F1 - The Fault-Tolerant Distributed RDBMS Supporting Google's Ad Business

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Today's Talk

F1 - A Hybrid Database combining the

- Scalability of Bigtable
- Usability and functionality of SQL databases

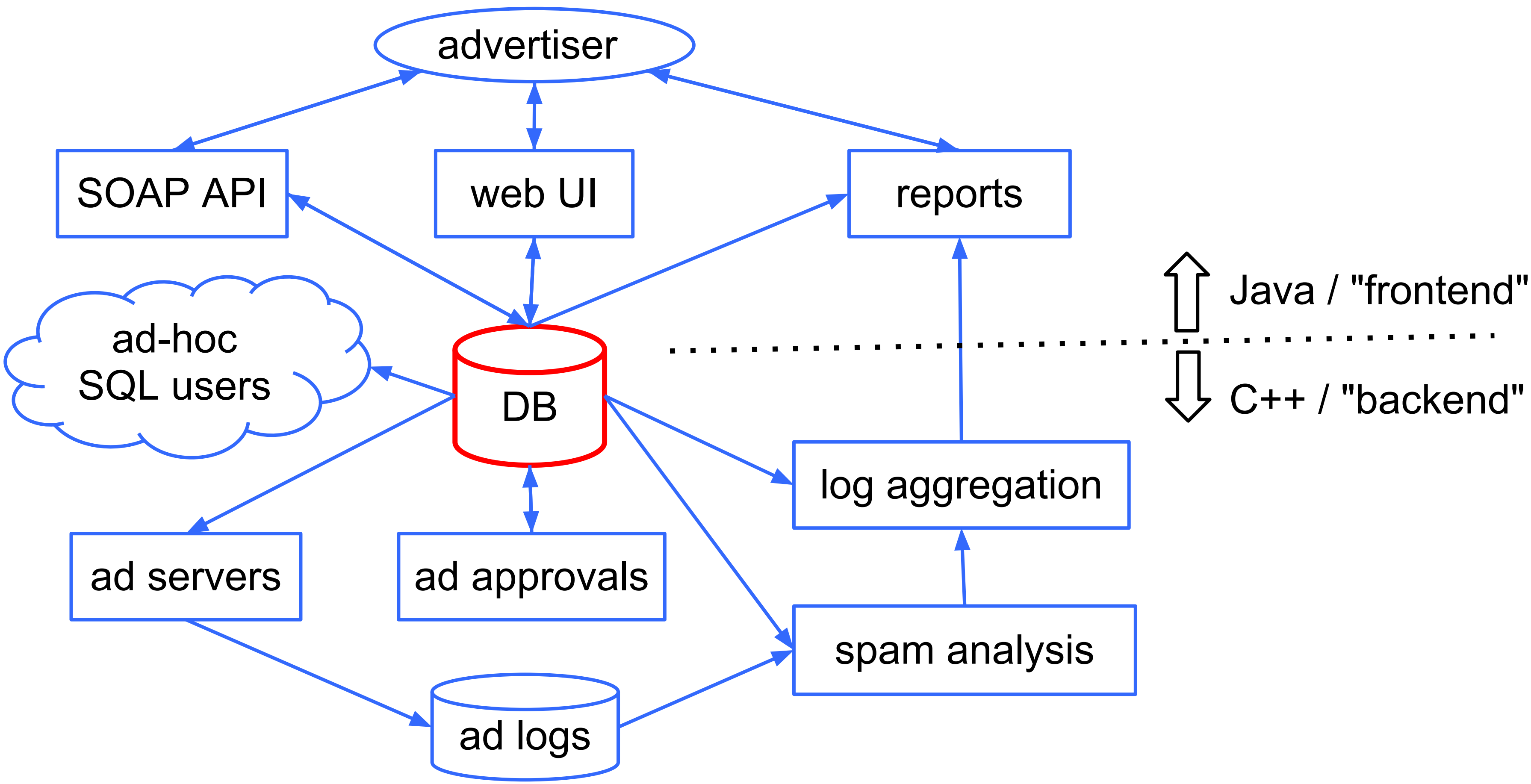
Key Ideas

- Scalability: Auto-sharded storage
- Availability & Consistency: Synchronous replication
- High commit latency: Can be hidden
  - Hierarchical schema
  - Protocol buffer column types
  - Efficient client code

Can you have a scalable database without going NoSQL? Yes.

The AdWords Ecosystem

One shared database backing Google's core AdWords business



Our Legacy DB: Sharded MySQL

Sharding Strategy

- Sharded by customer
- Apps optimized using shard awareness

Limitations

- Availability
  - Master / slave replication -> downtime during failover
  - Schema changes -> downtime for table locking
- Scaling
  - Grow by adding shards
  - Rebalancing shards is extremely difficult and risky
  - Therefore, limit size and growth of data stored in database
- Functionality
  - Can't do cross-shard transactions or joins

Demanding Users

Critical applications driving Google's core ad business

- 24/7 availability, even with datacenter outages
- Consistency required
  - Can't afford to process inconsistent data
  - Eventual consistency too complex and painful
- Scale: 10s of TB, replicated to 1000s of machines

Shared schema

- Dozens of systems sharing one database
- Constantly evolving - multiple schema changes per week

SQL Query

- Query without code

Our Solution: F1

A new database,

- built from scratch,
- designed to operate at Google scale,
- without compromising on RDBMS features.

Co-developed with new lower-level storage system, Spanner

Underlying Storage - Spanner

Descendant of Bigtable, Successor to Megastore

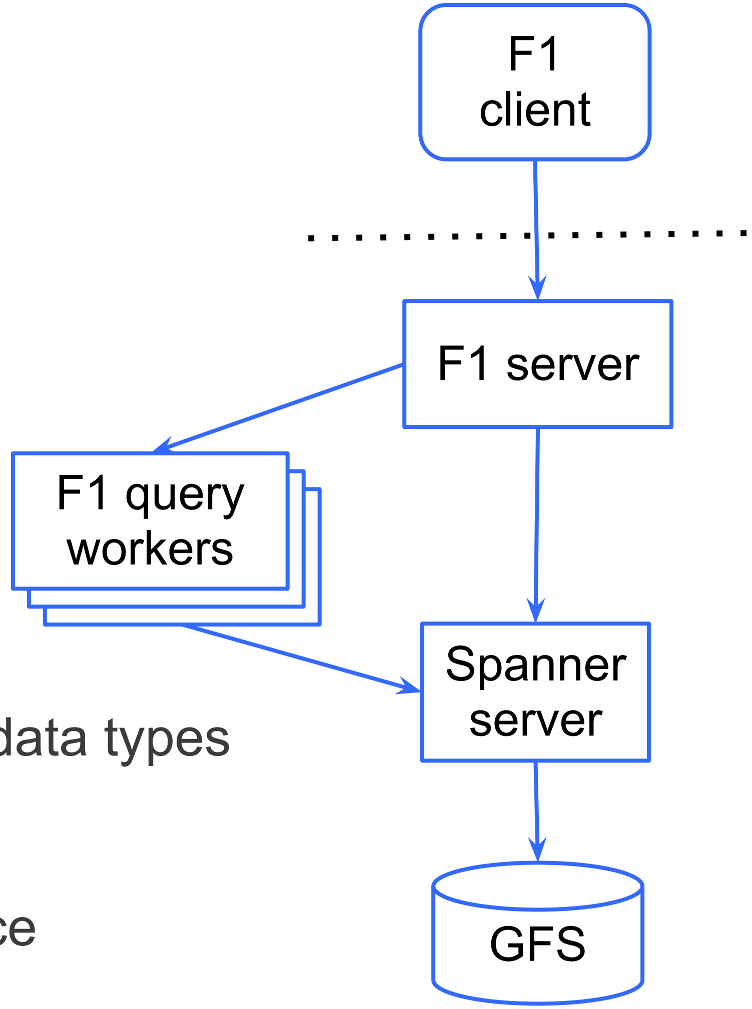
Properties

- Globally distributed
- Synchronous cross-datacenter replication (with Paxos)
- Transparent sharding, data movement
- General transactions
  - Multiple reads followed by a single atomic write
  - Local or cross-machine (using 2PC)
- Snapshot reads

F1

Architecture

- Sharded Spanner servers
  - data on GFS and in memory
- Stateless F1 server
- Pool of workers for query execution



Features

- Relational schema
  - Extensions for hierarchy and rich data types
  - Non-blocking schema changes
- Consistent indexes
- Parallel reads with SQL or Map-Reduce

How We Deploy

- Five replicas needed for high availability
- Why not three?
  - Assume one datacenter down
  - Then one more machine crash => partial outage

Geography

- Replicas spread across the country to survive regional disasters
  - Up to 100ms apart

Performance

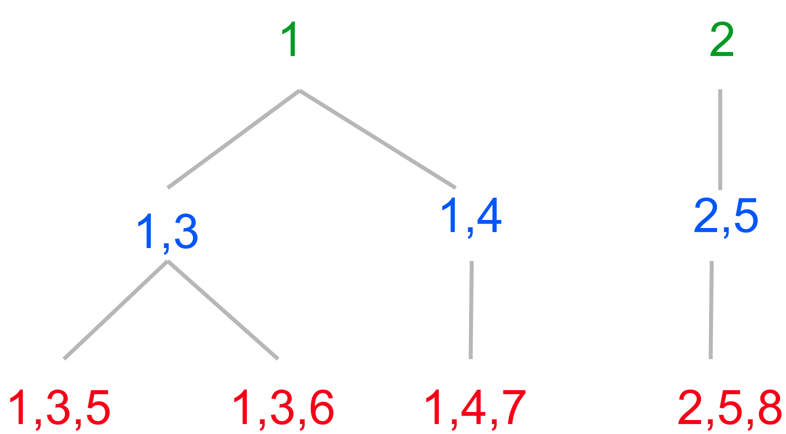
- Very high commit latency - 50-100ms
- Reads take 5-10ms - much slower than MySQL
- High throughput

Hierarchical Schema

Explicit table hierarchies. Example:

- Customer (root table): PK (CustomerId)
- Campaign (child): PK (CustomerId, CampaignId)
- AdGroup (child): PK (CustomerId, CampaignId, AdGroupId)

Rows and PKs



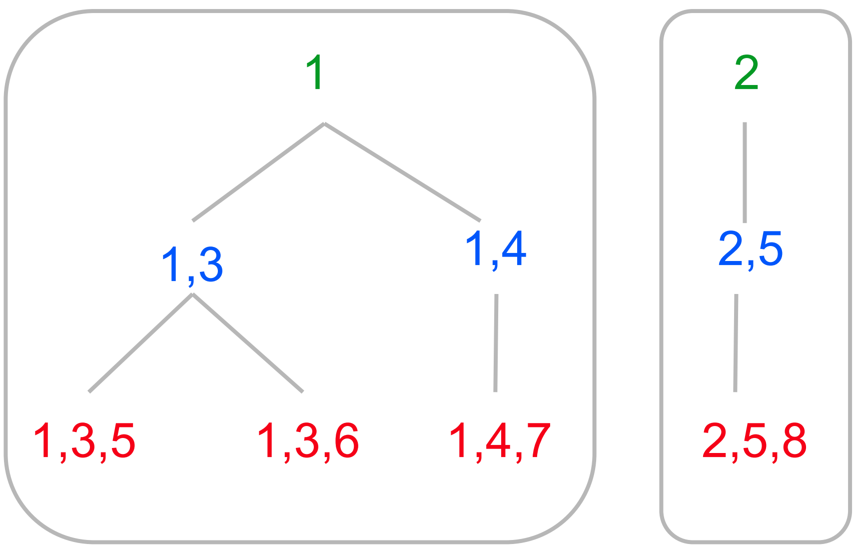
Storage Layout

```
Customer (1)
Campaign (1,3)
AdGroup  (1,3,5)
AdGroup  (1,3,6)
Campaign (1,4)
AdGroup  (1,4,7)
Customer (2)
Campaign (2,5)
AdGroup  (2,5,8)
```

Clustered Storage

- Child rows under one root row form a **cluster**
- Cluster stored on one machine (unless huge)
- Transactions within one cluster are most efficient
- Very efficient joins inside clusters (can merge with no sorting)

Rows and PKs



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```

Protocol Buffer Column Types

Protocol Buffers

- Structured data types with optional and repeated fields
- Open-sourced by Google, APIs in several languages

Column data types are mostly Protocol Buffers

- Treated as blobs by underlying storage
- SQL syntax extensions for reading nested fields
- Coarser schema with fewer tables - inlined objects instead

Why useful?

- Protocol Buffers pervasive at Google -> no impedance mismatch
- Simplified schema and code - apps use the same objects
    - Don't need foreign keys or joins if data is inlined

SQL Query

Google™

- Parallel query engine implemented from scratch
- Fully functional SQL, joins to external sources
- Language extensions for protocol buffers

```
SELECT CustomerId
FROM Customer c PROTO JOIN c.Whitelist.feature f
WHERE f.feature_id = 302
  AND f.status = 'STATUS_ENABLED'
```

Making queries fast

- Hide RPC latency
- Parallel and batch execution
- Hierarchical joins

Coping with High Latency

Preferred transaction structure

- One read phase: No serial reads
  - Read in batches
  - Read asynchronously in parallel
- Buffer writes in client, send as one RPC

Use coarse schema and hierarchy

- Fewer tables and columns
- Fewer joins

For bulk operations

- Use small transactions in parallel - high throughput

Avoid ORMs that add hidden costs

ORM Anti-Patterns

- Obscuring database operations from app developers
- Serial reads
  - `for` loops doing one query per iteration
- Implicit traversal
  - Adding unwanted joins and loading unnecessary data

These hurt performance in all databases.

They are disastrous on F1.

Our Client Library

- Very lightweight ORM - doesn't really have the "R"
  - Never uses Relational joins or traversal
- All objects are loaded explicitly
  - Hierarchical schema and protocol buffers make this easy
  - Don't join - just load child objects with a range read
- Ask explicitly for parallel and async reads

Results

Google™

Development

- Code is slightly more complex
  - But predictable performance, scales well by default
- Developers happy
  - Simpler schema
  - Rich data types -> lower impedance mismatch

User-Facing Latency

- Avg user action: ~200ms - on par with legacy system
- Flatter distribution of latencies
  - Mostly from better client code
  - Few user actions take much longer than average
  - Old system had severe latency tail of multi-second transactions

Current Challenges

- Parallel query execution
  - Failure recovery
  - Isolation
  - Skew and stragglers
  - Optimization

- Migrating applications, without downtime
  - Core systems already on F1, many more moving
  - Millions of LOC

Summary

We've moved a large and critical application suite from MySQL to F1.

This gave us

- Better scalability
- Better availability
- Equivalent consistency guarantees
- Equally powerful SQL query

And also similar application latency, using

- Coarser schema with rich column types
- Smarter client coding patterns

In short, we made our database scale, and didn't lose any key database features along the way.