Distributed Systems

18. Bigtable

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Bigtable

- Highly available distributed storage

- Built with semi-structured data in mind
  - URLs: content, metadata, links, anchors, page rank
  - User data: preferences, account info, recent queries
  - Geography: roads, satellite images, points of interest, annotations

- Large scale
  - Petabytes of data across thousands of servers
  - Billions of URLs with many versions per page
  - Hundreds of millions of users
  - Thousands of queries per second
  - 100TB+ satellite image data

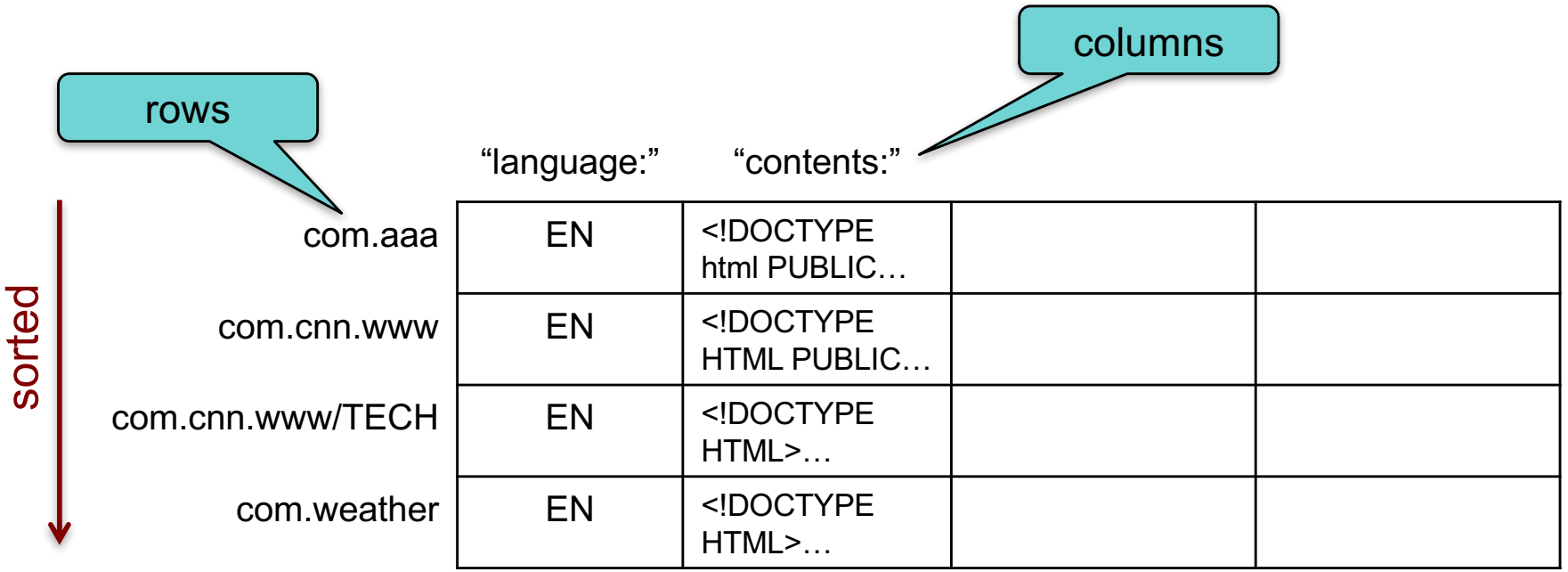
Uses

At Google, used for:

- Google Analytics
- Google Finance
- Personalized search
- Blogger.com
- Google Code hosting
- YouTube
- Gmail
- Google Earth & Google Maps
- Dozens of others…

A big table

- Bigtable is NOT a relational database
- Bigtable appears as a large table
  - "A Bigtable is a sparse, distributed, persistent multidimensional sorted map"*

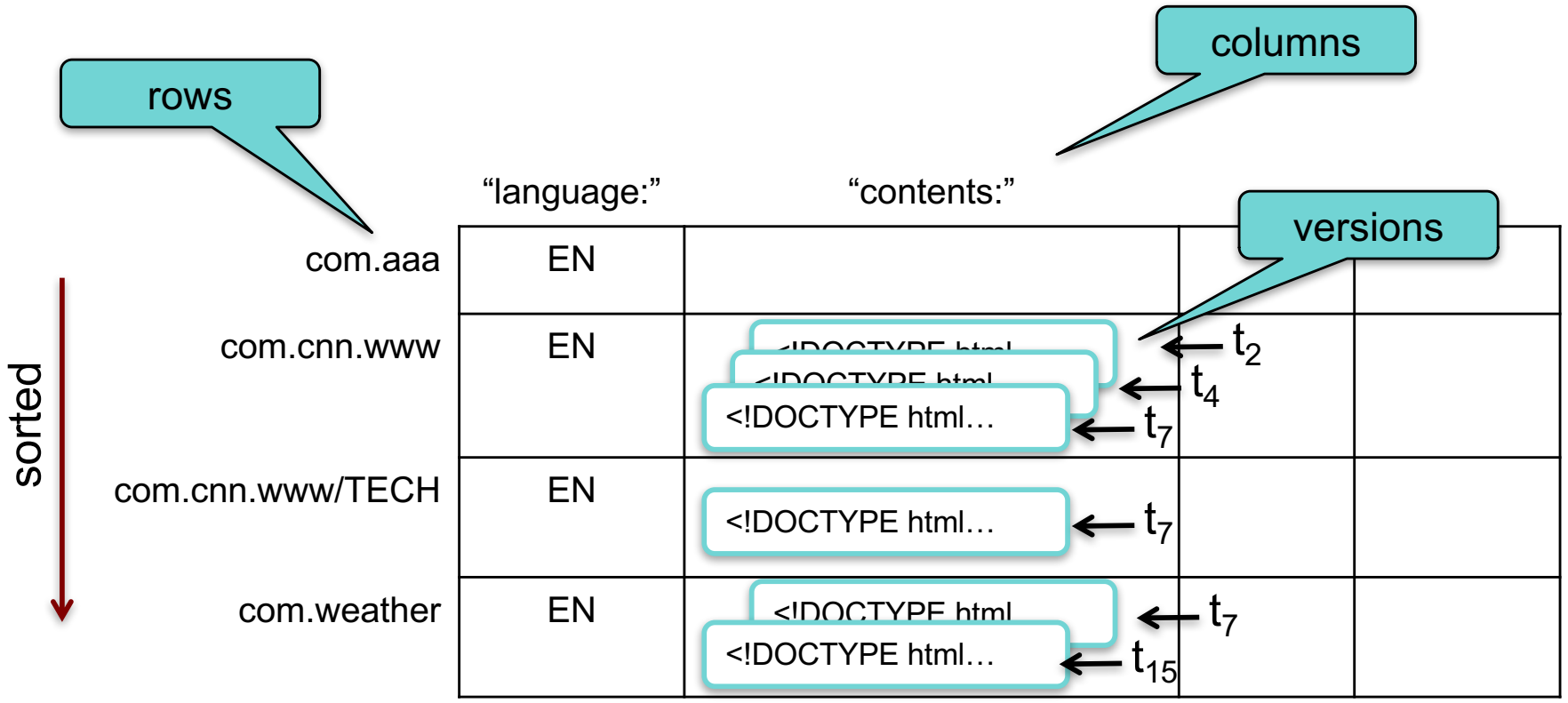


Web table example

*Bigtable: OSDI 2006

Table Model

- (row, column, timestamp) → cell contents
  - Contents are arbitrary strings (arrays of bytes)



Web table example

Tablets: Pieces of a Table

- Row operations are atomic
- Table partitioned dynamically by rows into tablets
- Tablet = range of contiguous rows
  - Unit of distribution and load balancing
  - Nearby rows will usually be served by the same server
  - Accessing nearby rows requires communication with a small # of machines
  - You need to select row keys to ensure good locality
    - E.g., reverse domain names:

      com.cnn.www instead of www.cnn.com

Table splitting

- A table starts as one tablet
- As it grows, it it split into multiple tablets
  - Approximate size: 100-200 MB per tablet by default

	"language:"	"contents:"		
com.aaa	EN	<!DOCTYPE html PUBLIC…		
com.cnn.www	EN	<!DOCTYPE HTML PUBLIC…		
com.cnn.www/TECH	EN	<!DOCTYPE HTML>…		
com.weather	EN	<!DOCTYPE HTML>…		

tablet

Splitting a tablet

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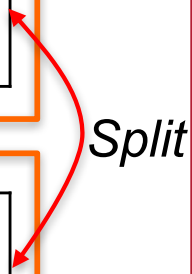
com.cnn.www/TECH	EN	<!DOCTYPE HTML>…		
com.weather	EN	<!DOCTYPE HTML>…		
com.wikipedia	EN	<!DOCTYPE HTML>…		
com.zcorp	EN	<!DOCTYPE HTML>…		
com.zoom	EN	<!DOCTYPE HTML>…		



Columns and Column Families

- Column Family
  - Group of column keys
  - Column family is the basic unit of data access
  - Data in a column family is typically of the same type
  - Implementation compresses data in the same column family
- Operations
  - (1) Create column family
  - (2) Store data in any key within the family
- Column families will typically be small
  - ≤ hundreds of keys; a table may have an unlimited # of column families
- Identified by

  family:qualifier

Column Families: example

Three column families

- "language:" – language for the web page
- "contents:" – contents of the web page
- "anchor:" – contains text of anchors that reference this page.
  - www.cnn.com is referenced by Sports Illustrated (cnnsi.com) and My-Look (mlook.ca)
  - The value of ("com.cnn.www", "anchor:cnnsi.com") is "CNN", the reference text from cnnsi.com.

Column family *anchor*

sorted

	"language:"	"contents:"	anchor:cnnsi.com	anchor:mylook.ca
com.aaa	EN	<!DOCTYPE html PUBLIC…		
com.cnn.www	EN	<!DOCTYPE HTML PUBLIC…	"CNN"	"CNN.com"
com.cnn.www/TECH	EN	<!DOCTYPE HTML>…		
com.weather	EN	<!DOCTYPE HTML>…		

Timestamps

- Each column family may contain multiple versions
- Version indexed by a 64-bit timestamp
  - Real time or assigned by client
- Per-column-family settings for garbage collection
  - Keep only latest *n* versions
  - Or keep only versions written since time *t*
- Retrieve most recent version if no version specified
  - If specified, return version where timestamp ≤ requested time

API: Operations on Bigtable

- Create/delete tables & column families
- Change cluster, table, and column family metadata (e.g., access control rights)
- Write or delete values in cells
- Read values from specific rows
- Iterate over a subset of data in a table
  - All members of a column family
  - Multiple column families
    - E.g., regular expressions, such as `anchor:*.cnn.com`
  - Multiple timestamps
  - Multiple rows
- Atomic read-modify-write row operations
- Allow clients to execute scripts (written in Sawzall) for processing data on the servers

Implementation: Supporting Services

- **GFS**
  - For storing log and data files
- **Cluster management system**
  - For scheduling jobs, monitoring health, dealing with failures
- **Google SSTable** (Sorted String Table)
  - Internal file format optimized for streaming I/O and storing <key,value> data
  - Provides a persistent, ordered, *immutable* map from keys to values
    - Append-only
  - Memory or disk based; indexes are cached in memory
  - If there are additions/deletions/changes to rows
    - New SSTables are written out with the deleted data removed
    - Periodic compaction merges SSTables and removes old retired ones

See http://goo.gl/McD6ex for a description of SSTable

Implementation: Supporting Services

- **Chubby**
  - Highly-available & persistent distributed lock (lease) service & file system
  - Five active replicas; one elected as master to serve requests
  - Majority must be running
  - Paxos algorithm used to elect master & keep replicas consistent
  - Provides namespace of files & directories
    - Each file or directory can be used as a lock

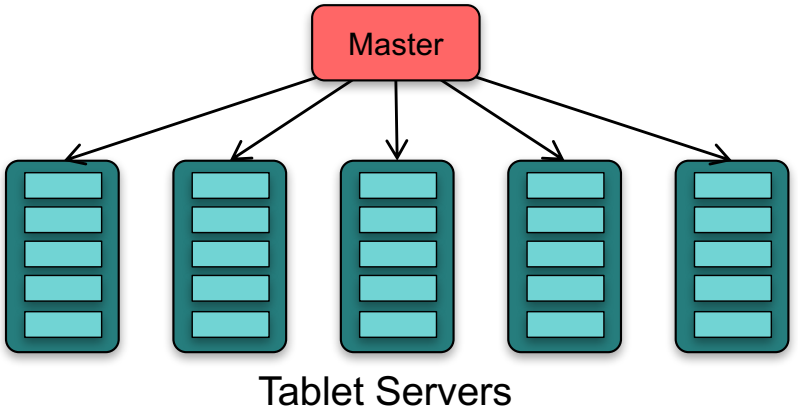
- In Bigtable, Chubby is used to:
  - Ensure there is only one active master
  - Store bootstrap location of Bigtable data
  - Discover tablet servers
  - Store Bigtable schema information
  - Store access control lists

Implementation

1. Many tablet servers – coordinate requests to tablets
   - Can be added or removed dynamically
   - Each manages a set of tablets (typically 10-1,000 tablets/server)
   - Handles read/write requests to tablets
   - Splits tablets when too large

2. One master server
   - Assigns tablets to tablet server
   - Balances tablet server load
   - Garbage collection of unneeded files in GFS
   - Schema changes (table & column family creation)

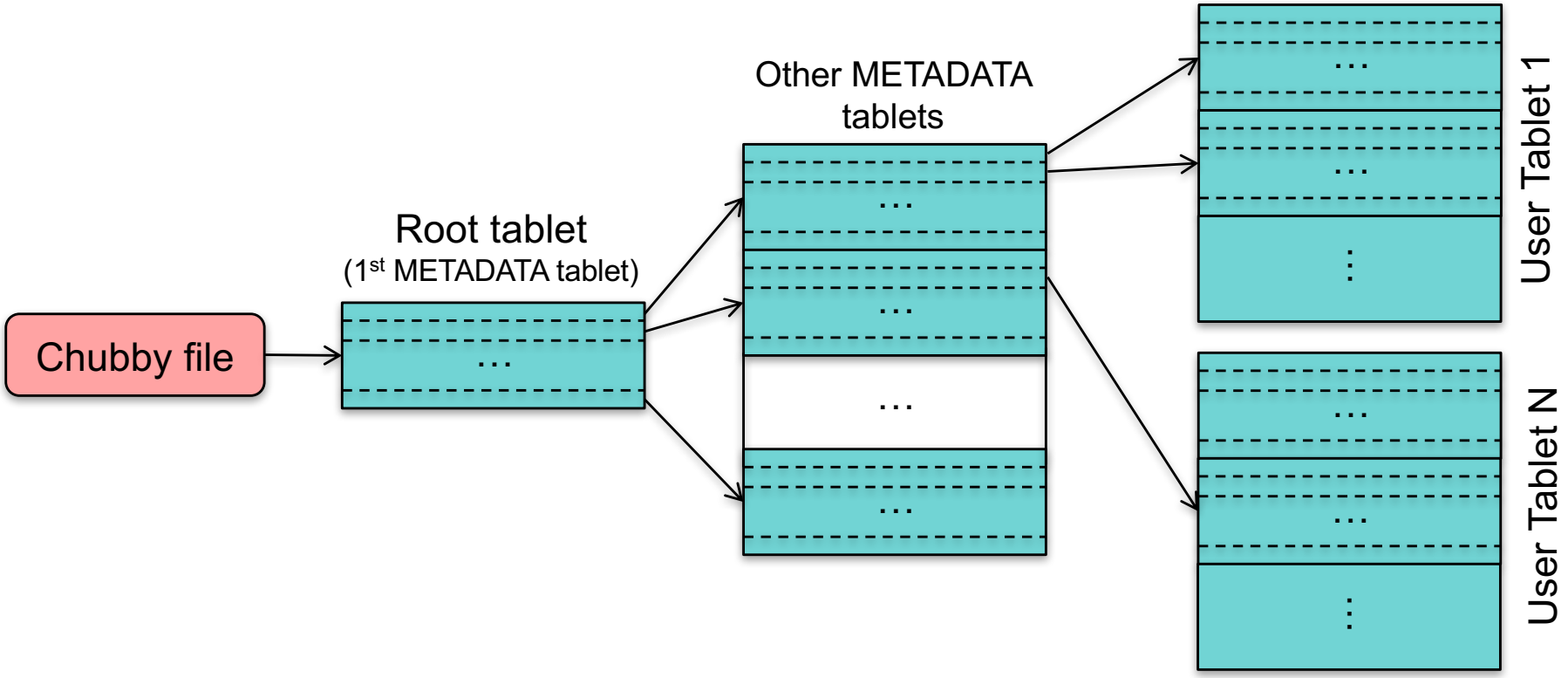
3. Client library



Implementation: METADATA table

Three-level hierarchy

- Balanced structure similar to a B+ tree
- Root tablet contains location of all tablets in a special METADATA table
- Row key of METADATA table contains location of each tablet
  f(table_ID, end_row) ⇒ location of tablet



Implementation

- Tablet assigned to one tablet server at a time
- Chubby keeps track of tablet servers
  - When tablet server starts:
    - It creates & acquires an exclusive lock on a uniquely-named file in a Chubby servers directory
    - Master monitors this directory to discover tablet servers
- When master starts:
  - Grabs a unique master lock in Chubby (prevent multiple masters)
  - Scans the servers directory in Chubby to find live tablet servers
  - Contacts each tablet server to discover what tablets are assigned to that server
  - Scans the METADATA table to learn the full set of tablets
    - Build a list of tablets not assigned to servers
      – These will be assigned by choosing a tablet server & sending it a *tablet load* request

Implementation

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Fault Tolerance

- Fault tolerance is provided by GFS & Chubby
- Dead tablet server
  - Master is responsible for detecting when a tablet server is not working
    - Asks tablet server for status of its lock
    - If the tablet server cannot be reached or has lost its lock
      - Master attempts to grab that server's lock
      - If it succeeds, then the tablet server is dead or cannot reach Chubby
      - Master moves tablets that were assigned to that server into an unassigned state
- Dead master
  - Master kills itself when its Chubby lease expires
  - Cluster management system detects a non-responding master
- Chubby: designed for fault tolerance (5-way replication)
- GFS: stores underlying data – designed for *n*-way replication

Bigtable Replication

- Each table can be configured for replication to multiple Bigtable clusters in different data centers

- Eventual consistency model

Sample applications

- Google Analytics
  - Raw Click Table (~200 TB)
    - Row for each end-user session
    - Row name: {website name and time of session}
      - Sessions that visit the same web site are sorted & contiguous
  - Summary Table (~20 TB)
    - Contains various summaries for each crawled website
    - Generated from the Raw Click table via periodic MapReduce jobs

Sample applications

- Personalized Search
  - One Bigtable row per user (unique user ID)
  - Column family per type of action
    - E.g., column family for web queries (your entire search history!)
  - Bigtable timestamp for each element identifies when the event occurred
  - Uses MapReduce over Bigtable to personalize live search results

Sample applications

- Google Maps / Google Earth
  - Preprocessing
    - Table for raw imagery (~70 TB)
    - Each row corresponds to a single geographic segment
    - Rows are named to ensure that adjacent segments are near each other
    - Column family: keep track of sources of data per segment
      (this is a large # of columns – one for each raw data image – but sparse)
  - MapReduce used to preprocess data
  - Serving
    - Table to index data stored in GFS
    - Small (~500 GB) but serves tens of thousands of queries with low latency

Bigtable outside of Google

Apache HBase

- Built on the Bigtable design
- Small differences (may disappear)
  - access control not enforced per column family
  - Millisecond vs. microsecond timestamps
  - No client script execution to process stored data
  - Built to use HDFS or any other file system
  - No support for memory mapped tablets
  - Improved fault tolerance with multiple masters on standby

Bigtable vs. Amazon Dynamo

- Dynamo targets apps that only need key/value access with a primary focus on high availability
  - key-value store versus column-store (column families and columns within them)
  - Bigtable: distributed DB built on GFS
  - Dynamo: distributed hash table
  - Updates are not rejected even during network partitions or server failures

The end