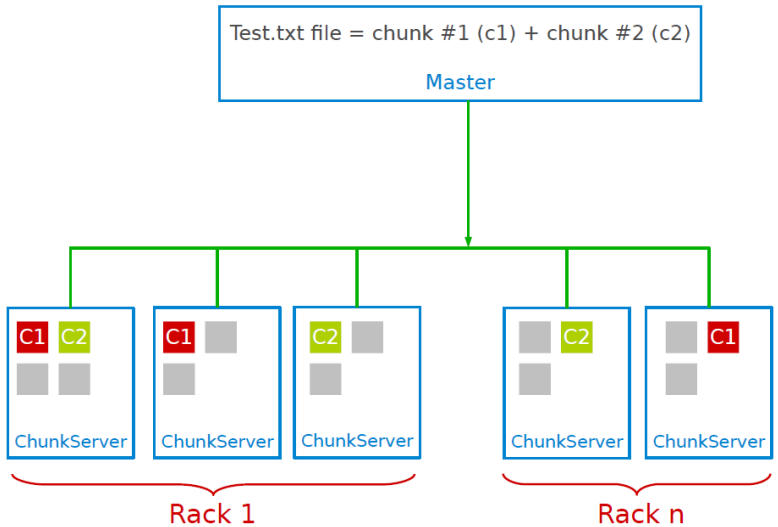
- Each master operation acquires a set of locks before it runs.
- Allowed concurrent mutations in the same directory.
- Read lock on directory prevents its deletion, renaming or snapshot.

Replica Placement

- Maximize data reliability, availability and bandwidth utilization.
- Replicas spread across machines and racks, for example:
  - 1st replica on the local rack.
  - 2nd replica on the local rack but different machine.
  - 3rd replica on the different rack.
- The master determines replica placement.



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- Creation
  - Place new replicas on chunk servers with below-average disk usage.
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  - Limit number of recent creations on each chunk servers.
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  - When number of available replicas falls below a user-specified goal.
- Rebalancing
  - Periodically, for better disk utilization and load balancing.
  - Distribution of replicas is analyzed.

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- File renamed to a hidden name with deletion timestamp.
- Master regularly deletes files older than 3 days (configurable).
- Until then, hidden file can be read and undeleted.
- When a hidden file is removed, its in-memory metadata is erased.

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- Need to distinguish between up-to-date and stale replicas.
- Chunk version number:
  - Increased when master grants new lease on the chunk.
  - Not increased if replica is unavailable.
- Stale replicas deleted by master in regular garbage collection.

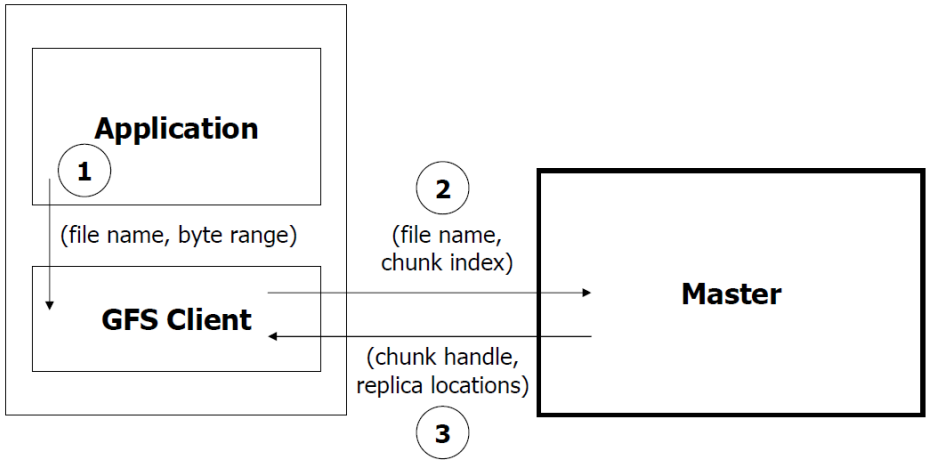
System Interactions

GFS API

- Not POSIX compliant
  - Supports only popular FS operations, and semantics are different.
- API:
  - Read operation: read
  - Update operations: write and append
  - Delete operation

Read Operation (1/2)

- 1. Application originates the read request.



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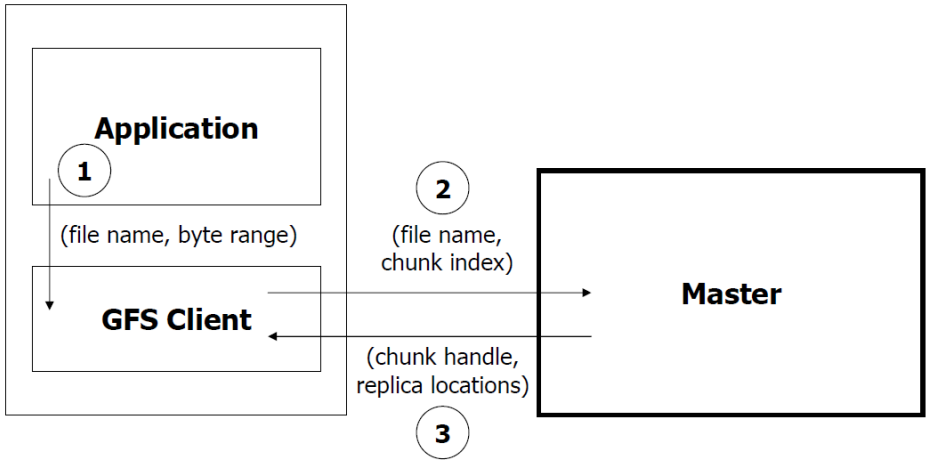

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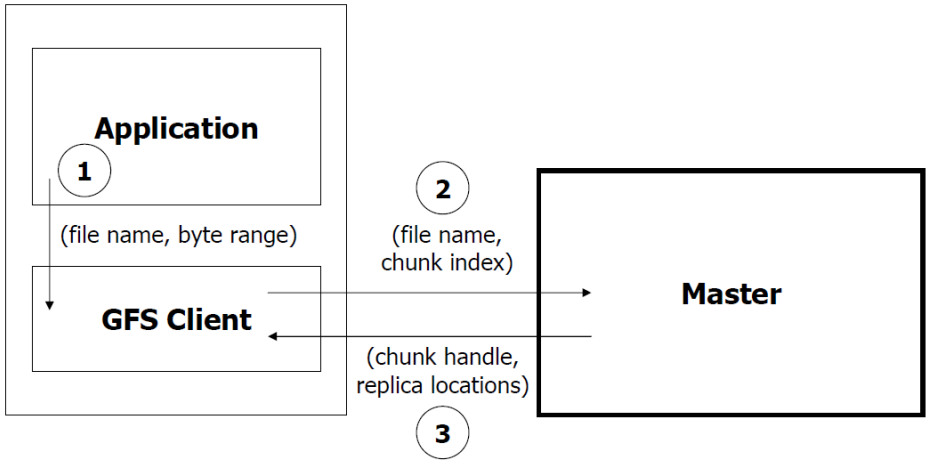

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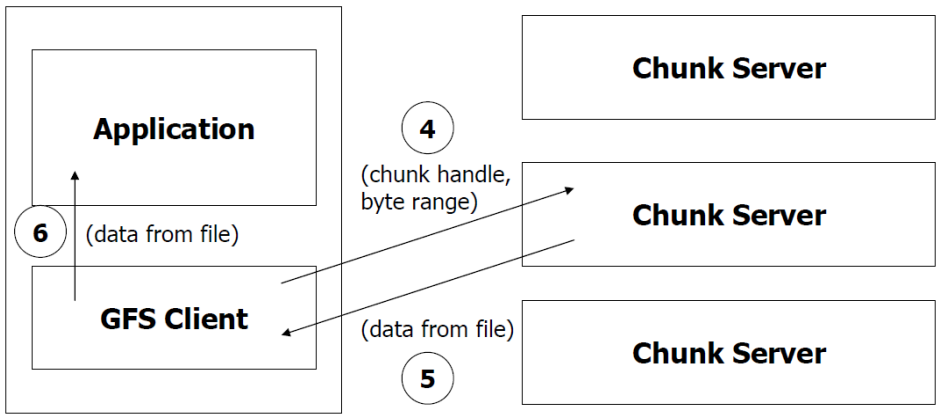
- 4. The client picks a location and sends the request.



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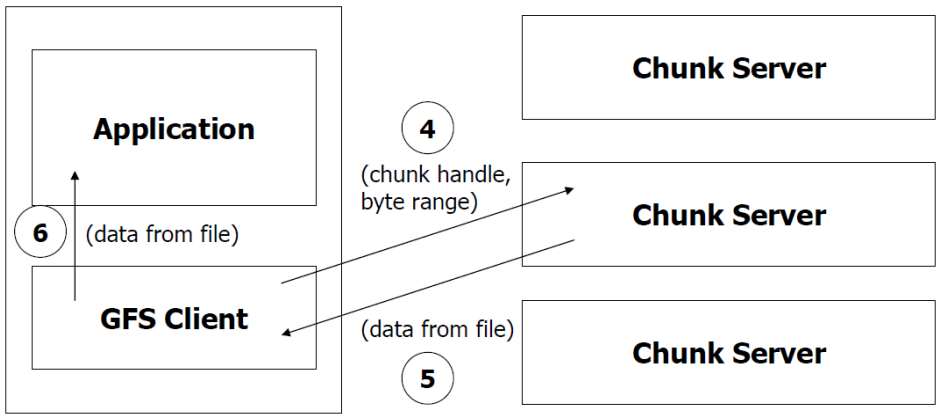
- 4. The client picks a location and sends the request.
- 5. The chunk server sends requested data to the client.



Read Operation (2/2)

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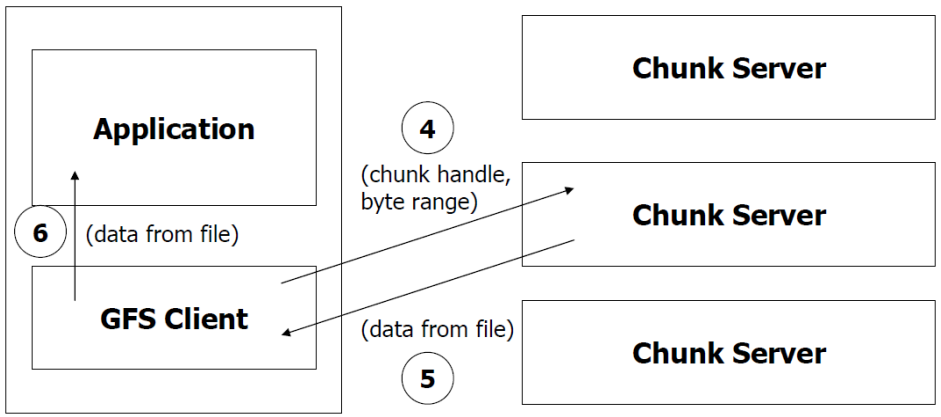
- 6. The client forwards the data to the application.



Update Order (1/2)

- Update (mutation): an operation that changes the contents or metadata of a chunk.

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- For consistency, updates to each chunk must be ordered in the same way at the different chunk replicas.
- Consistency means that replicas will end up with the same version of the data and not diverge.

Update Order (2/2)

- For this reason, for each chunk, one replica is designated as the primary.
- The other replicas are designated as secondaries
- Primary defines the update order.
- All secondaries follows this order.

Primary Leases (1/2)

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- For correctness, at any time, there needs to be one single primary for each chunk.
- At any time, at most one server is primary for each chunk.
- Master selects a chunk-server and grants it lease for a chunk.

Primary Leases (2/2)

- The chunk-server holds the lease for a period T after it gets it, and behaves as primary during this period.

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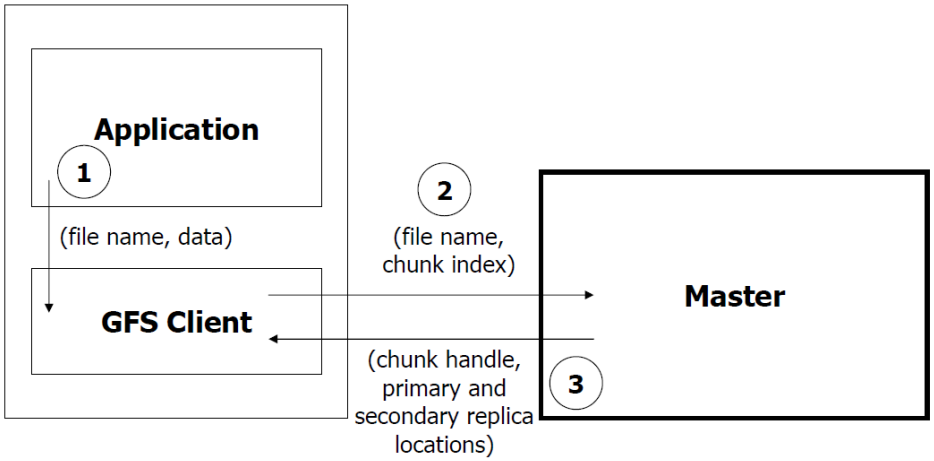
- The chunk-server holds the lease for a period T after it gets it, and behaves as primary during this period.
- The chunk-server can refresh the lease endlessly, but if the chunk-server can not successfully refresh lease from master, he stops being a primary.
- If master does not hear from primary chunk-server for a period, he gives the lease to someone else.

Write Operation (1/3)

- 1. Application originates the request.



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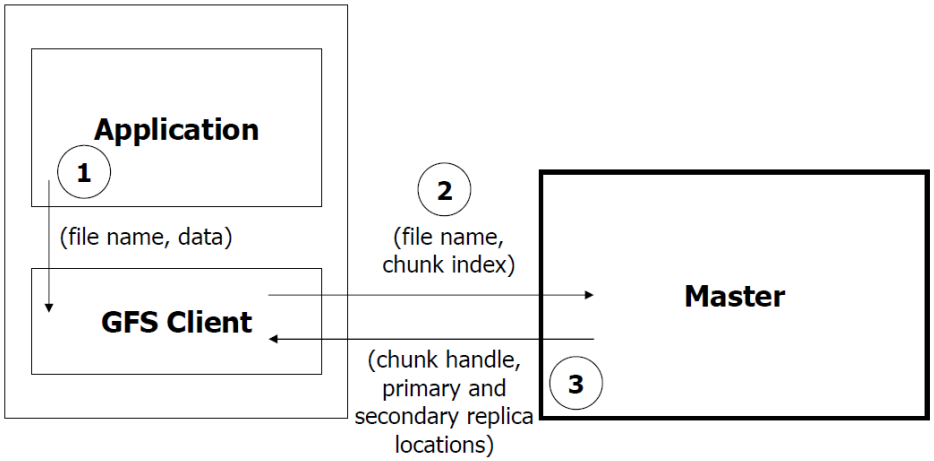

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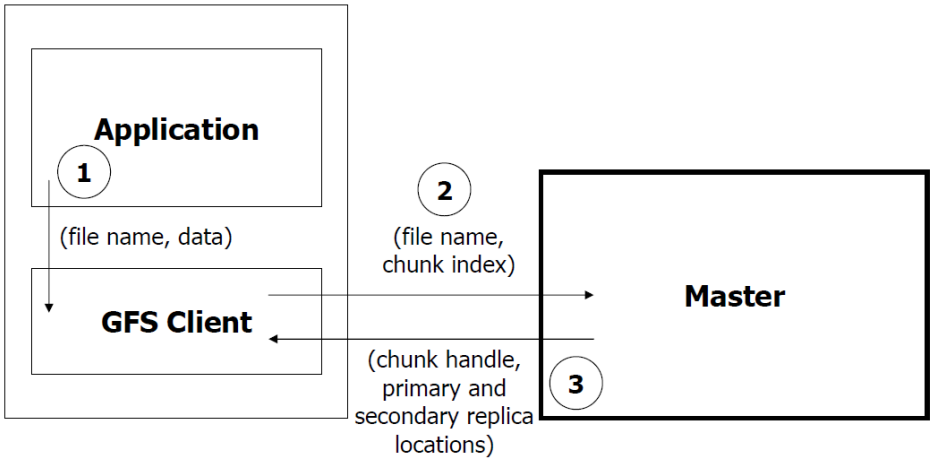
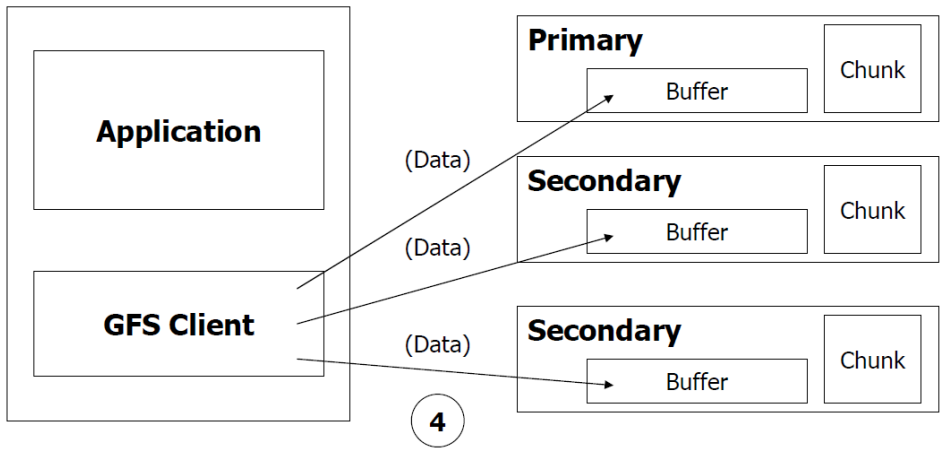


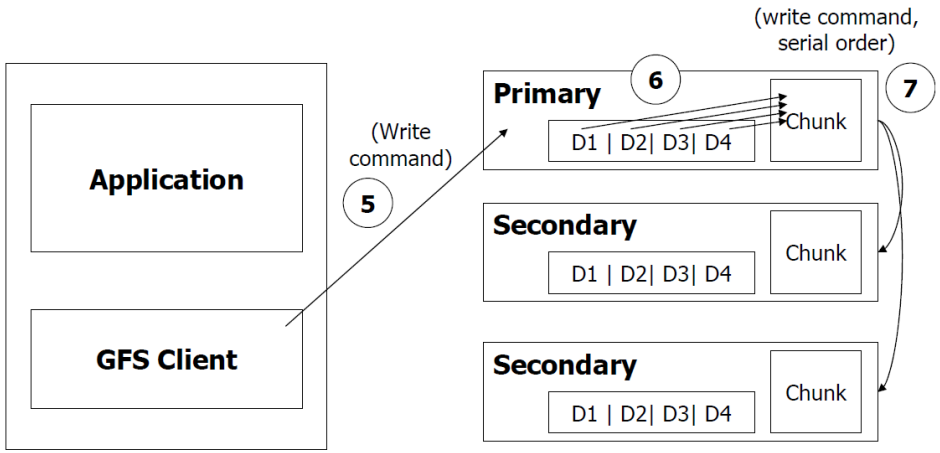
Write Operation (2/3)

- 4. The client pushes write data to all locations. Data is stored in chunk-server's internal buffers.



Write Operation (3/3)

- 5. The client sends write command to the primary.



Write Operation (3/3)

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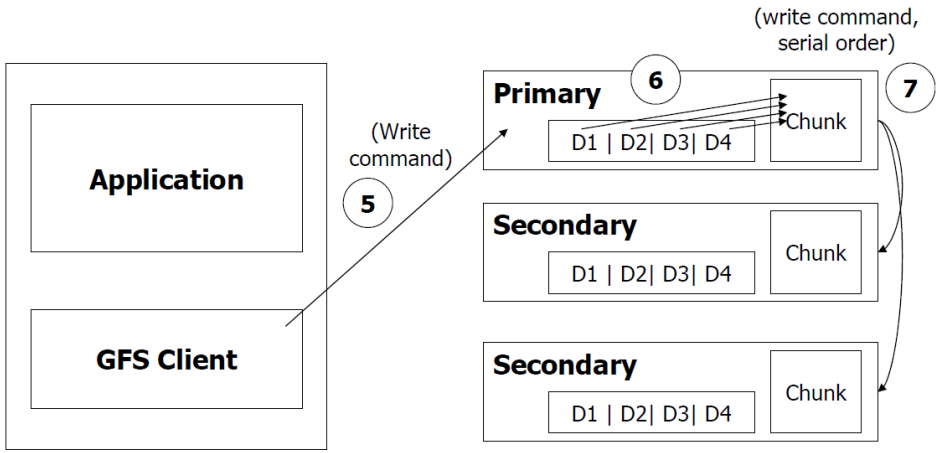
- 6. The primary determines serial order for data instances in its buffer and writes the instances in that order to the chunk.



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- 5. The client sends write command to the primary.
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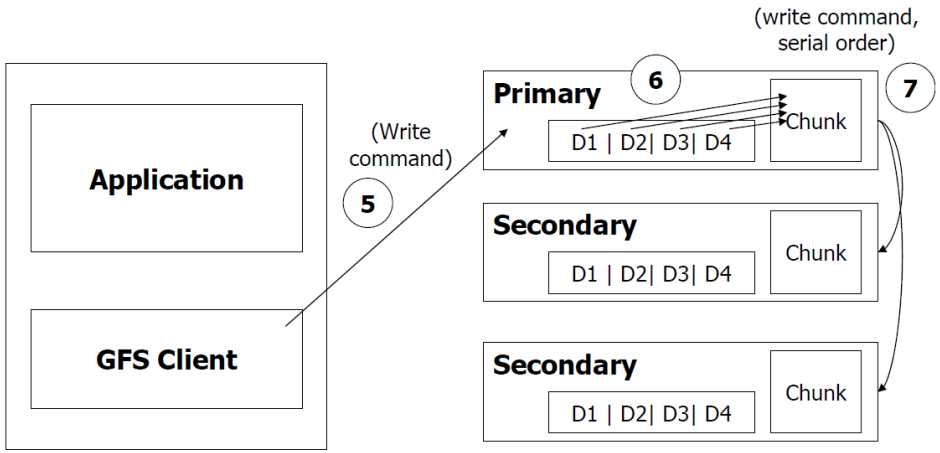
- 7. The primary sends the serial order to the secondaries and tells them to perform the write.



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- It also waits until a write finishes at the other replicas before it replies.
- Therefore:
  - We will have identical replicas.
  - But, file region may end up containing mingled fragments from different clients: e.g., writes to different chunks may be ordered differently by their different primary chunk-servers
  - Thus, writes are consistent but undefined state in GFS.

Record Append Operation (1/3)

- Operations that append data to a file.
  - Same as write, but no offset (GFS choses the offset)
- Important operation at Google
  - Merging results from multiple machines in one file.
  - Using file as producer-consumer queue.

Record Append Operation (2/3)

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  - And informs the client.
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- 7. If record fits, then the primary:
  - Appends the record,
  - Tells secondaries to do the same,
  - Receives responses from secondaries,
  - And sends final response to the client

Delete Operation

- Meta data operation.
- Renames file to special name.
- After certain time, deletes the actual chunks.
- Supports undelete for limited time.
- Actual lazy garbage collection.

Fault Tolerance

Fault Tolerance for Chunks

- Chunks replication (re-replication and re-balancing)
- Data integrity
  - Checksum for each chunk divided into 64KB blocks.
  - Checksum is checked every time an application reads the data.

Fault Tolerance for Chunk Server

- All chunks are versioned.
- Version number updated when a new lease is granted.
- Chunks with old versions are not served and are deleted.

Fault Tolerance for Master

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- Shadow (not mirror) master provides only read-only access to file system when primary master is down.

High Availability

- Fast recovery
  - Master and chunk-servers have to restore their state and start in seconds no matter how they terminated.

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- Fast recovery
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- Heartbeat messages:
  - Checking liveness of chunk-servers
  - Piggybacking garbage collection commands
  - Lease renewal


hadoop
HDFS

HDFS

- Sub-project of Apache Hadoop project
- Inspired by the Google File System
- Namenode: master
- Datanode: chunk server
- Block: chunk

Summary

Summary

- Google File System (GFS)
- Files and chunks
- GFS architecture: master, chunk servers, client
- GFS interactions: read and update (write and update record)
- Master operations: metadata management, replica placement and garbage collection

Questions?