Spanner: Becoming a SQL System

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What is Spanner

- Distributed transactional data management system
- Globally replicated, highly-available managed service
- Backs hundreds of mission-critical services at Google
    - AdWords, Google Play, Photos, etc.
    - 10s of millions QPS, 100s of petabytes, 5,000+ databases
- Publicly available on Google Cloud Platform (subset): http://cloud.google.com/spanner
- Builds on OSDI'12 paper
    - ACID transactions, replication, fault-tolerance
- This talk: making Spanner a SQL DBMS

Agenda

- Background
- SQL interface
- Distributed query processing
- Lessons learned

In the paper:

- Blockwise-columnar storage

Background

Logical data model

```
CREATE TABLE Singers (
  SingerId INT64 NOT NULL,
  SingerName STRING(MAX)
) PRIMARY KEY(SingerId);

CREATE TABLE Albums (
  SingerId INT64 NOT NULL,
  AlbumId INT64 NOT NULL,
  AlbumTitle STRING(MAX),
) PRIMARY KEY(SingerId, AlbumId),
  INTERLEAVE IN Singers;
```

SingerId	**SingerName**
1	Beatles
2	U2
3	Pink Floyd

SingerId	**AlbumId**	**AlbumTitle**
1	1	Help!
1	2	Abbey Road
3	1	The Wall

Database sharding

- Shard: horizontal slice of database, key-range partitioned
- Rows that agree on `SingerId` are co-located
- Can be physically interleaved

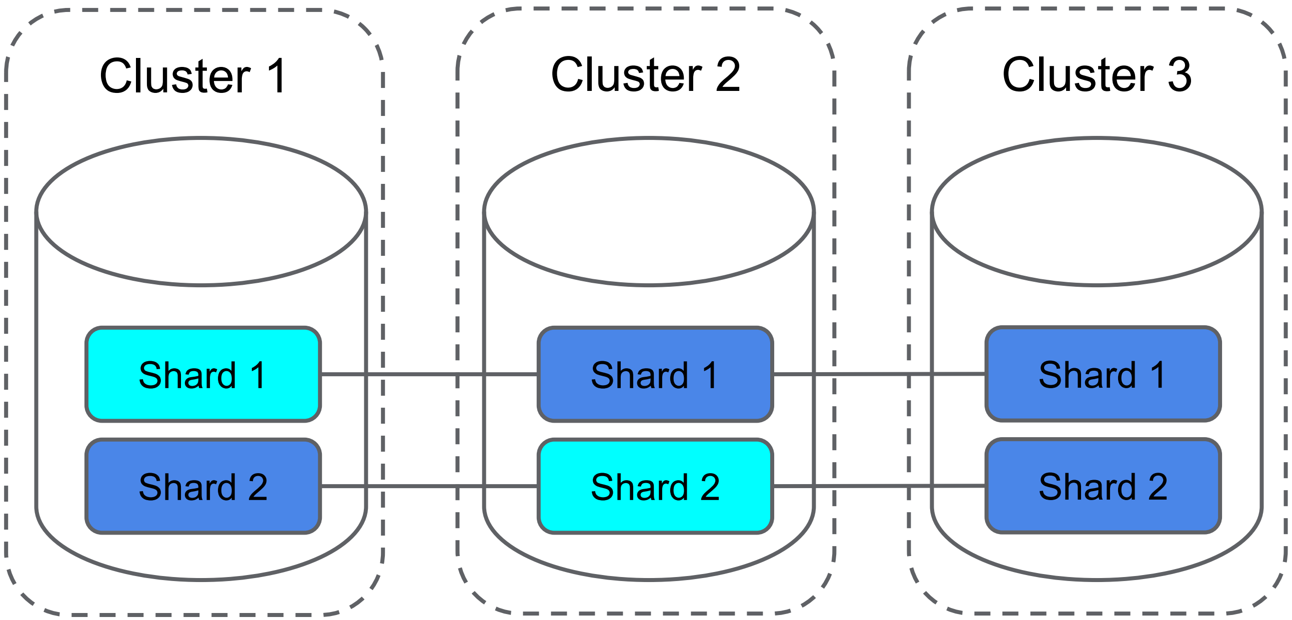
1	Beatles	
1	1	Help!
1	2	Abbey Road
2	U2	

Shard 1: SingerId ∈ (-INF, 3)

3	Pink Floyd	
3	1	The Wall

Shard 2: SingerId ∈ [3, +INF)

Shard replication



- Replication uses Paxos
- Sync and async replication protocols
- Leaders responsible for writes
- Non-leaders serve reads, may be behind

(cyan)	Leader
(blue)	Non-leader

Replica placement

Example: geo-replication of a mission-critical database

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Transactions

details in OSDI'12

- Pessimistic locking + timestamp versioning (MVCC)
- Externally consistent: respect wall-time order
  - Every Tx occurs at a timestamp T
  - Via atomic and GPS clocks
- Snapshot transactions: non-blocking
  - See consistent state of entire database at some timestamp T
  - Strong reads: effects of all Tx committed up to now
  - Stale reads: pick T in bounded past
- Read-Write transactions
  - All writes are buffered and committed at end of Tx
  - 2PL within a Paxos group
  - 2PC across Paxos groups
  - Tx use write-ahead redo log
  - Log entry is committed by replicating to a quorum of replicas

SQL interface

Common SQL dialect

- Standards-compliant
- Type system aligned with programming languages
  - INT64, FLOAT, STRING (UTF8), TIMESTAMP (nanoseconds)
  - Reduces impedance mismatch
- First-class support for nested data
  - ARRAY and STRUCT types
  - Protocol Buffers: schematized binary objects (currently internal only)

- Significant language design work across teams
- Shared with other Google systems: BigQuery/Dremel, F1 (Ads), etc.

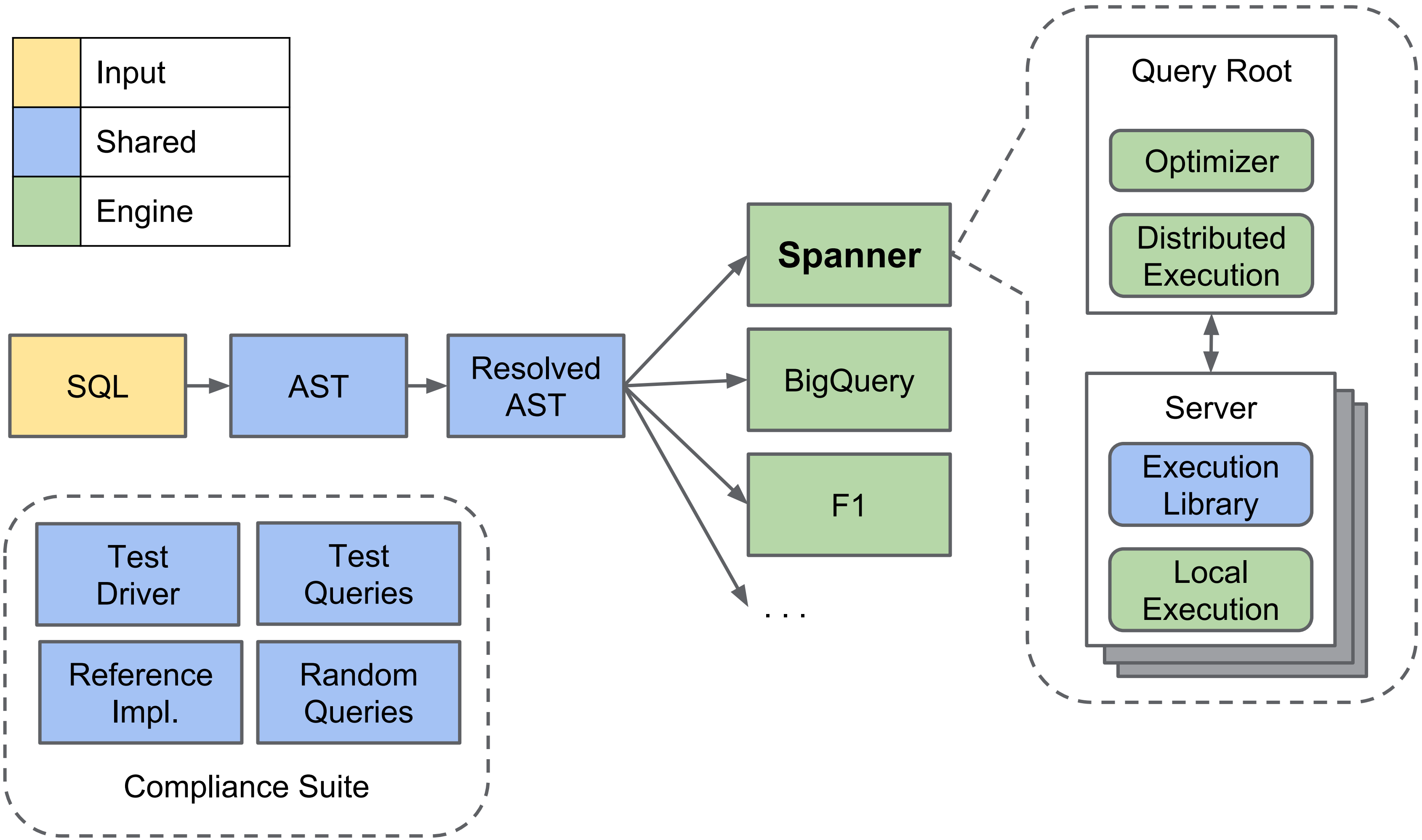
Sample query: name & titles

```
SELECT s.SingerName,
       ARRAY(SELECT a.AlbumTitle
             FROM Albums a
             WHERE a.SingerId = s.SingerId) titles
FROM Singers s
WHERE s.SingerId BETWEEN 1 AND 5
```

SingerName STRING	**titles** ARRAY<STRING>
Beatles	[Help!, Abbey Road]
U2	[ ]
Pink Floyd	[The Wall]

- Easier to use than outer joins or multiple roundtrips

Same query semantics across systems



Distributed Execution

Distributed query execution

- Tightly coupled architecture
  - Query processor inside the database server
  - Typical design for standalone DBMSes but less so for distributed systems
- Challenge of scale: data never sits still
  - Continuous resharding (due to load, capacity, config changes, ...)
  - Shard boundaries may change while query is running
  - Shards may become temporarily unavailable during query execution
  - Alternative replicas: near/far, loaded/idle, caught-up/behind
- Mechanisms used in Spanner
  - Query routing: key-range rpcs + range extraction
  - Parallelizing execution: partition work by shards, push it down
  - Dealing with failures: restartable query processing

Query routing: key-range rpcs

- Routes requests to row ranges
  - E.g., `WHERE SingerId BETWEEN @low AND @high`
- Hides complexity of locating data
- Finds nearest, sufficiently up-to-date replica for given concurrency mode
- Retries automatically
  - Unavailability, data movement, schema updates, ...
- Clients cache sharding information
- Clients cache "location hints" for queries
  - Send query to right server without extra hops or query analysis
  - E.g., `Singers/SingerId[@low]`

Query routing: range extraction

```
SELECT * FROM Albums
WHERE (SingerId = 1 AND AlbumId >= 10) OR
      (SingerId IN (2,3) AND AlbumId != 0)
```

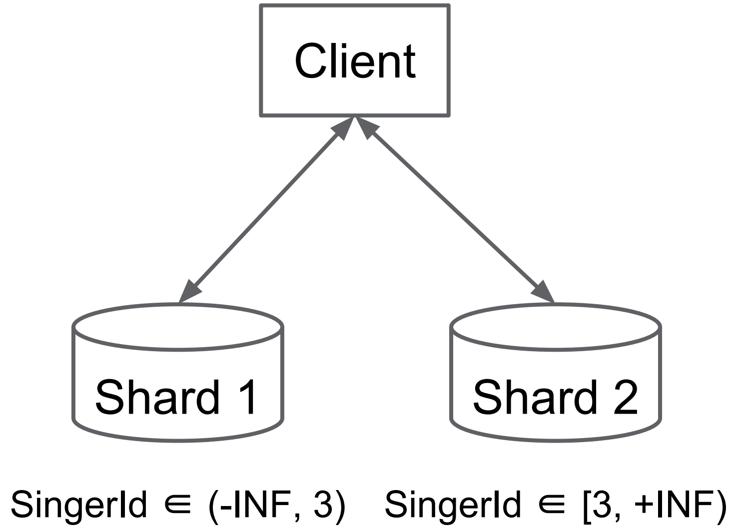
- Also used for restricting scan ranges
- Computed at runtime
  - May access data
- Uses efficient data structure
  - Filter tree (in the paper)

SingerId	AlbumId
[1..1]	[10, +INF)
[2..2]	(-INF, 0)
[2..2]	(0, +INF)
[3..3]	(-INF, 0)
[3..3]	(0, +INF)

Parallelizing Execution

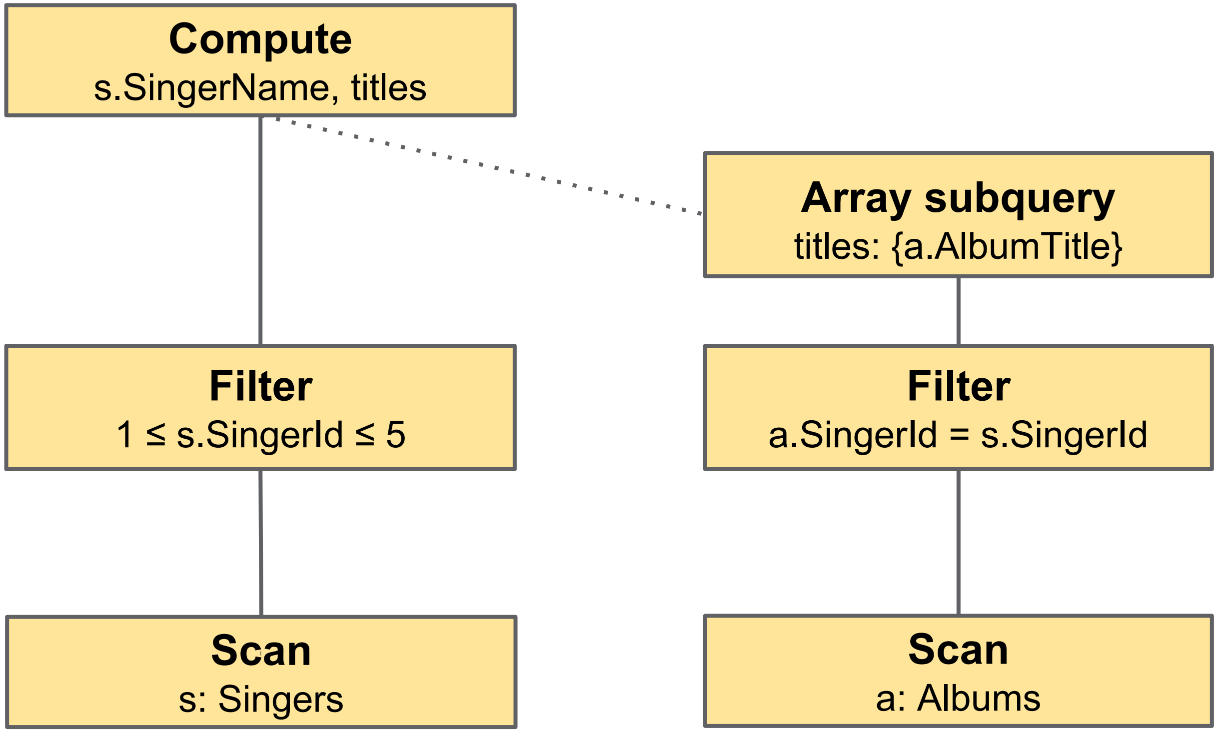
Parallelizing execution

```
SELECT SingerName, ARRAY(SELECT ...) titles
FROM Singers WHERE SingerId BETWEEN 1 AND 5
```

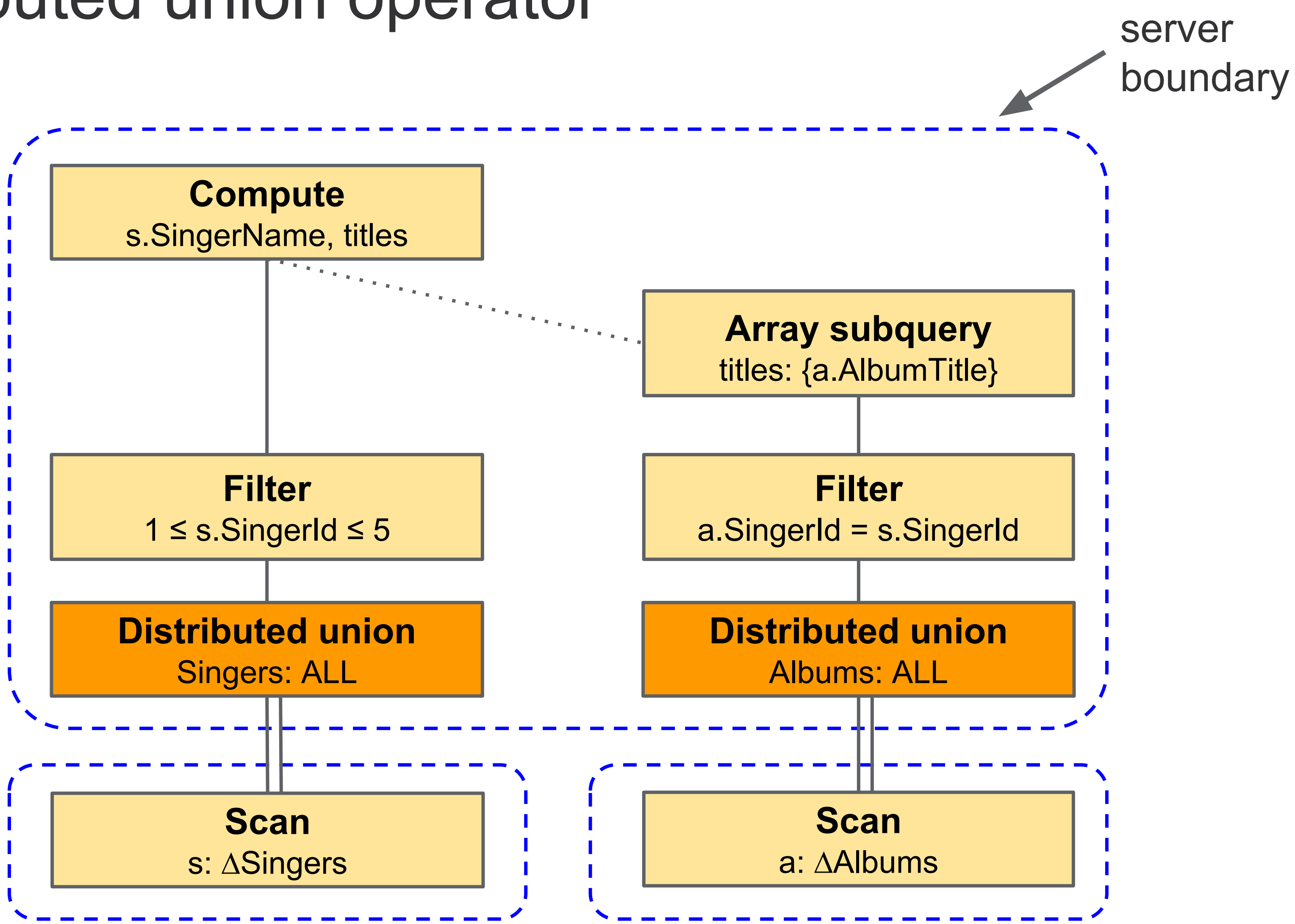


- Assume fixed shard boundaries for now

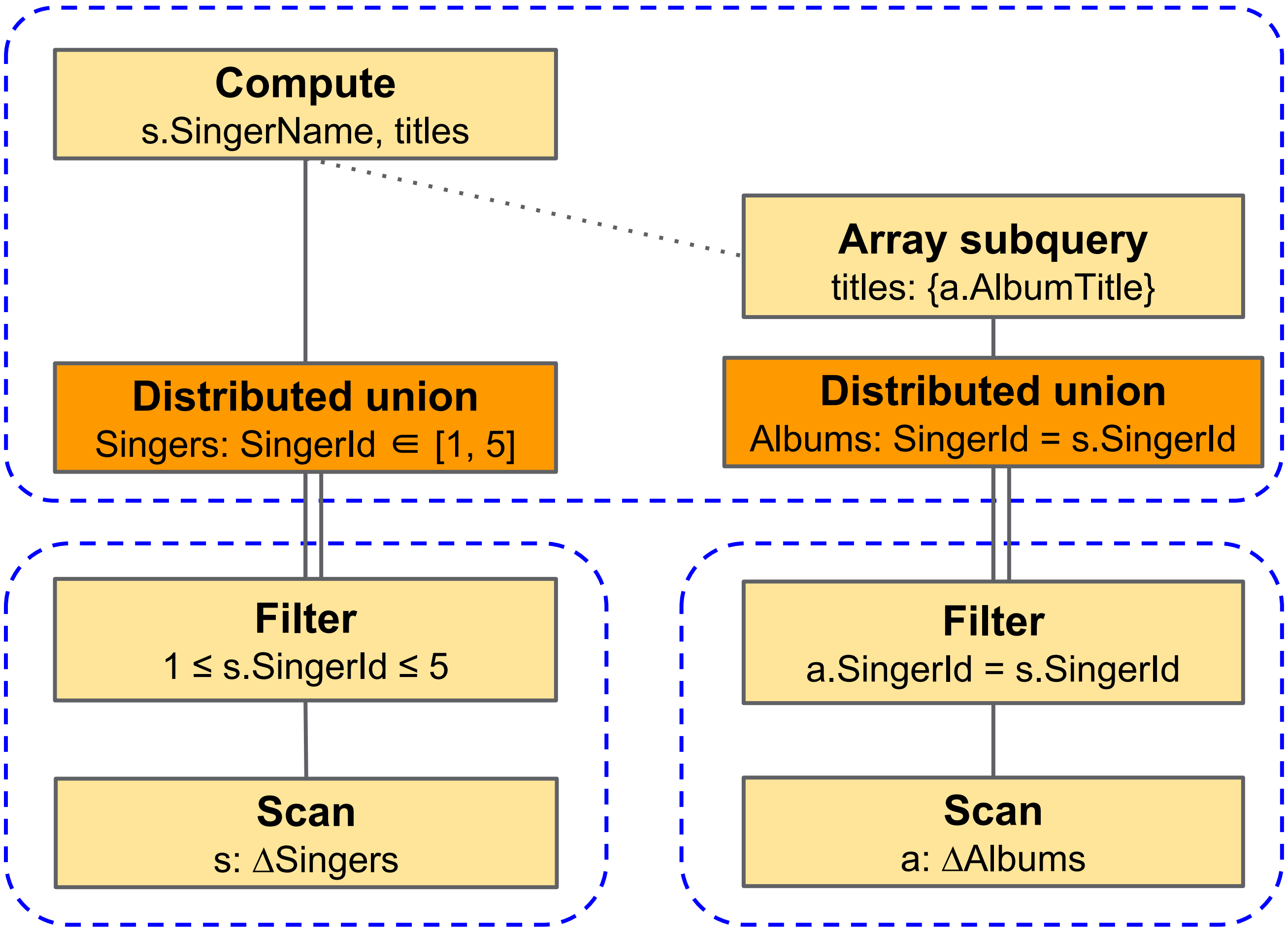
Initial logical plan



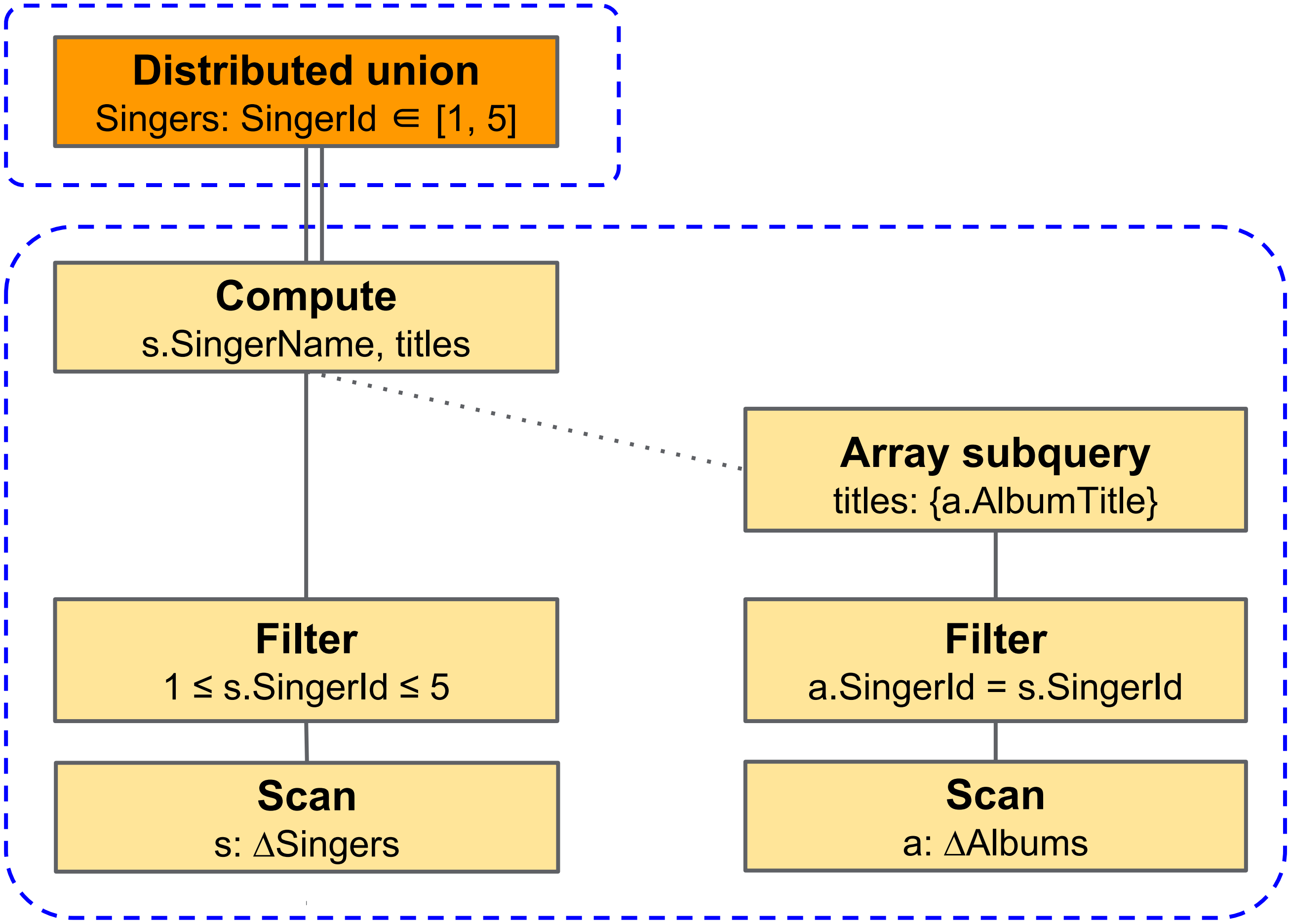
Distributed union operator



Push work to shards, extract distribution ranges



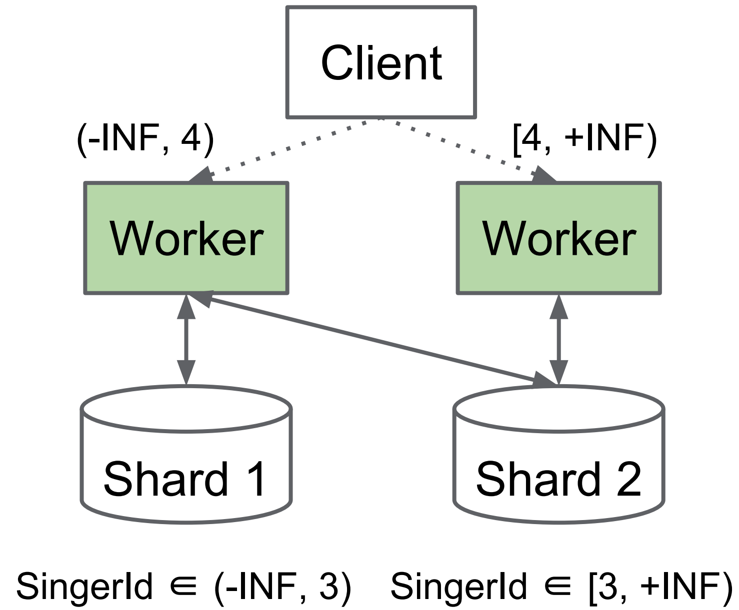
Exploiting co-location



Parallel-consumer API

```
SELECT SingerName, ARRAY(SELECT ...) titles
FROM Singers WHERE SingerId BETWEEN 1 AND 5
```

- Root-partitionable query:
  Q(Union of ∆T) = Union of Q(∆T)
- Same result up to order of rows
- Another main distribution operator: Distributed Cross Apply (in the paper)



Restartable snapshot queries

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Query restarts: overview

- Automatic compensation for failures
- For snapshot queries only
- Server yields "restart token" with each result batch
- Client can resume query execution after consuming partial results
- Contract: omit previously returned rows
  - No repeatability guarantee for subsequent rows

SingerName STRING	**titles** ARRAY<STRING>
Beatles	[Help!, Abbey Road]
U2	[ ]
Pink Floyd	[The Wall]

restart

Google

Query restarts: implementation challenges

- Naive solutions don't work well for "large" queries
  - Buffer final result, persist intermediate results, count rows, etc.
- Instead: efficiently capture distributed state of query execution
- Dynamic resharding
  - May restart on different row range
- Non-determinism
  - Memory size, parallelism, computer architecture, numerics, ...
- Restarts across server versions
  - Query plans, execution algorithms

Query restarts: hard but worth it

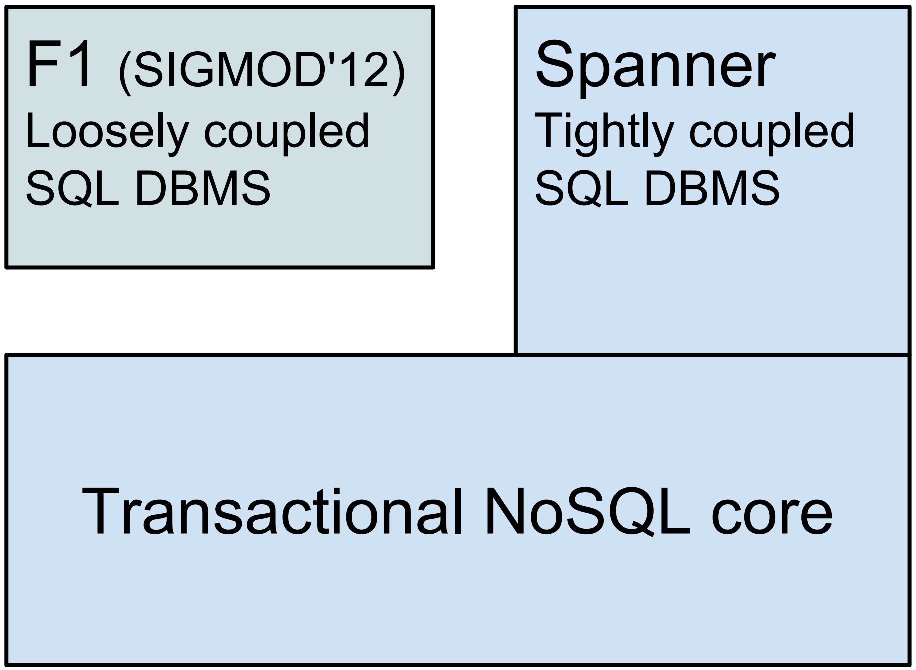
- Hide transient failures
- No retry loops: simpler programming model
- Streaming pagination
- Ensure forward progress for important class of long-running queries
- Improve tail latency of online requests
- Low-impact rolling server upgrades

Lessons learned

Rethinking DBMS architecture for scale

- Runs exclusively as a service
  - Huge economy of scale in centralizing & automating human load
  - Must never regress (query optimization is hard)
- Dynamic sharding
  - Essential for elasticity
- Requests to data ranges, not servers
  - Automatic replica selection
- Shard-level isolation
  - Shard can become unavailable without affecting workloads on other data in same table
- Restartable snapshot queries
  - Robustness & forward progress in presence of failures

System layering



- Relational model
- Schemas
- SQL
- Indexes

- Horizontal scalability
  - Web-scale systems
- Manageability
  - Transparent failover
  - Easy resharding
  - Control plane
- ACID transactions
  - Across arbitrary rows

Lessons learned

- Both loosely & tightly coupled SQL designs work well
  - Deployed simultaneously on same transactional NoSQL core
- Transactions are hugely helpful for system internals
  - Schema versioning, data movement/resharding, online index creation, backups, storage format changes, ...
- Relational model: better earlier than later
  - Well-known abstractions get developers on common page
  - Reduces cost of foreseeable future migration
- SQL vs. NoSQL dichotomy may no longer be relevant at Google

Questions?

http://cloud.google.com/spanner

Backup slides

Storage & Dist

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- This talk: making Spanner a SQL DBMS

Session 7: Storage and Distribution (2)
14:00-15:40 @ Continental C

Doh... Just implement the SQL standard

- NIST abandoned compliance testing in 1996
  - Before then, Fed Govt would only buy compliant DBMSes
- SQL:1999 specs onward are broad, imprecise
  - No implementation requirement (unlike W3C)
- Spec'ed features implemented differently by DBMSes
  - Many proprietary extensions

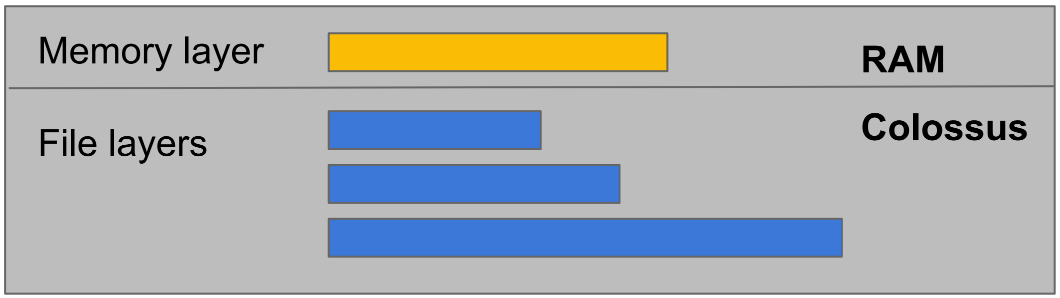
http://www.tdan.com/view-articles/4923/
Is SQL a real standard anymore?
by M. M. Gorman, ANSI/SQL committee secretary

Bottom line: substantial language design work

Blockwise-columnar storage

Persistent storage

- Log-structured merge tree:



- Original layer format: SSTables (from Bigtable)
  - Optimized for schema-less key/value pairs
- Improved format: Ressi (mid 2017)
  - Essentially, PAX layout (Ailamaki et al 2002)
  - For schematized data & hybrid OLTP/OLAP workloads

SSTables vs. Ressi

```
CREATE TABLE Singers (
   SingerId INT64 NOT NULL,
   SingerName STRING(MAX),
   URL STRING(MAX)
) PRIMARY KEY(SingerId);
```

Key	T	Value
1		Beatles
1		beatles.com
1		thebeatles.com
2		U2
2		u2.com
3		Pink Floyd
3		pinkfloyd.com

SingerId
1
2
3

URL
thebeatles.com
u2.com
pinkfloyd.com

SingerName
Beatles
U2
Pink Floyd

- Columnar within blocks
- Old versions & large values stored separately:

URL
beatles.com

Challenges

- Query optimization: never regress
- Transaction: read uncommitted results in active Tx
  - Essential for SQL DML
- Physical design
  - Wrong choices can kill performance
- Versatility
  - OLTP, OLAP, full-text, JSON, etc.