Bigtable: A Distributed Storage System for Structured Data

Course: CS655

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Thursday 17 October 2013
1. **Databases: Generalities**
   - Relational database
   - Other SQL database models
   - Why is this not enough?

2. **Bigtable**
   - Description
   - Google FS: underlying FS
   - Chubby: Failure resilience
   - Paxos
   - Some optimizations

3. **Other NoSQL**
   - An old problem
   - Extensible Record Stores
   - Document stores
   - Key-value stores
   - RAM databases

4. **Thoughts**

5. **Conclusion**
Plan

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4. Thoughts

5. Conclusion
Reminders on relational database model

SQL family
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First order predicate
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- Based on two values: true and false.
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- A query = a formula
  \( \forall students, \text{Nationality} = \text{French} \land \text{Position} = \text{GRA} \)
### Hierarchical Databases

Hierarchical databases are a type of database system that organizes data in a hierarchical structure, typically represented as a tree. This structure allows for efficient access to data but can be limiting in its flexibility compared to other database models.

- **Hierarchical Databases**
  - Tree structure.
  - Efficient implementations.
  - Overkill if the data has simple relations.

**Other SQL database models**
- [ ] Hierarchical Databases
- [ ] Relational Databases
- [ ] Object Databases

**Bigtable**
- [ ]
- [ ]
- [ ]
- [ ]
- [ ]

**Other NoSQL**
- [ ]
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Object Databases
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✓ Close to programming languages.
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Why is this not enough?

How to express query on a text?
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You have to reconstruct some kind of relation more or less manually even if some solutions exists [JDG08].
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How do you do if a single server is not enough?
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- Partitioning → write expensive
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**How do you do if a single server is not enough?**

- Partitioning → write expensive small scheme showing why it requires two-phase commit
- Replications → write expensive
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BigData

Usage of the architecture

- URLs
BigData

Usage of the architecture

- URLs
- Locations
BigData

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- URLs
- Locations
- Data Personalized: settings, search
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- Goal is to let users handle data storage structure
- Locality is important
- A data = an uninterpreted string
- Goes nicely with Map Reduce.
Challenges

- Unstructured Data.
## Challenges

- **Unstructured Data.**
- **Scale.**
Challenges

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- Continuous Update (crawling).
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Challenges

- Unstructured Data.
- Scale.
- Continuous Update (crawling).
- Read should be allowed at any time.
- Very high rates of accesses $\rightarrow$ load-balancing.
- Failure resilient (adding and removing servers at any time).
Data Model
Column-oriented database

Properties
Column-oriented database

Properties

- Row writes are atomic.
Column-oriented database

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- Column family is other group.
- Several versions: usage of timestamp.
  - last n versions.
  - fresh enough (age limit).
## Architecture

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**Description**
Architecture

[Diagram of Chubby, Master, M1, M2]
Architecture

Chubby

Master

$M_1$

$M_2$

GFS Master

Scheduler
Architecture
Architecture
Architecture

Chubby

Master

M₁  M₂

GFS Master

Scheduler

TS₁

TS₂
Architecture

- **Chubby**
  - Master
    - M₁
    - M₂
  - TS₁
  - TS₂
- **GFS Master**
- **Scheduler**
Architecture

Chubby

Master

\( M_1 \)

\( M_2 \)

GFS Master

Scheduler

TS1

TS2

Client

Description
Architecture

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  - Master
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    - $M_2$

- **GFS Master**

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- **Client**
  - $TS_1$
  - $TS_2$
Architecture

Chubby

Master

M₁

M₂

GFS Master

Scheduler

TS₁

TS₂

Client
Internal Storage

**Key** | **Value**  
--- | ---  
**Key** | **Value**  
**Key** | **Value**  
**Index**
Internal Storage

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  - Increase the number of SSTables.
  - Persistence can be achieved by differential instead of using a full copy.
**Tablets Location**

B-Tree+ to store tablet location.
## Tablets Assignment and Serving

- No duplication of tablets.
Tablets Assignment and Serving

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![Diagram of tablets assignment and serving](image-url)
Reminder on GFS

- Moderate number of Huge Files
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Chubby in BigTable

Used for:
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Used for:

- Electing a unique master.
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- Discover tablets.
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- Column family lists.
Some details

- 5 replicas; one will be the Chubby master.
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- Based on the Paxos algorithm.
Some details

Session

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- ✗ slow failure detection by the client.
- ✔ few redundant packets
- ✗ why clients should fail?
Some details

Failovers
If a master fails a new master need to take over the system.
Chubby: Failure resilience

Some details

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❌ Complicated.
Paxos algorithm

Originally for parliament decree.
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Properties wanted
Paxos algorithm

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**Paxos algorithm**

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**Properties wanted**

- At most one decree decided (safety)
- At least one decree (liveness)
### Properties on ballots

Make liveness possible and ensure consistency (safety property)
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Properties on ballots

Make liveness possible and ensure consistency (safety property)

- Each ballot has a unique number.
- Every quorum has at least one priest in common.
- For every ballot B, if a priest in the quorum has voted in a earlier ballot then the decree in B is equal to the lastest ballot where the priest voted.
Back to Paxos in Chubby

Consensus
Back to Paxos in Chubby

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- Several coordinators will propose a value.
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- Since we want to have a consensus on several values, Paxos will be repeated: Need a catch-up mechanism for slow machines.
Properties of Paxos/Chubby
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✓ Handle disk corruption
## Properties of Paxos/Chubby

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3. major compaction: merging compaction using all the SSTables.
Locality

Grouping column families into a locality group.
Locality

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Some optimizations

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### Locality

Grouping column families into a locality group. Each locality group will have an SSTable.

- ✔ Will provide performance improvement if columns that are not accessed together are on separate SSTables.
- ✗ Actually difficult to know how to do it dynamically.
Compression and caching

- Clients can decide what compression scheme to use for SSTables (portion of it, different per SSTable).
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### Compression and caching

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  - Typical compression:
    - First algorithm will look for similarities over a large window.
    - Second algorithm will look for common string in a small window 16KB.
- Tablet server will use cache to improve latency.
### Logging

How would you store the logs about the tablets?
Logging

How would you store the logs about the tablets?

- A separate log for each tablet?
Some optimizations

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Logging

How would you store the logs about the tablets?

- A separate log for each tablet? GFS is used for accessing a moderate number of files...
- One huge log? What about failure recovery time?
- Two logs are used (only one is active) and they are sorted using table id, row name and sequence number
Some optimizations

Bloom filters

**Problem**
Read requires accessing all SSTables inside a tablet.
**Bloom filters**

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Read requires accessing all SSTables inside a tablet.
Stressful for the disk.
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Bloom filters

Problem
Read requires accessing all SSTables inside a tablet. Stressful for the disk.

- A blooming filter can be used to help locate the data when knowing the column and the row.
- A blooming filter is an improved hashing method.
Bloom filters

**FILTER**

Do you have 'key1'?
- No

Do you have 'key2'?
- Yes: here is key2

Do you have 'key3'?
- False Positive
  - Filter: Yes
  - Storage: No

**STORAGE**

Filter: No
- Storage: No

Filter: Yes
- disk access
- Yes: here is key2

Filter: Yes
- disk access
- No
- unnecessary disk access
- Storage: No
- Storage: Yes
Plan

1. Databases: Generalities
   - Relational database
   - Other SQL database models
   - Why is this not enough?

2. Bigtable
   - Description
   - Google FS: underlying FS
   - Chubby: Failure resilience
   - Paxos
   - Some optimizations

3. Other NoSQL
   - An old problem
   - Extensible Record Stores
   - Document stores
   - Key-value stores
   - RAM databases

4. Thoughts

5. Conclusion
Semistructured database is an old problem.

Lore [MAG$^+$97] and [Abi97]
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Semistructured database is an old problem.
Data model: Object Exchange Model
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Lore

Properties about Lore

- Very general: graph with label.
### Lore

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Lore

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- Very general: graph with label. (~tree)
- Hide irregularities in the structure when doing queries.
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Properties about Lore

■ Very general: graph with label. (~tree)
■ Hide irregularities in the structure when doing queries.
■ Pattern match possible.
■ Merging new data.
## An old problem

### Some Comparison

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- Join support.
- Virtualization of data placement at the time of the paper.
- Dataguides: visualization of database.
- Code length (60,000 lines of C++ vs 550,000 for MongoDB)

- More general than Column-key model.
- Query will be optimized. (~compilation)

- Performance issue. (~traversal of graphs)
An old problem

Some Comparison

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**Cassandra [LM10]**

Very similar to Bigtable (column-oriented).
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Some features

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Some features

- Dynamic partitionning of data.
- Consistent hashing for distributing the data.
- Replication is done by data replication on N nodes.
- Global Knowledge of the network (hashing)
- Failure detection.
- Efficient anti-entropy gossiping protocol
### Consistency

#### Strong Consistency

\[ \#\text{Writers} + \#\text{Readers} > \text{NbReplication} \]
Consistency

**Strong Consistency**

#Writers + #Readers > NbReplication

**Consistency level**

Read and write can have different levels of consistency (1 node to respond, majority, all).
## Some Comparison

### Extensible Record Stores

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- P2P structure
- Super Family.
- Load balancing (move lightly loaded nodes in the ring”)
- Some locality knowledge in replication (rack aware, datacenter aware)
- Consistent hashing (reduce cost if changed)
- (Eventual) Consistency
Some Comparison

✓ P2P structure
## Bigtable

- P2P structure
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## Other NoSQL

### Thoughts

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MongoDB (No precise article)

- Scability by sharding
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**Document stores**

**MongoDB (No precise article)**

- Scability by sharding
- Document oriented
Amazon Dynamo\cite{DHJ07}

- Weak Consistency.
Amazon Dynamo[DHJ+07]

- Weak Consistency.
- Consistent hashing.
Amazon Dynamo [DHJ^+07]

- Weak Consistency.
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- Object versionning
Key-value stores

Amazon Dynamo\cite{DHJ07}

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## Key-value stores

### Amazon Dynamo\[^{DHJ+07}\]

- Weak Consistency.
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- Failure detection
Amazon Dynamo[DHJ+07]

- Weak Consistency.
- Consistent hashing.
- Object versionning
- Decentralized
- Replication using quorum
- Failure detection
- Merkle tree for Eventual Consensus (Used in Cassandra)
### Key-value stores

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#### Some Comparison

- Caching
- Snapshot

(original article) key/value schema will affect speed if value are huge (to write into the data you need to read it).
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**Key-value stores**

### Some Comparison

⚠️ **Caching?**

...
Some Comparison

☒ Caching?
☒ Snapshot?
Some Comparison

✗ Caching ?
✗ Snapshot ?
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VoltDB http://voltdb.com

- Based on H-Store[SMA⁺07]
VoltDB http://voltadb.com

- Based on H-Store\[SMA^+07\]
- Idea is to use main memory as storage.
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- Cost ?

- Bigtable: 6 stars
- Other NoSQL: 2 stars
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- **Cost ?**
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- Cost ?
- Size ?
- RAM is not persistent.
Plan

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   - An old problem
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4. Thoughts

5. Conclusion
Mapreduce

Using HBase.
Mapreduce

Using HBase.
One mapReduce job per tablets.
Mapreduce

Using HBase.
One map-reduce job per tablets.
Compaction

Size-Tiered
Compaction is done if the number of sstables hits a threshold.

✗ Need a lot of space to do the copy (and the size of sstables increases).
Compaction

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Leveled compaction
SSTable are smaller and grouped by levels.
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How to choose from this two policies?
SSTable assignment

- The master is capable of maintaining the list: $	ext{TI}[TS_{id}] = \text{all tablets handle by } TS_{id}$. 
**SSTable assignment**

- The master is capable of maintaining the list: \( T_I[TS_{id}] = \) all tablets handle by \( TS_{id} \).
- Creations, Merges and Deletions are handle by the master.
The master is capable of maintaining the list: $TI[TS_{id}] = \text{all tablets handle by } TS_{id}$.

- Creations, Merges and Deletions are handled by the master.
- Split are initiated by the tablet server but it notifies the master.
\[ \times \text{ No Join} \]
× No Join
× ACID (Atomicity, Consistency, Isolation, Durability): eventual consistency
Limitations

× No Join

× ACID (Atomicity, Consistency, Isolation, Durability): eventual consistency

■ Problem that arise with semi structured data (texts):
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**Limitations**

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Paxos

Why use a tree for locating tables ?
Limitations

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- **Paxos**
- **Why use a tree for locating tables ?**
- **No real solution for the number of tablets.**
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Conclusion

NoSQL ≠ SQL.
Conclusion

\[ \text{NoSQL} \neq \text{SQL}. \]

Old problem but new data pattern.
Conclusion

NoSQL \neq SQL.

Old problem but new data pattern.
Conclusion

Thank You for your attention!
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