CSE 444: Database Internals

Lectures 26

NoSQL

References

- **Scalable SQL and NoSQL Data Stores**, Rick Cattell, SIGMOD Record, December 2010 (Vol. 39, No. 4)
- **Bigtable: A Distributed Storage System for Structured Data**. Fay Chang, Jeffrey Dean, et. al. OSDI 2006
- Online documentation: Amazon SimpleDB, Google App Engine Datastore, VoltDB, etc.

Motivation

- Originally motivated by Web 2.0 applications
- Goal is to scale simple OLTP-style workloads to thousands or millions of users
- Users are doing both updates and reads

Why NoSQL as the Solution?

- Scaling a relational DBMS is hard
- We saw how to scale queries with parallel DBMSs
- Much more difficult to scale ***transactions***
  - Need to partition the database across multiple machines
  - If a transaction touches one machine, life is good
  - If a transaction touches multiple machines, ACID becomes extremely expensive! Need two-phase commit
- Replication
  - Replication can help to increase throughput and lower latency
  - Create multiple copies of each database partition
  - Spread queries across these replicas
  - Easy for reads but writes, once again, become expensive!

NoSQL Key Feature Decisions

- Want a data management system that is
  - Elastic and highly scalable
  - Flexible (different records have different schemas)
- To achieve above goals, willing to give up
  - Complex queries: e.g., give up on joins
  - Multi-object transactions
  - ACID guarantees: e.g., eventual consistency is OK
  - *Not all NoSQL systems give up all these properties*

Cattell, SIGMOD Record 2010

"Not Only SQL" or "Not Relational"

Six key features:

1. Scale horizontally "simple operations"
   - key lookups, reads and writes of one record or a small number of records, simple selections
2. Replicate/distribute data over many servers
3. Simple call level interface (contrast w/ SQL)
4. Weaker concurrency model than ACID
5. Efficient use of distributed indexes and RAM
6. Flexible schema

Cattell, SIGMOD Record 2010

Terminology

- Sharding = horizontal partitioning by some key, and storing records on different servers in order to improve performance
- Horizontal scalability = distribute both data *and* load over many servers (Scale-out)
- Vertical scaling = when a dbms uses multiple cores and/or CPUs (Scale-up)

ACID Vs BASE

- ACID = Atomicity, Consistency, Isolation, and Durability
- BASE = Basically Available, Soft state, Eventually consistent

Data Models

- Tuple = row in a relational db
- Document = nested values, extensible records (think XML, JSON, attribute-value pairs)
- Extensible record = families of attributes have a schema, but new attributes may be added
- Object = like in a programming language, but without methods

Cattell, SIGMOD Record 2010

Different Types of NoSQL

Taxonomy based on data models:

- Key-value stores
  - e.g., Project Voldemort, Memcached
- Document stores
  - e.g., SimpleDB, CouchDB, MongoDB
- Extensible Record Stores
  - e.g., HBase, Cassandra, PNUTS
- New types of RDBMSs.. not really NoSQL

Key-Value Stores Features

- **Data model**: (key,value) pairs
  - A single key-value index for all the data
- **Operations**
  - Insert, delete, and lookup operations on keys
- **Distribution / Partitioning**
  - Distribute keys across different nodes
- **Other features**
  - Versioning
  - Sorting

Key-Value Stores Internals

- Data remains in main memory
- One type of impl.: distributed hash table
- Most systems also offer a persistence option
- Others use replication to provide fault-tolerance
  - Asynchronous or synchronous replication
  - Tunable consistency: read/write one replica or majority
- Some offer ACID transactions others do not
- Multiversion concurrency control or locking

Cattell, SIGMOD Record 2010

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Amazon SimpleDB

A Document Store

- **Partitioning**
  - Data partitioned into domains: queries run within a domain
  - Domains seem to be unit of replication. Limit 10GB
  - Can use domains to manually create parallelism
- **Data Model / Schema**
  - No fixed schema
  - Objects are defined with attribute-value pairs

Amazon SimpleDB (2/3)

- **Indexing**
  - Automatically indexes all attributes
- **Support for writing**
  - PUT and DELETE items in a domain
- **Support for querying**
  - GET by key
  - Selection + sort
  - A simple form of aggregation: count
  - Query is limited to 5s and 1MB output (but can continue)

```
select output_list
from domain_name
[where expression]
[sort_instructions]
[limit limit]
```


Amazon SimpleDB (3/3)

- **Availability and consistency**
  - "Fully indexed data is stored redundantly across multiple servers and data centers"
  - "Takes time for the update to propagate to all storage locations. The data will eventually be consistent, but an immediate read might not show the change"
  - Today, can choose between consistent or eventually consistent read
- **Integration with other services**
  - "Developers can run their applications in Amazon EC2 and store their data objects in Amazon S3."
  - "Amazon SimpleDB can then be used to query the object metadata from within the application in Amazon EC2 and return pointers to the objects stored in Amazon S3."

Cattell, SIGMOD Record 2010

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Extensible Record Stores

- Based on Google's BigTable
- Data model is rows and columns
- Scalability by splitting rows and columns over nodes
  - Rows partitioned through sharding on primary key
  - Columns of a table are distributed over multiple nodes by using "column groups"
- HBase is an open source implementation of BigTable

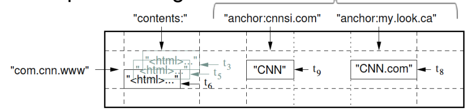
What is Bigtable?

- Distributed storage system
- Designed to
  - Hold structured data
  - Scale to thousands of servers
  - Store up to several hundred terabytes (maybe even petabytes)
  - Perform backend bulk processing
  - Perform real-time data serving
- To scale, Bigtable has a limited set of features

Chang, OSDI 2006

Bigtable Data Model

- Sparse, multidimensional sorted map
  `(row:string, column:string, time:int64)` ➔ `string`
  Notice how everything but time is a string
- Example from Fig 1:



Chang, OSDI 2006

BigTable Key Features

- Read/writes of data under single row key is atomic
  - Only single-row transactions!
- Data is stored in lexicographical order
  - Improves data access locality
- Column families are unit of access control
- Data is versioned (old versions garbage collected)
  - Ex: most recent three crawls of each page, with times

Chang, OSDI 2006

BigTable API

- Data definition
  - Creating/deleting tables or column families
  - Changing access control rights
- Data manipulation
  - Writing or deleting values
  - Supports single-row transactions
  - Looking up values from individual rows
  - Iterating over subset of data in the table
    - Can select on rows, columns, and timestamps

Cattell, SIGMOD Record 2010

Megastore

- BigTable is implemented, used within Google
- Megastore is a layer on top of BigTable
  - Transactions that span nodes
  - A database schema defined in a SQL-like language
  - Hierarchical paths that allow some limited joins
- Megastore is made available through the Google App Engine Datastore

Google App Engine

- "Run your web applications on Google's infrastructure"
- Limitation: app must be written in Python or Java
- Key features (examples for Java)
  - A complete development stack that uses familiar technologies to build and host web applications
  - Includes: Java 6 JVM, a Java Servlets interface, and support for standard interfaces to the App Engine scalable datastore and services, such as JDO, JPA, JavaMail, and Jcache
  - JVM runs in a secured "sandbox" environment to isolate your application for service and security (some ops not allowed)

Google App Engine Datastore (1/3)

- "Distributed data storage service that features a query engine and transactions"
- **Partitioning**
  - Data partitioned into "entity groups"
  - Entities of the same group are stored together for efficient execution of transactions
- **Data Model / Schema**
  - Each entity has a key and properties that can be either
    - Named values of one of several supported data types (includes list)
    - References to other entities
  - Flexible schema: different entities can have different properties

Google App Engine Datastore (2/3)

- **Indexing**
  - Applications define indexes: must have one index per query type
- **Support for writing**
  - PUT and DELETE entities (for Java, hidden behind JDO)
- **Support for querying**
  - GET an entity using its key
  - Execute a query: selection + sort
  - Language bindings: invoke methods or write SQL-like queries
  - Lazy query evaluation: query executes when user accesses results

Google App Engine Datastore (3/3)

- **Availability and consistency**
  - Every datastore write operation (put/delete) is atomic
    - Outside of transactions, get READ_COMMITTED isolation
  - Support transactions (many ops on many objects)
    - Single-group transactions
    - Cross-group transactions with up to 5 groups
    - Transactions use snapshot isolation
    - Transactions use optimistic concurrency control

Cattell, SIGMOD Record 2010

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VoltDB

Not a NoSQL system… it's really a new type of RDBMS
So rather goes into NewSQL category

- Main-memory RDBMS: no disk IO! no buffer mngmt!
- Sharded across a shared-nothing cluster
  - One transaction = one stored procedure
  - So both the data and processing are partitioned
- Transaction processing
  - SQL execution single-threaded for each shard
  - Avoids all locking and latching overheads
- Synchronous multi-master replication for HA
- Durability through snapshots and command logs