Datamanagement in the Cloud

1. Introduction

Recap ACID:

- **Atomicity:** "all or nothing" the whole transaction or no transaction are committed
- **Consistency:** transactions never observe or result in inconsistent data
- **Isolation:** transactions are not aware of concurrent transactions
- **Durability:** once committed, the state of a transaction is permanent

Cloud Computing is:

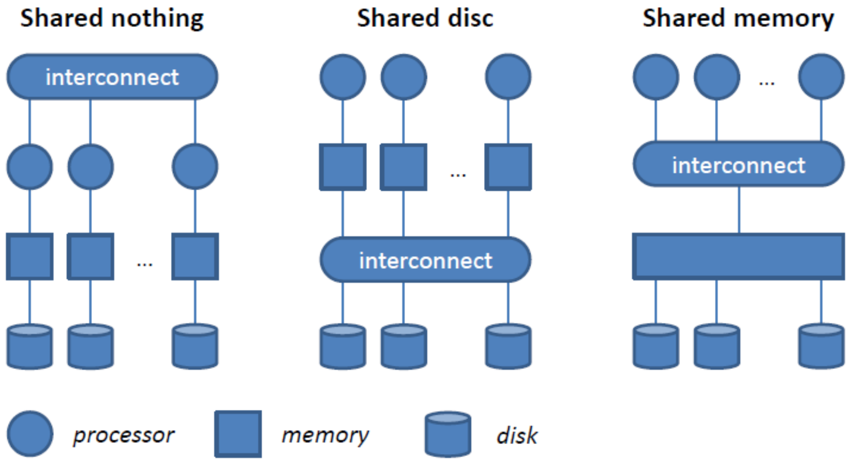
- "Software as a Service (SaaS)": applications delivered over the Internet as services
- a pay-as-you-go-model
- not an internal data center
- utility computing
    - illusion of infinite computing resources
    - no up-front cost or commitment by users
    - pay for use on short-term basis in need
- virtualization:
    - virtual resources abstract from physical resources
    - centralize and ease administrative tasks
    - improve scalability and work loads
    - increase stability and fault-tolerance
    - provide standardized, homogenous computing platform through hardware virtualization

Six key features:

1. ability to **horizontally scale simple operation** throughput over many servers
2. ability to **replicate and distribute** (partition) data over many servers
3. simple **call level interface** or protocol
4. **weaker concurrency model** than ACID transactions of most relational DBS
5. efficient use of **distributed indexes and RAM** for data storage
6. ability to **dynamically add new attributes** to data records

Simple operation:
- only key lookups
- read and writes of one or a small number of records
- no complex queries or

1.1. Scaling Databases



- ***Horizontal:*** Add more nodes
- ***Vertical:*** up-size existing node by adding CPUs, memory
- Move data to where it is needed
- Manage replication for availability and reliability

1.2. Data partitioning

- ***Horizontal:*** distribute groups of tuples of a relation onto different nodes
- ***Vertical:*** distribute groups of columns of a relation onto different nodes
- ***"sharding" -> horizontal***

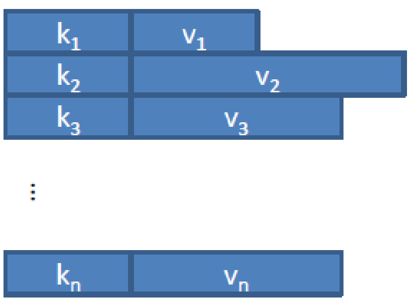
1.3. Data Models

Terminology

- **Tuple:** row in a relational table, where attribute names and types are defined by a schema, and values must be scalar
- **Document:** supports both scalar values and nested documents, and the attributes are dynamically defined for each document
- **Column family:** groups key/value pairs (columns) into families to partition and replicate them; one column family is similar to a document as new (nested, list-valued) attributes can be added

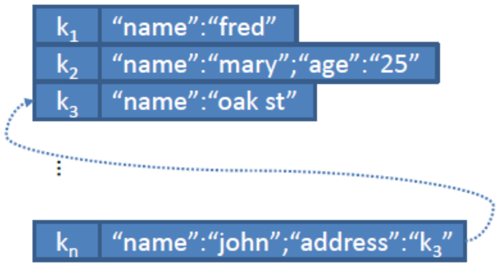
1.3.1. Key/Value Data Model

- Interface:
  - put(key, value)
  - get(key): value
- Data Storage:
  - Values (data) are stored based on programmer-defined keys
  - System does not (need to) know about the structure (semantics) of the value



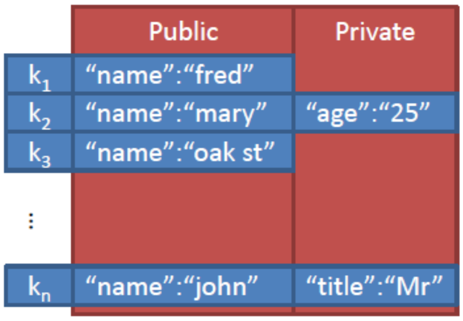
- Queries are expressed in terms of keys
- Indexes are defined over keys:
    - Some systems support secondary indexes over (part of) the value

1.3.2. Document Data Model



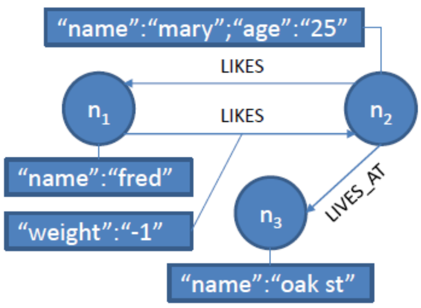
- Interface:
    - set(key, document)
    - get(key): document
    - set(key, name, value)
    - get(key, name): value
- Data storage:
    - Documents (data) is stored based on programmer-defined keys
    - System is aware of the (arbitrary) document structure
    - Support for lists, pointers and nested documents
- Queries expressed in terms of key (or attribute, if index exists)
- Support for key-based indexes and secondary indexes

1.3.3. Column Family Data Model



- Interface:
    - define(family)
    - insert(family, key, columns)
    - get(family, key): columns
- Data storage:
    - <name, value, timestamp> triples (so-called columns) are stored based on a column family and key; a column family is similar to a document
    - System is aware of (arbitrary) structure of column family
    - System uses column family information to replicate and distribute data
- Queries are expressed based on key and columns family
- Secondary indexes per column family are typically supported

1.3.4. Graph Data Model



- Interface:
    - create: id
    - get(id)
    - connect(id1, id2): id
    - addAttribute(id, name, value)
    - getAttribute(id, name): value
- Data Storage:
    - Data is stored in terms of nodes and (typed) edges
    - Both nodes and edges can have (arbitrary) attributes
- Queries are expressed based on system ids (if no indexes exists)
- Secondary indexes for nodes and edges are supported
    - Retrieve nodes by attributes and edges by type, start and/or end node, and/or attributes

1.4. Consistency Models

1.4.1. CAP Theorem

- Three properties are desirable and expected from a real-world shared-data systems
  - **C:** data consistency
  - **A:** availability
  - **P:** tolerance of network partition
- Only two of these properties can be satisfied by a system at any given time

Data Consistency

- Database systems typically implement ACID transactions
- There are aplications that can deal with looser consistency guarantees and periods of inconsistency

Availability

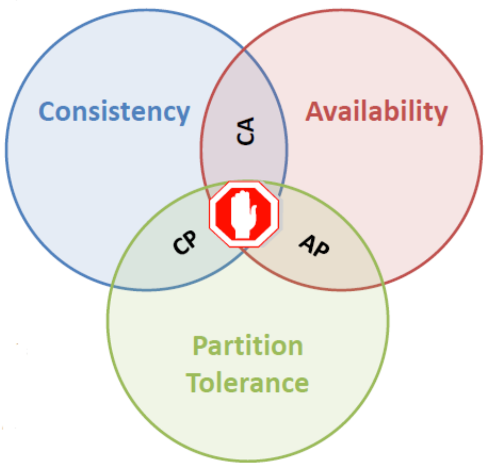
- Services are expected to be highly available
  - Every request should receive a response
  - It can create real-world problems when a service goes down
- Realistic goal
  - Service should be as available as the network it run on
  - If any service on the network is available, the service should be available

Partition-Tolerance

- A service should continue to perform as expected if some nodes crash or some communication links fail
- One desirable fault tolerance property is resilience to a network partitioning into multiple components

Classification of Systems

- Available-Partition-Tolerant:
  - Dynamo, Riak, Voldemort, TokioCabinet
  - SimpleDB, CouchDB
  - Cassandra
- Consistent-Available
  - RDBMS
  - GreenPlum
- Consistent-Partition-Tolerant
  - MomCacheDB. Redis, Scalaris
  - MongoDB



- BigTable, HBase, HyperTable
- VoltDB

Criticism

- Asymmetry of CAP properties:
  - Consistency is a property of the system in general
  - Availability is a property of the system only when there is a partition
- There are not three different choices
  - In practice, CA and CP are indistinguishable, since A is only sacrificed when there is a partition
  - Used as an excuse to not bother with consistency
- Other costs to consistency:
  - Overhead of synchronization schemes
  - Latency

1.4.2. Strong vs. Weak Consistency

Strong consistency

- After an update is committed, each subsequent access will return the update value

Weak consistency

- A number of conditions might need to be met before the updated value is returned
- **Inconsistency window:** period between update and the point in time when every access is guaranteed to return the updated value

1.4.3. Eventual Consistency

- Specific form of weak consistency
- "If no new updates are made, eventually all accesses will return the last updated values"
- In the absence of failures, the maximum size of the **inconsistency window** can be determined based on:
  - Communication delays
  - System load
  - Number of replicas
  - …

Models of Eventual Consistency

- Causal consistency
  - If A communicated to B that it has updates a value, as subsequent access by B will return the updated value, and a write is guaranteed to supersede the earlier write
  - Access by C that has no causal relationship to A is subject to normal eventual consistency rules

- Read-your-writes consistency
  - After updating a value, a process will always read the updated value and never see an older value
- Session consistency
  - Data is accessed in a session where read-your-writes is guaranteed
  - Guarantees do not span over sessions
- Monotonic read consistency
  - If a process has seen a particular value, any subsequent access will never return any pervious value
- Monotonic Write consistency
  - System guarantees to serialize the writes of one process

- Properties can be combined
  - E.g. monotonic read + session-level consistency
  - E.g. monotonic reads + read-your-own-writes

Configurations

- Definitions:
  - **N:** number of nodes that store a replica
  - **W:** number of replicas that need to acknowledge a write operation
  - **R:** number of replicas that are accessed for a read operation
- W+R> N
  - E.g. **synchronous replication** (N=2, W=2, R =1)
  - Write set and read set always overlap
  - Strong consistency can be guaranteed through **quorum protocols**
  - Risk of reduced availability: in basic quorum protocols, operations fail if fewer than the required number of nodes respond, due to node failure
- W+R=N
  - E.g. **asynchronous replication** (N=2, W=1, R =1)
  - Strong consistency cannot be guaranteed
- R=1, W=N
  - Optimized for **read access:** single read will return a value
  - Write operation involves all nodes and risks not to succeed
- R=N, W=1
  - Optimized for **write access:** write operation involves only one node and relies on lazy (epidemic) technique to update other replicas
  - Read operation involves all nodes and returns “latest” value
  - Durability is not guaranteed in presence of failures
- W < (N+1)/2
  - Risk of conflicting writes
- W+R <= N
  - **Weak/eventual consistency**

BASE = **B**asically **A**vailable, **S**oft state, **E**ventual Consistency