F1: A Distributed SQL Database That Scales

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10/21/2013

What is F1?

- Distributed relational database
- Built to replace sharded MySQL back-end of AdWords system
- Combines features of NoSQL and SQL
- Built on top of Spanner

Goals

- Scalability
- Availability
- Consistency
- Usability

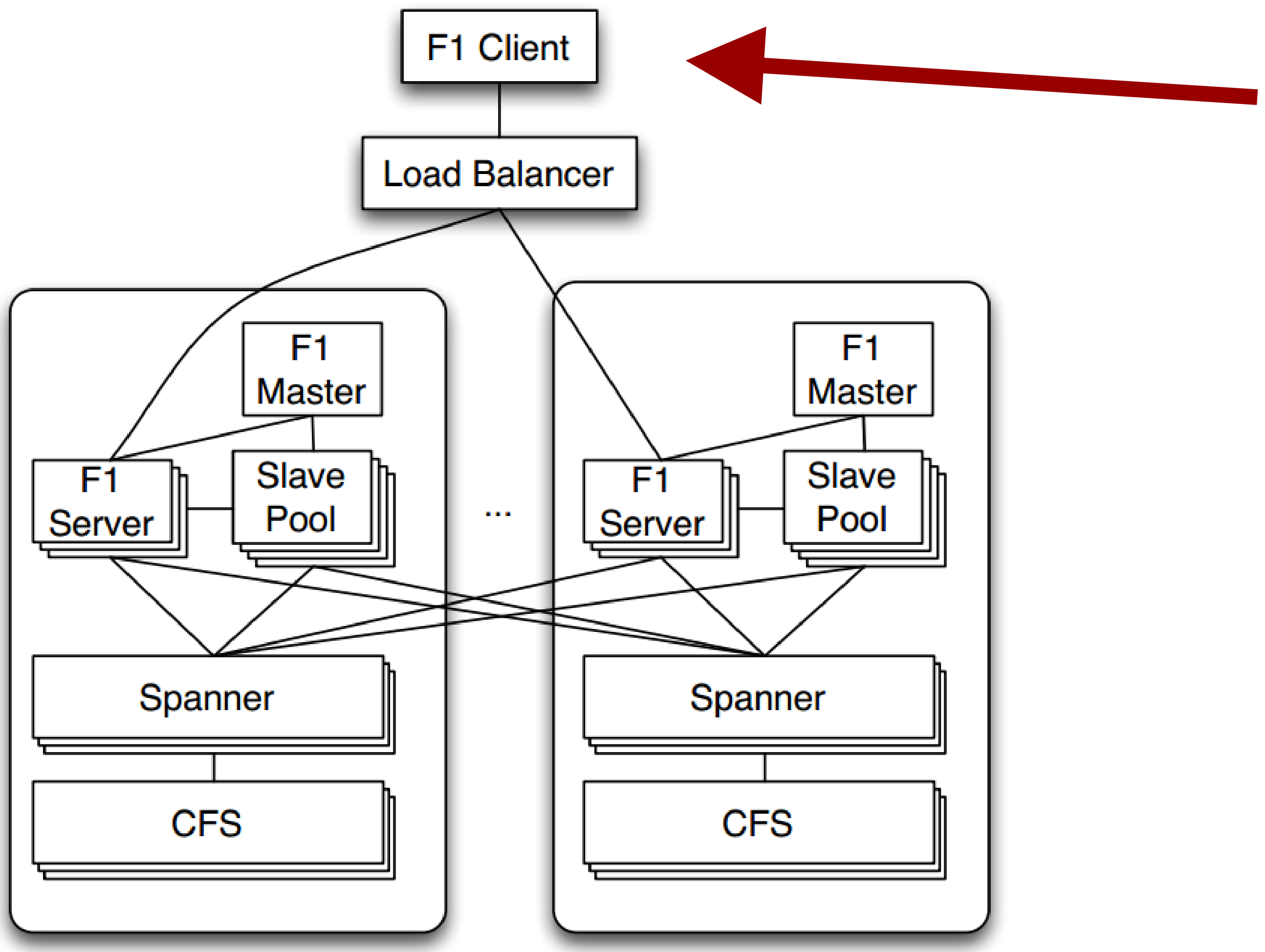
Features Inherited From Spanner

- Scalable data storage, resharding, and rebalancing
- Synchronous replication
- Strong consistency & ordering

New Features Introduced

- Distributed SQL queries, including joining data from external data sources
- Transactionally consistent secondary indexes
- Asynchronous schema changes including database reorganizations
- Optimistics transactions
- Automatic change history recording and publishing

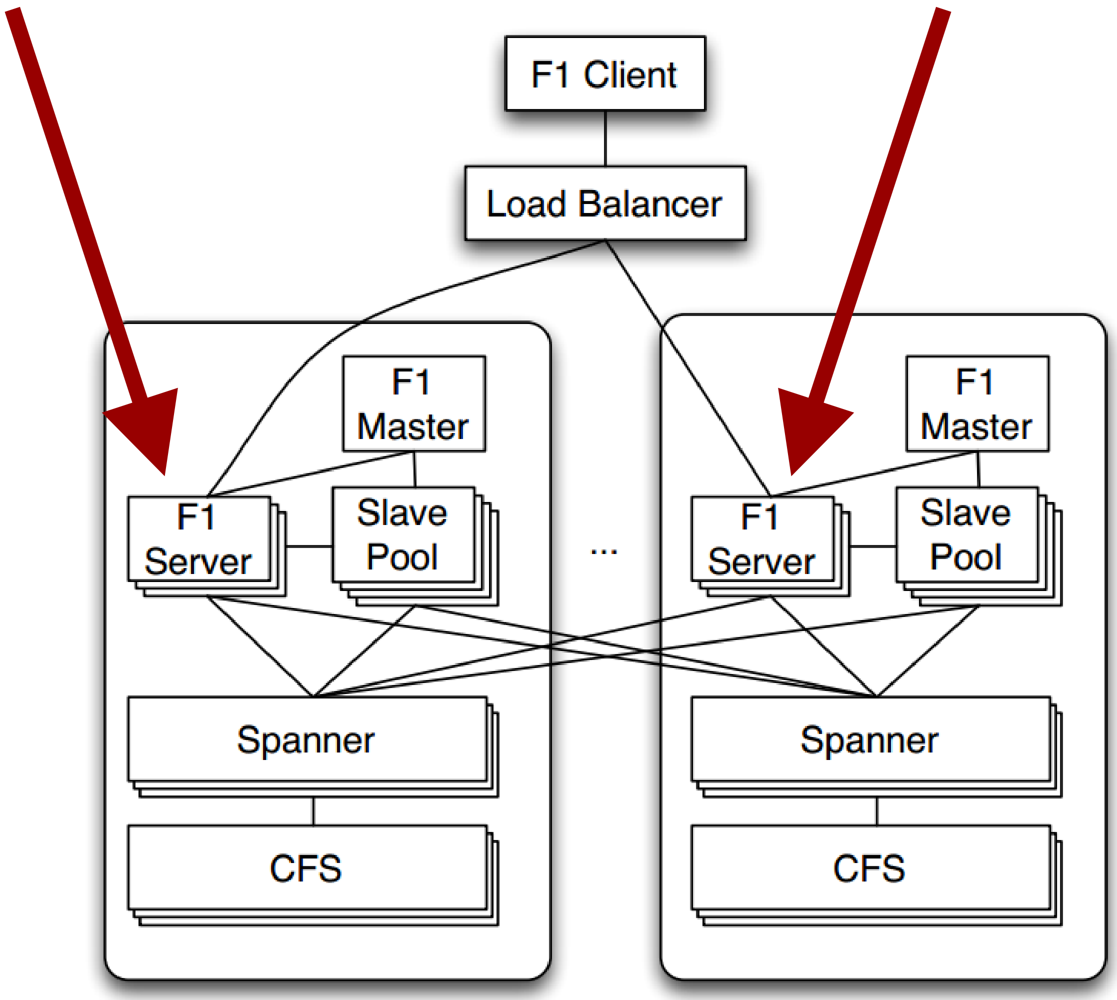
Architecture



Architecture - F1 Client

- Client library
- Initiates reads/writes/transactions
- Sends requests to F1 servers

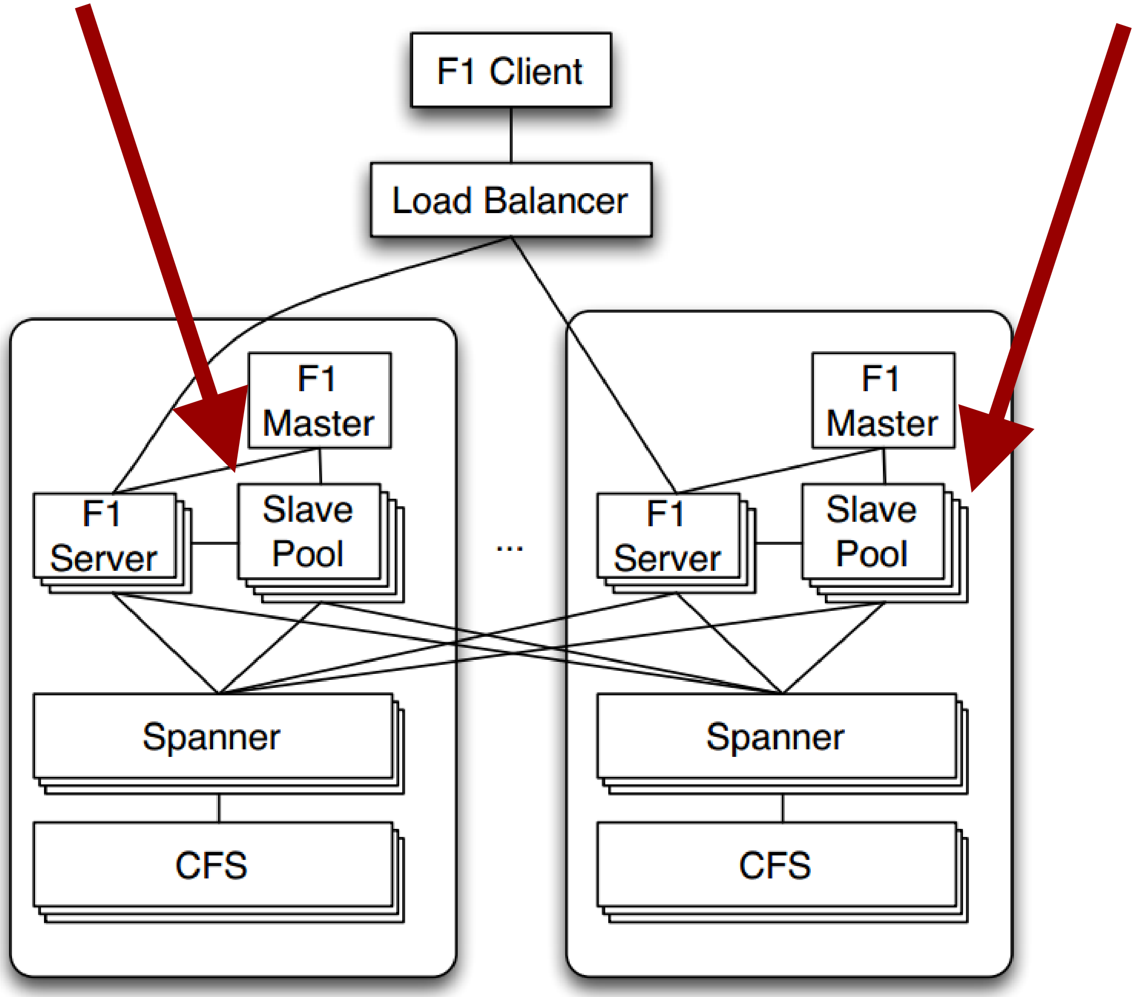
Architecture



Architecture - F1 Server

- Coordinates query execution
- Reads and writes data from remote sources
- Communicates with Spanner servers
- Can be quickly added/removed

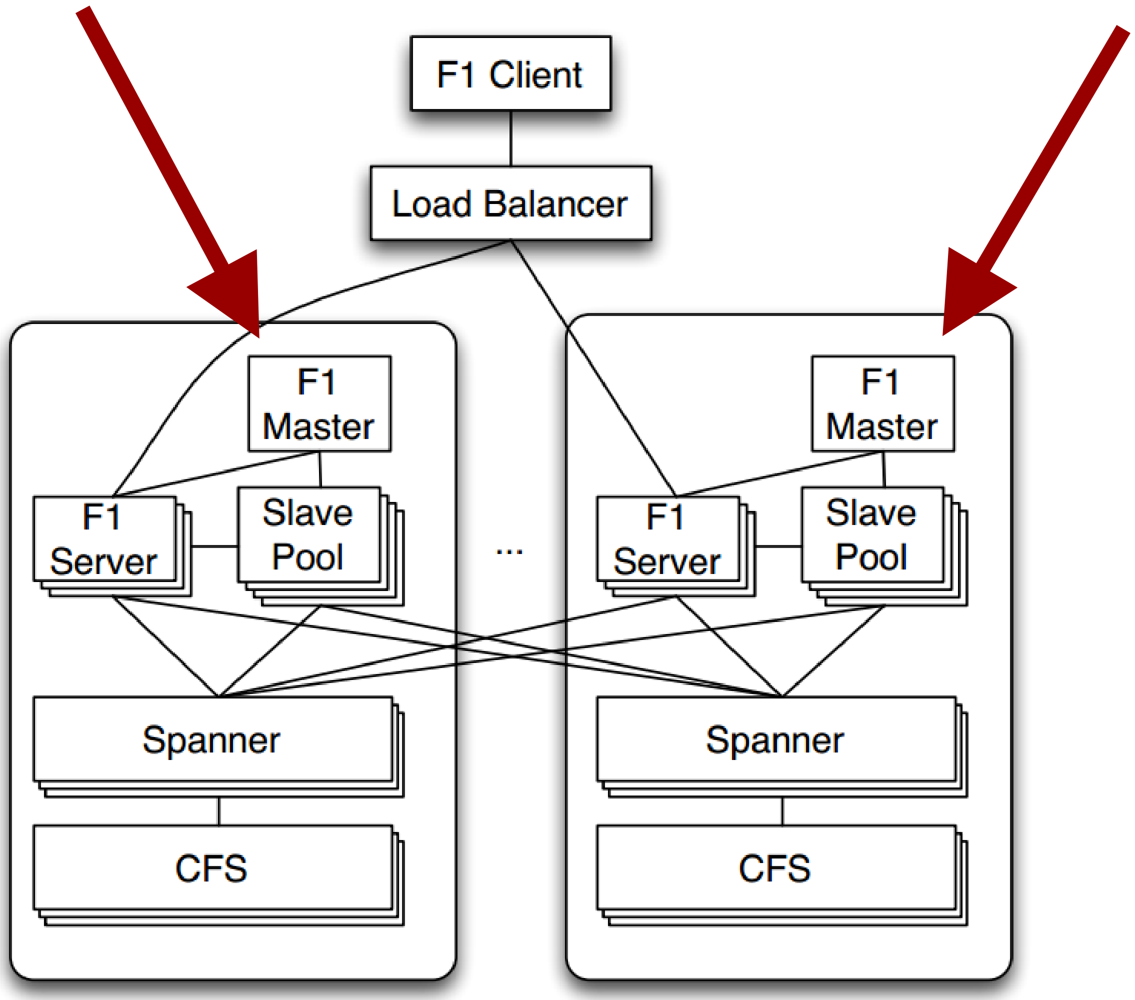
Architecture



Architecture - F1 Slaves

- Pool of slave worker tasks
- Processes execute parts of distributed query coordinated by F1 servers
- Can also be quickly added/removed

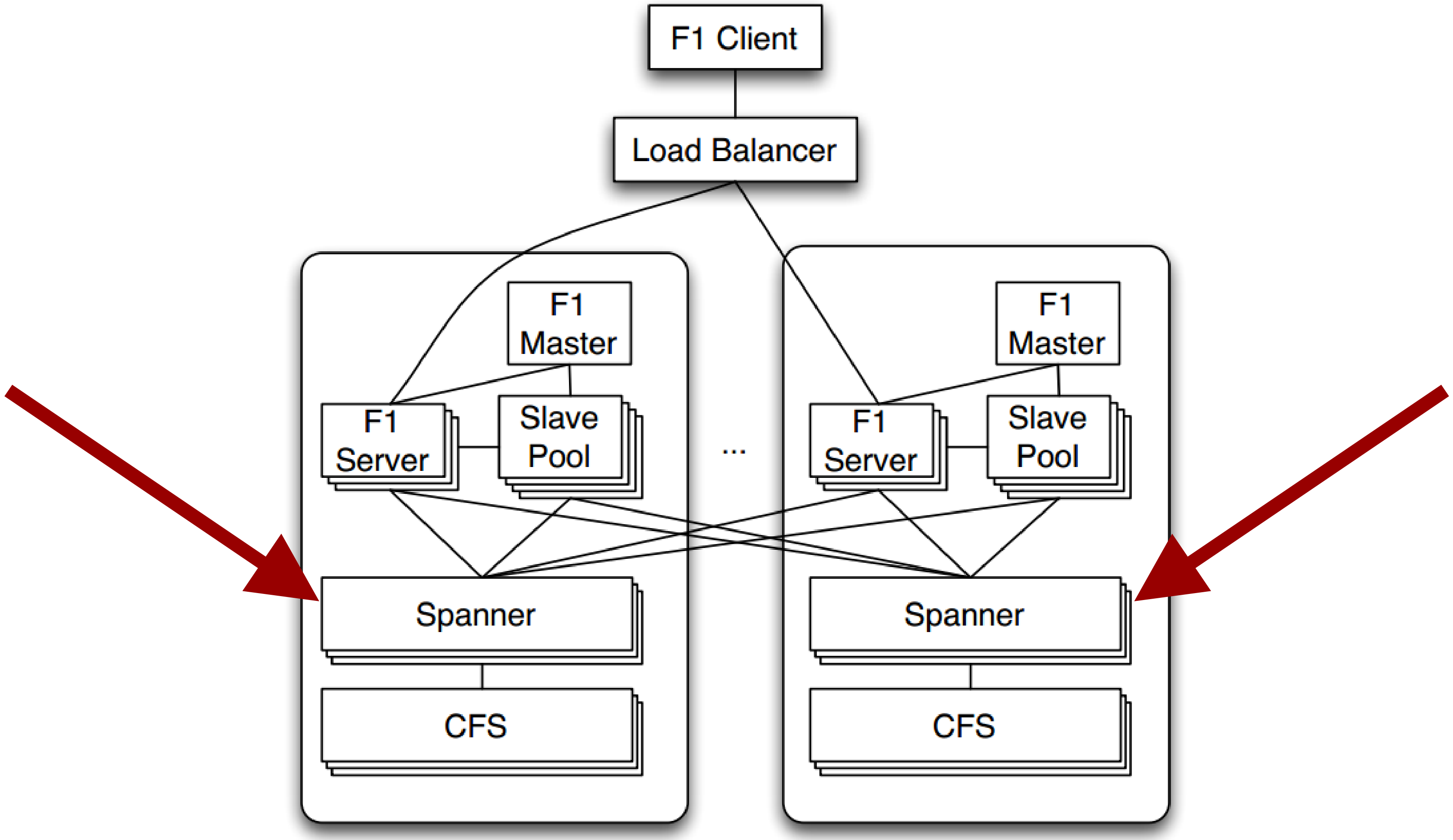
Architecture



Architecture - F1 Master

- Maintains slave membership pool
- Monitors slave health
- Distributes list membership list to F1 servers

Architecture



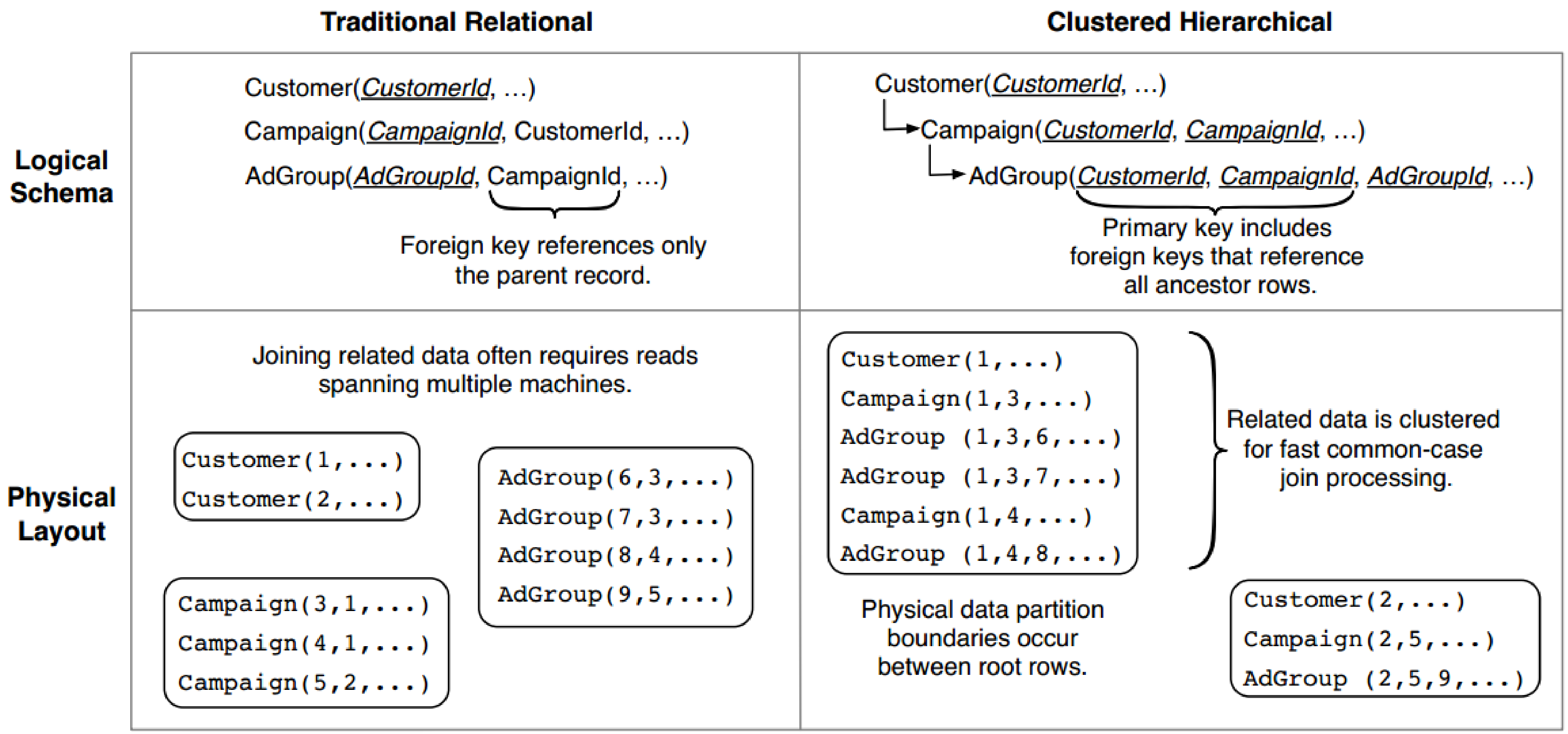
Architecture - Spanner Servers

- Hold actual data
- Re-distribute data when servers added
- Support MapReduce interaction
- Communicates with CFS

Data Model

- Relational schema (similar to RDBMS)
- Tables can be organized into a hierarchy
- Child table clustered/interleaved within the rows from its parent table
  - Child has foreign key as prefix of p-key

Data Model



Traditional Relational | **Clustered Hierarchical**

Logical Schema

Traditional Relational:

Customer(*CustomerId*, …)

Campaign(*CampaignId*, CustomerId, …)

AdGroup(*AdGroupId*, CampaignId, …)

Foreign key references only the parent record.

Clustered Hierarchical:

Customer(*CustomerId*, …)

→Campaign(*CustomerId*, *CampaignId*, …)

→AdGroup(*CustomerId*, *CampaignId*, *AdGroupId*, …)

Primary key includes foreign keys that reference all ancestor rows.

Physical Layout

Traditional Relational:

Joining related data often requires reads spanning multiple machines.

```
Customer(1,...)
Customer(2,...)
```

```
AdGroup(6,3,...)
AdGroup(7,3,...)
AdGroup(8,4,...)
AdGroup(9,5,...)
```

```
Campaign(3,1,...)
Campaign(4,1,...)
Campaign(5,2,...)
```

Clustered Hierarchical:

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

Related data is clustered for fast common-case join processing.

Physical data partition boundaries occur between root rows.

```
Customer(2,...)
Campaign(2,5,...)
AdGroup (2,5,9,...)
```

Secondary Indexes

- Transactional & fully consistent
- Stored as separate tables in Spanner
- Keyed by index key + index table p-key
- Two types: Local and Global

Local Secondary Indexes

- Contain root row p-key as prefix
- Stored in same spanner directory as root row
- Adds little additional cost to a transaction

Global Secondary Indexes

- Does not contain root row p-key as prefix
- Not co-located with root row
  - Often sharded across many directories and servers
- Can have large update costs
- Consistently updated via 2PC

Schema Changes - Challenges

- F1 massively and widely distributed
- Each F1 server has schema in memory
- Queries & transactions must continue on all tables
- System availability must not be impacted during schema change

Schema Changes

- Applied asynchronously
- Issue: concurrent updates from different schemas
- Solution:
  - Limiting to one active schema change at a time (lease on schema)
  - Subdivide schema changes into phases
    - Each consecutively mutually compatible

Transactions

- Full transactional consistency
- Consists of multiple reads, optionally followed by a single write
- Flexible locking granularity

Transactions - Types

- Read-only: fixed snapshot timestamp
- Pessimistic: Use Spanner’s lock transactions
- Optimistic:
  - Read phase (Client collects timestamps)
  - Pass to F1 server for commit
  - Short pessimistic transaction (read + write)
    - Abort if conflicting timestamp
    - Write to commit if no conflicts

Optimistic Transactions: Pros and Cons

Pros

- Tolerates misbehaving clients
- Support for longer transactions
- Server-side retryability
- Server failover
- Speculative writes

Cons

- Phantom inserts
- Low throughput under high contention

Change History

- Supports tracking changes by default
- Each transaction creates a change record
- Useful for:
  - Pub-sub for change notifications
  - Caching

Client Design

- MySQL-based ORM incompatible with F1
- New simplified ORM
  - No joins or implicit traversals
  - Object loading is explicit
  - API promotes parallel/async reads
  - Reduces latency variability

Client Design

- NoSQL interface
  - Batched row retrieval
  - Often simpler than SQL
- SQL interface
  - Full-fledged
  - Small OLTP, large OLAP, etc
  - Joins to external data sources

Query Processing

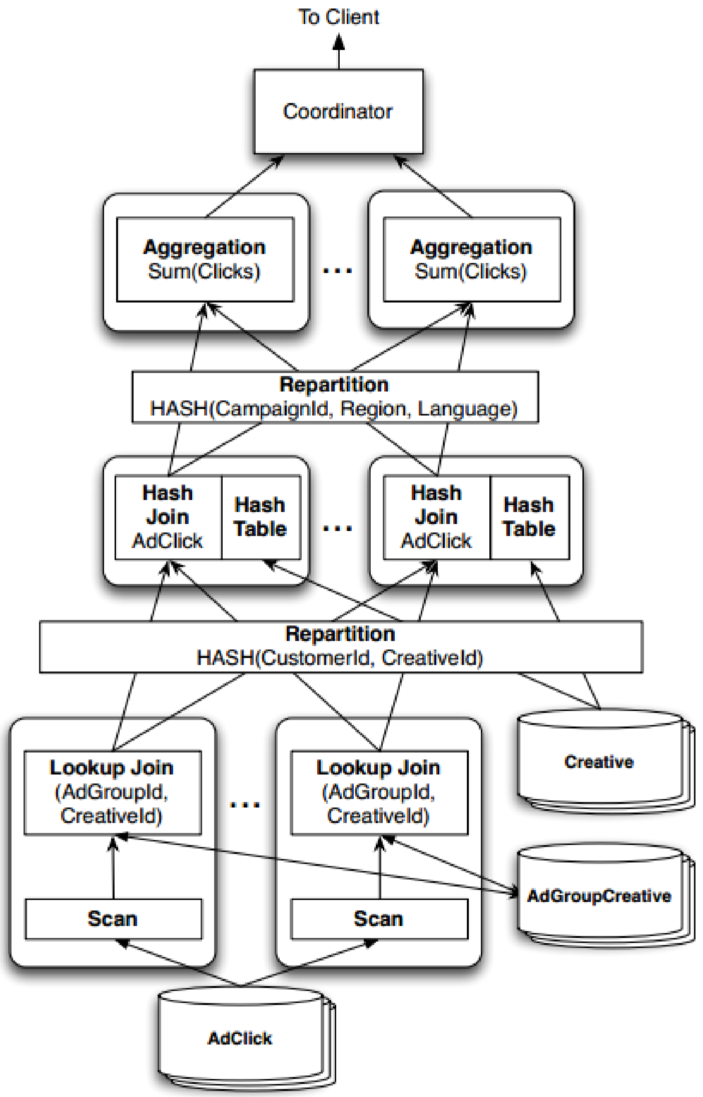
- Centrally executed or distributed
- Batching/parallelism mitigates latency
- Many hash re-partitioning steps
- Stream to later operators ASAP for pipelining
- Optimized hierarchically clustered tables
- PB-valued columns: structured data types
- Spanner’s snapshot consistency model provides globally consistent results

Query Processing Example

```
SELECT agcr.CampaignId, click.Region,
       cr.Language, SUM(click.Clicks)
FROM AdClick click
  JOIN AdGroupCreative agcr
    USING (AdGroupId, CreativeId)
  JOIN Creative cr
    USING (CustomerId, CreativeId)
WHERE click.Date = '2013-03-23'
GROUP BY agcr.CampaignId, click.Region,
         cr.Language
```

Query Processing Example

- Scan of AdClick table
- Lookup join operator (SI)
- Repartitioned by hash
- Distributed hash join
- Repartitioned by hash
- Aggregated by group



Distributed Execution

- Query splits into plan parts => DAG
- F1 server: query coordinator/root node and aggregator/sorter/filter
- Efficiently re-partitions the data
  - Can’t co-partition
  - Hash partitioning BW: network hardware
- Operate in memory as much as possible
- Hierarchical table joins efficient on child table
- Protocol buffers utilized to provide types

Evaluation - Deployment

- AdWords: 5 data centers across US
- Spanner: 5-way Paxos replication
- Read-only replicas

Evaluation - Performance

- 5-10ms reads, 50-150ms commits
- Network latency between DCs
  - Round trip from leader to two nearest replicas
  - 2PC
- 200ms average latency for interactive application - similar to previous
- Better tail latencies
- Throughput optimized for non-interactive apps (parallel/batch)
  - 500 transactions per second

Issues and Future work

- High commit latency
- Only AdWords deployment show to work well - no general results
- Highly resource-intensive (CPU, network)
- Strong reliance on network hardware
- Architecture prevents co-partitioning processing and data

Conclusion

- More powerful alternative to NoSQL
- Keep conveniences like SI, SQL, transactions, ACID but gain scalability and availability
- Higher commit latency
- Good throughput and worst-case latencies

References

- Information, figures, etc.: J. Shute, et al., F1: A Distributed SQL Database That Scales, VLDB, 2013.
- High-level summary: http://highscalability.com/blog/2013/10/8/f1-and-spanner-holistically-compared.html