Google File System

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- Google needed a good distributed file system
- Why not use an existing file system?
  - Different workload and design priorities
  - GFS is designed for Google apps
  - Google apps are designed for GFS!

- What are the applications and the workload considerations that drives the design of GFS?

Google Workload

- Hundreds of web-crawling application
- Files: few million of 100MB+ files
- Reads: small random reads and large streaming reads
- Writes:
    - many files written once, read sequentially
    - random writes non-existent, mostly appends

Life without random writes

- E.g., results of a previous search:

  www.page1.com -> www.my.blogspot.com
  www.page2.com -> www.my.blogspot.com

- Let's say new results: page2 no longer has the link, but there is a new page, page3:

  www.page1.com -> www.my.blogspot.com
  www.page3.com -> www.my.blogspot.com

- Option: delete the old record (page2), and insert a new record (page3). This is cumbersome!
  - requires locking; just way too complex.
  - better: delete the old file, create a new file where this program (run on more than one machines) can append new records to the file "atomically"

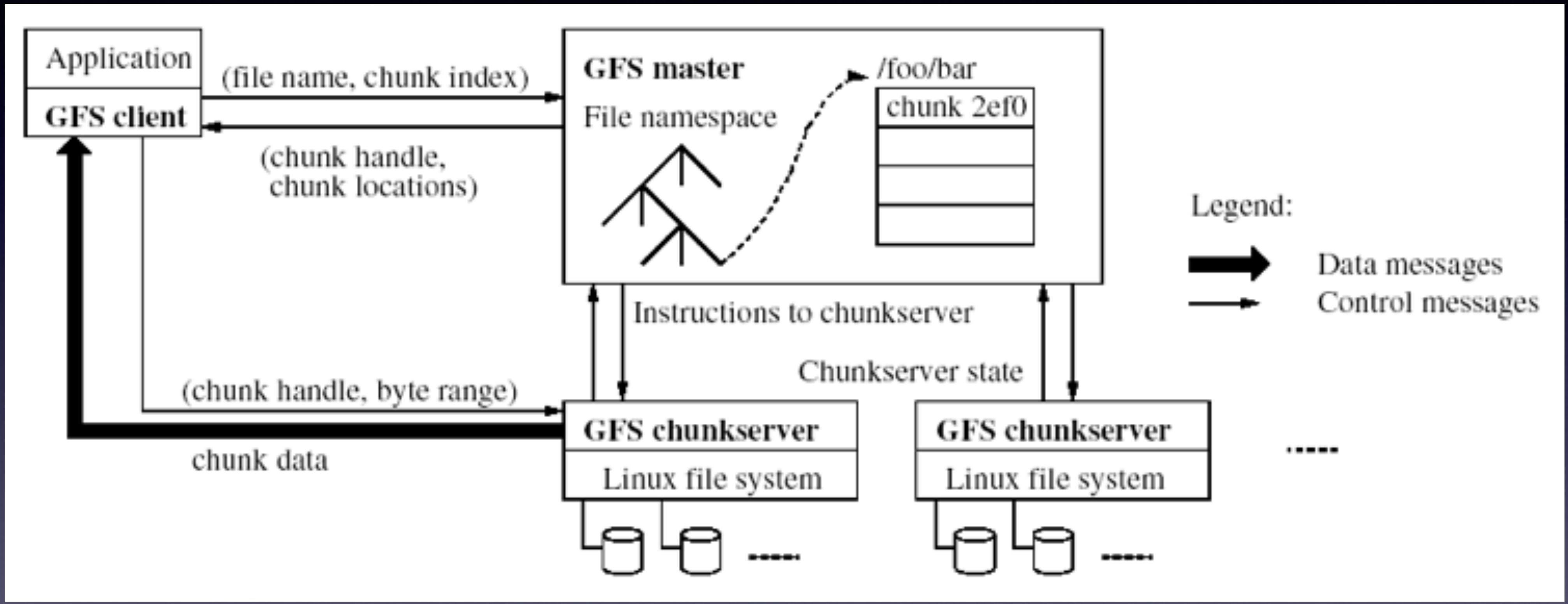
Atomic Record Append

- GFS client contacts the master
- Master chooses and returns the offset
- Client appends the data to each replica at least once
- No need for a distributed lock manager; actual write can be an idempotent RPC (like in NFS)

GFS Design Decisions

- Files stored as chunks (fixed size: 64MB)
- Reliability through replication
  - each chunk replicated over 3+ chunkservers
- Simple master to coordinate access, keep metadata
- No data caching! Why?
- Familiar interface, but customize the API
  - focus on Google apps; add snapshot and record append operations

GFS Architecture



- What are the implications of this design?

Key Design Choices

- Shadow masters
- Minimize master involvement
  - Never move data through it (only metadata)
  - Cache metadata at clients
  - Large chunk size
  - Master delegates authority to primary replicas in data mutations

Metadata

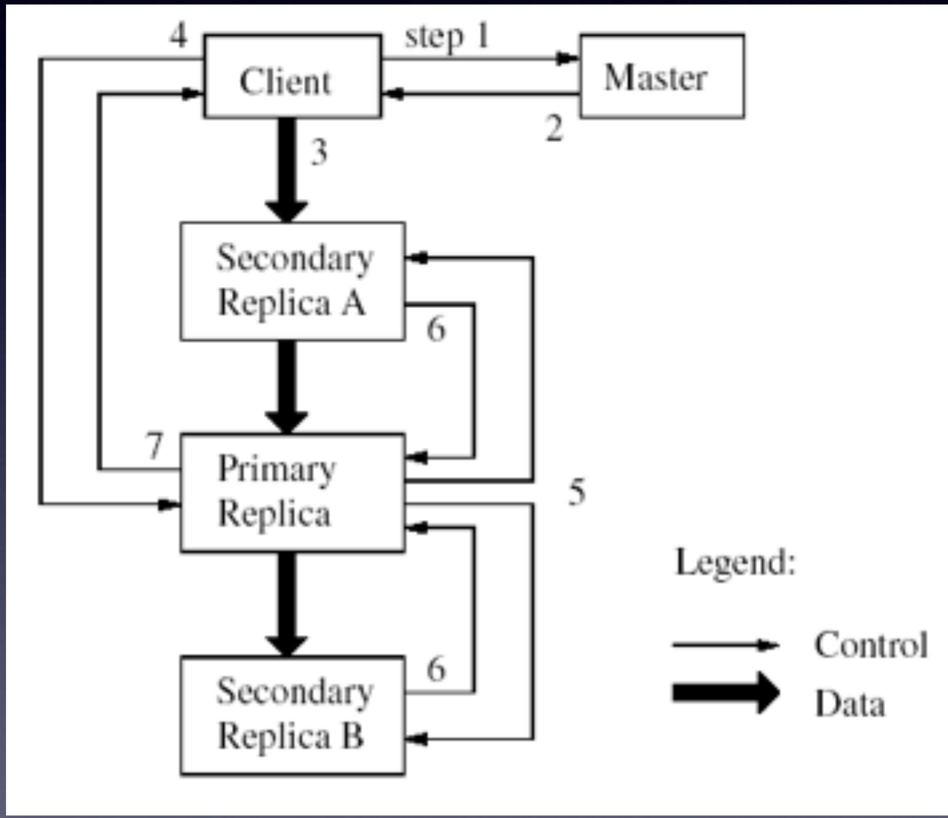
- Global metadata is stored on the master
  - File and chunk namespaces
  - Mapping from files to chunks
  - Locations of each chunk's replicas
- All in memory (64B/chunk)
  - Few million files ==> can fit all in memory

Durability

- Master has an operation log for persistent logging of critical metadata updates
  - each log write is 2PC to multiple remote machines
  - replicated transactional redo log
  - group commit to reduce the overhead
  - checkpoint all (log) state periodically; essentially mmap file to avoid parsing
  - checkpoint: switch to new log and copy snapshot in background

Mutable Operations

- Mutation is write or append
- Goal: minimize master involvement
- Lease mechanism
  - Master picks one replica as primary; gives it a lease
  - Primary defines a serial order of mutations
- Data flow decoupled from control flow



Write Operations

- Application originates write request
- GFS client translates request from (fname, data) --> (fname, chunk-index) sends it to master
- Master responds with chunk handle and (primary+secondary) replica locations
- Client pushes write data to all locations; data is stored in chunkservers' internal buffers
- Client sends write command to primary

Write Operations (contd.)

- Primary determines serial order for data instances stored in its buffer and writes the instances in that order to the chunk
- Primary sends serial order to the secondaries and tells them to perform the write
- Secondaries respond to the primary
- Primary responds back to client
- Note: if write fails at one of the chunkservers, client is informed and retries the write

BigTable Motivation

- Lots of (semi)-structured data at Google
  - URLs: contents, crawl metadata, links
  - Per-user data: preference settings, recent queries
  - Geographic locations: physical entities, roads, satellite image data
- Scale is large:
  - Billions of URLs, many versions/page
  - Hundreds of millions of users, queries/sec
  - 100TB+ of satellite image data

Why not use commercial DB?

- Scale is too large for most commercial databases
- Even if it weren't, cost would be very high
  - Building internally means system can be applied across many projects
- Low-level storage optimizations help performance significantly
  - Much harder to do when running on top of a database layer

Goals

- Want asynchronous processes to be continuously updating different pieces of data
  - want access to most current data
- Need to support:
  - very high read/write rates (million ops/s)
  - efficient scans over all or interesting subsets
  - efficient joins of large datasets
- Often want to examine data changes over time
  - E.g., contents of web page over multiple crawls

Building blocks

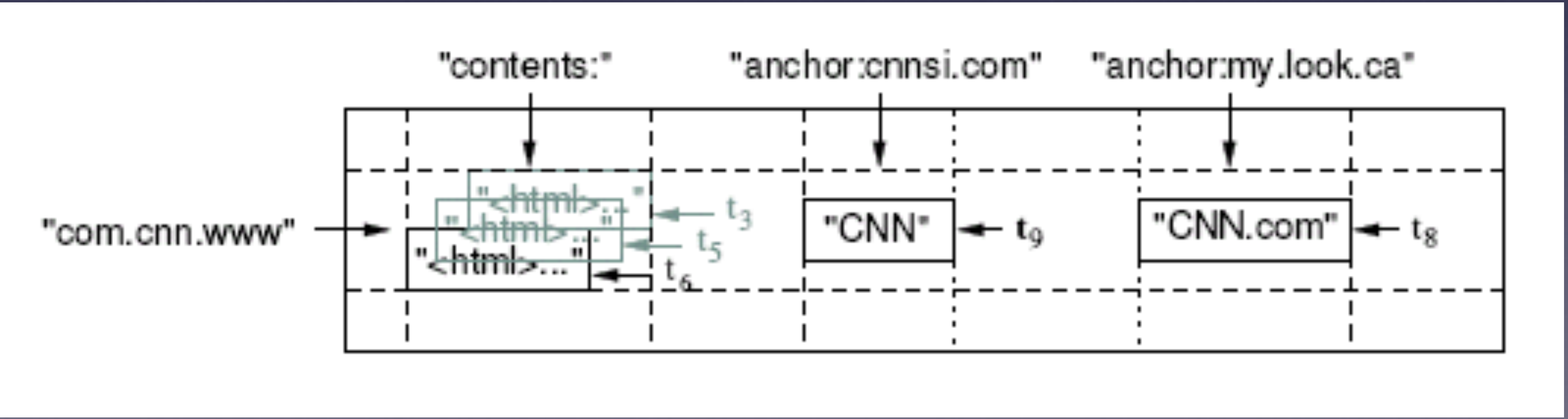
- GFS: stores persistent state
- Scheduler: schedules jobs involved in BigTable serving
- Lock service: master election
- MapReduce: often used to read/write BigTable data

BigTable Overview

- Data Model
- Implementation structure
  - Tablets, compactions, locality groups, ...
- API
- Details
  - Shared logs, compression, replication, ...

Basic Data Model

- Distributed multi-dimensional sparse map
- (row, column, timestamp) --> cell contents
- Good match for most of Google's applications



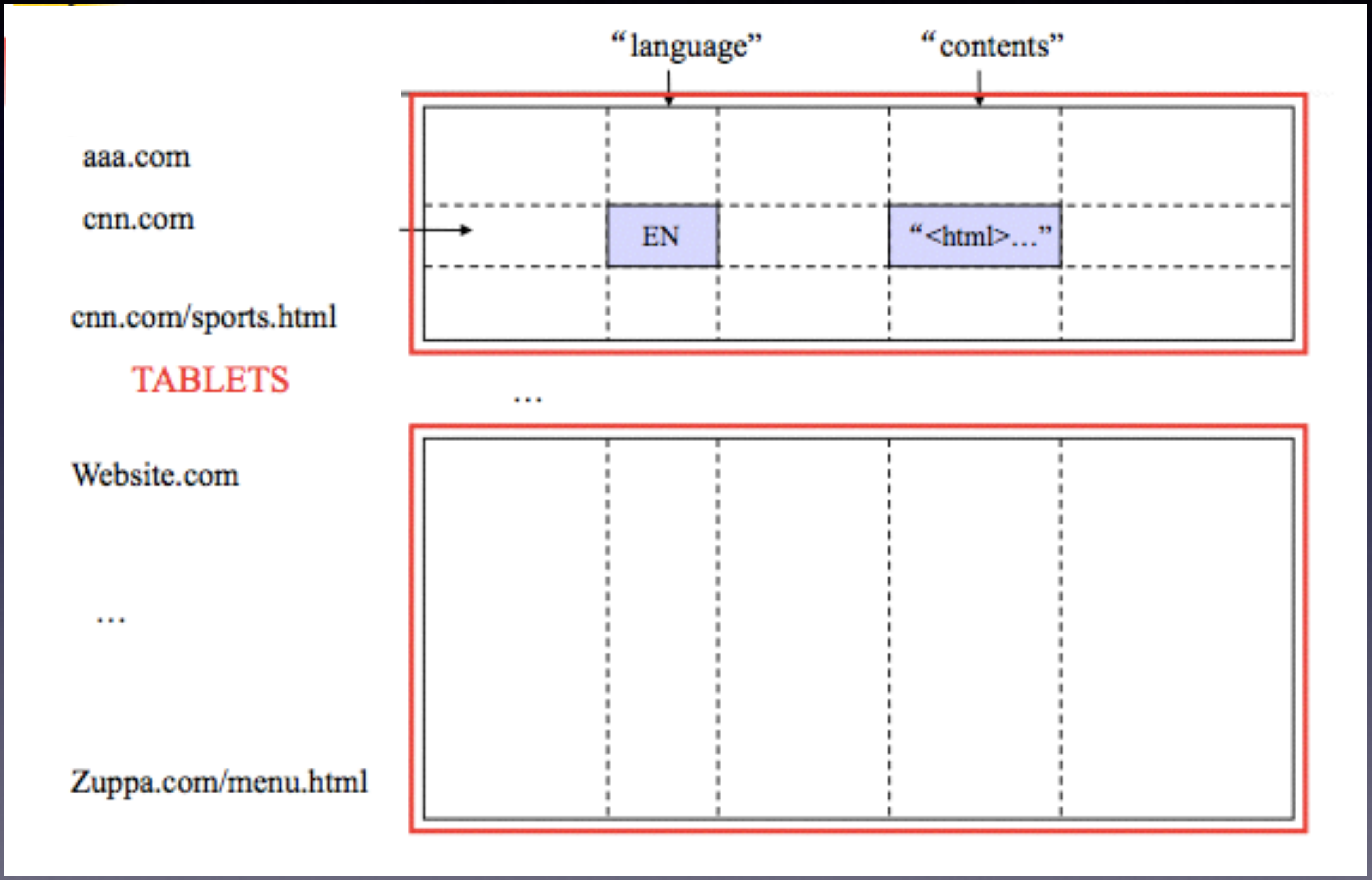
Rows

- Name is an arbitrary string
  - Access to data in a row is atomic
  - Row creation is implicit upon storing data
- Rows ordered lexicographically
  - Rows close together lexicographically usually on one or a small number of machines

Tablets

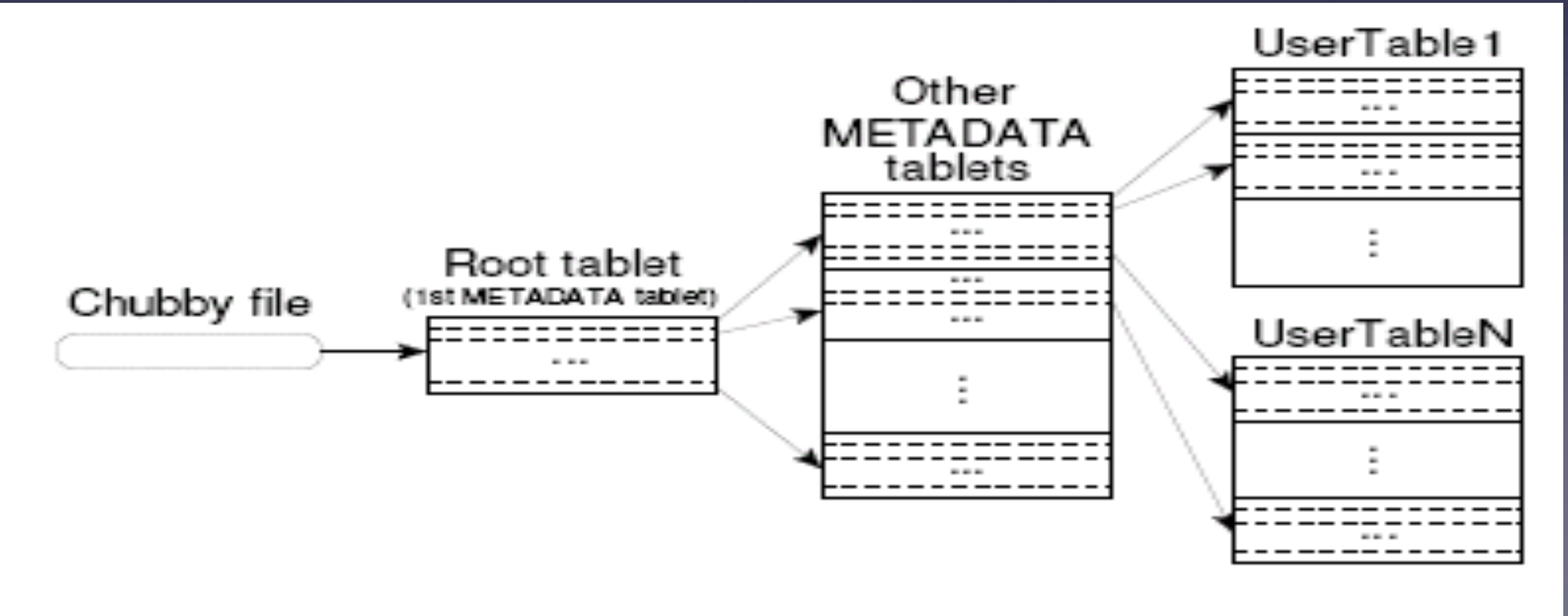
- Large tables broken into “tablets” at row boundaries
  - Tablet holds contiguous range of rows
  - Aim for 100MB to 200MB of data/tablet
- Serving machine responsible for about 100 tablets
  - Fast recovery (100 machines each pick up 1 tablet from failed machine)
  - Fine-grained load balancing

Tablets & Splitting



Locating Tablets

- Approach: 3-level hierarchical lookup scheme for tablets
  - Location is ip:port of relevant server
  - 1st level: bootstrapped from lock server, points to META0
  - 2nd level: Uses META0 data to find owner of META1 tablet
  - 3rd level: META1 table holds location of tablets of all other tables



Basic Implementation

- Writes go to log then to in-memory table "memtable" (key, value)
- Periodically move in-memory table to disk
  - SSTable is immutable ordered subset of table; range of keys & subset of their columns
  - Tablet = all of the SSTables for one key range plus the memtable
  - some values maybe stale (due to new writes)

Basic Implementation

- Reads: maintain in-memory map of keys to SSTables
  - current version is in exactly one SSTable or memtable
  - reading based on timestamp requires multiple reads
  - may also have to read many SSTables to get all of the columns
- Compaction:
  - SSTables similar to segments in LFS
  - need to clean old SSTables to reclaim space
  - clean by merging multiple SSTables into new one

Bloom filters

- Goal: efficient test for set membership: member(key) -> true/false
    - false ==> definitely not in the set
    - true ==> probably is in the set
- Generally supports adding elements but not removing them
- Basic version: m bit positions, k hash functions
    - For insert: compute k bit locations, set to 1
    - For lookup: compute k locations, check for 1
- BigTable: avoid reading SSTables for elements that are not present; saves many seeks