Do Relational Databases Belong in the Cloud?

Michael Stiefel
www.reliablesoftware.com
development@reliablesoftware.com

How do you model data in the cloud?

Relational Model

A query operation on a relation (table) produces another relation (table).

Based on the relational algebra and calculus, a query engine can produce provably correct results.

Declarative Language Allows Optimization

Architectural Assumption:

Data Outlasts Implementation

Data Separate From Code

Consistency Required

Transactional consistency

- No specification of insert, update or delete.
- Non clustered indices consistent with data

Design consistency

- Denormalized data must be kept consistent
- Lossless join decompositions

Transactional Consistency Means Holding Database Locks

Holding Locks Interferes With Availability and Scalability

Do Availability and Consistency Conflict?

Laws of Physics

Technology Limits

Economics

Laws of Physics

Latency Exists

Speed of light in fiber optic cable: 124,000 miles per second

Ideal ping Japan to Boston takes 100 ms.

Fetch 10 images for a web site: 1 second

Ignores Latency of the operation

Bandwidth is Not Cheap

Shannon's Law: $C = B \log_2 (1 + S / N)$

Capacity = bit / second

Bandwidth (hertz)

S/N * 5 to double capacity given bandwidth

Latency is Not Bandwidth

Size of the shovel vs. how fast you can shovel

Infinite shovel capacity(bandwidth) is limited by how fast one can shovel (latency).

Great Bandwidth Terrible Latency

Buy a two terabyte disk drive

Drive with it from Boston to New York

You can only move data so fast

You can only move so much data

Technology Limits

Connectivity is Not Always Available

Cell phone

Data Center Outages

Equipment Upgrades

Data redundancy to improve reliability

Offline mode on client for availability

Expensive to Move Data

Data naturally lives in multiple places

Computational Power gets cheaper faster than network bandwidth

Cheaper to compute where data is instead of moving it

Distributed Computing Economics Jim Gray

Economics Dictate Scale Out, Not Up

Cheap, commodity hardware argues for spreading load across multiple servers

Relational Databases were not designed to be run on clusters (shared disk subsystem)

Wind up Building a Distributed System

Can the relational database scale?

Traditionally, focus was on optimizing specific problems

Optimize Insert/Update or Read?

Data intensive relational applications:

- frequent small read / writes
- large size reads, but infrequent writes

Problems:

- Heavy workloads with frequent writes
- Scanning over large indices for queries
- Dirty reads can mean inconsistent data

What does it mean to scale?

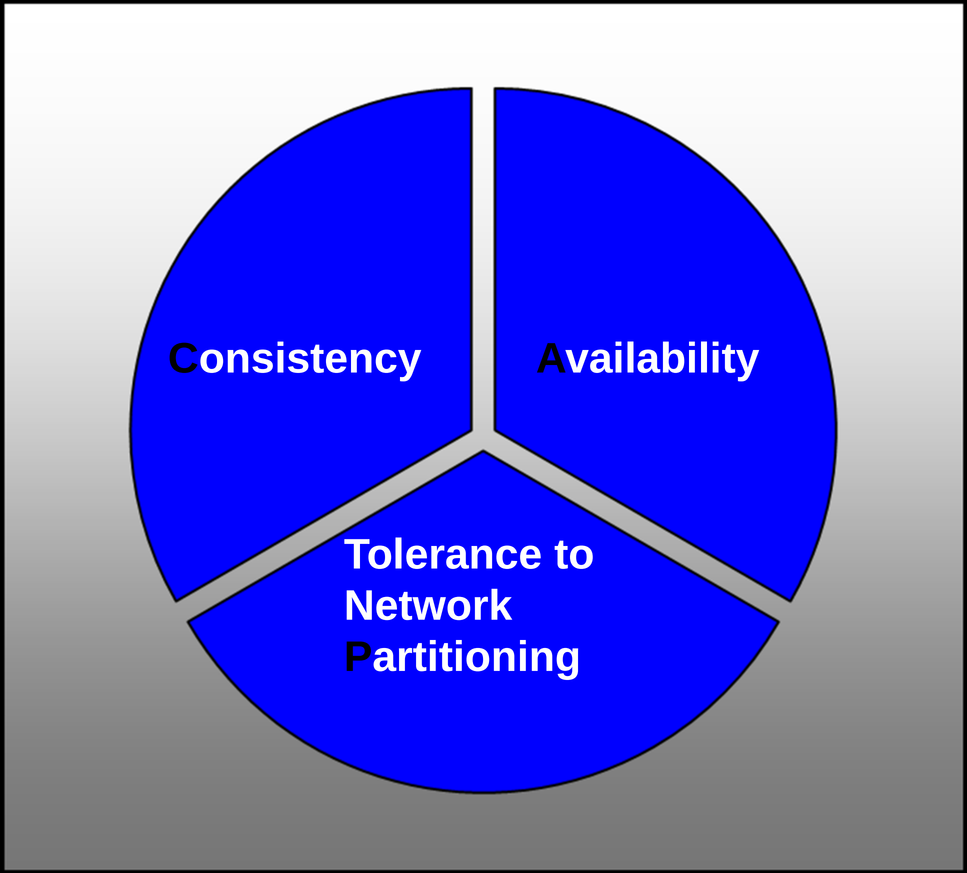
Large Number of Users

Geographic Distribution

Hugh Amounts of Data

To Scale a Distributed System
Focus on Data, Not Just Computation

CAP Theorem

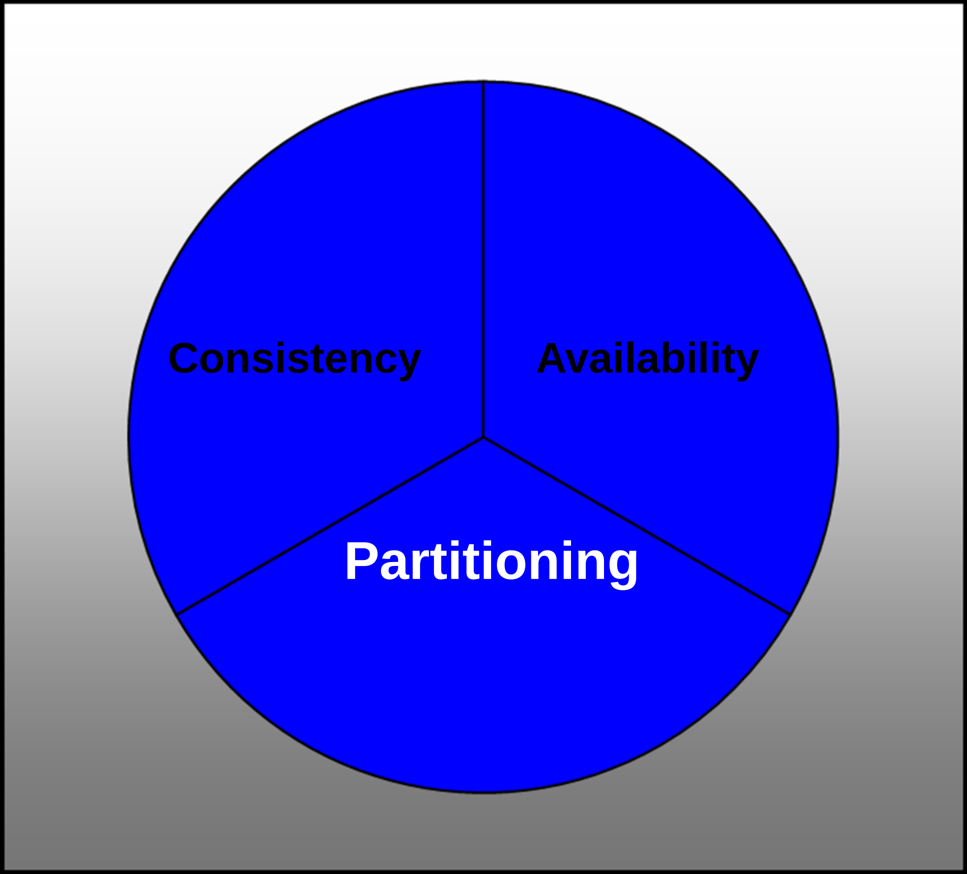


Can Have Any Two

Eric Brewer
UC Berkeley, Founder
Inktomi

http://www.cs.berkeley.edu/~brewer/cs262b-2004/PODC-keynote.pdf

Consistency and Availability



Single site Database

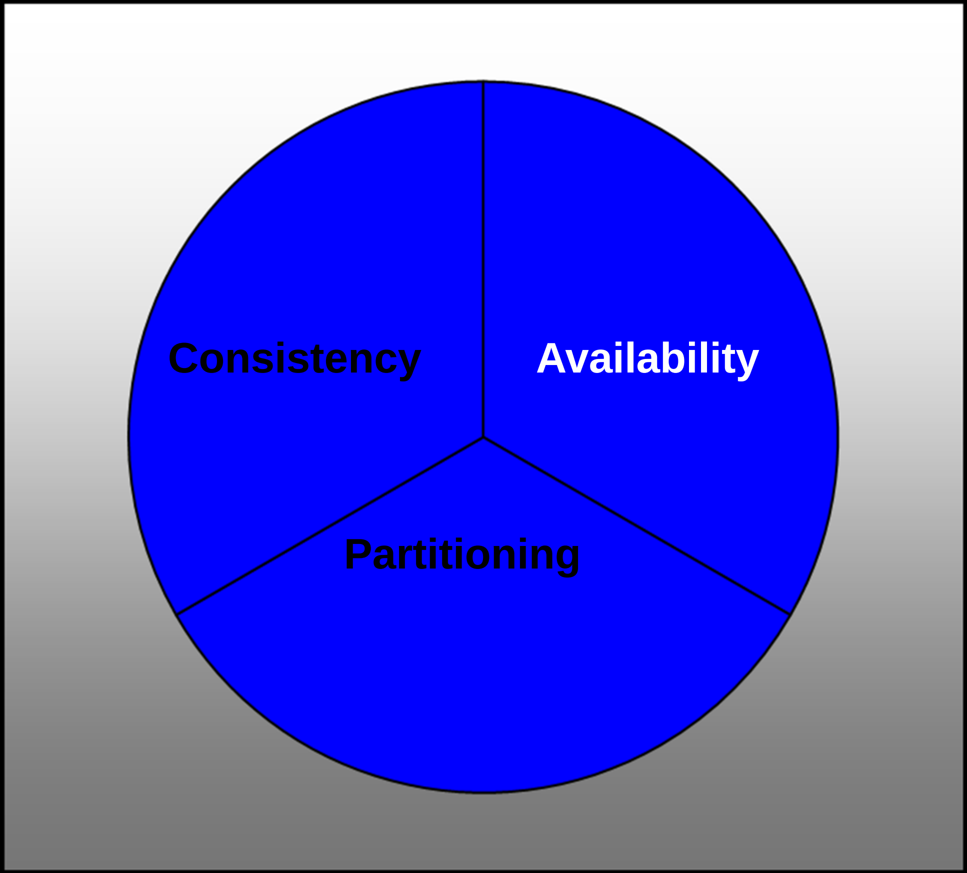
Database Cluster

LDAP

Two phase commit

Validate Cache

Consistency and Partitioning



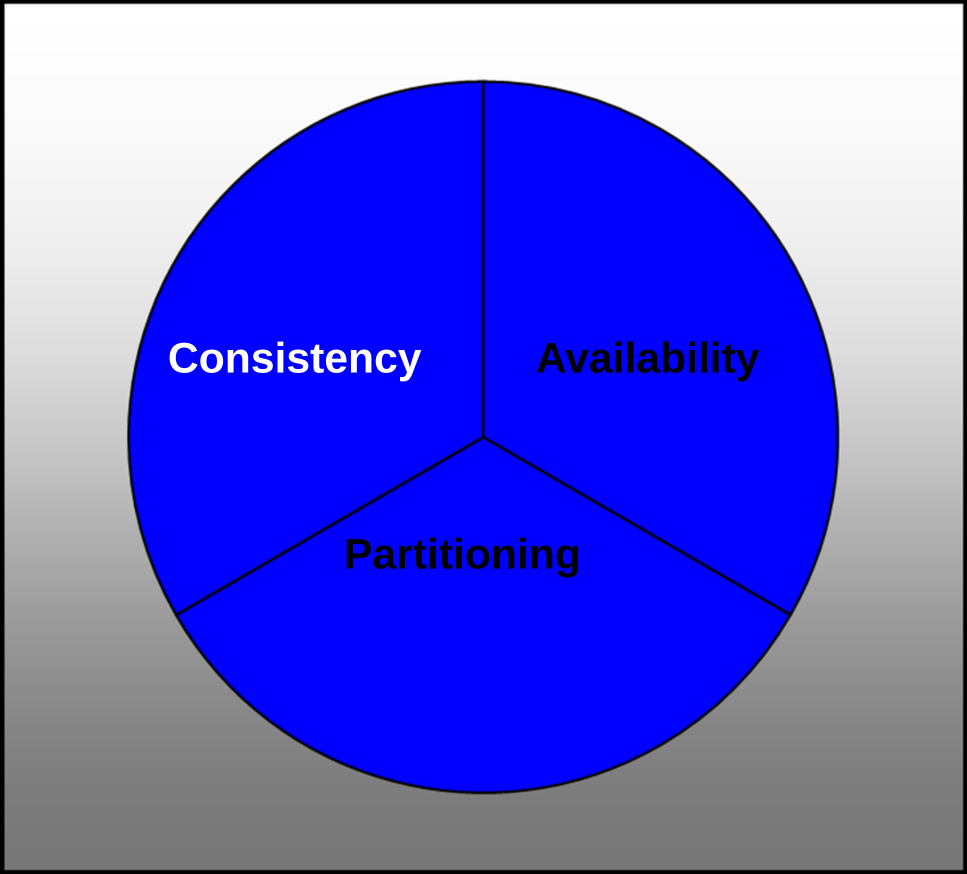
Distributed Database

Distributed Locking

Pessimistic Locking

Minority Partitions invalid

Availability and Partitioning



Forfeit Consistency

Google Big Table

Amazon Simple DB

Azure Storage Tables

Optimistic Locking

Can Denormalize

CAP Does ***Not*** Imply:

Never give up on Durability

Atomicity within a Partition

Inconsistency should be the exception

Partition Everywhere

No ACID within a Partition

Give up on Declarative Languages such as SQL

Then…

If we give up Consistency, how do we Partition?

If we Partition how do we recover system invariants?

Classic Ways to Partition

Distributed Objects

- Distributed Objects Fail
  - Separate Address Space
  - Disparate Lifetimes
  - Location is Not Transparent
- RPC Model Fails
- Cannot Hide Network

Distributed Transactions

- Relational Model works with single node/ cluster
  - Complexity of relations
  - Query plans with hundreds of options which query analyzer evaluates at runtime
  - Normalization
  - ACID Transactions
- Quick hardware scale up difficult
- Two Phase Commit works with infinite time

Better Ways to Partition

- Non-Relational Approach
  - Key Value / Tuple Store
  - Document Store
  - Column Family Store
  - Graph Store
- Relational Approach
  - Sharding
- NewSQL

For Better Partitioning, Look at Data Model

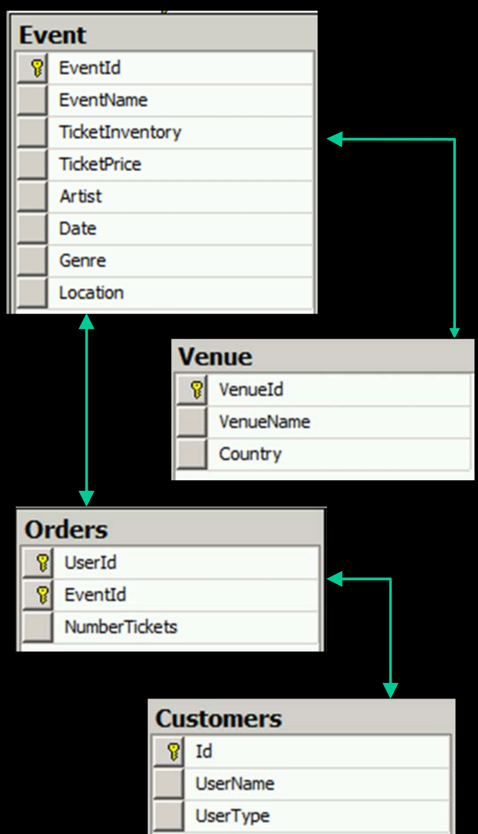
Relational: Given the structure of the data, what kind of questions can I ask?

Non Relational: Given the questions I want to ask, how do I structure the data?

Model Application Specific Questions

The aggregate is the unit of atomicity in a NoSql Data Model

Relational vs. Aggregate




```
Venue {
   Name
   Country
   Event []
      {
          Name
          Ticket Inventory
          Artist
          Date
          Genre
          Location
       }
}

Customers
{
   Name
   Orders[]
   Event Name
   Number Tickets
}
```

Prioritized Query Restrictions

1. How many tickets are left for an event?
   date, location, event
2. What events occur on which date?
   date, artist, location
3. When is a particular artist coming to town?
   artist, location
4. When can I get a ticket for a type of event?
   genre
5. Which artists are coming to town?
   artist, location

Query Analysis

Most common combination: artist *or* date / location

Most common query: event / date / location

Partition based on location or venue

Allows for geographic sensitivity

Partitioning may or may not imply denormalization

Each NoSql Data Model Treats Aggregates Differently

In general….

Code has integrity constraints

Code handles joined queries

No standard among vendors (lock in)

Key-Value treats the aggregate as opaque

- Might have a opaque set of attributes

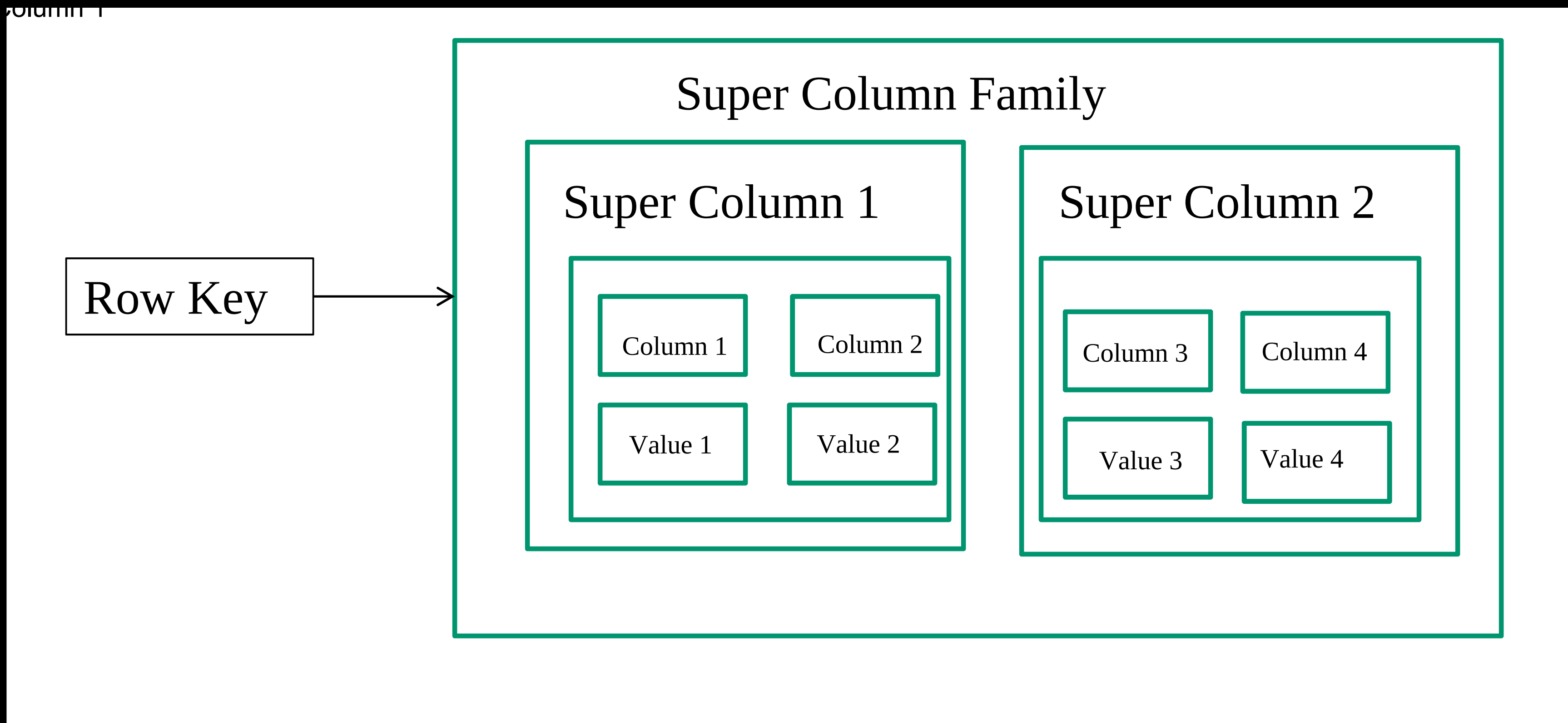
Key is the index to the aggregate

Ordered Key-Value allows for range queries

Only the application knows the schema

- Column Family is a Two Level Aggregate
  - Keys are first level
  - Aggregates are the second level
  - Aggregate is composed of other aggregate
- Reads are common, Writes rare

Column Family Data Model (Cassandra)



Example

```
Event
{
   key 100
   {
       Boston Symphony {phone: 617-555-1212, desc: Beethoven concert.},
       Lady Gaga {phone: 310-539-4242, desc: Monster concert},
   } //end concerts

   key 200
   {
       Boston Common Walk {desc: Swan boats are here.},
       Community Boating {phone: 617-555-1000, desc: Join us this summer.}
    } // end community events
}
```

Super Column Family

Column

Key

Super Column

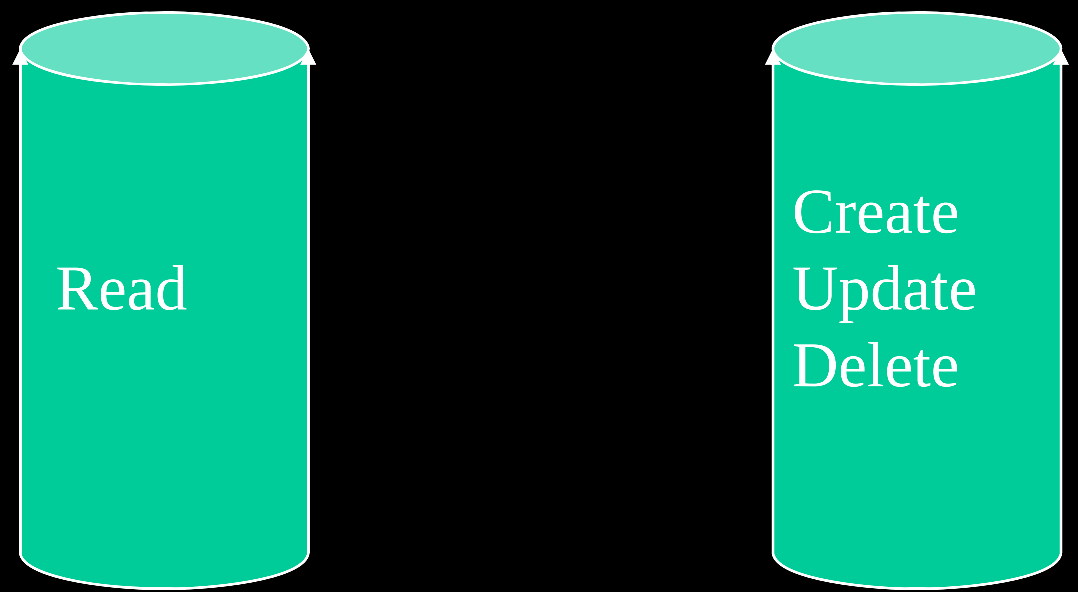
Flexible Schema

Document Database has aggregate of arbitrary complexity with an index on attribute data.

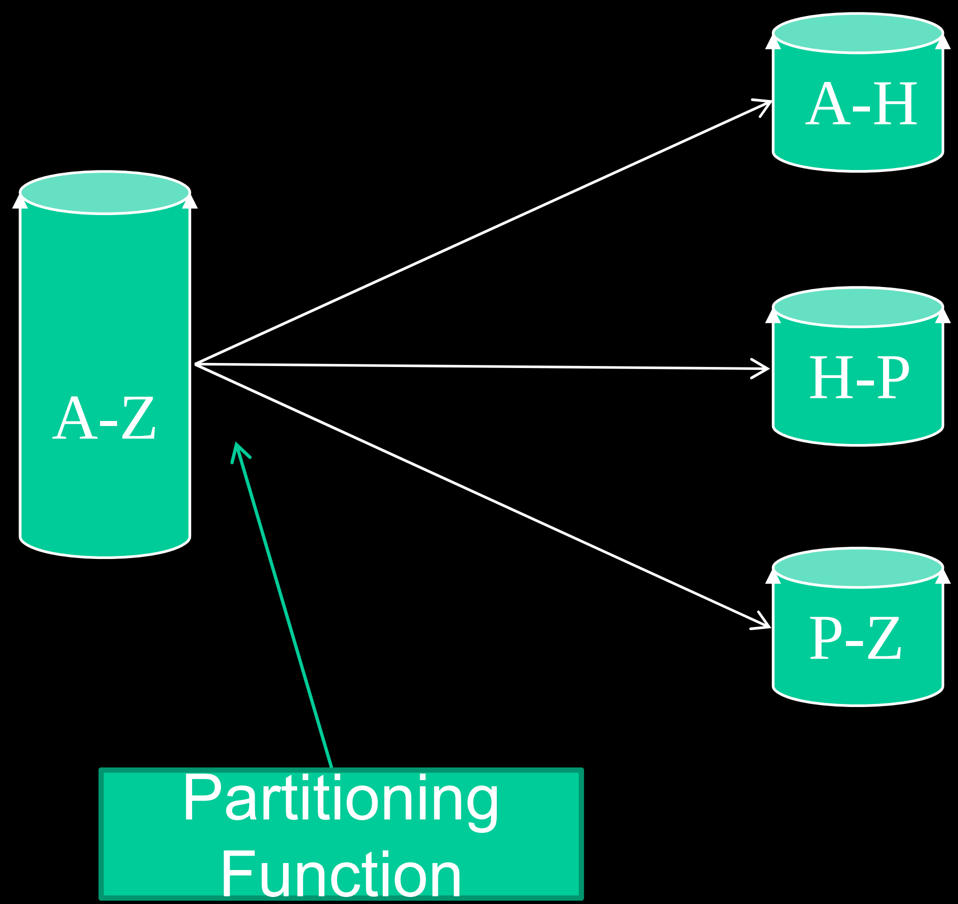
Mechanics of Relational Database Partitioning

Find Independent Units of Data

Separate Transactions From Queries



Transactional Units Across Databases



Partitioning Mechanisms

Horizontal Partitioning

- Divide table rows across databases

Vertical Partitioning

- Divide table columns across databases
- Different tables in different databases
- Reference data can be copied
- Queries scan less data

Horizontal Partitioning

- Each table contains identical columns
- Data is partitioned into different databases. Each part is referred to as a *shard*.
- Table is a single logical entity for updates and queries
- Indices for a shard must be in the same shard
- Sharding strategy based on use or query patterns

Implementing Horizontal Partitions

Function that converts sharding property into a database location

Primary keys unique across all shards

- Shards hand out distinct ranges
- Shard id is part of primary key
- Pool hands out unique identifiers

No secondary keys across shards

No distributed transactions across databases

May need to UNION query results

Vertical Partitioning

Divide table columns across databases

Primary key identical for a given "row"

Data may or may not be normalized

A join across the partitions recreates the "row"

Vertical Partitioning Strategy

- Columns used in different queries go in different partitions
- Different business processes "own" a table.
  - Leads to service oriented approach
  - Design business processes to avoid cross table joins
  - Transactions within service boundary

Implementing Vertical Partitions

Primary or foreign keys may be used to recreate the row

No secondary keys across databases

Secondary indices in different partitions might diverge

Normalize columns not frequently used

No distributed transactions

NewSQL

New Relational Database Architectures

Examples:

- In-memory databases
- Google Spanner

In-memory Data Model

equivalent to relational

short lived transactions

index look ups (no table scans)

repeated queries with different parameters

Google Spanner

Globally distributed relational database

Synchronizes with atomic and GPS clocks

Uses Paxos protocol for consensus

Availability or Consistency ?

What is the Cost of an Apology?

Amazon

Airline reservations

Stock Trades

Deposit of a Bank Check

Deleting a photo from Flickr or Facebook

Sometimes the cost is too high

Authentication

- SAML tokens expire

Launching a nuclear weapon

Businesses Apologize Anyway

Vendor drops the last crystal vase

Check bounces

Double-entry bookkeeping requires compensation

- at least 13th century

Eventually make consistent (partition healing)

Software State ≠ State of the World

Software approximates the state of the world

Best guess possible

Could be wrong

Other computers might disagree

How consistent?

Business Decision

What is the cost to get it absolutely right?

What is the cost of lost business?

Computers can remember their guesses

Can replicate to share guesses

May be cheaper to forget, and reconcile later

Design For Eventual Consistency

Decouple unrelated application functionality

Focus on atomic or invariant business operations, not database reads or writes.

No distributed transactions

Asynchronous processing

Eventual Consistency

Different computations might come to different conclusions

Define message based workflows for ultimate reconciliation and replication of results

Not the Whole Story

Databases are not the best integration technology

- Object-Relational Mismatch
- Certain problems match other data models

Services, not Data, Outlast Implementation

Application or Service Specific Databases

Case Study: Amazon Four Day Outage

Facts

April 21, 2011

One Day of Stabilization, Three Days of Recovery

Problems: EC2, EBS, Relational Database Service

Affected: Quora, Hootsite, Foursquare, Reddit

Unaffected: Netflix, Twillo

Netflix Explicitly Architected For Failure

Although more errors, higher latency, no increase in customer service calls or inability to find or start movies.

Key Architectural Decisions

- Stateless Services
- **Data stored across isolation zones**
  - **Could switch to hot standby**
- Had Excess Capacity (N + 1)
  - Handle large spikes or transient failures
- **Used relational databases only where needed.**
  - **Could partition data**
- Degraded Gracefully

Data Architecture

Separate databases:

- User, Accounts, Feedback, Transactions

Split by primary access path

No business logic in database

CPU intensive work in service tier

- Referential Integrity, Joins, Sorting

Avoids deadlock

Degraded Gracefully

Fail Fast, Aggressive Timeouts

Can degrade to lower quality service

- no personalized movie list, still can get list of available movies

Non Critical Features can be removed.

Suggested Reading

"Life Beyond Distributed Transactions: An Apostate's View" by Pat Helland

Conclusions

Scalability means Users, Bandwidth, Geography

Partitioning Changes the Data Model

Service Orientation Changes the Data Model

Design for Eventual Consistency

No need for scalability or service orientation,
Relational Model works

Unified Data Model makes it hard to meet rapid change.