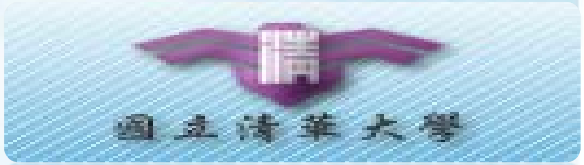
Cloud Programming: Lecture8 – Storage: GFS & Big Table

National Tsing-Hua University

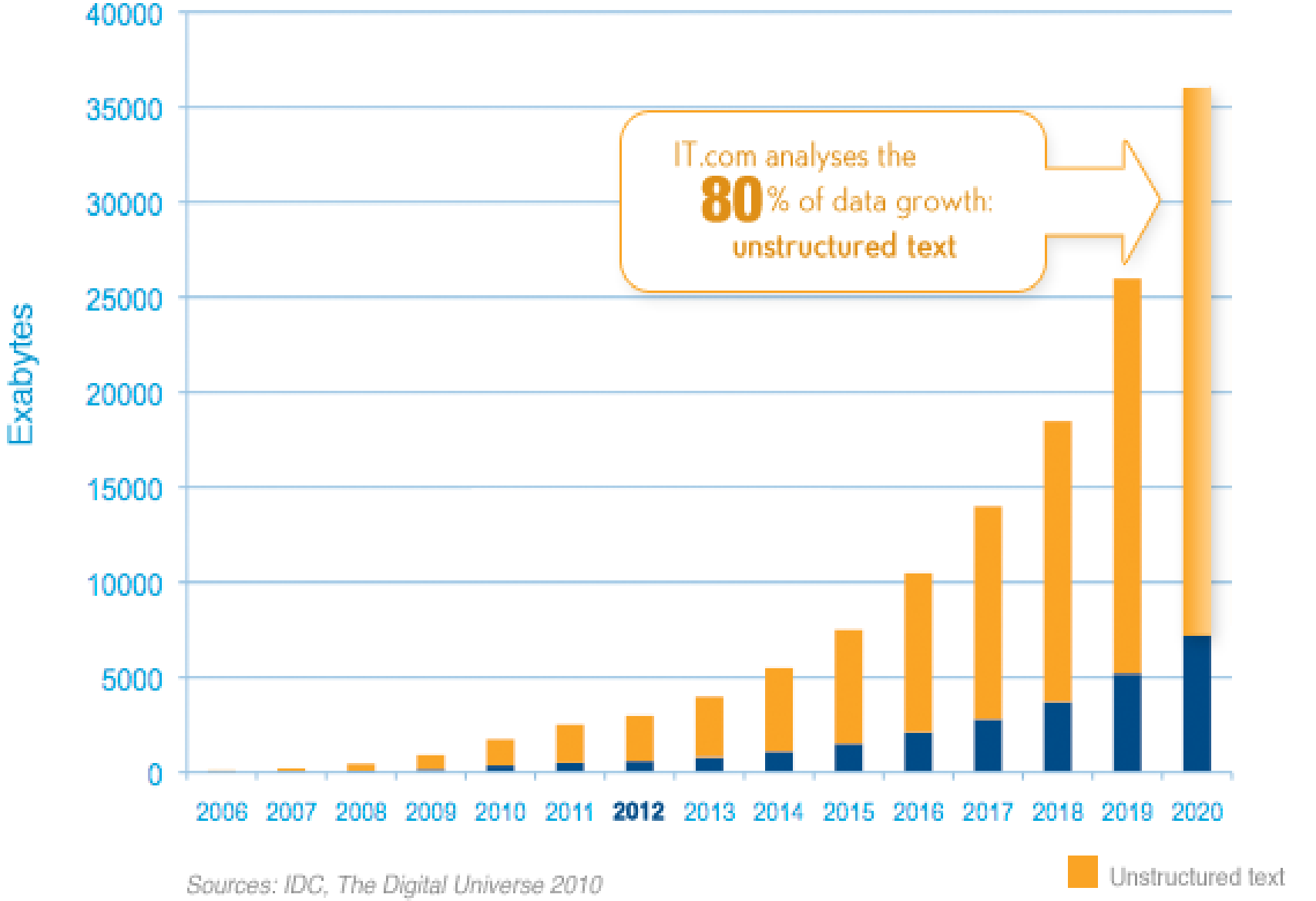
2016, Spring Semester



Outline

- Background
  - Unstructured data
  - File system
  - DBMS
- Google File System (HDFS)
- BigTable (HBase)

Worldwide Corporate Data Growth



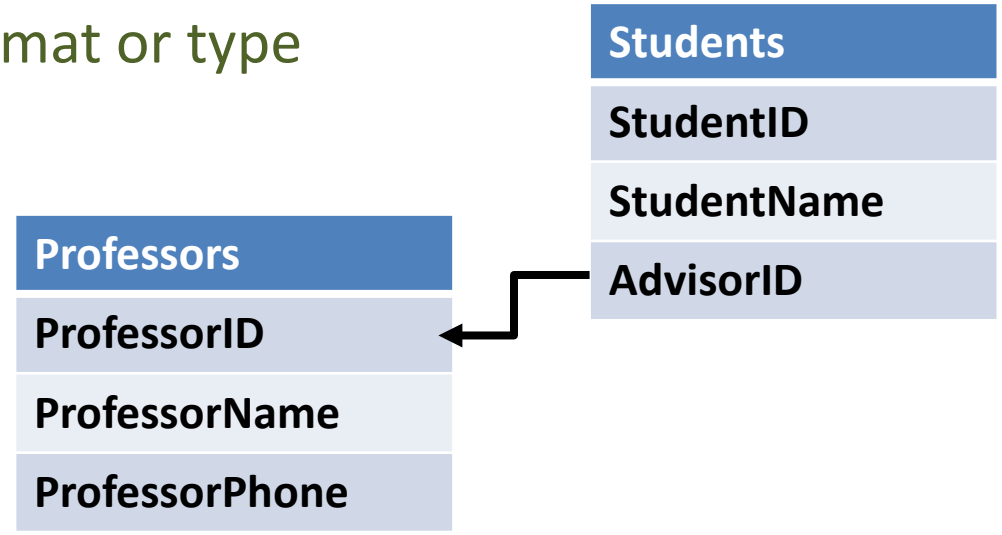
Sources: IDC, The Digital Universe 2010

Unstructured Data

- Data can be of any type
  - Not necessarily following any format or sequence
  - Not follow any rules, so is not predictable
- Two Categories
  - Bitmap Objects
    - Inherently non-language based, such as image, video or audio files
  - Textual Objects
    - Based on a written or printed language, such as Microsoft Word documents, e-mails or Microsoft Excel spreadsheets

Structured Data

- Data is organized in semantic chunks (entities)
- Entities in the same group have the same descriptions (attributes)
- Entities are grouped together (relations or classes)
- Descriptions for **ALL** entities in a group (**schema**)
  - The same defined format or type
  - A predefined length
  - The same ordering



Semi-Structured Data

- Organized in semantic entities
- Similar entities are grouped together
- Entities in same group may not have same attributes
  - Order of attributes not necessarily important
  - Not all attributes may be required
  - Size of same attributes in a group may different
  - Type of same attributes in a group may different

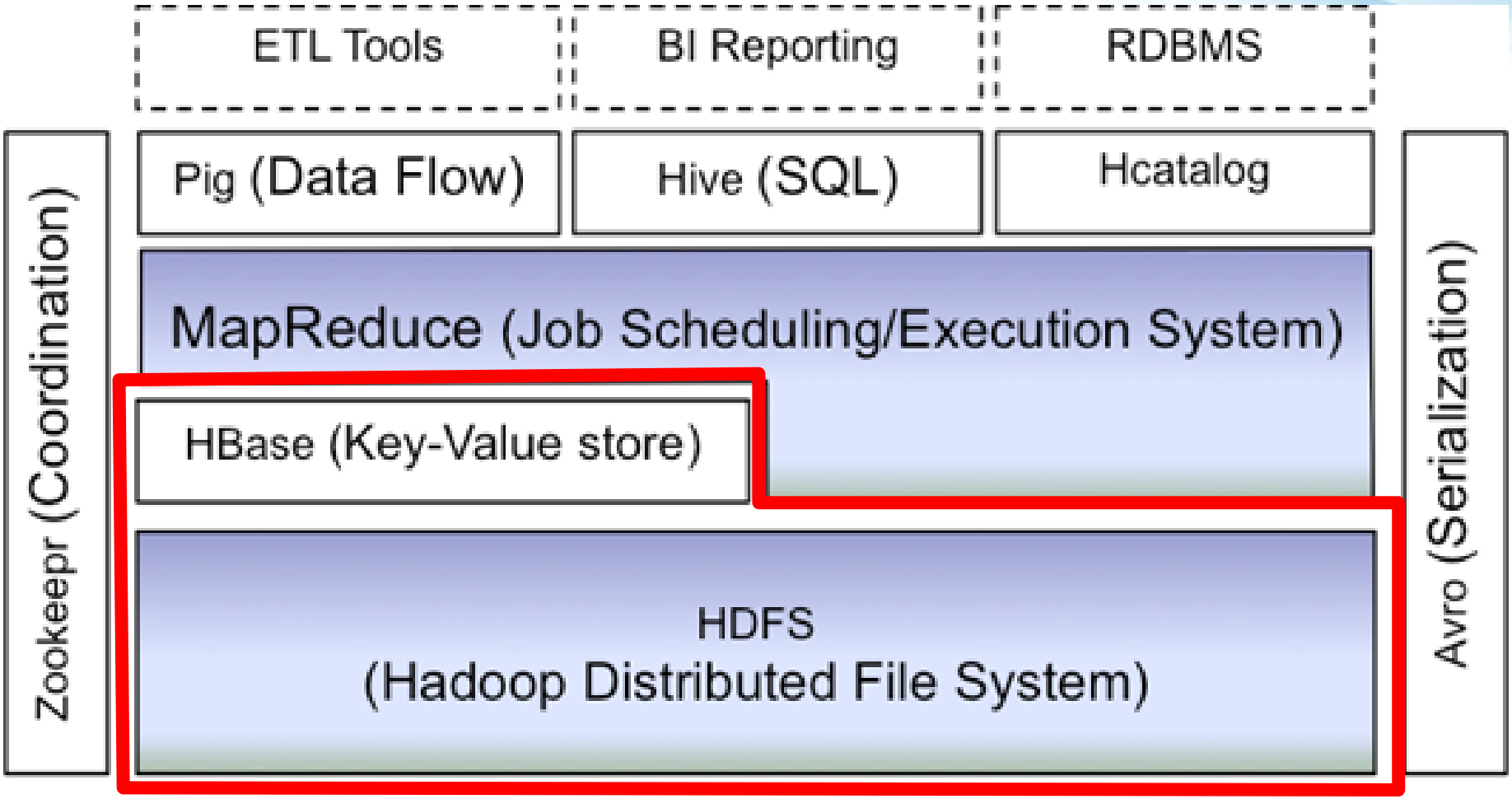
Example of Semi-Structured Data

- Name: Computing Cloud
- Phone_home: 035715131

- Name: TA Cloud
- Phone_cell: 0938383838
- Email: cloudTA@gmail.com

- Name: Student Cloud
- Email: hiCloud@hotmail.com

Hadoop Data Processing Platform



File System Overview

- Physically, a file is a collection of disk blocks.
- Logically, a file is a unit of data on disks or other media.
- File system is a system that manages files
  - **Maps file names** and offsets to disk blocks
  - The set of valid paths form the "**namespace**" of the file system.
  - Manages file attributes, such as file size, date, types, owner, etc.
  - Manages volume properties, such free size etc.

FS Design Considerations

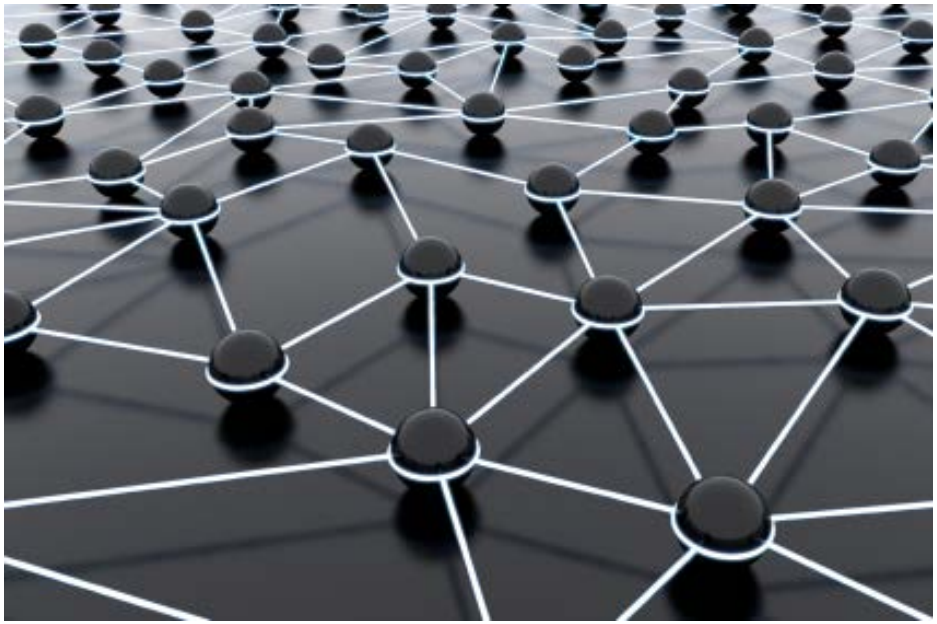
- Namespace: How to find a file?
  - Logical volume and physical mapping
- Consistency: What to do when more than one user reads/writes on the same file?
  - Caching and replication
- Security: Who can do what to a file?
  - Authentication/Access Control List (ACL)
- Reliability: How to insure data never lost?
  - Computer fails all the time due to various reasons
  - HW/SW failure, power outage, malicious users….

Local FS on Unix-like Systems

- Namespace
  - root directory "/", followed by directories and files.
- Consistency
  - "sequential consistency", newly written data are immediately visible to open reads
- Security
  - Account security: password
  - File permission: uid/gid, R/W/X mode of files
- Reliability
  - fsck: command to check & repair a linux FS
  - Journaling: Change is logged before it is committed
  - Snapshot: Copy-on-write, any changes create a new file

Distributed File Systems (DFS)

- Allows access to files from multiple hosts sharing via networks
  - File sharing
  - More space
  - Replication
  - Data Locality
- Major problems
  - Concurrency
  - Dropped connections (reliability)



Why File System Is Not Enough?

1. What we need is not only data, but also the relations among them.
   - The relations of data are also data
   - Also need data to describe data (metadata)
2. Common data operations are easier to perform using DataBase Management System (DBMS)
   - Search: retrieve data from the database
   - Update: update existing data
   - Insertion: insert new data
   - Deletion: remove existing data

DB & DBMS

- DataBase (DB)
  - A collection of **data** stored in a **standardized format** designed to be shared by multiple users
- DataBase Management System (DBMS)
  - **Software** that defines and operates a database
  - Provides storage, query, security, backup and other facilities

RDBMS

- Database management systems for **relational DB**
- Support **SQL language**
- Enforce **ACID property** for transaction
- Almost all databases today is RDBMS & support SQL
  - Oracle, SQL Server, MySQL, DB2
- Advantages
  - Simplicity, Robustness, Flexibility, Performance
- However,
  - To offer all of these, relational databases have to be incredibly complex internally

Relational Database

- First defined in 1970 by Edgar Codd, of IBM
- In a ***relational database*** (the most commonly used one), records are organized using tables
  - Columns for attributes; rows for records

Name	StudentID	Major	Grade	B-day	Gender	…
Tom	123456	CS	2yr	1-1-11	M	…
Mike	789012	EE	1yr	2-2-22	F	…
…	…	…	…			…

  - Primary key: one (or multiple) attributes that can be used to **uniquely** identify each row/entity in a table

Relations: EM Model

- The relations among objects are described by the ER model (Entity-Relation model)

- Relations are also organized as tables

CourseTaking

StudentID	CourseID	Grade	Status
123456	990110	-1	Normal
234567	990221	-1	Dropped

CourseTeaching

TeacherID	CourseID
888999	990110
777666	990221

SQL: Structured Query Language

- SQL: a special-purpose **programming language** designed for **managing data** in relational database
  - Data query: retrieve data
  - Data manipulation: add, update and delete data or tables
  - Data definition: define data schema
  - Data control: authorize data access permission
- 1974: first commercial languages for **relational DB**
- 1986: become a **standard** for ANSI & ISO

```
SELECT *
        FROM students
        WHERE ClassRank < 3
        ORDER BY StudentID;
```

Students
StudentID
StudentName
ClassRank

Update, Insertion, Deletion

- Suppose you want to add a course for next semester.

  INSERT INTO CourseTaking VALUES ('123456', '990110');

- A transaction is more than just an insertion like that.

  A sequence of operations must happen all together

  - Before insertion
    - The system needs to check if there is a schedule confliction
    - Also, the capacity of the class, the pre-requirement, …
  - After insertion
    - Suppose there is an attribute in Course, called "NoStudent", that records the total number of students taking this course.

  UPDATE Course SET NoStudent=ns+1 WHERE CourseID='990110';

Joint Query

- Select data from multiple tables needs join operation
  - Costly due to lookup & matching among tables

Name	Course
Tom	English
John	English
…	…

Student

Name	Schedule	Teacher
English	M3M4W3	Mark
Chinese	T3T4H3H4	Kevin
…	…	…

Course

Name	Schedule	Teacher
Tom	English	Mark

```
SELECT  Student.Name, Student.Course, Course.Teacher
FROM    Course, Student
WHERE   Student.Name="Tom" AND
        Student.Course=Course.Name
```

Usually will build a "**view**" to speedup common queries

ACID Properties of Transactions

- **A**tomicity: either all the operations of a transaction are executed or none of them are.
- **C**onsistency: the database is in a legal state before and after a transaction
- **I**solation: the effects of one transaction are isolated from other transactions.

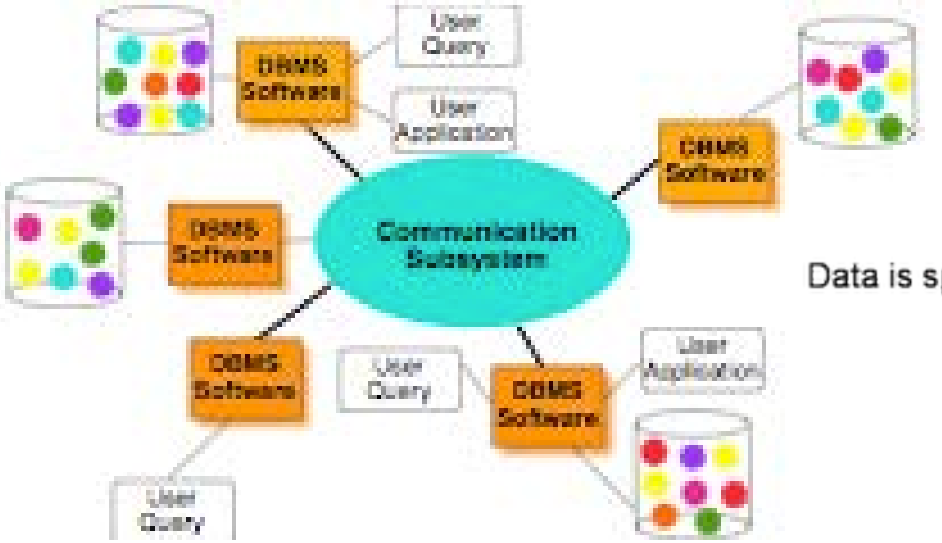
- **D**urability the effects of successfully completed transactions endure subsequent failures.

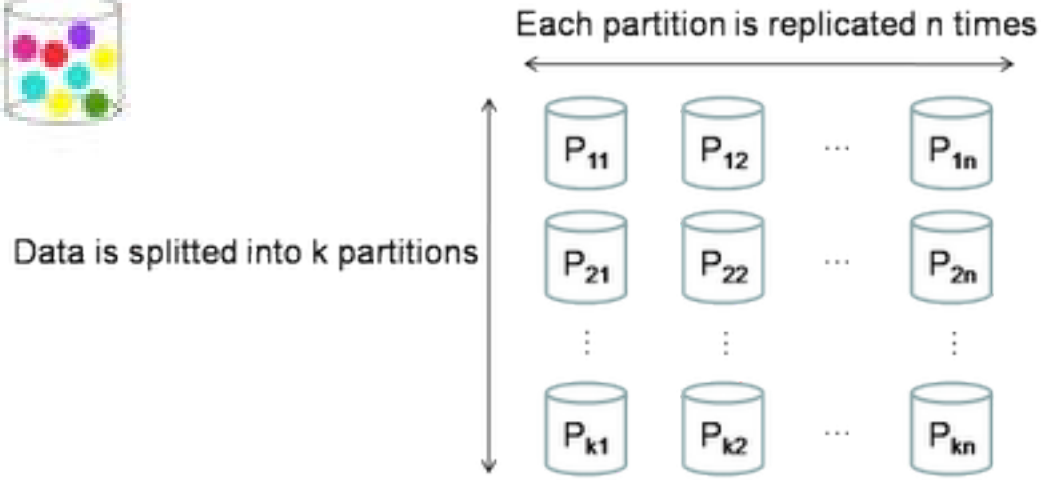
Database Integrity

- RDBMS need to maintain database integrity
  - **Transaction log:** non-volatile record of each transaction's activities, built before the transaction is allowed to happen.
  - **Locking:** preventing others from accessing data being used by a transaction.
  - **Roll-back:** procedure to undo a failed, partially completed transaction.

Distributed RDBMS

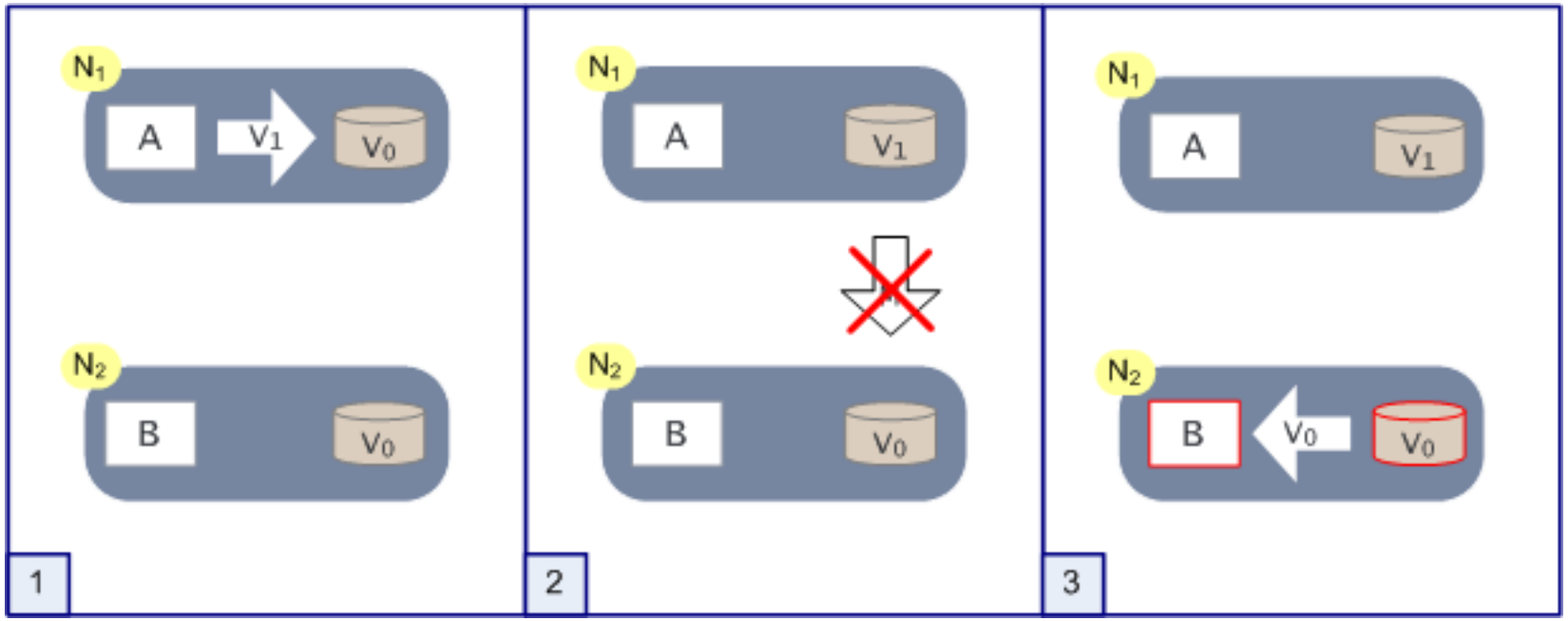
- Distributed database management systems is a software for managing databases stored on multiple computers in a network.
- A natural way to scale up the DBMS





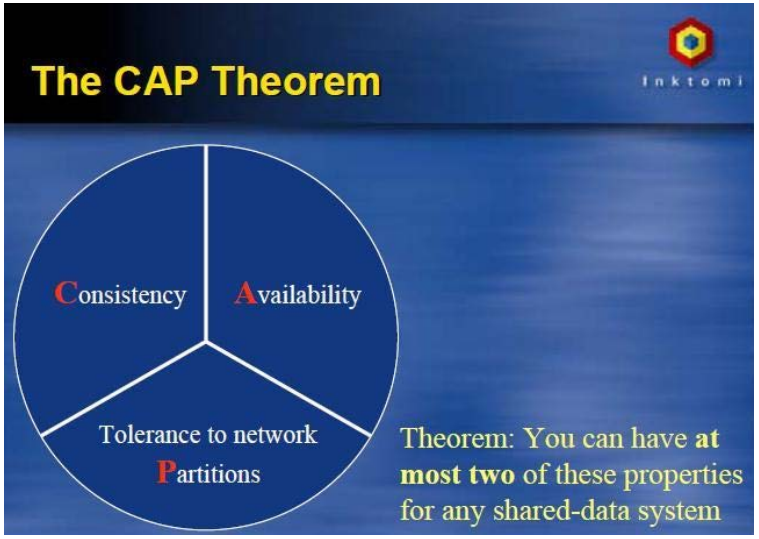
Consistency Problem

- Ex: A writes v1 to DB and B reads the data



Brewer's CAP Theorem

- It is impossible for a distributed computer system to provide all three of
  - **C**onsistency: all nodes see the same data at the same time
  - **A**vailability: a guarantee that every request receives a response about whether it was successful or failed
  - **P**artition tolerance: the system continues to operate despite arbitrary message loss



NOSQL

- Not Only SQL
  - A term used to designate database management systems differ from classic relational database management systems
- Properties
  - May not require fixed table **schemas**
  - Easy for **scale out**
  - Usually avoid **join** operations
  - Relax one of the requirement in CAP theorem

Types of NoSQL

- **Column**:
  - BigTable , HBase, Cassandra, AWS SimpleDB
- **Document**:
  - MongoDB , Apache CouchDB
- **Key-value**:
  - Dynamo(S3), CouchDB, MemcacheDB
- **Graph**:
  - Neo4J, Allegro, InfiniteGraph, Virtuoso

Strength of NoSQL

- **Scalability**:
  - Efficient, scale-out architecture well-suited for big data. It's horizontal scaling meshes extremely well with the cloud.
- **Flexibility**:
  - It is not locked into any one specific data mode or schema, so it can handle virtually any structure or format of data including unstructured data.
- **Cost-Effectiveness**:
  - Its implementations are typically cheap, low-grade commodity devices. Its software is entirely open-source.

Weakness of NoSQL

- **Performance and Scaling > Consistency**
  - Relax the data consistency requirement.
- **Standardization:**
  - No standard API or query language.
- **Maturity:**
  - There really aren't many reliable standards for NoSQL databases quite yet. Most products are from start-up companies with limited support to customers.
- **Ad-hoc query & analysis:**
  - Even a simple query requires significant programming expertise, and commonly used BI tools do not provide connectivity to NoSQL. (Pig & Hive are solving this problem.)

GOOGLE FILE SYSTEM (HDFS)

Assumptions/Motivation

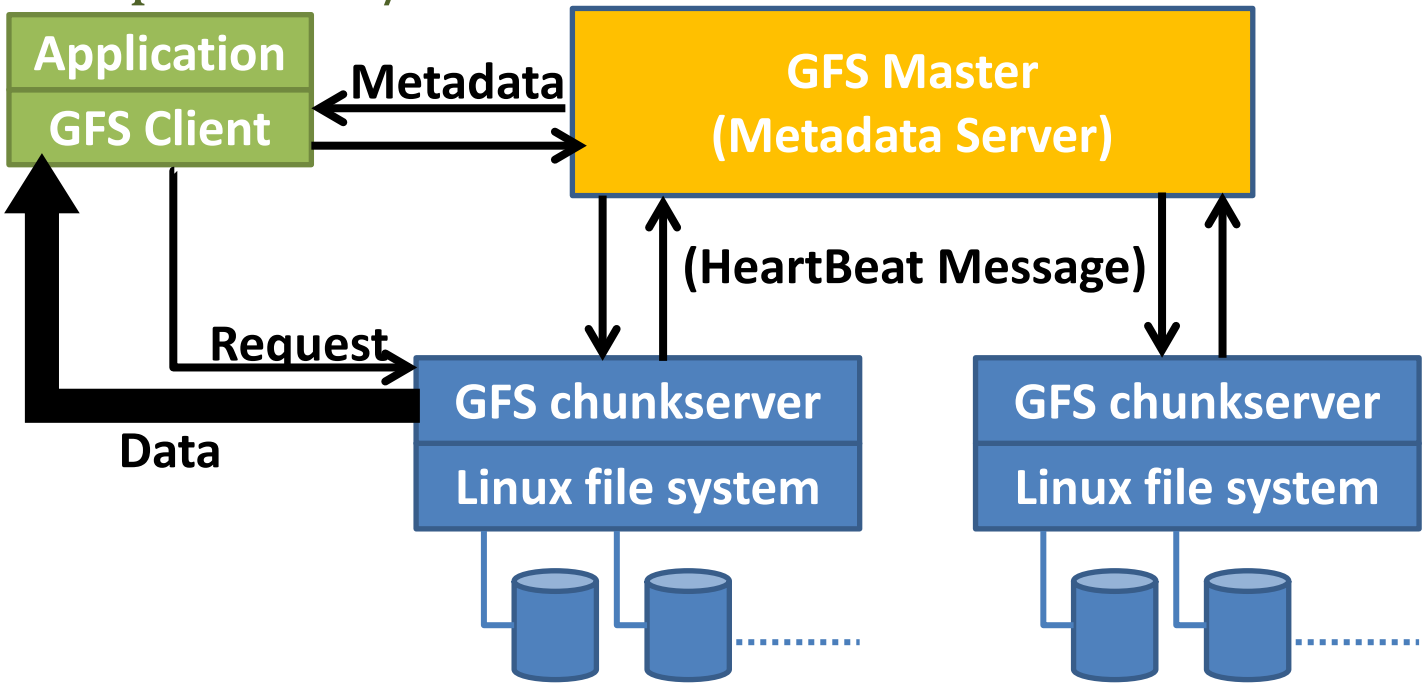
- Take failure as norm than exception
  - Inexpensive commodity components fail all the time
  - Fault-tolerance and auto-recovery need to be built into the system
- Modest number of large files
  - Expect a few million files, each 100 MB or larger
  - Multi-GB files are common and should be managed efficiently
- Co-design with the Google applications (Web-based Search)
  - Primary consist of large streaming reads & small random reads
  - Multiple clients concurrent append data instead of write
  - Seldom or No random write
- High sustained BW is more important than low latency
  - Place a premium on processing data in bulk at a high rate, while have stringent response time

Design Decisions

- Reliability through replication
  - Replication over both nodes & racks
- Single master to coordinate access and to keep metadata
  - Simple centralized management
- No data caching
  - Little benefit on client: large data sets / streaming reads
  - Eliminating cache coherence issues
- Relax consistency model
  - Trade consistency for performance
- Familiar interface, but customize the API
  - No POSIX: simplify the problem; focus on Google apps
  - Add *snapshot* and *record append* operations

Architecture

- Components:
  - Master holds metadata
  - Chunkservers hold data
  - Client produces/consumes data

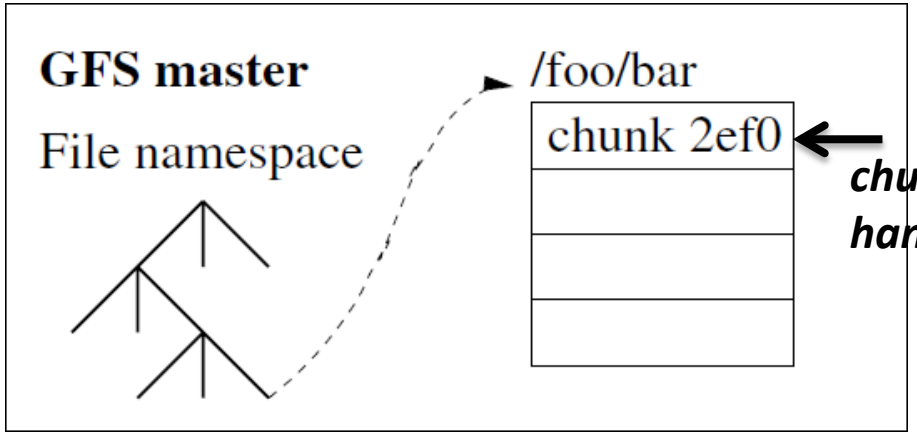


Single Master

- The master have global knowledge of chunks
  - Easy to make decisions on placement, replication and recovery
- Drawback:
  - Single point of failure
  - Scalability bottleneck
- GFS solutions:
  - Shadow masters (Replication of master)
  - Minimize master involvement
    - Separate data flow from control flow: master only involve for metadata not data
    - cache metadata at clients (not data itself)
    - large chunk size (64MB per req.)
    - lease management: master delegates authority to primary replicas in data mutations

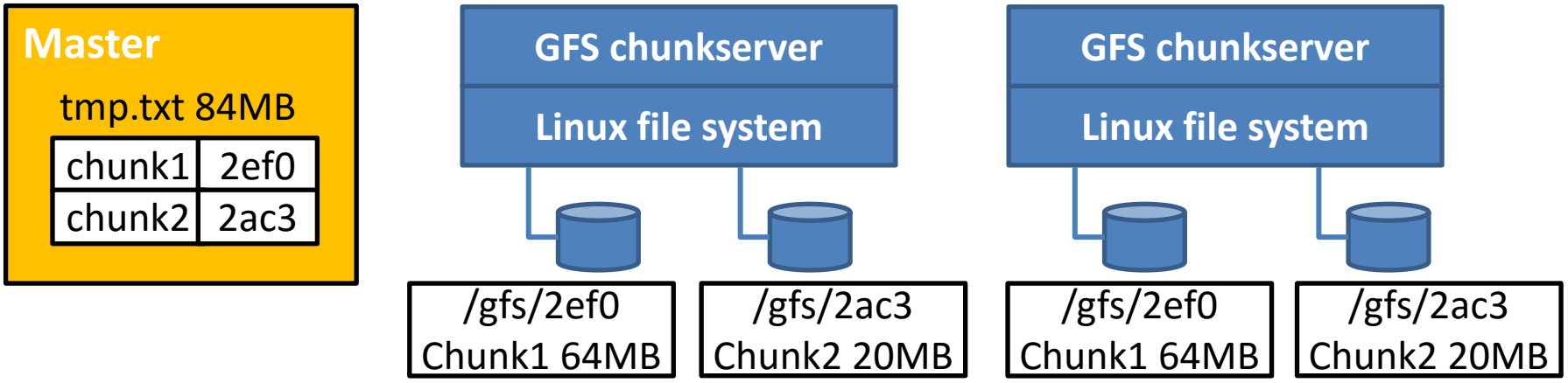
Metadata

- Information:
  - Namespace tree
  - File to chunks mapping
    - A file is split into multiple chunks
    - Each chunk has a chunk handle Identified by an immutable and globally unique 64 bit
  - Chunk locations
    - Chunkserver IP, file path
  - Access control info
- Management:
  - Keep in **memory**
  - Use **checkpoint** & **log** to insure persistency



Chunkserver - Data

- Files stored in *chunks* (c.f. "*blocks*" in disk file systems)
  - A chunk is a **Linux file** on local disk of a chunckserver
  - Unique chunk handles assigned by master at creation time
  - Read/write by (chunk handle, byte range)
  - Fixed large chunk size (i.e. 64MB)
  - Each chunk is replicated across 3+ chunkservers



Chunk Size

- Typical chunk size is 64 MB
- A large chunk size offers important advantages when stream reading/writing
  - Less communication between client and master
  - Less memory space needed for metadata in master
  - Less network overhead between client and chunkserver (one TCP connection for larger amount of data)
- On the other hand, a large chunk size has its disadvantages
  - Hot spots
  - Fragmentation

Replica Placement

- Traffic between racks is slower than within the same rack
- A replica is created for 3 reasons
  - Chunk creation: new chunks
  - Chunk re-replication: missing chunks
  - Chunk rebalancing: migrating chunks
- Master has a replica placement policy
  - Maximize data reliability and availability
  - Maximize network bandwidth utilization

Lease Management

Read/Write File

Consistency Model

Concurrent Write

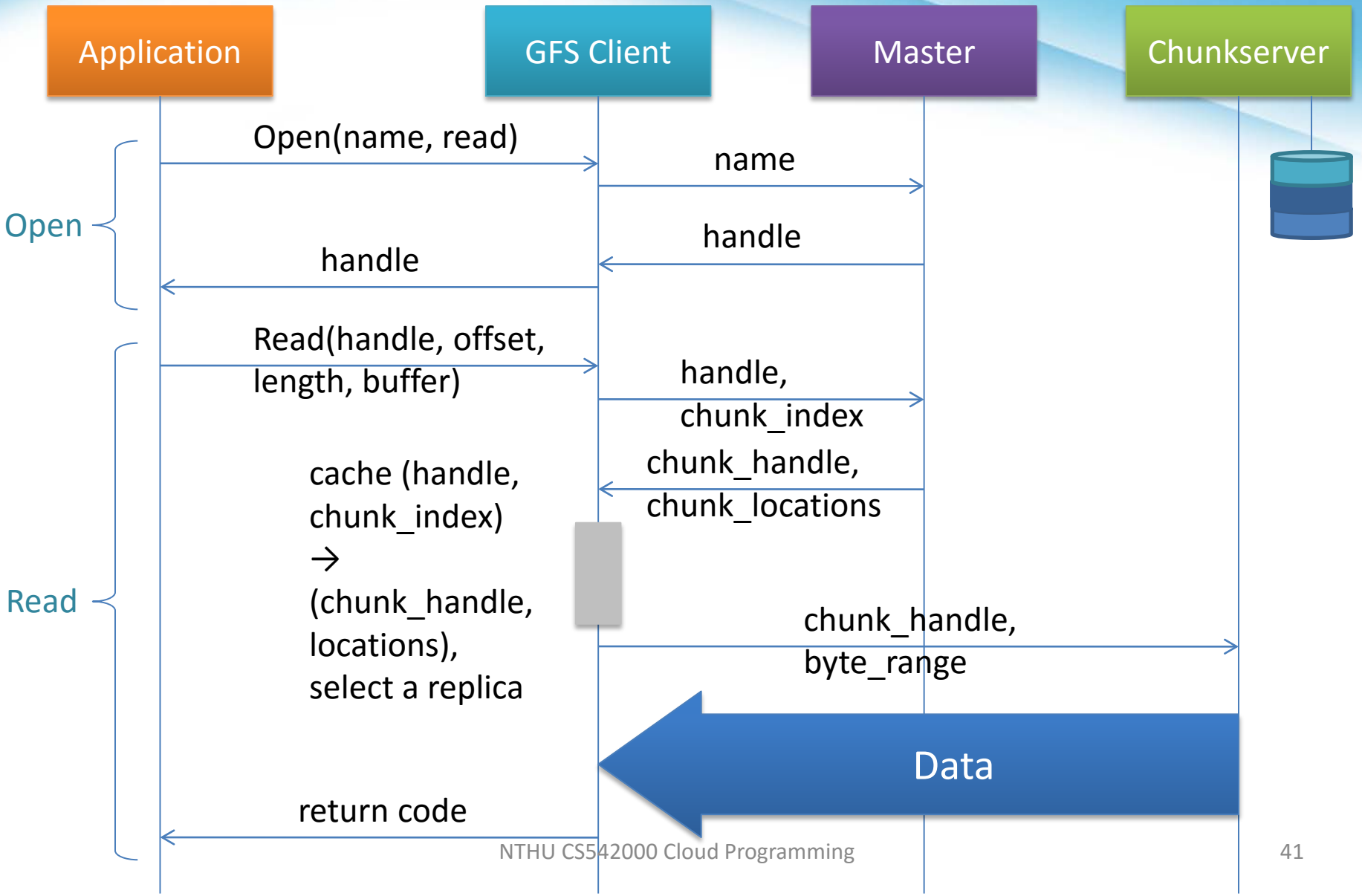
Atomic Append

GFS: SYSTEM INTERACTION

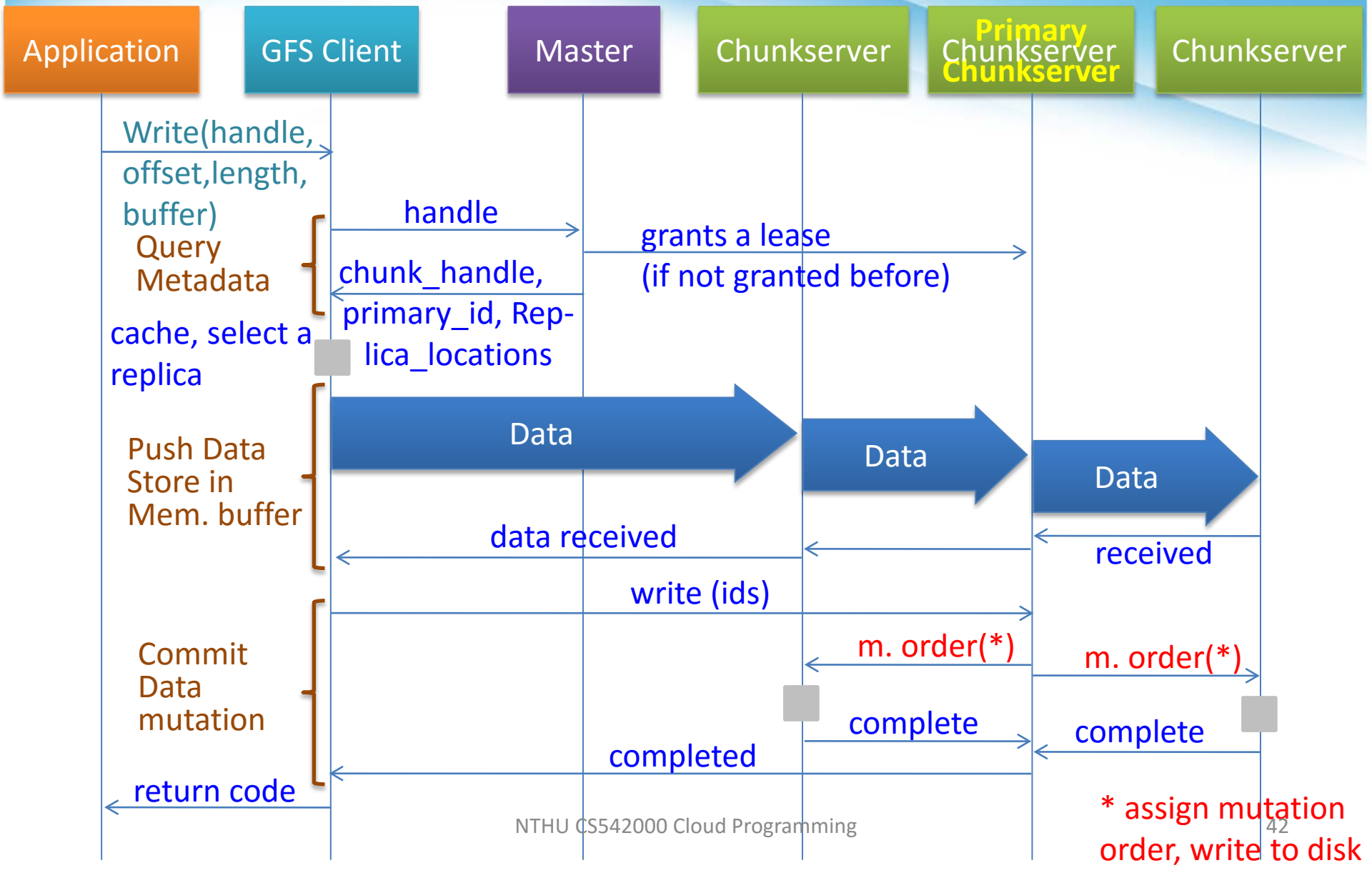
Lease Management

- Goal
  - Minimize master overhead by authorizing a datacenter to make decision during **data mutation** (i.e. write/append)
- One lease per chunk
  - master picks one replica as primary; gives it a "lease"
  - a lease = a lock that has an expiration time
  - primary defines a serial order of mutations, all replicas follow this order
- The primary still can
  - renew the lease before it expires
  - revoke a lease (e.g., for snapshot)
  - grant the lease to another replica if the current lease expires (primary crashed, etc)

While reading a file



While writing to a File



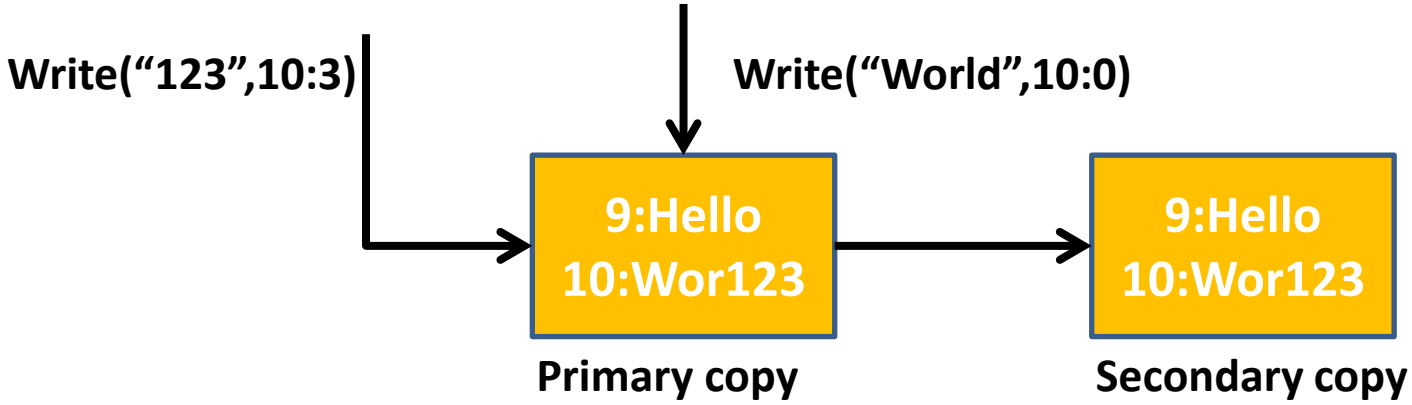
Consistency Model

- GFS has a relaxed consistency model
- File **namespace** mutations are atomic and consistent
  - handled exclusively by the master
  - namespace lock guarantees atomicity and correctness
  - order defined by the operation logs
- File ***region*** mutations: complicated by replicas
  - "Consistent" = all replicas have the same data
  - "Defined" = consistent & reflects the mutation **entirely** (i.e. you see what you write)
  - A relaxed consistency model: not always consistent, not always defined, either

Concurrent Write

- If two clients concurrently write to the same region of a file, **any** of the following may happen to the overlapping portion:
  - Eventually the overlapping region may contain data from exactly one of the two writes.
  - Eventually the overlapping region may contain a mixture of data from the two writes.

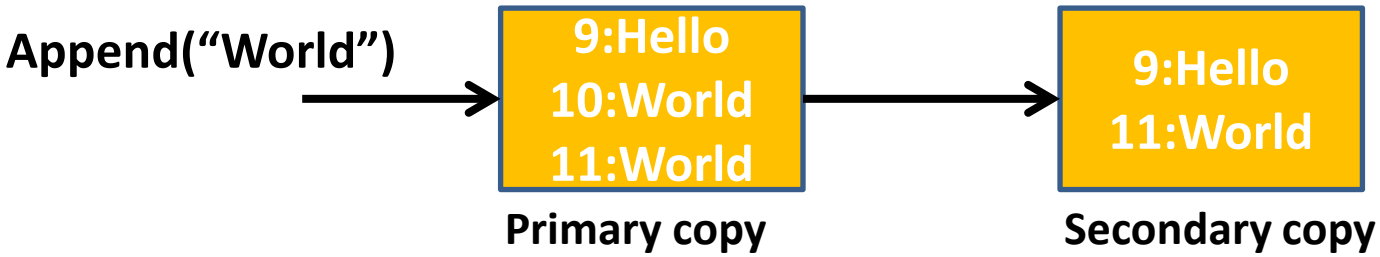
➔Consistent, not defined



Atomic Record Appends

- GFS provides an atomic append operation called "**record append**"
- GFS guarantees that the data is appended to the file **atomically at least once**
  - GFS picks the offset, and **returns the offset to user**
  - GFS client **automatically retries** if any replica fails
- Used heavily by Google apps
  - serve as multiple-producer/single-consumer queues
  - merged results from many different clients

➔Defined interspread with inconsistent



Consistency Summary

- Applications are responsible for
  - self-validating, self-identifying records

	Write	Record Append
Serial success	*defined*	*defined* interspersed with *inconsistent*
Concurrent successes	*consistent* but *undefined*	
Failure	*inconsistent*	

Summary of GFS

- GFS demonstrates how to support large-scale processing workloads on commodity hardware
  - designed to tolerate frequent component failures
  - uniform logical namespace
  - optimize for huge files that are mostly appended and read
  - relax and extend FS interface as required
  - relaxed consistency model
  - go for simple solutions (e.g., single master, garbage collection)

Motivation & Data Model

Data Storage

Operations

Vs Hbase & Hive

BIG TABLE

Motivation

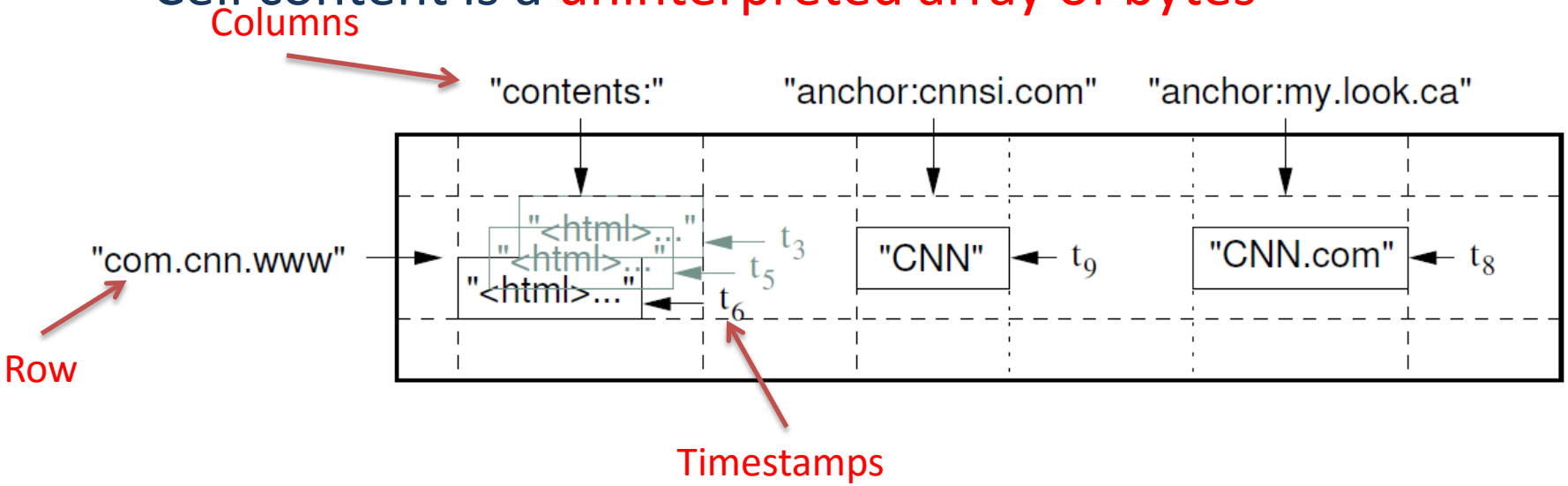
- Lots of (semi-)structured data at Google
  - Web: contents, crawl metadata, links/anchors/pagerank, …
  - Per-user data: user preference settings, recent queries, search results, …
  - Geographic locations: physical entities (shops, restaurants, etc.), roads, satellite image data, user annotations, …
- Scale is large
  - Billions of URLs, many versions/page (~20K/version)
  - Hundreds of millions of users, thousands of queries/sec
  - 100TB+ of satellite image data

What is BigTable

- For random, realtime read/write access of data
  - A column-based **key-value store** that runs on top of GFS for storing **semi-structured** and **untyped** data
  - Provides real-time key based access to data with the features like memcached, compression, bloom filter (instead of MapReduce jobs)
  - Tables in BigTable can serve as the input and output for MapReduce jobs.

Data Model

- Semi-structured: multi-dimensional **sparse map (key-value pair)**
  - (row, column, timestamp) → cell contents
- Cell content is a uninterpreted array of bytes



- Good match for most of Google's applications

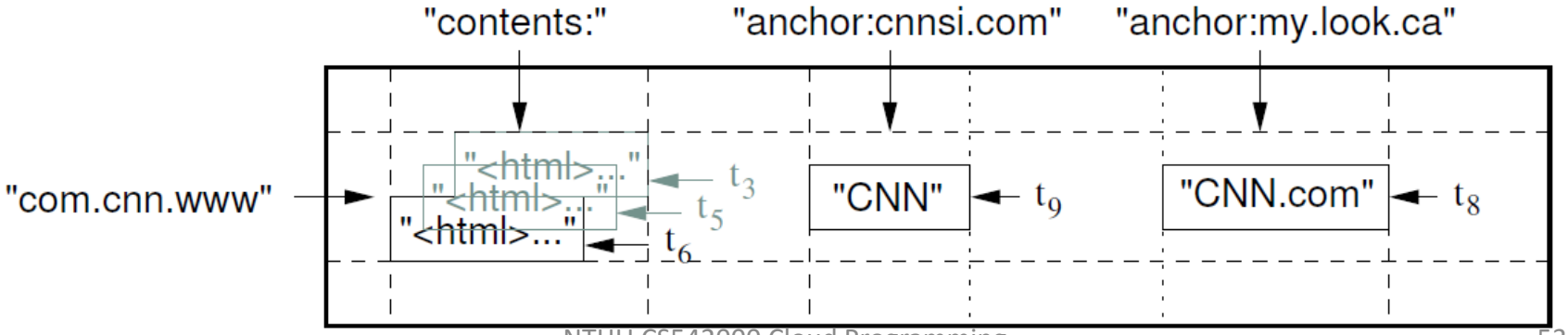
Rows

- Name is an arbitrary string
  - Access to data in a row is **atomic**
  - Row creation is implicit upon storing data
- Rows ordered lexicographically by key
  - Rows are **dynamically** partitioned and **stored on multiple machines**
  - Clients can exploit this property to get good **data locality**
  - E.g.: reversing the hostname components of the URLs.
    - pages from the same domain are stored in a **single tablet server**

Key	contents	……
com.google.maps/index		
com.google.calendar/index		
com.google.gmail/index		

Columns

- Columns have two-level name structure
  - ***family:qualifier***
- Column family
  - All the data in a column family is stored into a single **GFS file** (i.e. data stores in **column major** instead of row major)
  - Basic unit of **access control**: readOnly, writeAble, etc
  - Has associated type information
- Qualifier gives **unbounded number of columns**
  - **But number of family has limit**



Timestamps

- Used to store different **versions** of data in a cell
  - New writes default to current time, but timestamps for writes can also be set explicitly by clients
  - Sorted in decreasing order ➔ latest version on top
- Lookup options
  - "Return most recent K values"
  - "Return all values in timestamp range (or all values)"
- Column families can be marked with attributes
  - "Only retain most recent K values in a cell"
  - "Keep values until they are older than K seconds"

Motivation & Data Model

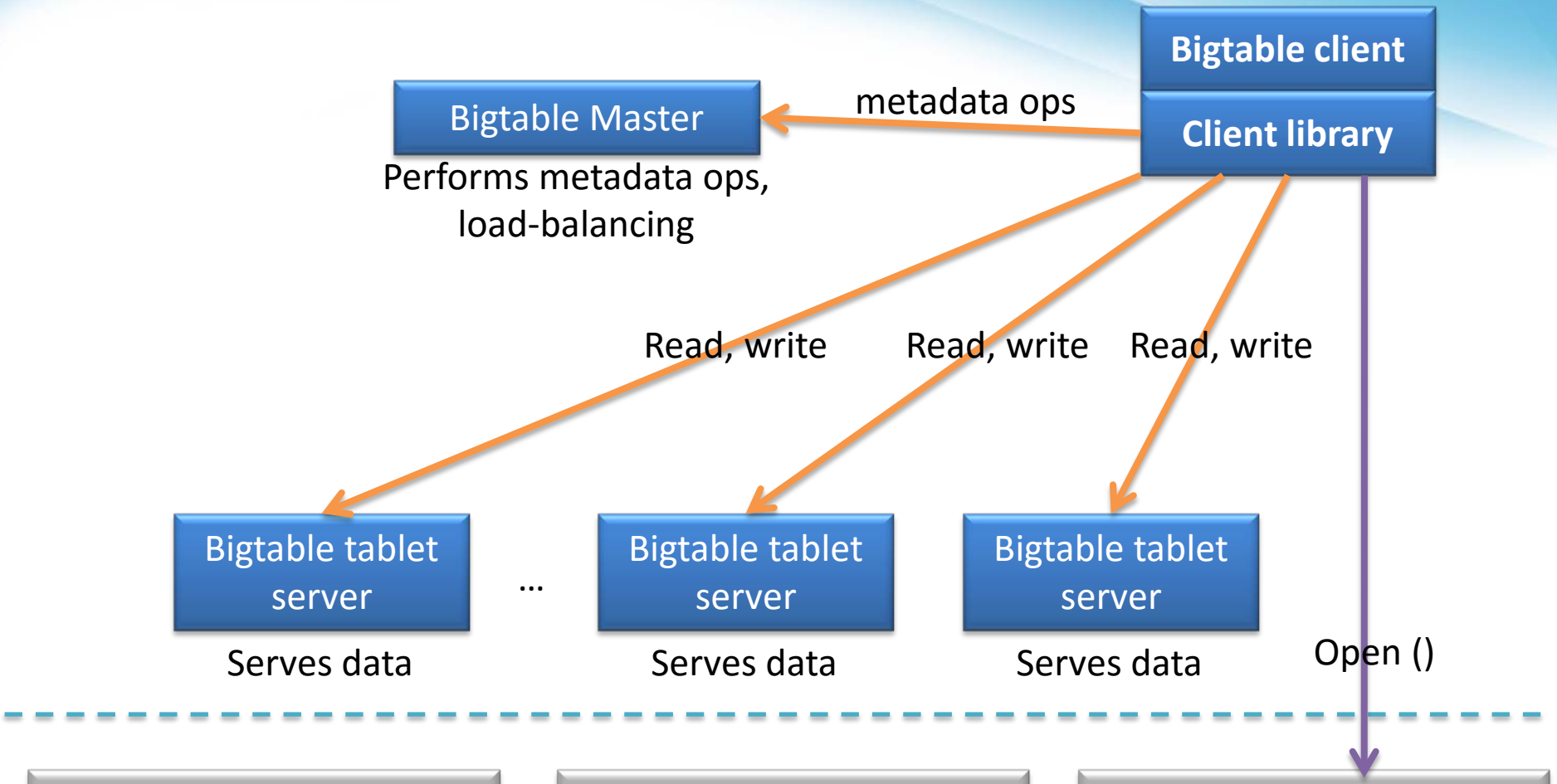
Data Store

Operations

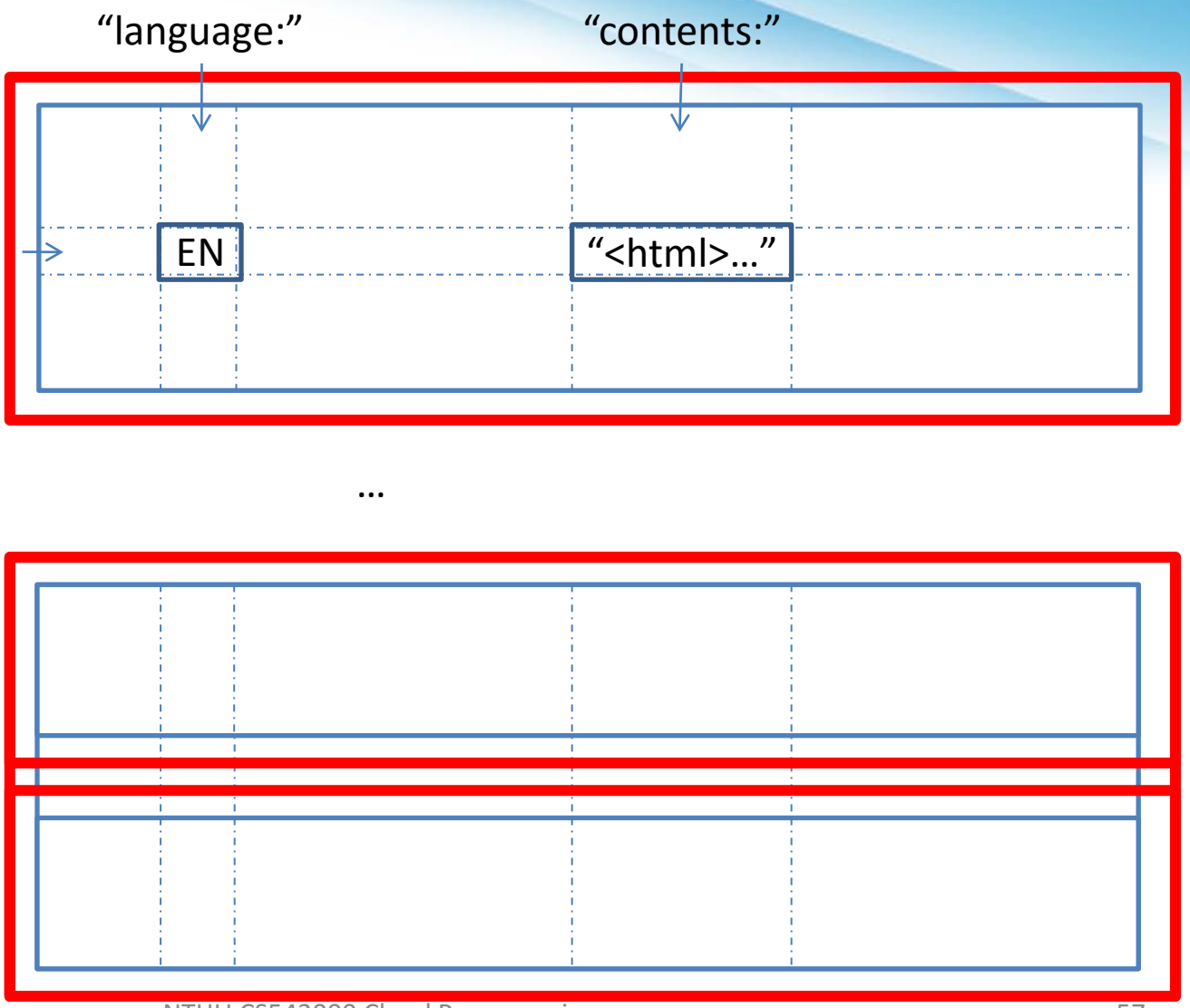
Vs Hbase & Hive

BIG TABLE

System Architecture



Tablets & Splitting



Tablets

- Large tables broken into *tablets at row boundaries*
  - Tablet holds contiguous range of rows
  - Aim for ~100MB to 200MB of data per tablet
- Dynamic fragmentation of rows
  - Distributed over tablet servers: each responsible for ~100 tablets
  - Unit of load balancing: Migrate tablets away from overloaded machine
  - Tablets split and merge
    - automatically based on size and load
    - or manually

How Tablet is Stored?

Row Key	Time Stamp	Column "contents:"	Column "anchor:"		Column "mime:"
"com.cnn.www"	t9		"anchor:cnnsi.com"	"CNN"	
	t8		"anchor:my.look.ca"	"CNN.com"	
	t6	"<html>..."			"text/html"
	t5	"<html>..."			
	t3	"<html>..."			

How Tablet is Stored?

Row Key	Time Stamp	Column "contents:"	Column "anchor:"		Column "mime:"
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	t8		"anchor:my.look.ca"	"CNN.com"	
	t6	"<html>..."			"text/html"
	t5	"<html>..."			
	t3	"<html>..."			

Conceptual View

Row Key	Time Stamp	Column "contents:"
"com.cnn.www"	t6	"<html>..."
	t5	"<html>..."
	t3	"<html>..."

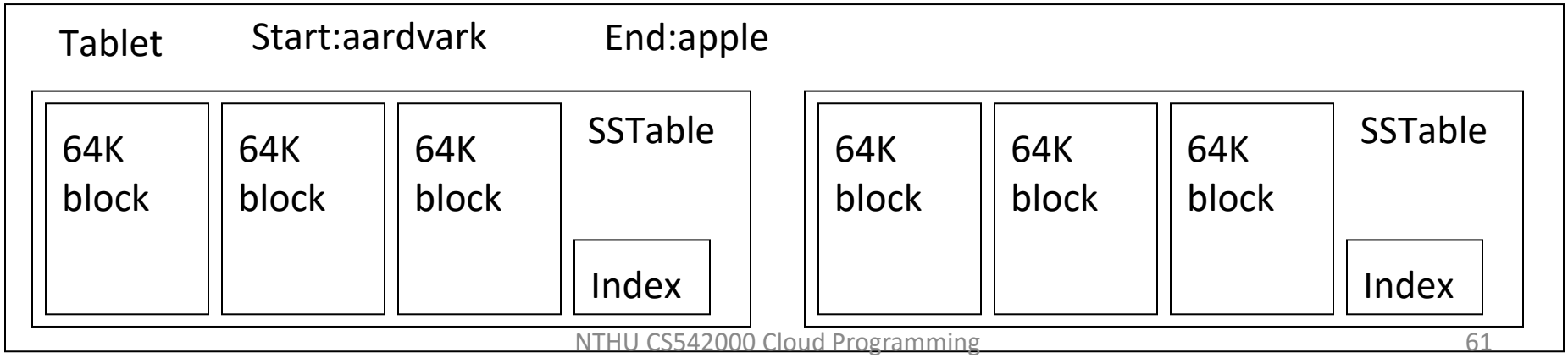
Row Key	Time Stamp	Column "mime:"
"com.cnn.www"	t6	"text/html"

Row Key	Time Stamp	Column "anchor:"	
"com.cnn.www"	t9	"anchor:cnnsi.com"	"CNN"
	t8	"anchor:my.look.ca"	"CNN.com"

Physical Storage View

SSTable

- Tablet is built out of SSTables (GFS File)
  - Persistent, **ordered, immutable** **<key, value> pair**
  - Contains a sequence of blocks
    - Operations: lookup(key), iterate(key_range)
  - A block index store the block location of each keys
    - Index loaded into memory ➔ One disk seek per block read
    - The whole SSTable can also be mapped into memory



Motivation & Data Model

Data Store

Operation

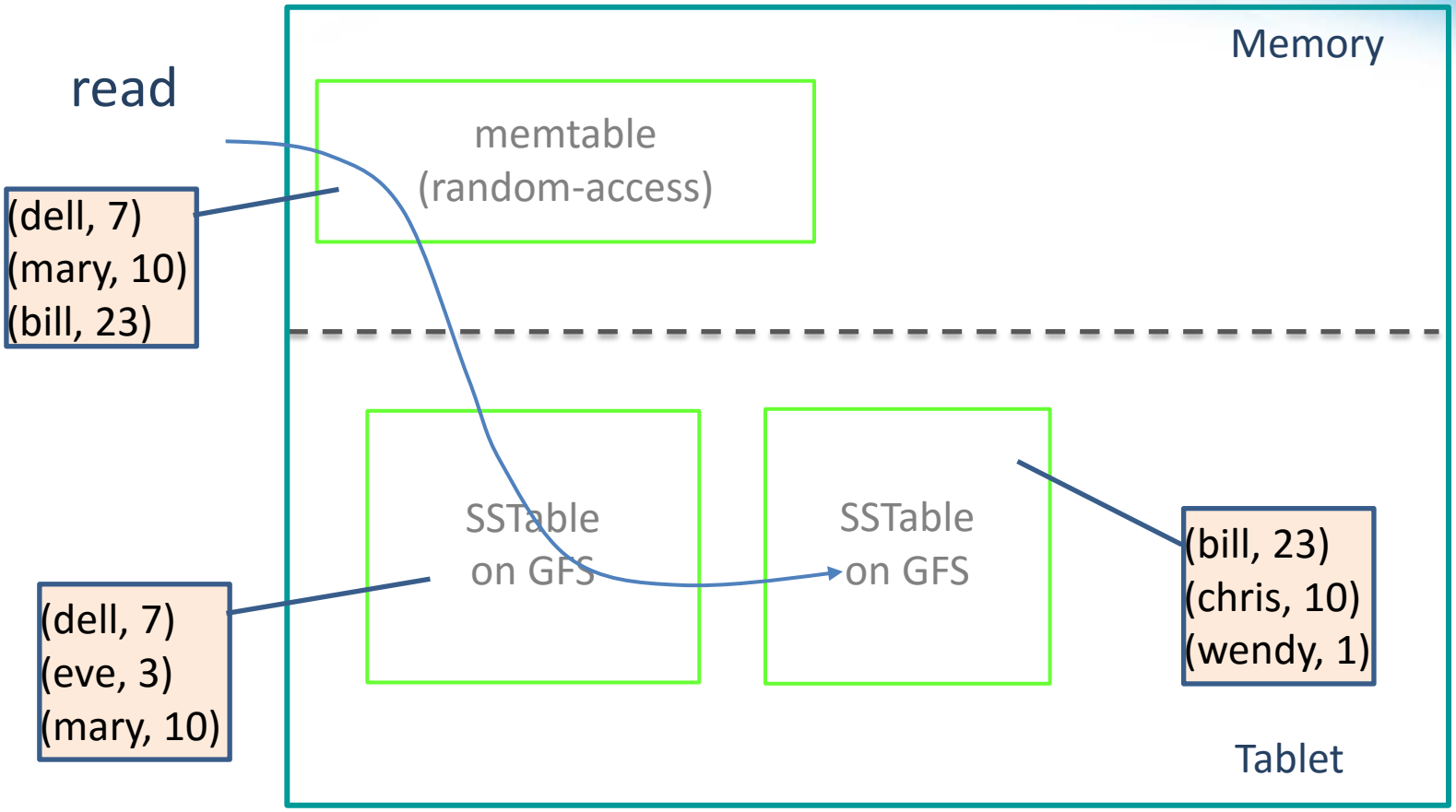
Vs Hbase & Hive

BIG TABLE

Sequential Write

- BigTable is highly optimized for **write**
  - **Appending a transaction entry to a log file**
    - the disk write is **sequential** with no disk seek
  - Write the data into an in-memory Memtable
    - When memtable fills up, it is frozen and **converted to an SSTable written to GFS at once**
  - When machine crashes
    - Reconstruct Memtable by **replaying the updates in the log file.**

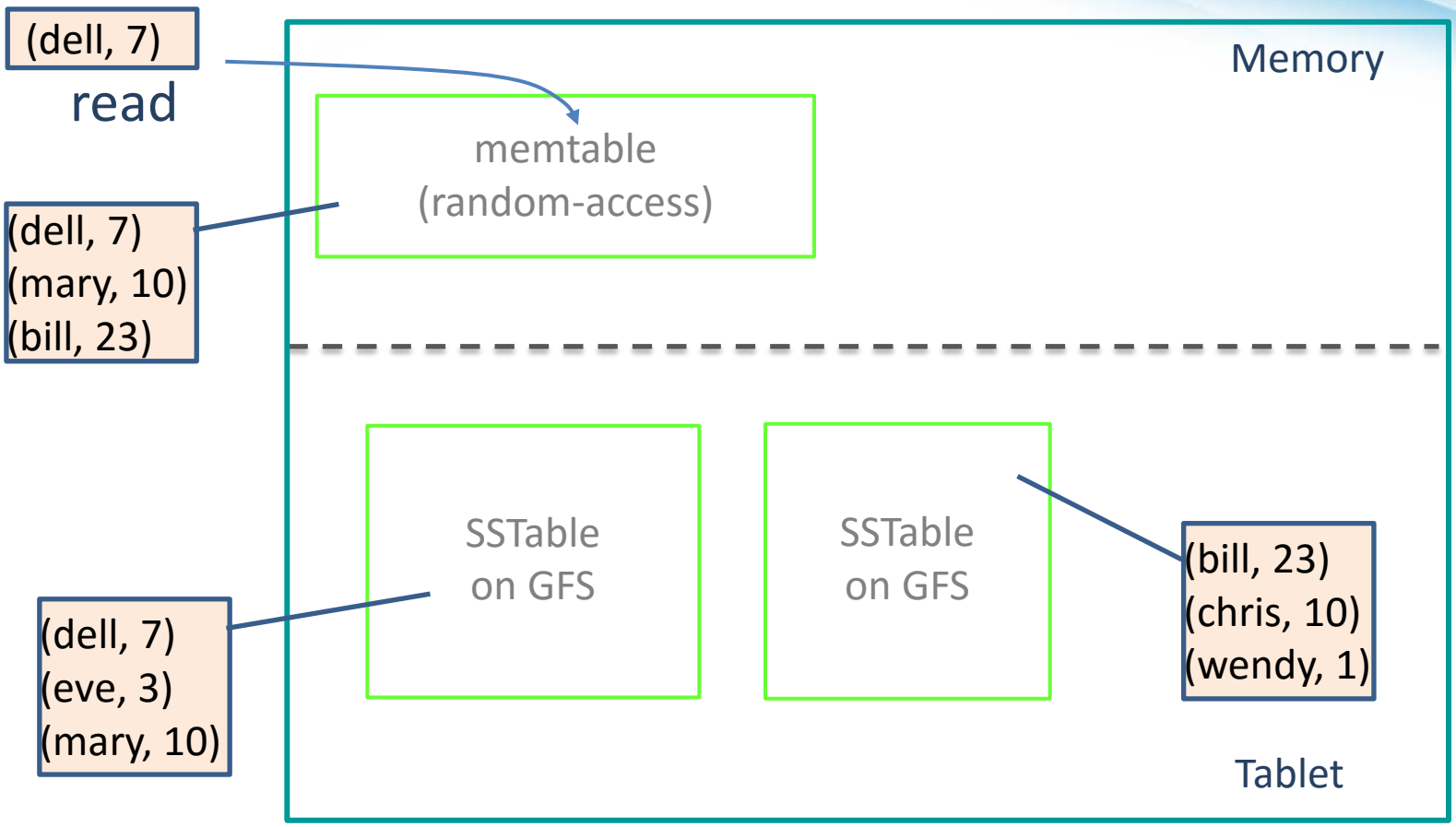
Tablet Serving



SSTable: Immutable on-disk ordered map from string->string

string keys: *<row, column, timestamp> triples*

Tablet Serving



SSTable: Immutable on-disk ordered map from string->string

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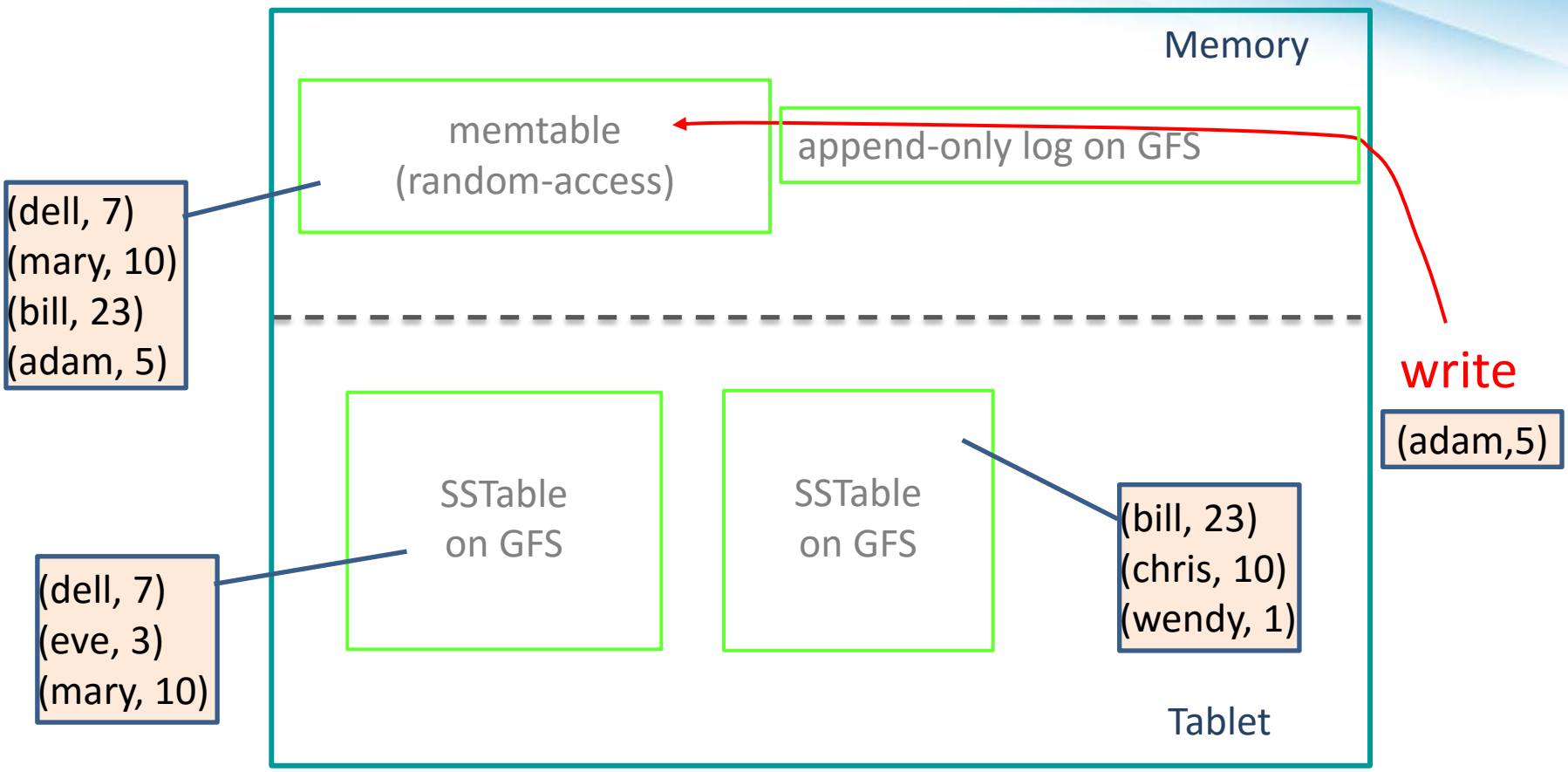
Tablet Serving



SSTable: Immutable on-disk ordered map from string->string

string keys: *<row, column, timestamp> triples*

Tablet Serving Optimization

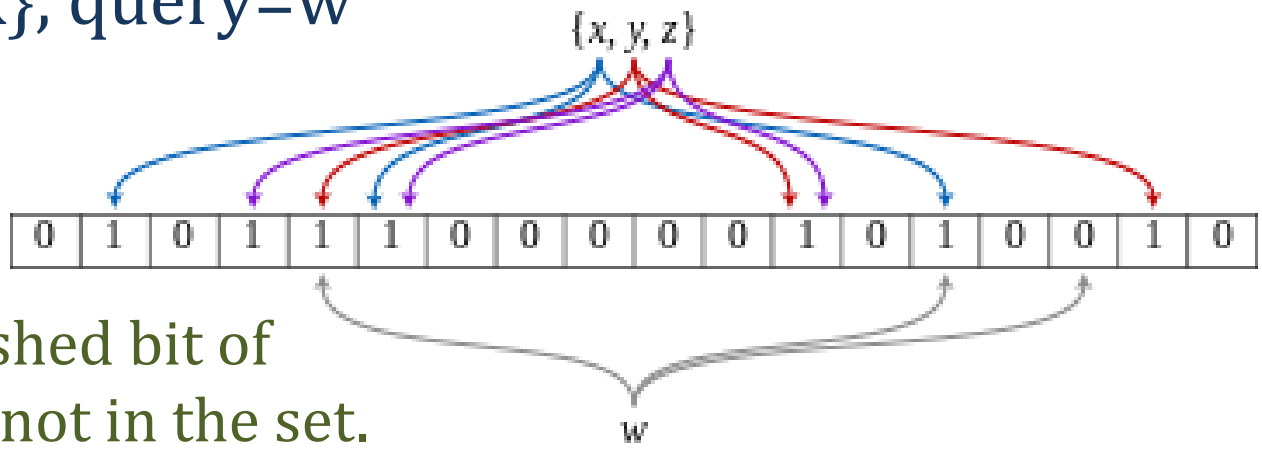
- What happen if cache is full
  - Minor compaction: create new SSTable
- How to lookup multiple SSTables efficiently?
  - Bloom filter: hashing/indexing
- Can we reduce the number of SSTables?
  - Major compaction: merge sort files of SSTables

Merged Read

- ”Merged Read" means multiple places to lookup data when a read request is arrived.
  - It first looks at the Memtable by the row key of request. If not, it will look at the on-disk SSTables
  - Multiple SSTables are created for a tablet due to **write**
- It is inefficient for read when there are too many SSTables scattering around.
  - To speed up the detection, SSTable has a companion Bloom filter such that it can rapidly detect the absence of the row-key.
  - The system periodically merge the SSTables.

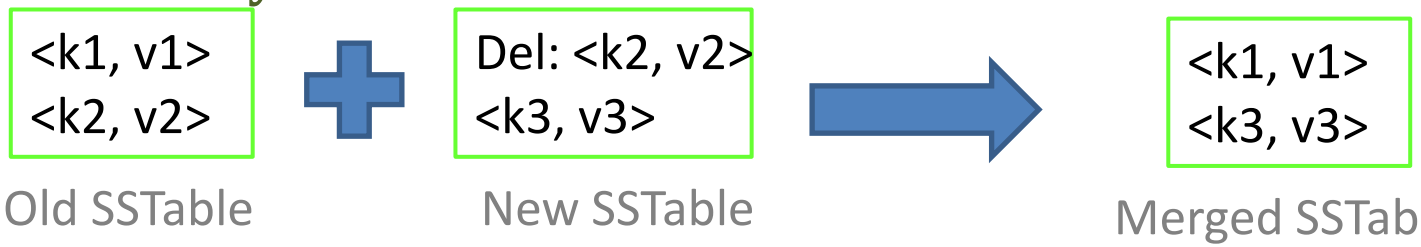
Bloom Filter

- Conceived by Burton Howard Bloom in 1970
- A probabilistic data structure that is used to test whether an element is a member of a set.
  - **False positives** are possible, but not **false negatives.**
- Ex: a set={x,y,x}, query=w
  - Elements are hashed to different bits
  - One of the hashed bit of w is 0, so it is not in the set.

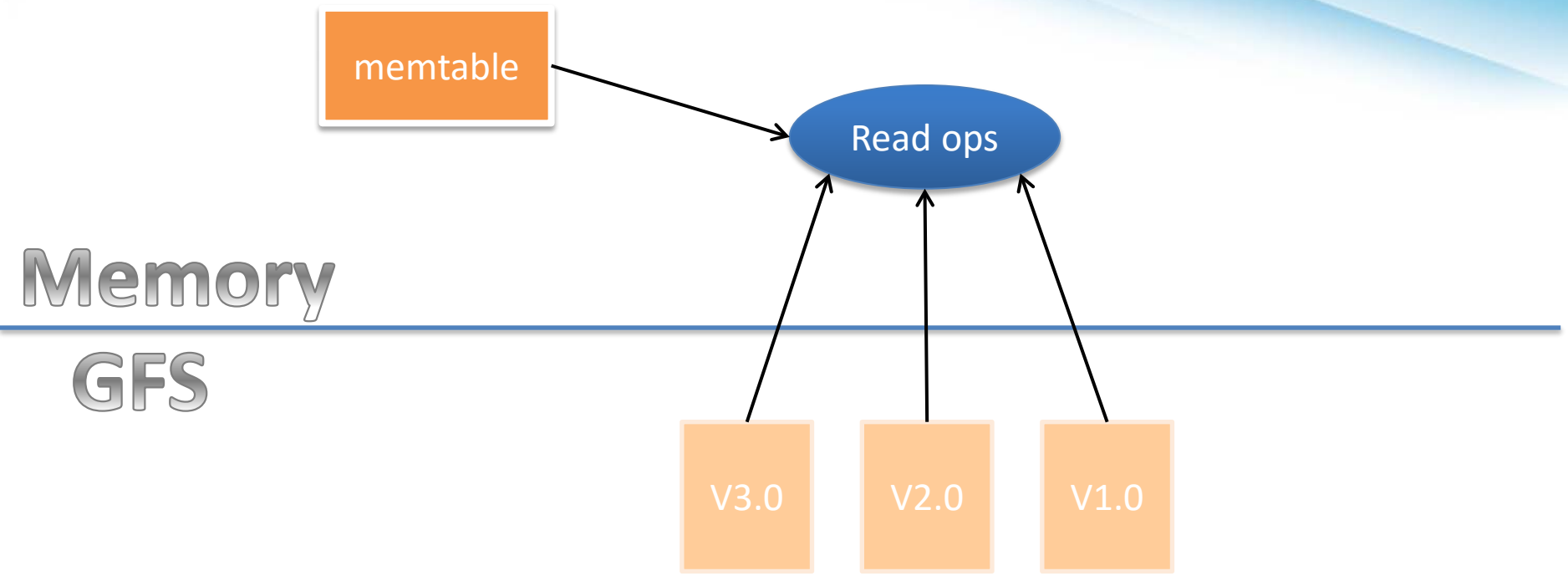


Periodic Data Compaction

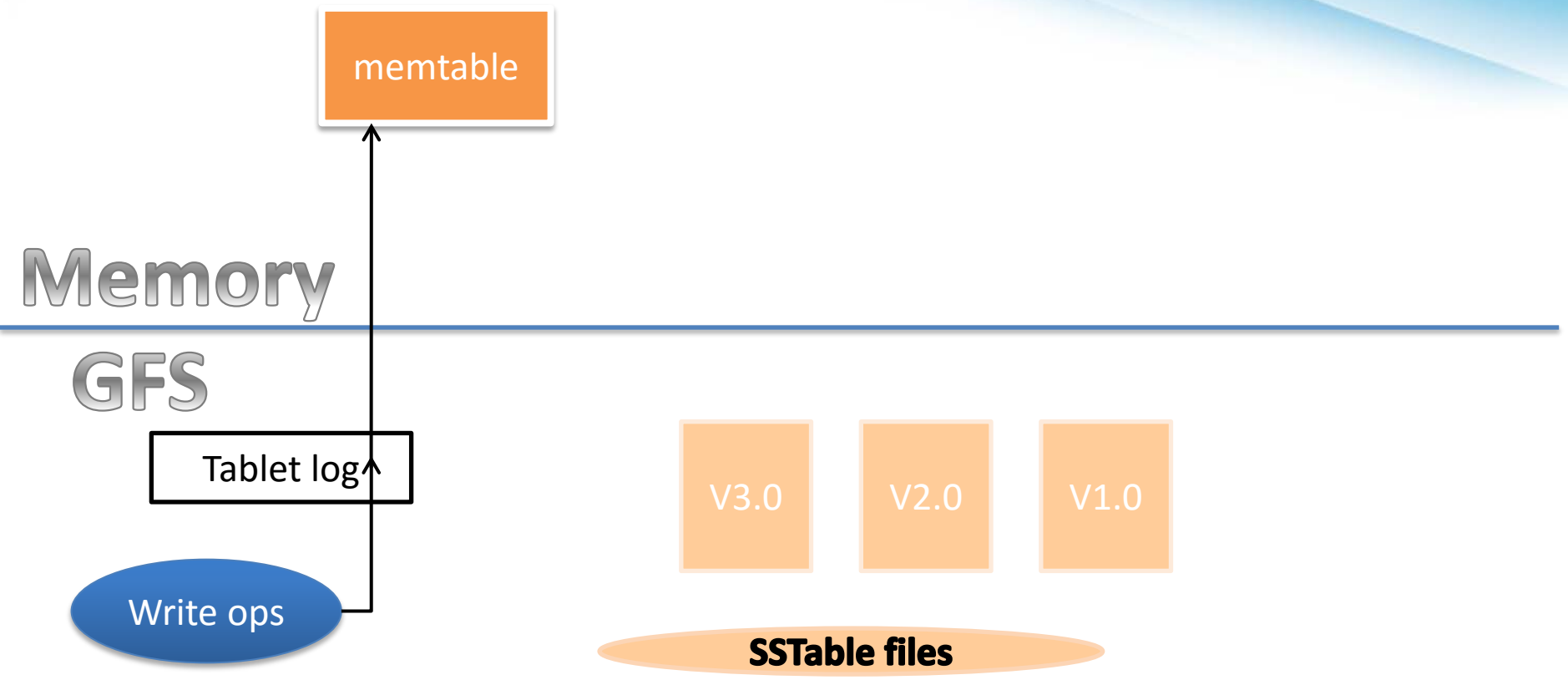
- SSTables are merged periodically
  - Each SSTable is individually **sorted by key**
  - A simple "merge sort" is sufficient to merge multiple SSTable into one
- Deleted entries/data are removed
  - Reclaim resources used by deleted data
  - Ensure delete data disappears from the system in a timely fashion



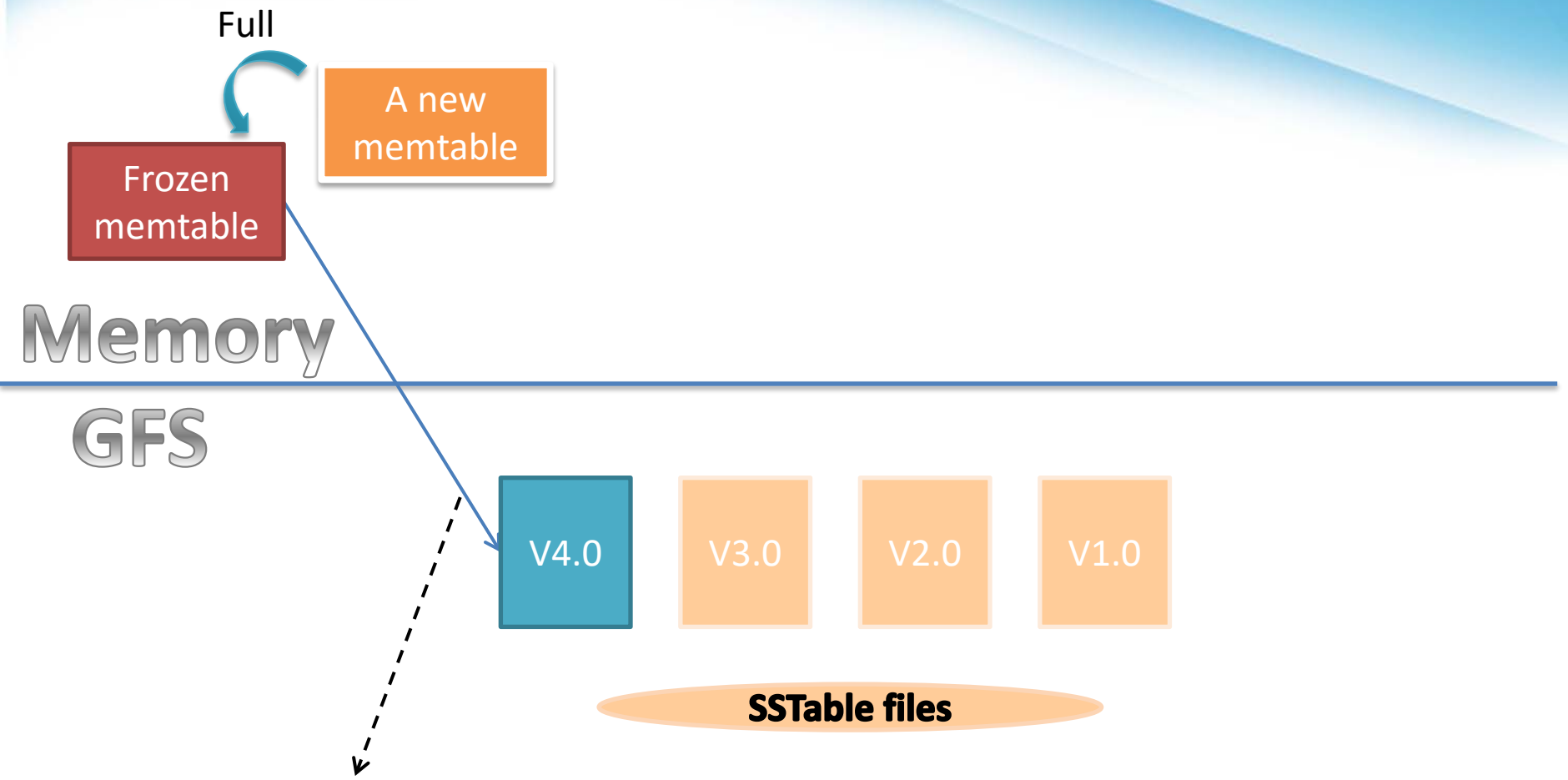
Read



Write


memtable
Memory
GFS
Tablet log
Write ops
V3.0
V2.0
V1.0
SSTable files

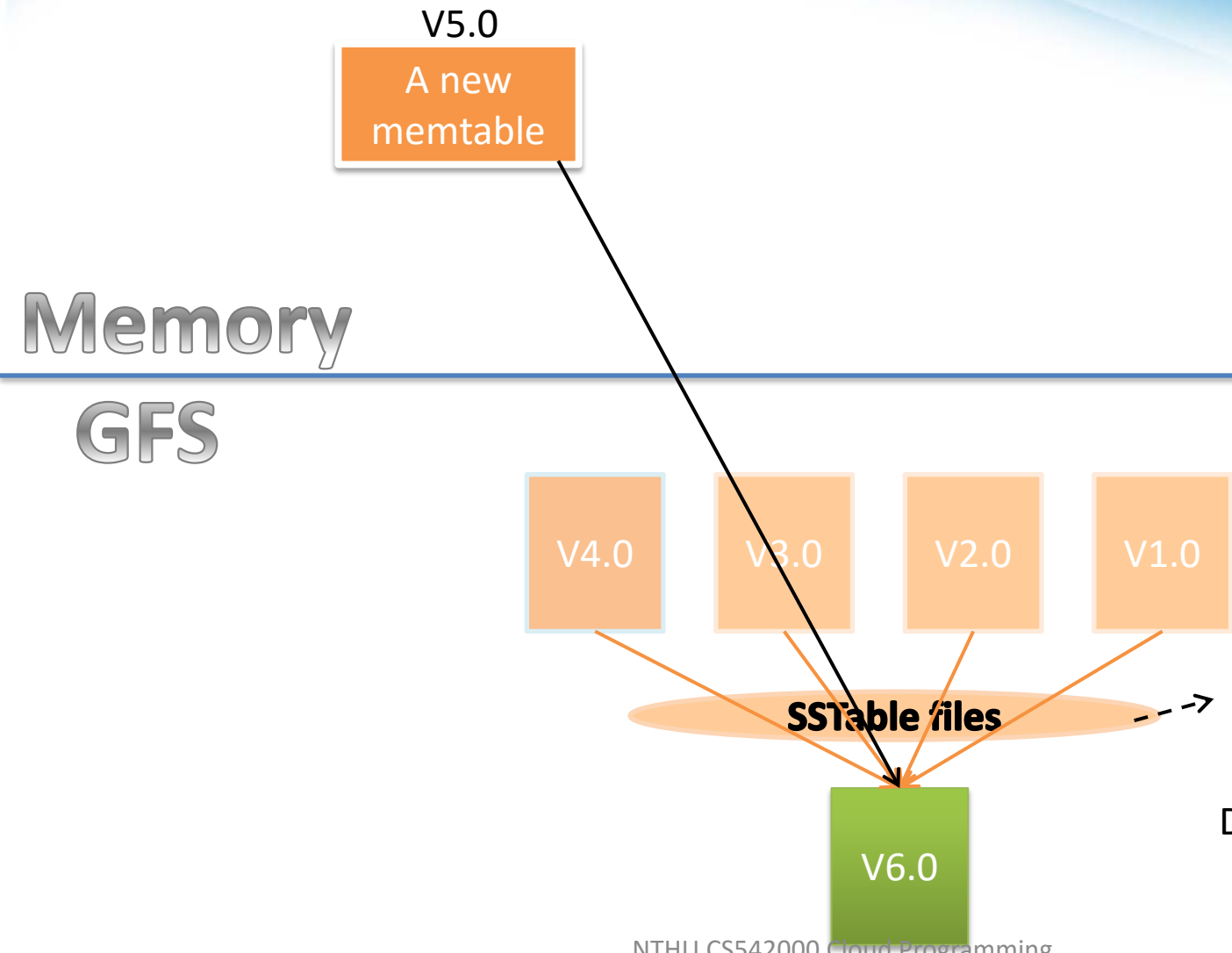
Minor Compactions



Minor compaction

Memtable -> a new SSTable

Major Compactions



Major compaction

Memtable + all SSTables -> to one SSTable

Deleted data are removed
Storage can be re-used

Motivation & Data Model

Data Store

Operation

Vs Hbase & Hive

BIG TABLE

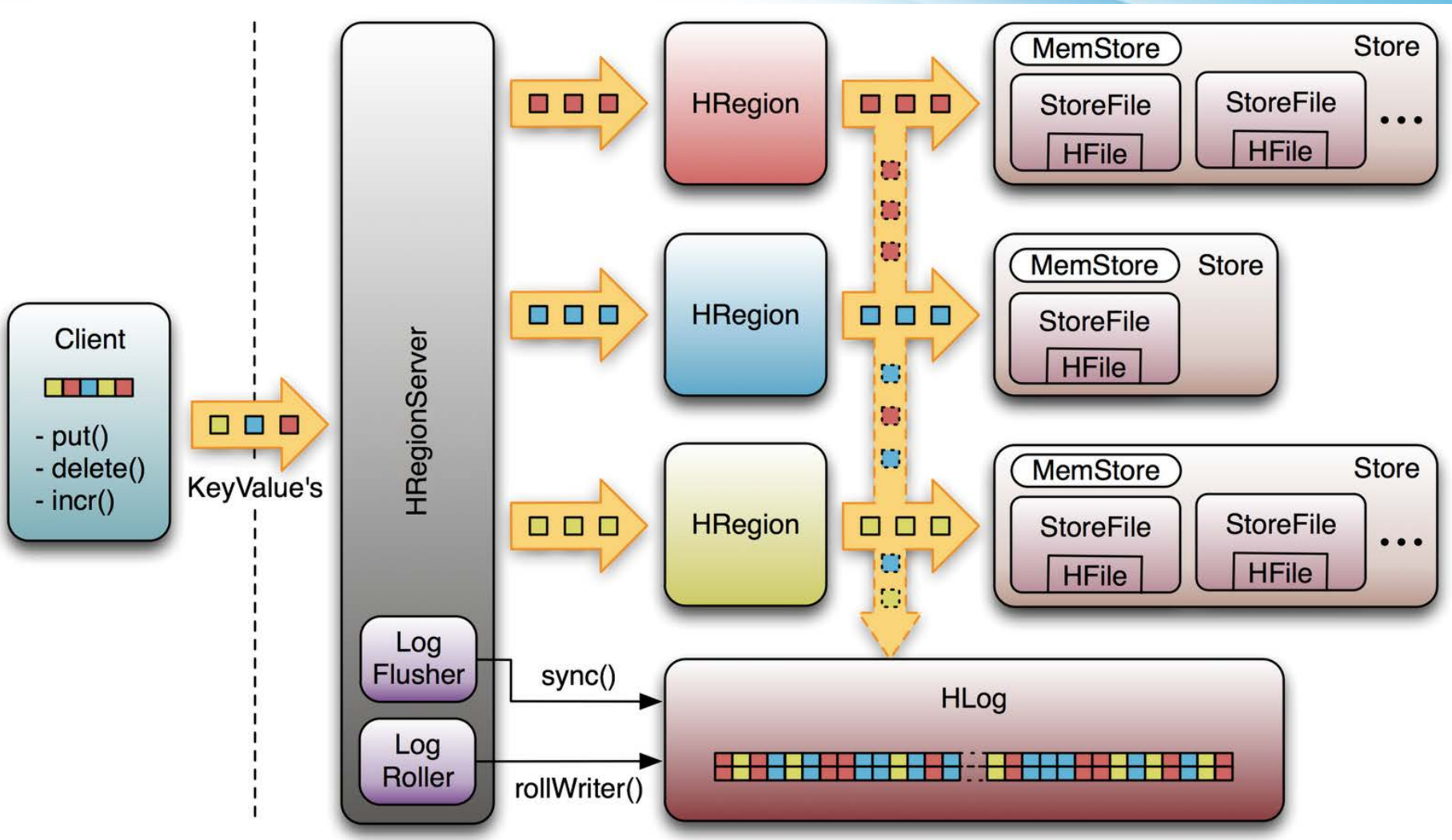
HBase

- Based on the BigTable, HBase uses the Hadoop Filesystem (HDFS) as its data storage engine.
- HBase doesn't need to worry about data replication, data consistency and resiliency because HDFS has handled it already.
  - It is also constrained by the characteristics of HDFS, which is not optimized for random read access.
  - There will be an extra network latency between the DB server to the File server (which is the data node of Hadoop).

BigTable v.s. HBase

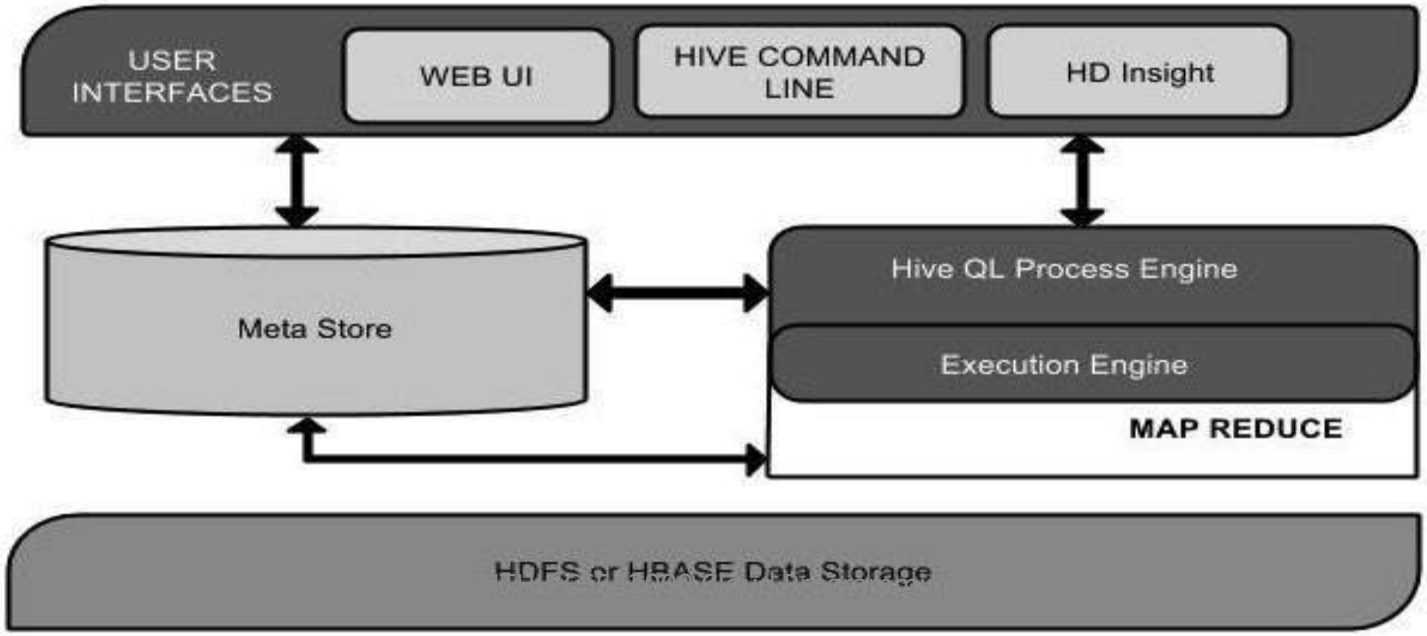
BigTable	HBase
Master	Master
Tablet server	Region server
Google file system	HDFS
SSTable	HFile
Chubby	Zookeeper
Memtable	Memcached

How does Hbase work?



Hive

- Converts queries to map/reduce, Apache Tez and Spark jobs
- Provides indexes, including bitmap indexes
- Metadata storage in an RDBMS (Apache Derby)
- Access stored in Hadoop's HDFS and compatible file systems, such as Amazon S3 filesystem



Data Model: Tables

- These are analogous to Tables in Relational Databases
  - All the columns of a rows are serialized and stored in a single file
- Typed columns
  - Primitive: integer, floating, double, string, Boolean, binary
  - Complex: array, maps, structs, union
- Ex:
  - CREATE TABLE table_name(id int, country string, state string, score double);
  - Files:

/hbase/table_name/

id, country, state, score
0, USA, CA, 90
1, USA, CA, 5
3, USA, TX, 75

Data Model: Partitions

- Partitions
  - Each Table can have one or more partition keys which determine how the data is stored
  - Hive creates nested subdirectories based on the order of partition columns in the table definition.
- Ex:
  - CREATE TABLE table_name(id int, score double) partitioned by (country string, state string);
  - Files:

/hbase/table_name/country=US/state=CA/

```
id, country, state, score
0, USA, CA, 90
1, USA, CA, 5
```

/hbase/table_name/country=US/state=TX/

```
id, country, state, score
3, USA, TX, 75
```

Data Model: Buckets

- Buckets
  - Data in each partition may in turn be divided into Buckets based on the hash of a column in the table.
  - Useful for sampling, join optimization
    - SELECT * FROM source TABLESAMPLE(BUCKET 3 OUT OF 32 ON rand());
- Ex:
  - CREATE TABLE t(id int, score double) partitioned by (country string, state string) cluster by (id) into 2 buckets;
  - Files:

/hbase/t/country=US/state=CA/file0

id, country, state, score
0, USA, CA, 90

/hbase/t/country=US/state=CA/file1

id, country, state, score
1, USA, CA, 5

ACID Transaction in Hive

- By default, Hive only updated partitions
  - INSERT …. OVERWRITE rewrote an entire partition
  - Force daily or even hourly partitions
  - No way to delete or update rows
- Reasonable:
  - Hadoop and Hive have always worked without ACID and treat it as a tradeoff for performance
  - But in many case, data is not STATIC…..

New SQL in Hive 0.14

- New DML
  - INSERT INTO T VALUES(1, 'fed', …)
  - UPDATE T SET (x=5) WHERE ….
  - DELETE FROM T WHERE …
- Restrictions
  - Table must have format that extends AcidInputFormat (ORC)
  - Table must be bucketed and not sorted
  - Table must be marked transactional

  ➔create table T (…) clustered by (a) into 2 buckets stored as orc TBLPROPERTIES (transactional='true')

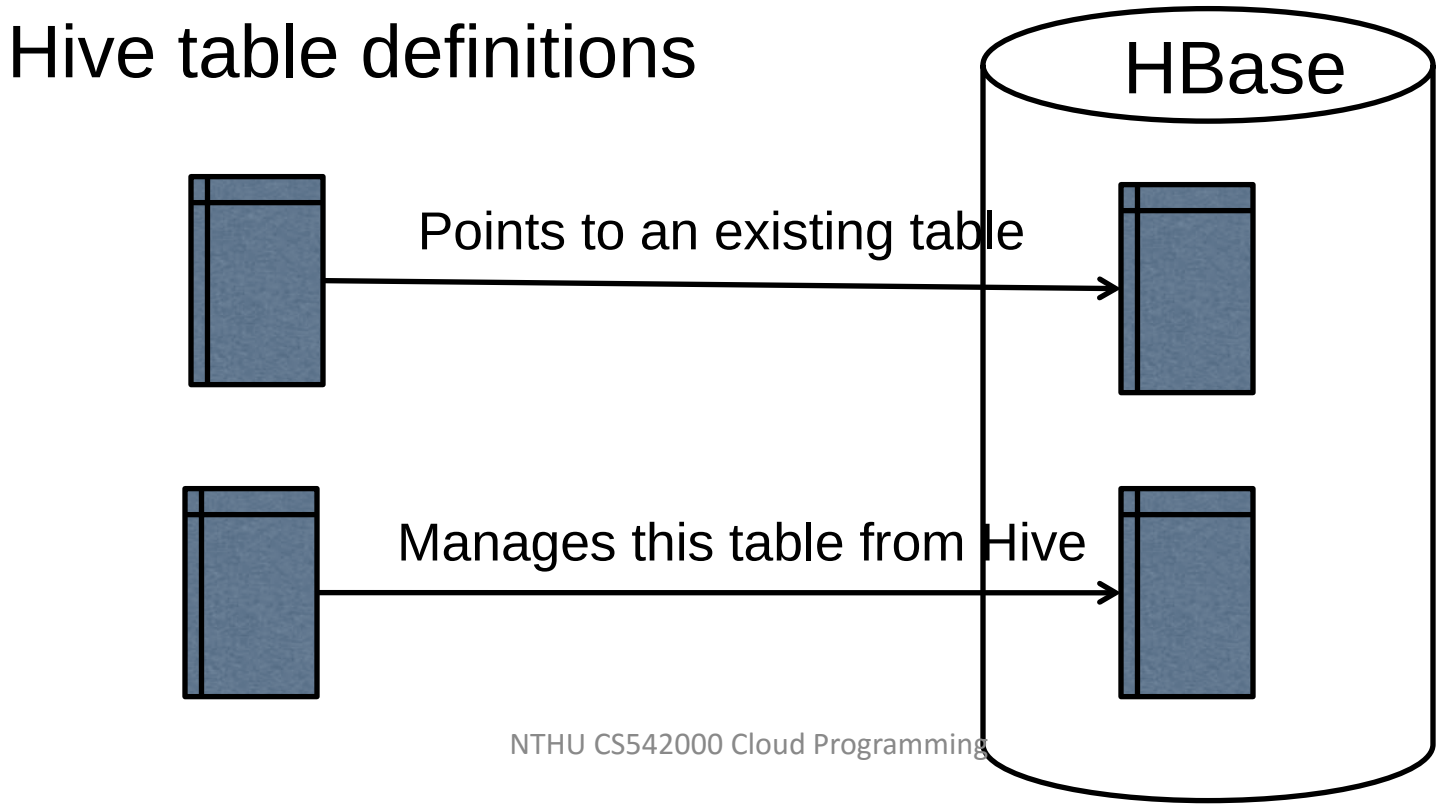
https://cwiki.apache.org/confluence/display/Hive/Hive+Transactions

Use case for Transactions

- Streaming ingest of data:
  - Users may use tools (e.g., Flume, Storm, Kafka) to stream data into Hadoop cluster at rates of hundreds or more rows per second. But, Hive can only add partitions every fifteen minutes to an hour. Enabling transactions can allow readers to get a consistent view of the data.
- Slow changing dimensions:
  - In a typical star schema data warehouse, dimensions tables change slowly over time. These changes lead to inserts of individual records or updates of records.
- Data restatement:
  - Sometimes collected data is found to be incorrect and needs correction. Or a user may be contractually required to remove their customer's data upon termination of their relationship.

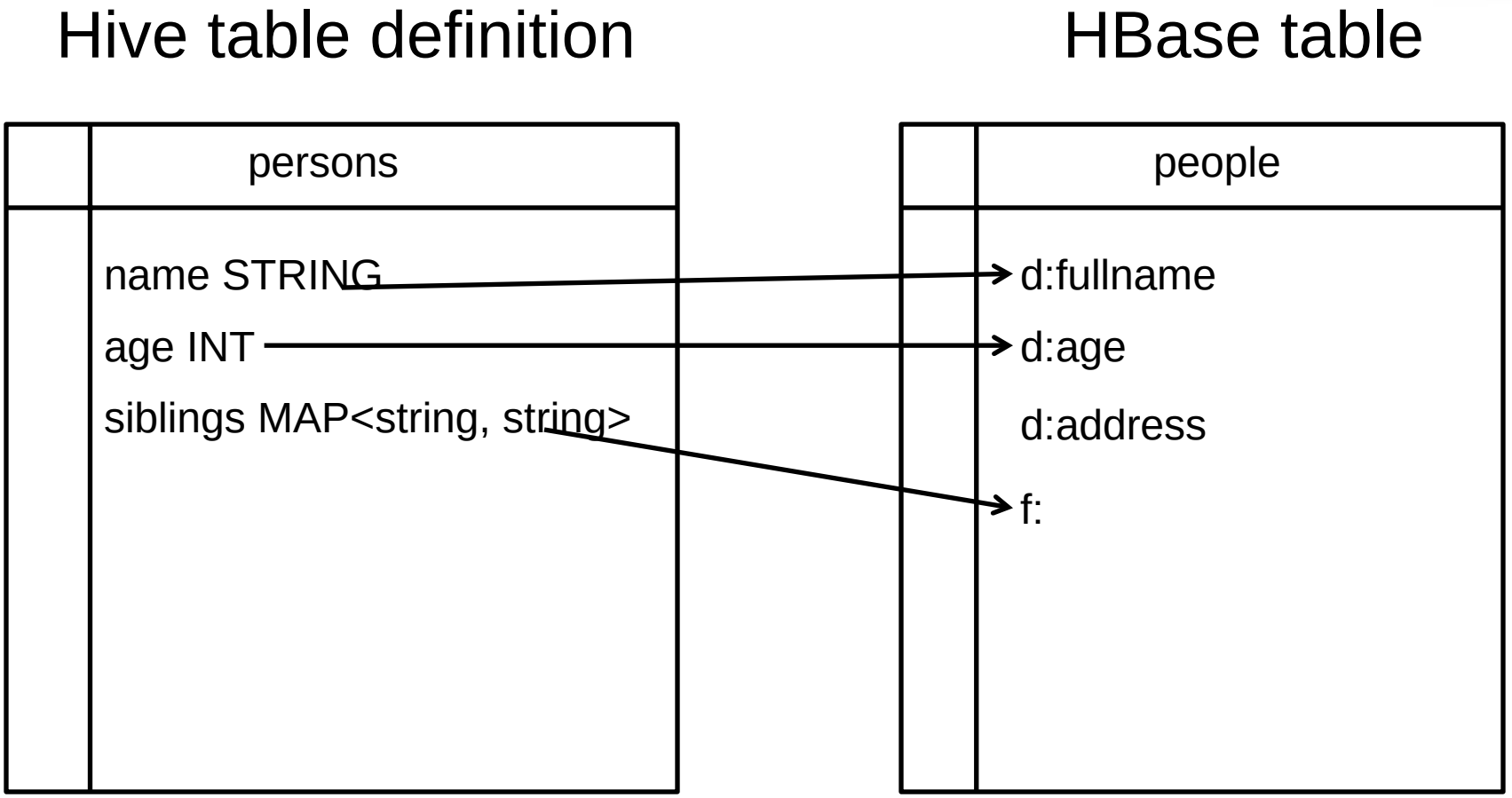
Hive over HBase

- Hive can use tables that already exist in HBase or manage its own ones, but they still all reside in the same HBase instance



Hive over HBase

- Columns are mapped with giving names and types



Hive vs HBase

	Hive	HBase
Design goal	Provide query capability over Hbase (But not a real-time query engine)	A scalable storage infrastructure that keeps data online
Data model	Structured: Typed columns	Unstructured: Un-typed
	RDMS	Key-value store
Operation	Only support overwrite, append, load	Support random read/write (i.e. cell)
Latency	High: batch job	Low: real-time operation
Interface	SQL-like lang.	Low level

Integration

- Reasons to use Hive on HBase:
  - Data sitting in HBase due to its usage in a real-time environment, but never used for analysis
  - Give access to data in HBase to people that don't code (business analysts)
  - When needing a more flexible storage solution, so that rows can be updated live by either a Hive job or an application and can be seen immediately to the other
- Reasons not to do it:
  - Run SQL queries on HBase to answer live user requests (it's still a MR job)
  - Hoping to see interoperability with other SQL analytics systems

References

- Nancy Lynch and Seth Gilbert, "Brewer's conjecture and the feasibility of consistent, available, partition-tolerant web services", *ACM SIGACT News*, Volume 33 Issue 2 (2002), pg. 51-59.
- S. GHEMAWAT, H. GOBIOFF, and S.-T. LEUNG, "The Google file system," In Proc. of the 19th ACM SOSP (Dec. 2003)
- Chang, F., et al. "Bigtable: A distributed storage system for structured data." In OSDI (2006).
- Hortonwork. "Hive does ACID" slides.
- Apache Hbase: http://hbase.apache.org/
- Apache Hive: https://hive.apache.org/

Backup

Data Integrity

Garbage Collection

Snapshot

GFS: FAULT TOLERANCE

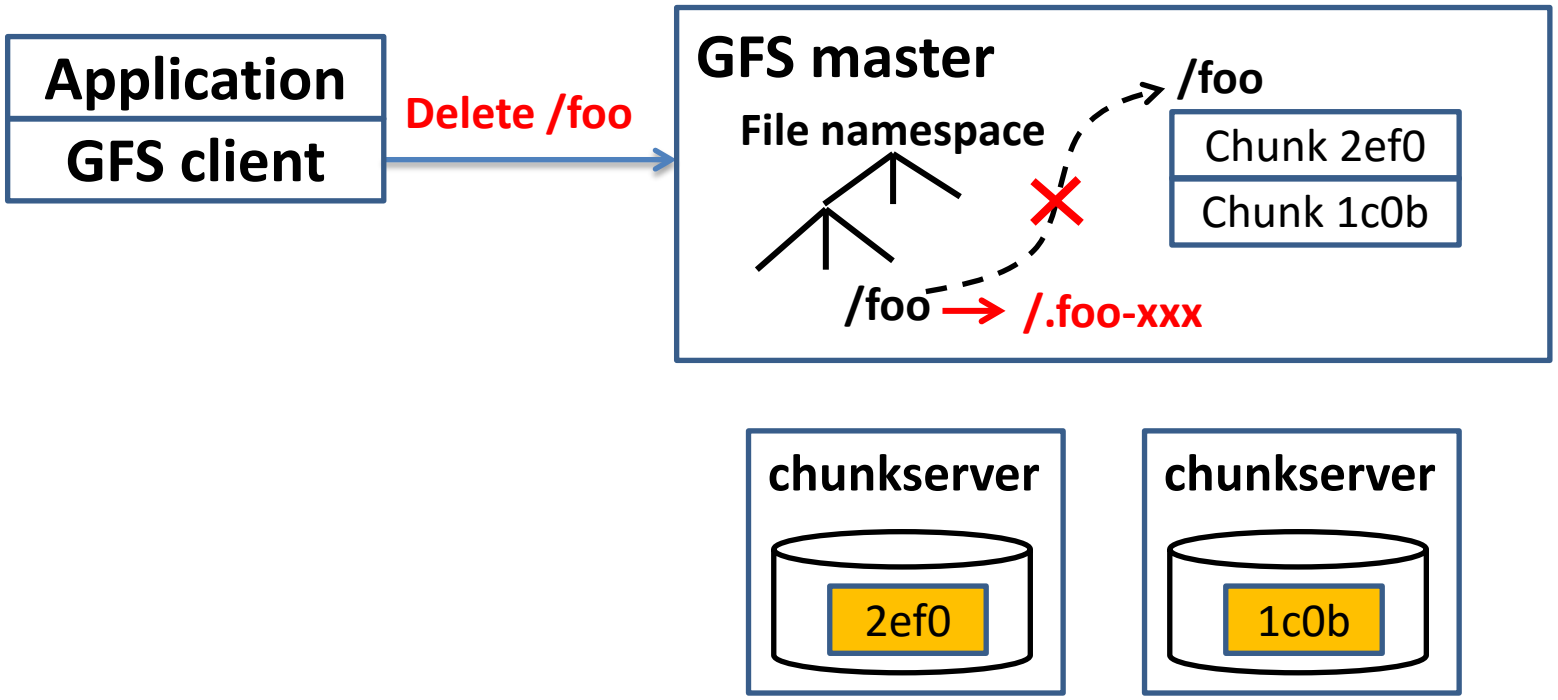
Data Integrity

- Integrity:
  - Data can’t be modified due to unexpected event, such as disk failure
- A responsibility of chunkservers, not master
  - GFS doesn't guarantee identical replica, independent verification is necessary
  - 32 bit checksum for every 64 KB block of data
  - chunkserver verifies checksum before every read
- If checksum mismatch occurs
  - Return error to client, report to master to delete the chunk
  - Client reads from another replica
  - Master makes another replica

Garbage Collection

- Chunks of deleted files are not reclaimed immediately

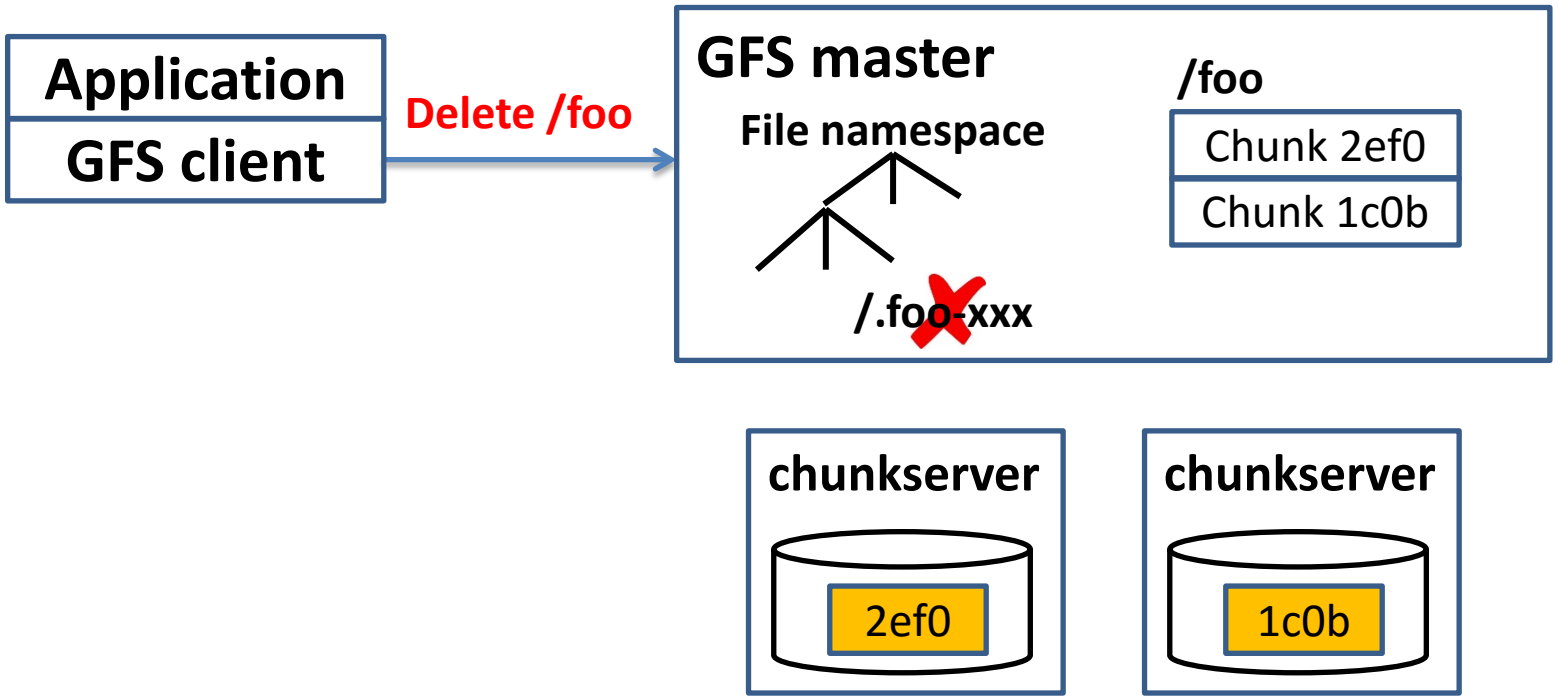
1. renames the file to a hidden name with timestamp, and record in log



Garbage Collection

- Chunks of deleted files are not reclaimed immediately

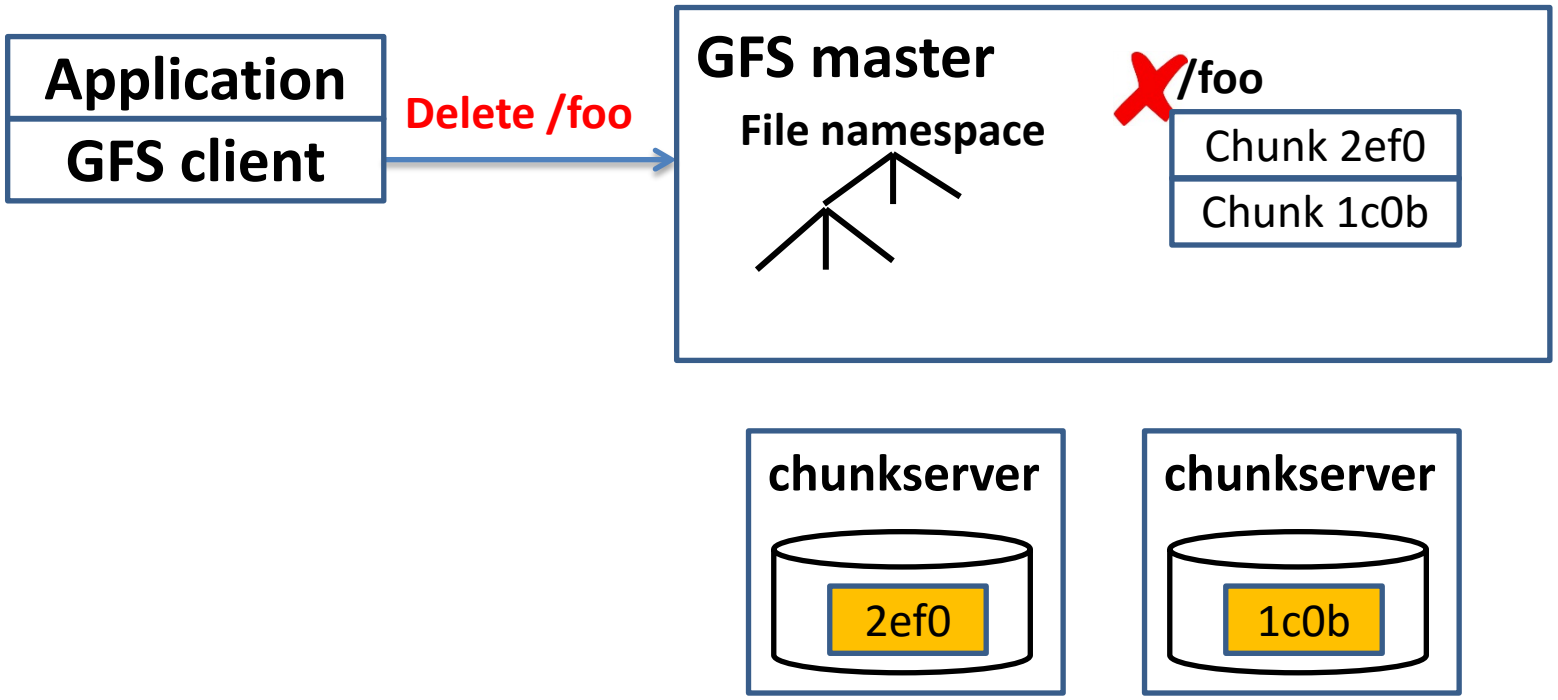
2. Master scans file namespace regularly to remove metadata of hidden files older than 3 days



Garbage Collection

- Chunks of deleted files are not reclaimed immediately

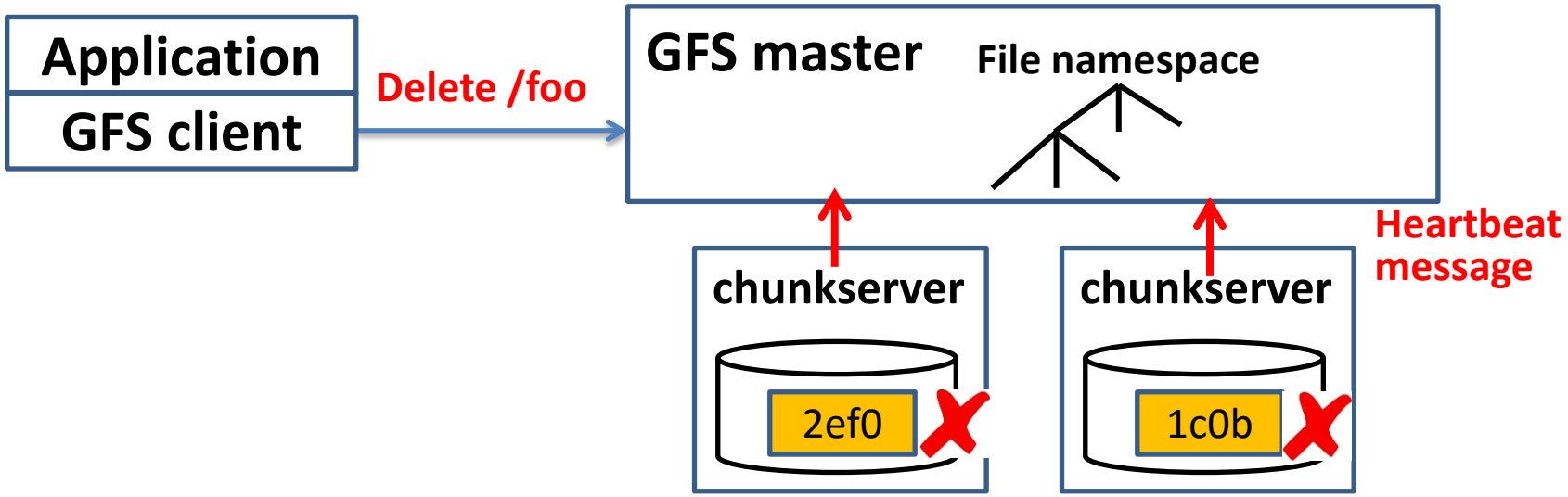
3. Master scans chunk table regularly to remove metadata of orphaned chunks



Garbage Collection

- Chunks of deleted files are not reclaimed immediately

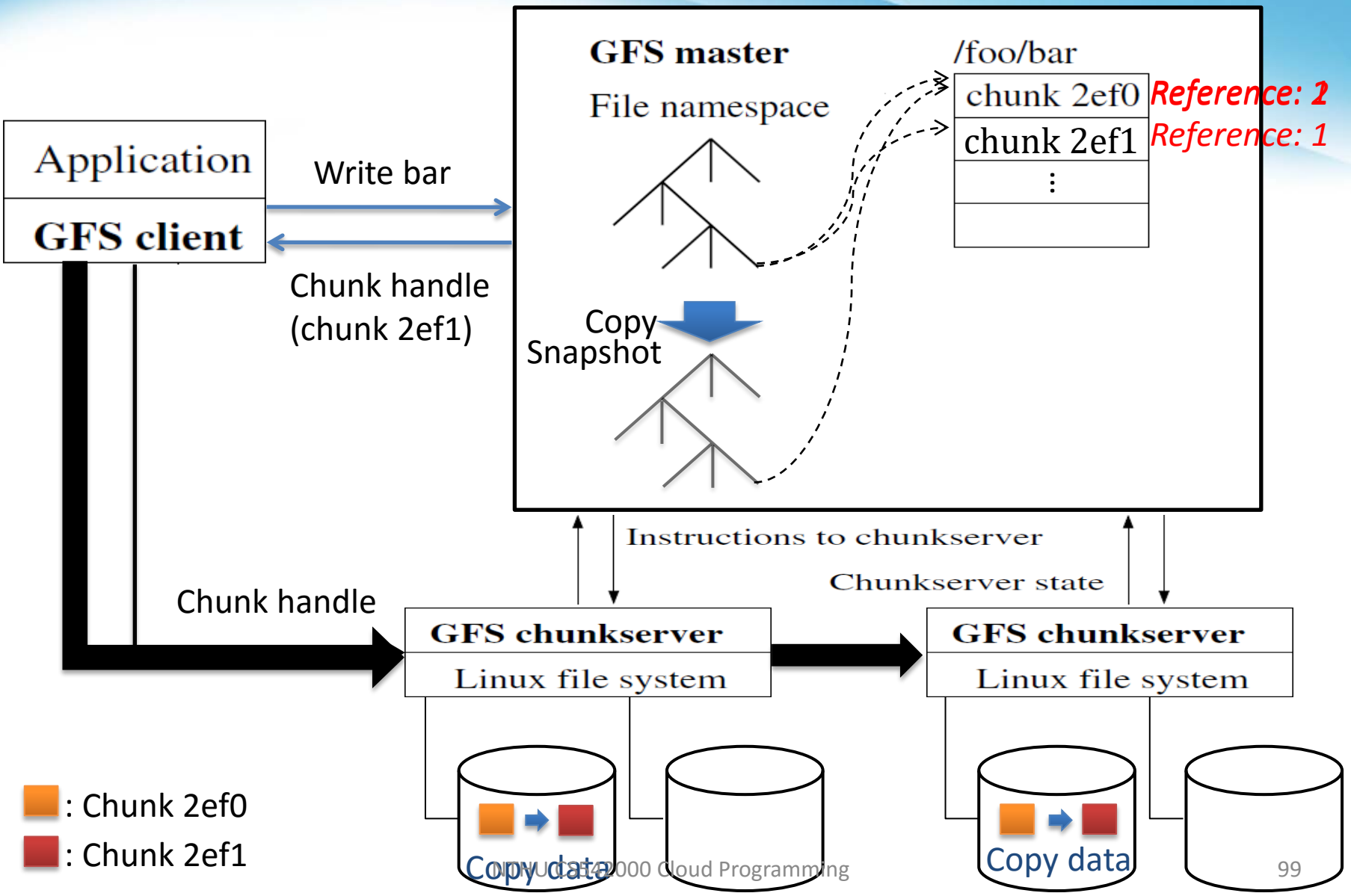
4. Chunkserver sends master a list of chunk handles it has in regular HeartBeat message
   - Master replies the chunks not in namespace
   - Chunkserver is free to delete the chunks



Snapshot

- Makes a copy of a file or a directory tree almost instantaneously for fault tolerance
  - minimize interruptions of ongoing mutations
  - copy-on-write with reference counts on chunks
- Steps:
  1. a client issues a snapshot request for source files
  2. master revokes all leases of affected chunks
  3. master logs the operation to disk
  4. master duplicates metadata of source files, pointing to the same chunks, increasing the reference count of the chunks
  5. New chunks are created on write request
  6. Perform write on new created chunk

Snapshot


GFS master
File namespace
/foo/bar
chunk 2ef0
Reference: 1
chunk 2ef1
Reference: 1
Application
GFS client
Write bar
Chunk handle
(chunk 2ef1)
Copy
Snapshot
Instructions to chunkserver
Chunkserver state
Chunk handle
GFS chunkserver
Linux file system
GFS chunkserver
Linux file system
: Chunk 2ef0
: Chunk 2ef1
Copy data
Copy data