An overview of Google F1
(with an emphasis on schema change)

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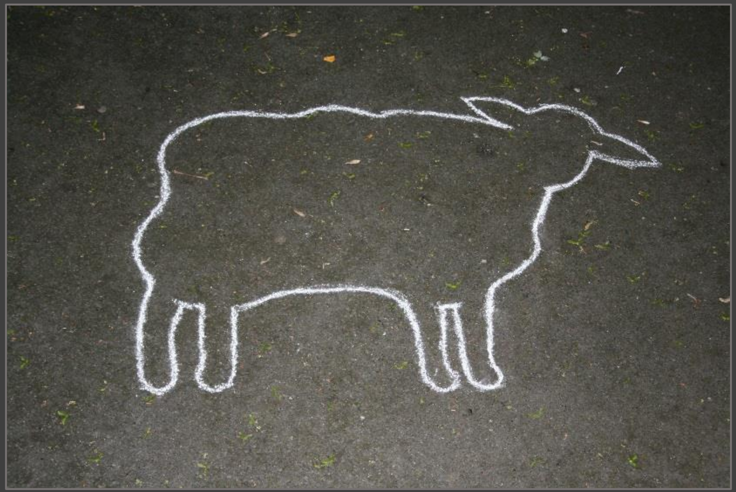
Talk outline



Introduction and background

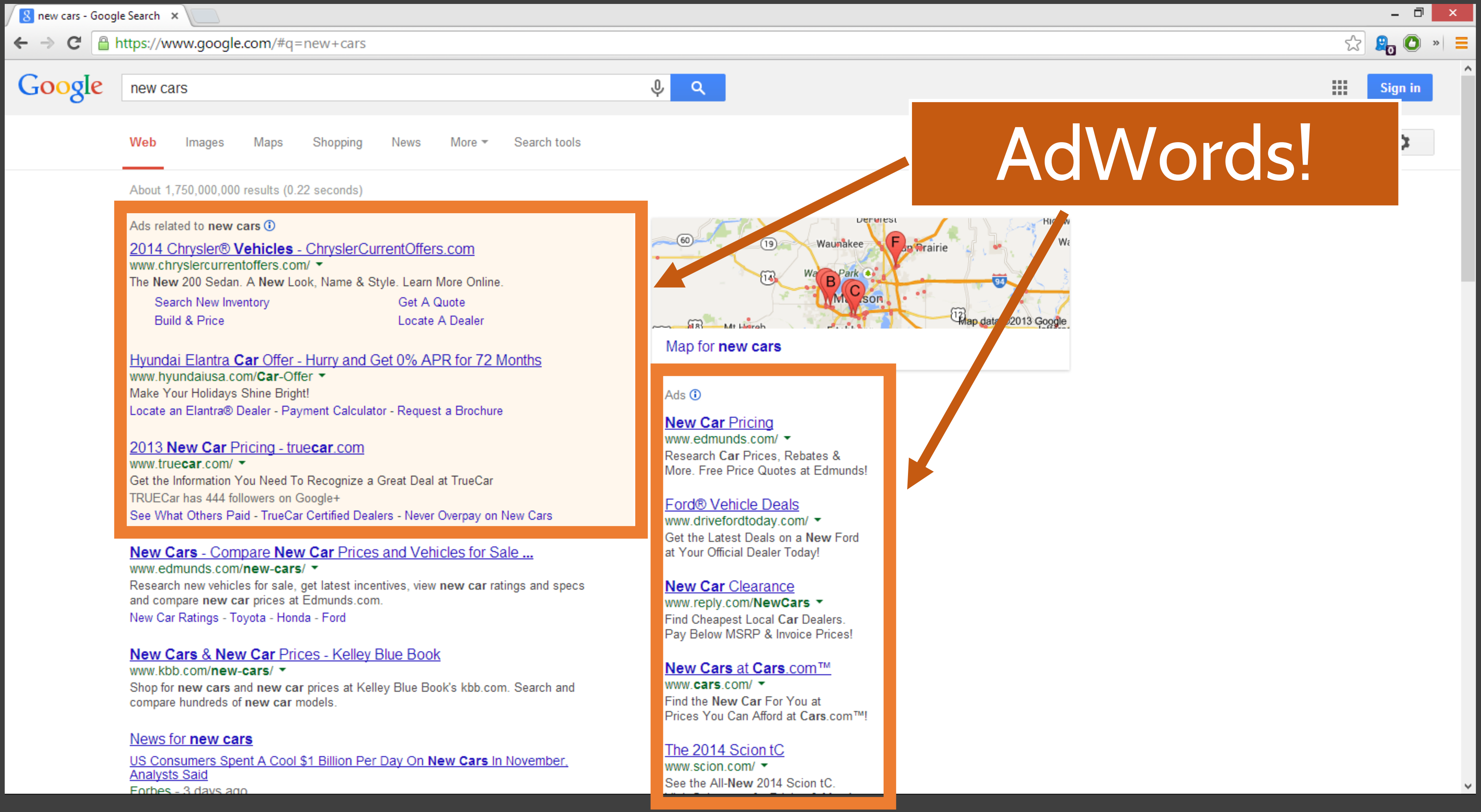
Design overview

Schema changes

Conclusion

Introduction and background

Where Google makes its cash

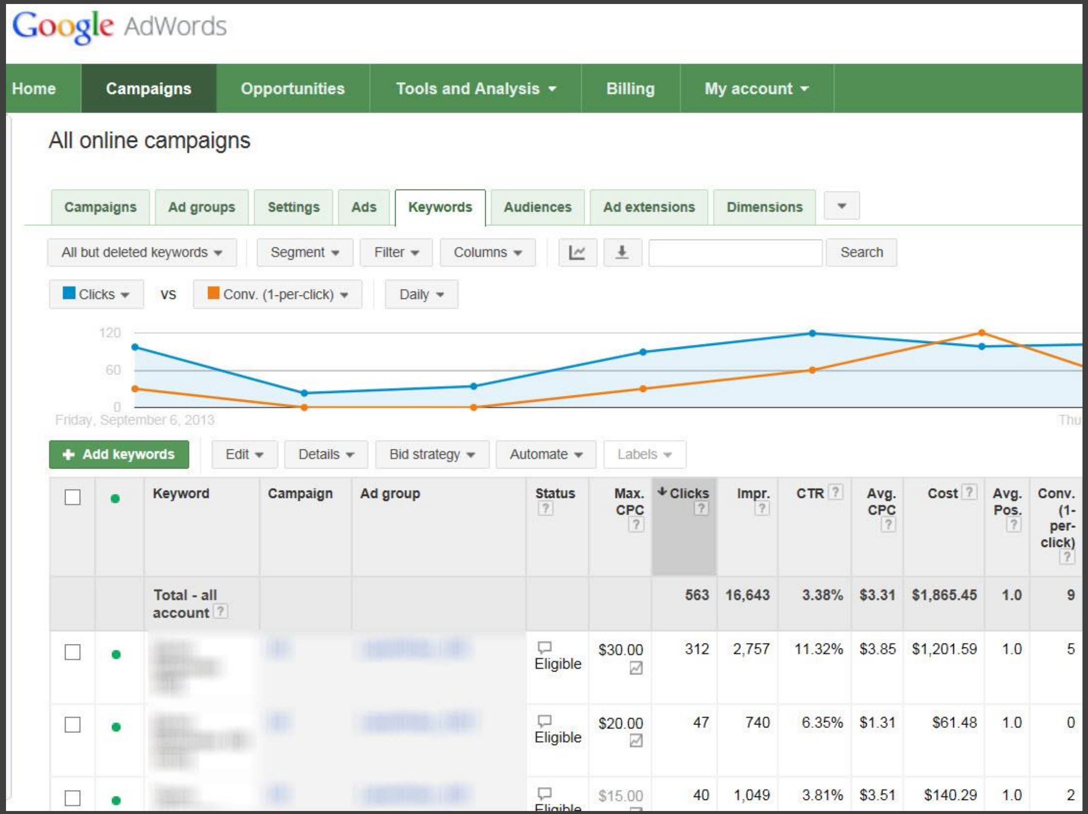


AdWords overview

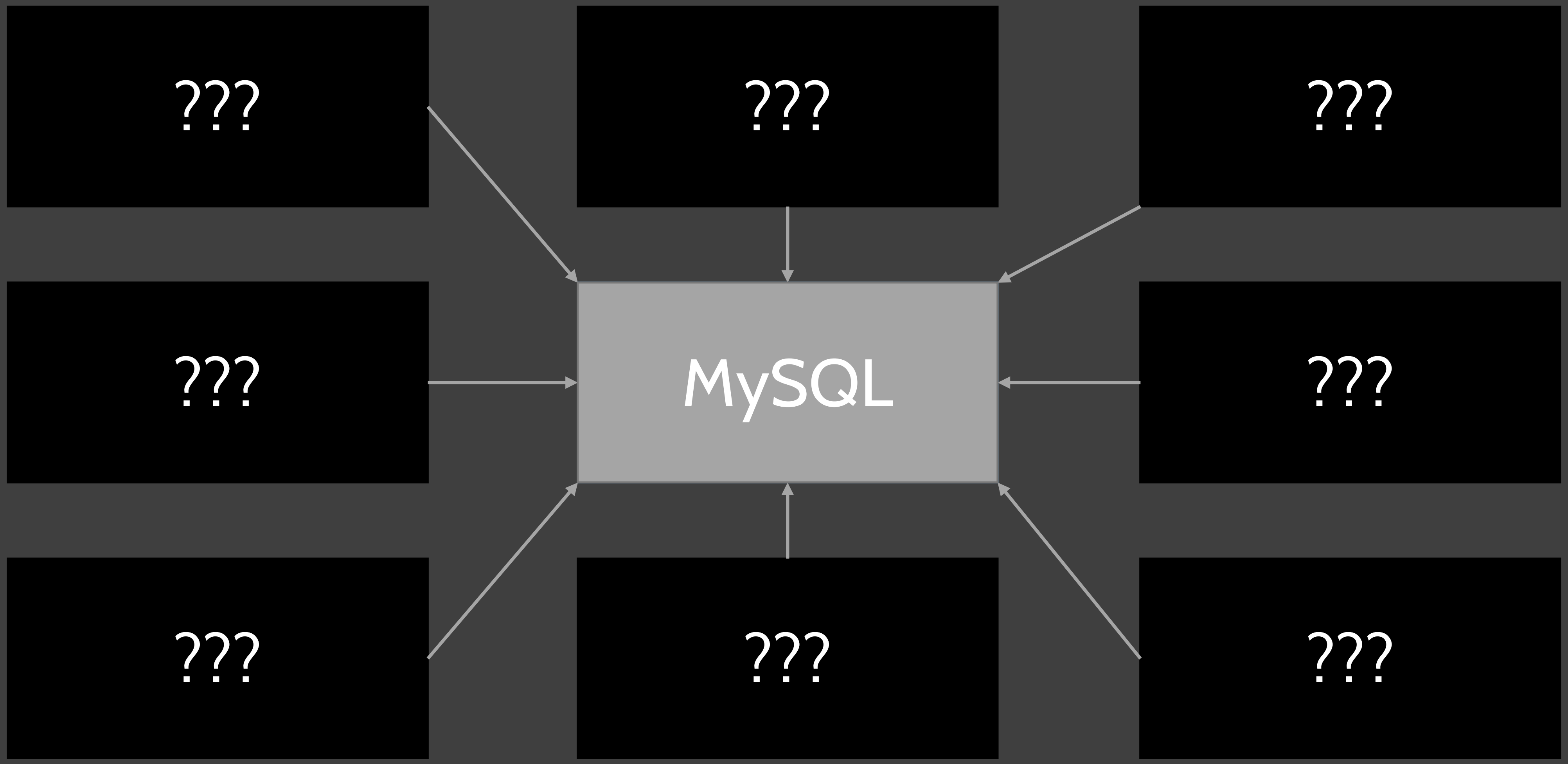
~**97%** of Google's revenue is from **advertising**!

Need to track lots of info:

- Customer information
- Ad campaign preferences
- Displayed ads
- Clicked ads
- Follow-through purchases
- …



AdWords technology ecosystem



The homegrown parallel RDBMS blues

Data **partitioned** across **dozens** of **MySQL instances**.

Have to **manually repartition** to add servers.

Developers make **assumptions** about **where data lives**.

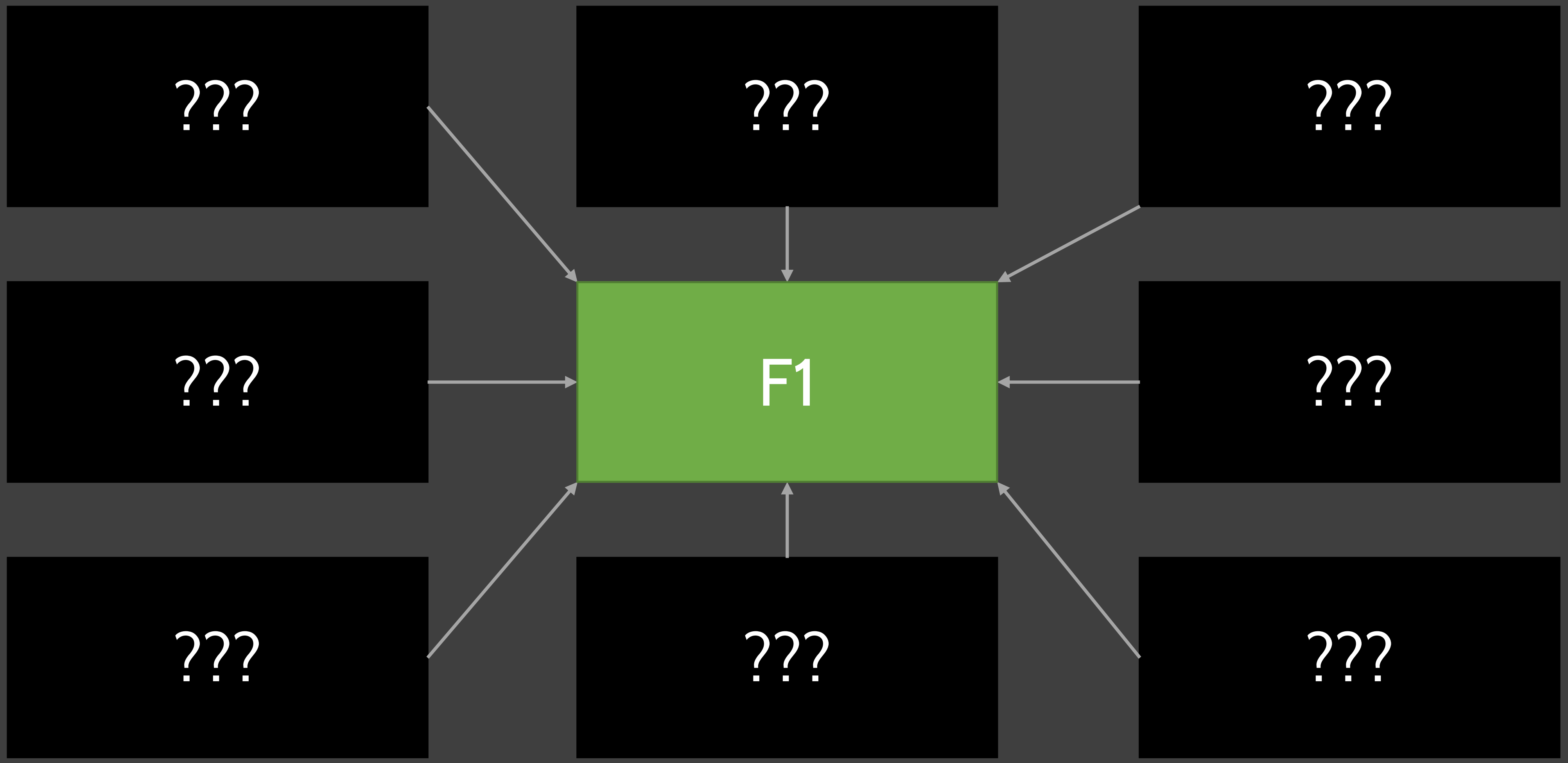
Limited **cross-machine** transactions.

Revenue paranoia

Data **synchronously replicated** across multiple machines.

Can handle machine failure; what about **datacenter failure**?

AdWords technology ecosystem



F1 design overview

What is F1?

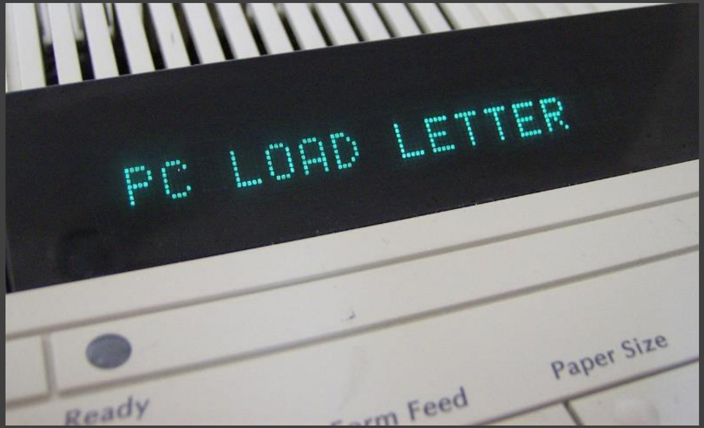
F1 is a **distributed, relational database** designed for both OLAP and OLTP.

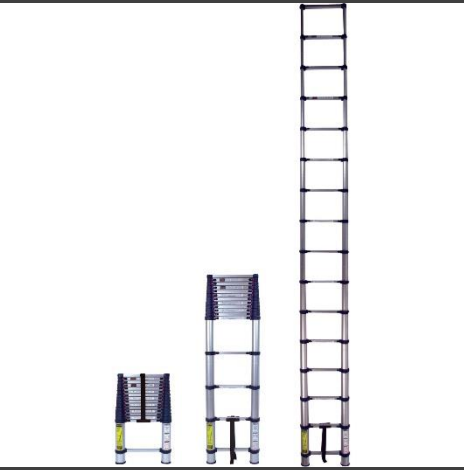
Full SQL support with **ACID semantics** for transactions.

Shute, J., Vingralek, R., Samwel, B., et al. (2013). "F1: A Distributed Database That Scales," *VLDB*, 6(11).

Two main design goals

Fault tolerance

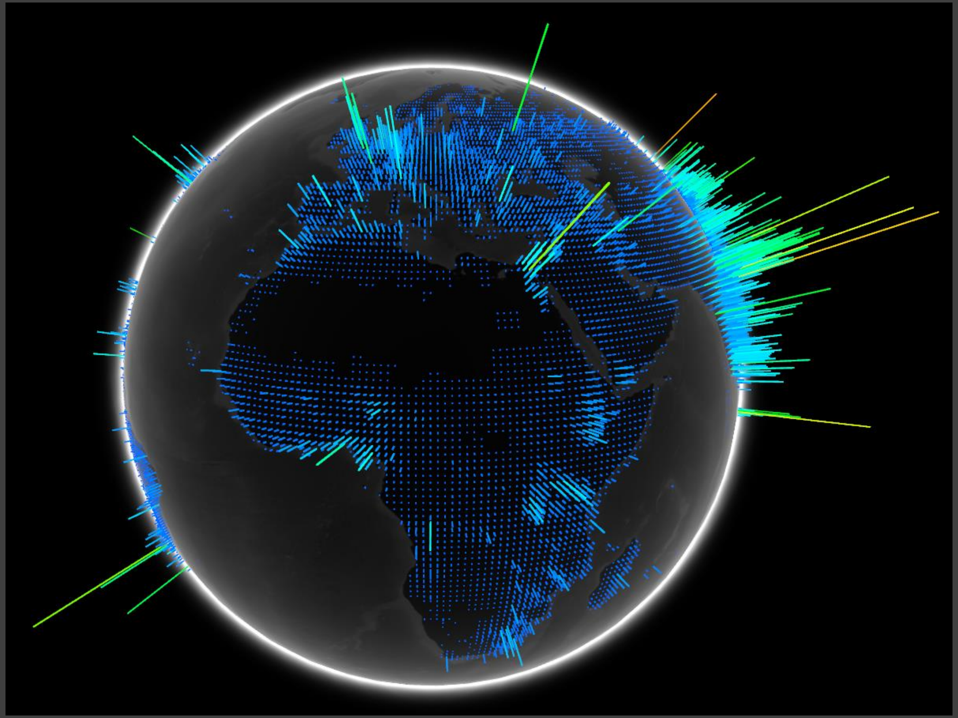




Scalability

Fault tolerance

F1 is globally distributed



A single F1 instance consists of **thousands of servers** in datacenters **across the globe**.

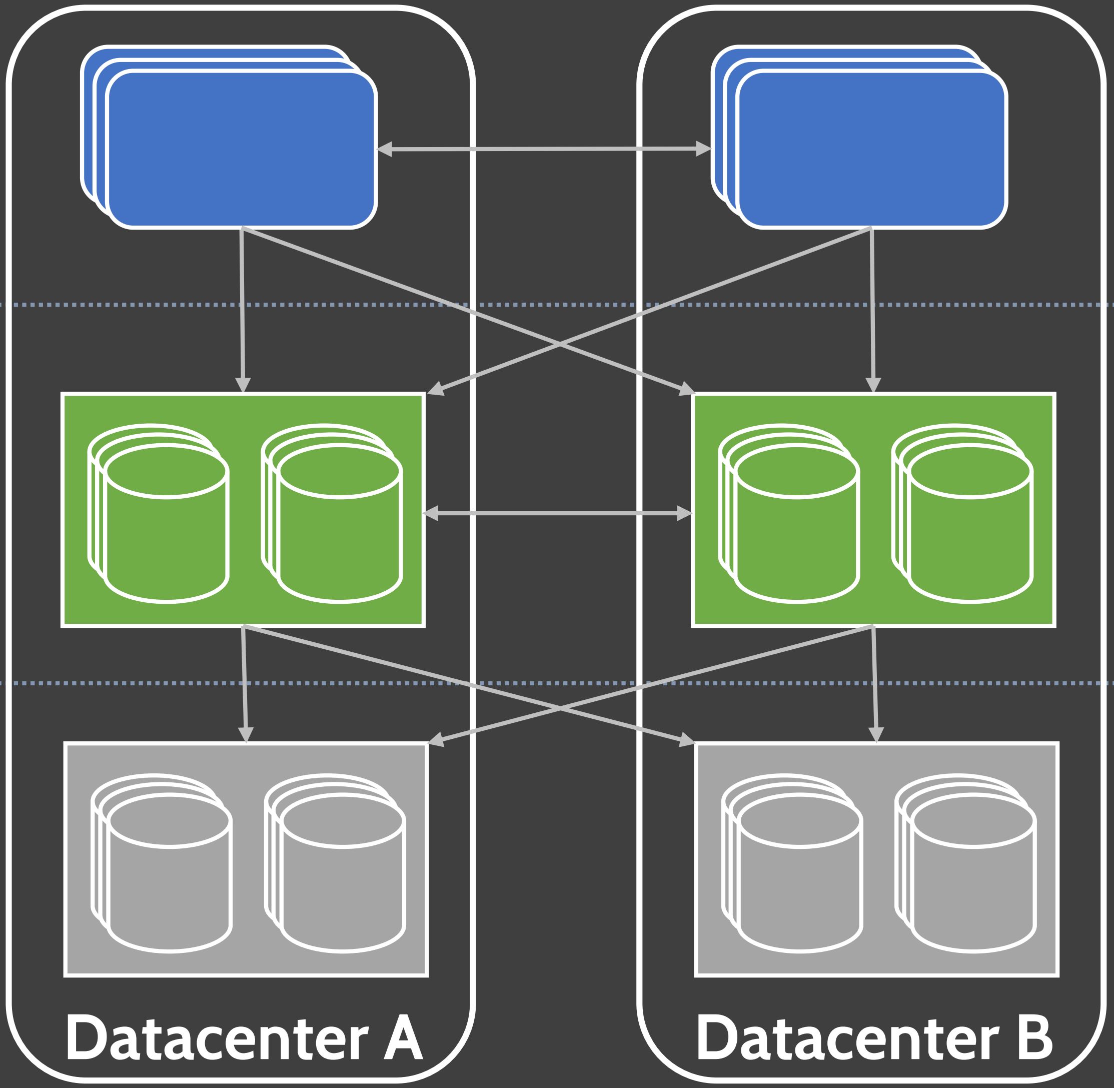
Data is **synchronously replicated across datacenters**.

F1 architecture

F1 servers
(query processing)

Spanner
(cross-datacenter storage)

Colossus
(distributed filesystem)



Spanner: next-generation BigTable

Spanner does the **storage-related "heavy lifting"** for F1.

Spanner uses **Paxos** and **2PC** to **synchronously replicate data across datacenters**.

Corbett, J. C., Dean, J., Epstein, M., et al. (2012). "Spanner: Google's Globally-Distributed Database," *OSDI*.

More Spanner features

Spanner supports **strict two-phase locking** for **pessimistic transactions**.

Spanner provides **guaranteed unique commit timestamps** for transactions.

F1 and Spanner

F1 uses Spanner mostly as a **key-value store**:

Get(key prefix)
Put(key, value)
Delete(key)

Spanner pessimistic transactions are used to enable **atomic test-and-set of multiple values**.

Scalability

Stateless servers

All data is shared among all servers.

Servers can be added or removed with **no data movement**.

Clients can send a request to **any server**, even different requests that are **part of the same transaction**.

Transactions in F1

Use a form of **optimistic concurrency control**, with **all state stored on the client** (not F1 server).

Limited to **one atomic write** operation (**implicitly commits**).

Spanner **pessimistic** transactions also supported, but **not stateless**.

Optimistic lock columns

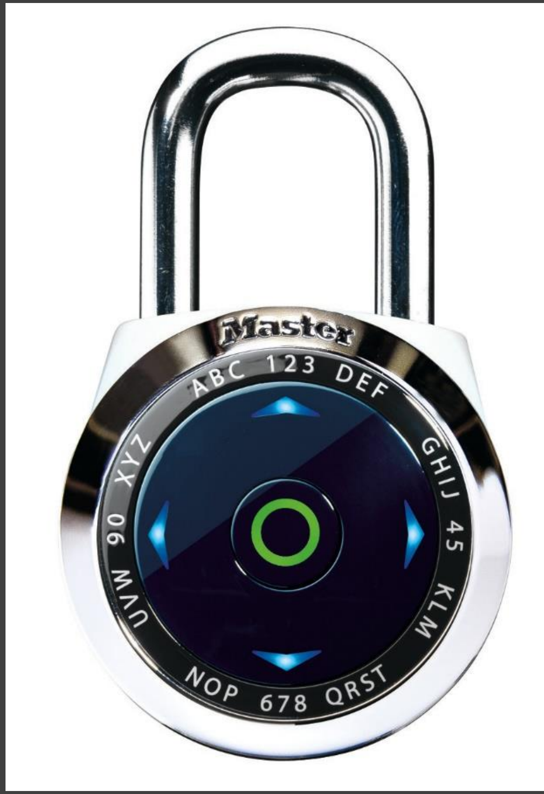
Every column is **covered by** a hidden **optimistic lock column** containing a last-modified timestamp.

When a column is updated, the **commit timestamp** of the updating transaction is **stored in its covering lock column**.

Configurable locking granularity

Users **can specify which lock covers a column**.

By default, all columns in a row are covered by a **default lock**.



Optimistic transactions: reads

Lock name	Buffered timestamp
Lock1	ts_1
Lock7	ts_2
Lock3	ts_3

When an optimistic transaction **reads a column value**, it also **reads the corresponding lock timestamp**.

Lock timestamps for all reads are **buffered on the client** for the duration of the transaction.

Optimistic transactions: write + commit

Lock name	Buffered timestamp	Current timestamp
Lock1	ts_1	ts_1
Lock7	ts_2	ts_4
Lock3	ts_3	ts_3

At commit, **all buffered timestamps** are validated against the **lock timestamps currently in the database**.

If there is a **mismatch**, the transaction **aborts**.

Optimistic transaction example

Name	Age	Lock1
John Doe	27	ts_2

T1: read (Age) -> get value 26, read lock1 and get ts_1

T2: write (Age) -> set value = 27, lock1 is updated to ts_2

T1: commit -> validate lock1 (ts_1 != ts_2), abort

Schema changes

Schemas in F1

F1 servers use a **schema** to **interpret key-value pairs as rows** and to **translate relational operations** into key-value operations.

Why is schema change in F1 important?

Data in F1 is **critical** to Google's business.

- Any **downtime** or **corruption** is **measured in dollars**!

The AdWords F1 instance is **shared** by many teams with **hundreds of developers**.

- Schema changes requested **daily**.

Why is schema change in F1 hard?

Every F1 server has a **local cached copy** of the schema.

To **change the schema**, we need to **update all the caches**, but **synchronizing** across all F1 servers is **slow**.

Until the change finishes, no operations can execute -> no money!

The goal for schema changes in F1

Enable changes to the logical and physical schema of an F1 instance in a way that is **online** and **asynchronous**.

Online

All data accessible, no downtime, and without large delays for transactions.

Asynchronous

Different servers transition to a new schema at different times.

A paper is available

A **protocol** for online, asynchronous schema change that permits no database corruption.

A **formal model** for reasoning about and proving the correctness of our protocol.

Rae, I., Rollins, E., Shute, J., et al. (2013). "Online, Asynchronous Schema Change in F1," *VLDB*, 6(11).

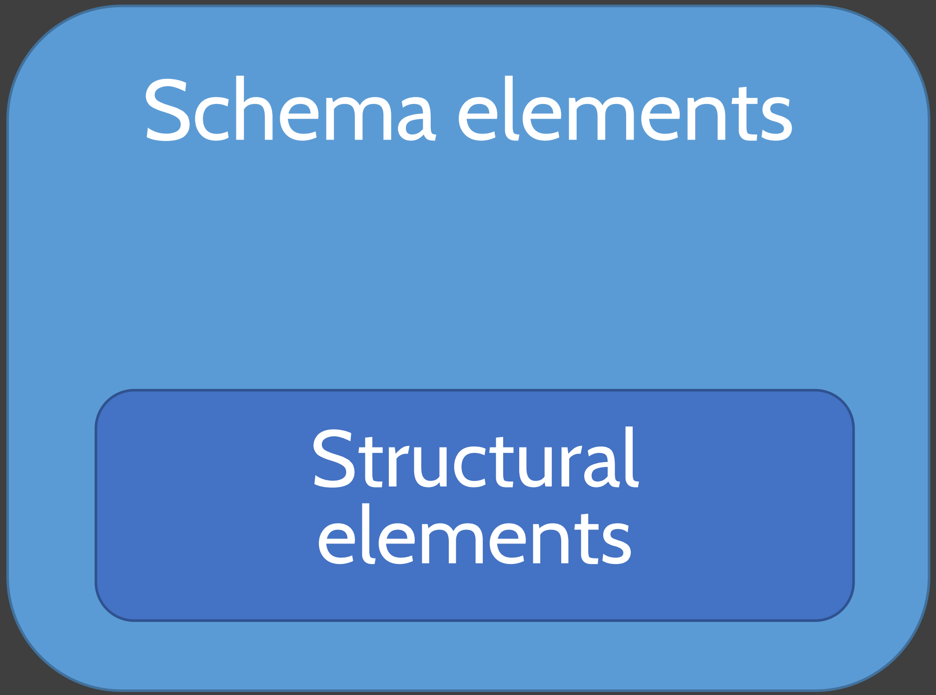
Some terminology

Schema elements

Any part of the schema, e.g.,
tables, columns, constraints, etc.

Structural elements

Tables
Columns
Indexes
Locks



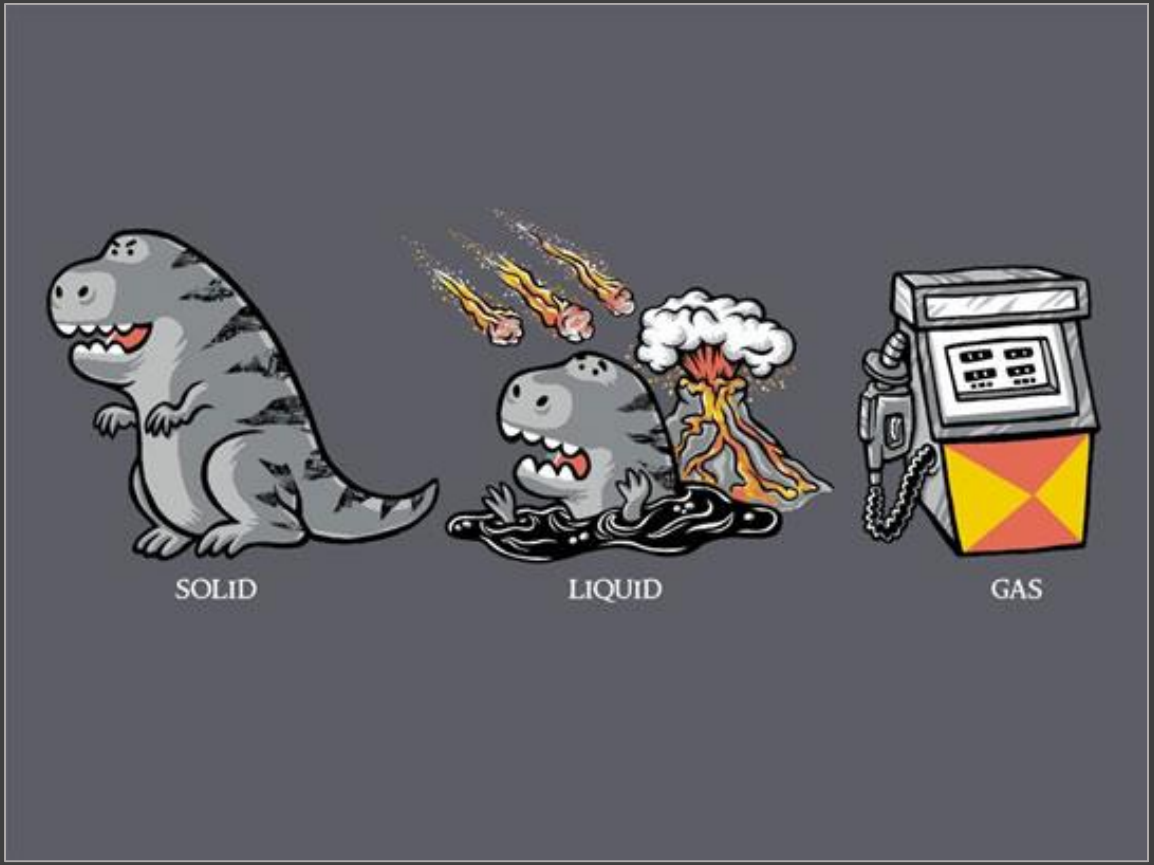
User-visible states of schema elements

Absent

Doesn’t exist!

Public

Available for **all** operations.



Ensuring correctness

Use **intermediate states** that restrict allowed operations on an element.

Decompose **incompatible** schema changes into a **series of changes** that are **pair-wise compatible**.

An illustration

All servers on **old** schema.

All servers on **new** schema.

Both schemas in use!

Supported schema changes

Add/drop structural elements

- Table add + drop
- Column add + drop
- Index add + drop
- Lock add + drop

Concurrency control

- Change lock coverage

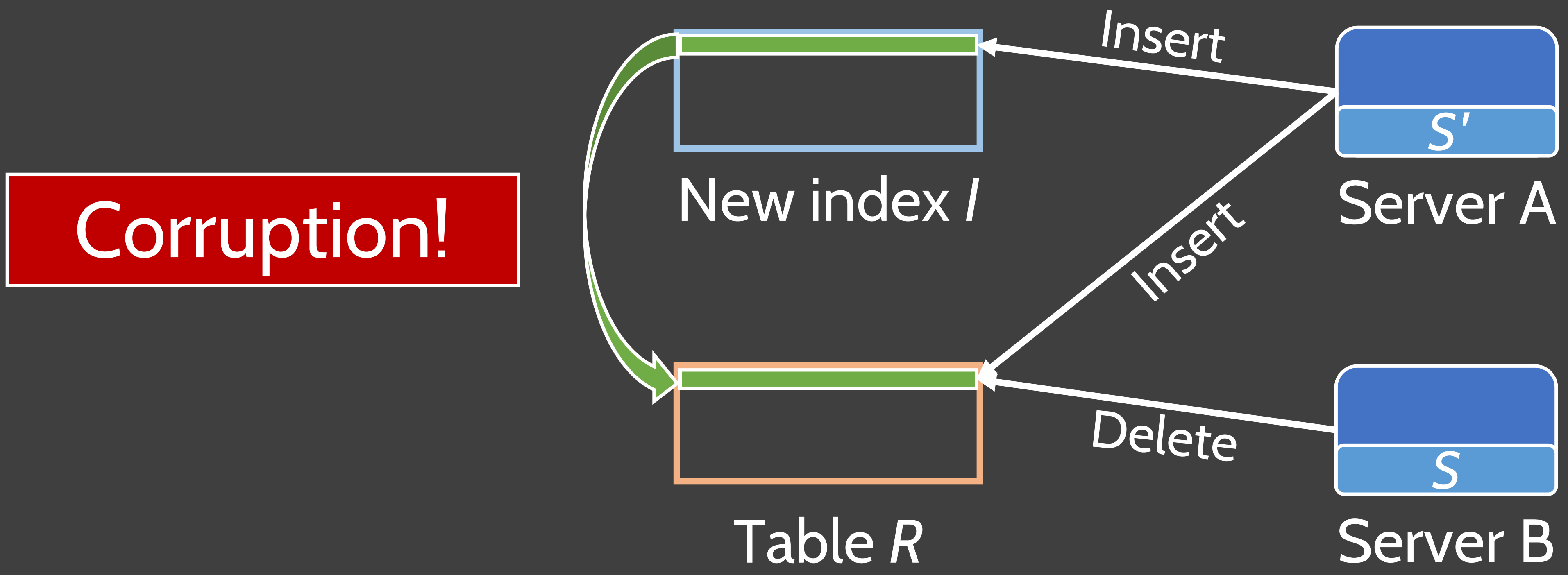
Add/drop constraints

- Change column type
- Make column unique/non-unique
- Foreign key add + drop
- Make column required/optional
- Change protocol buffer definition
- …

Adding and dropping **structural elements**

Index add corruption

Change from schema S to S', **adding index I** on table R.



Intermediate states for structural elements

Delete only

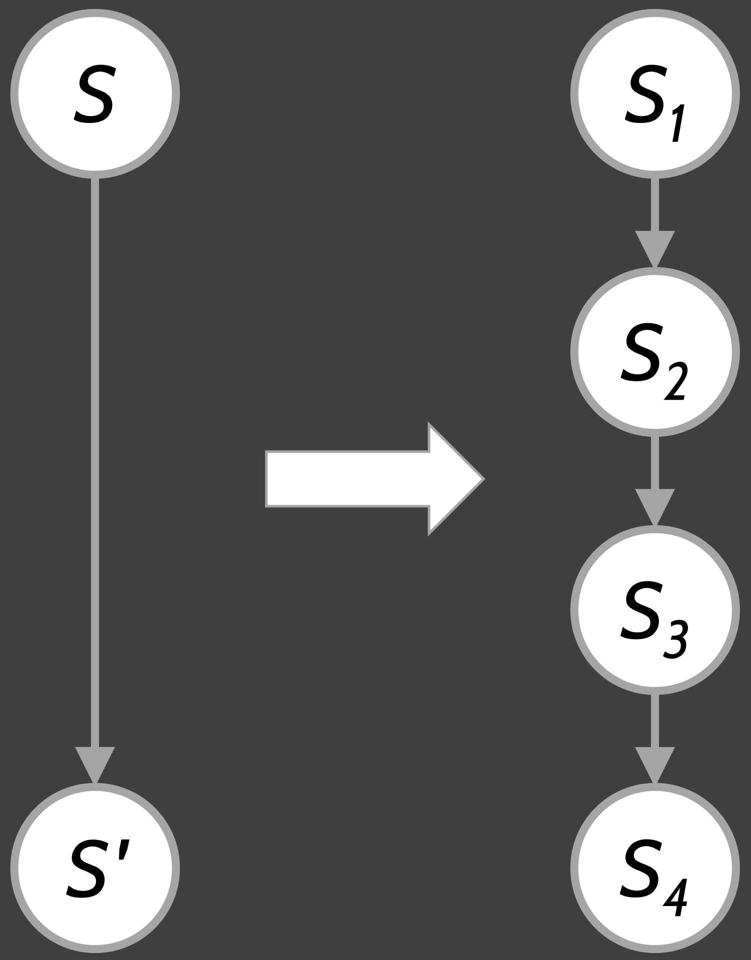
Updated by **delete** operations; cannot be read.

Write only

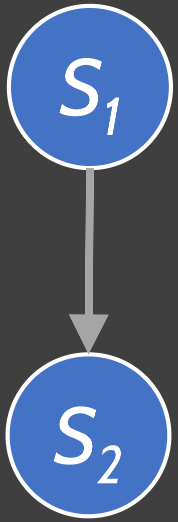
Updated by **delete and insert** operations; cannot be read.

Index add revisited

Change from schema S_1 to S_4, **adding index *I*** on table *R*.



Index add: absent to delete only

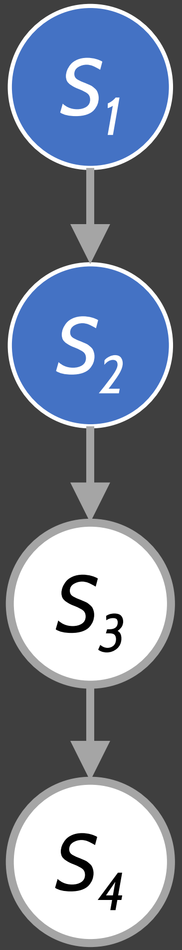


Index *I* doesn't exist.

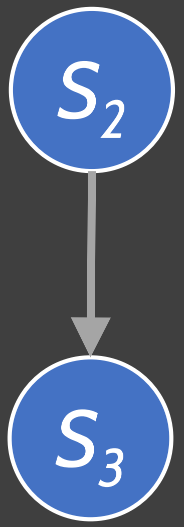
Index *I* exists, updated only by **deletes**.

Index *I* is **not used** for reads.

Index is always empty, but unused.



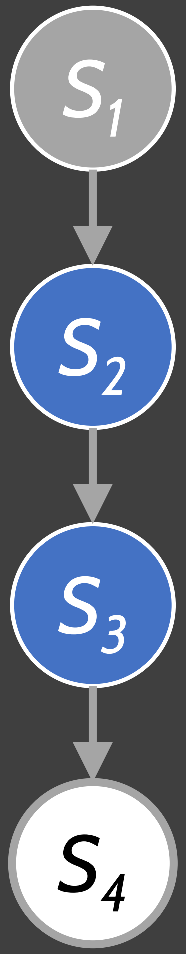
Index add: delete only to write only



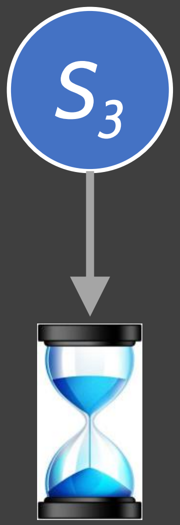
Index *I* exists, updated only by **deletes**.
Index *I* is **not used** for reads.

Index *I* exists, updated by **deletes & inserts**.
Index *I* is **not used** for reads.

All servers delete entries, so no dangling entries are possible.



Index add: backfill

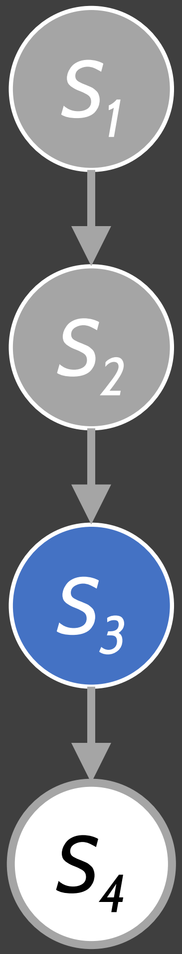


Index *I* exists, updated by **deletes & inserts**.

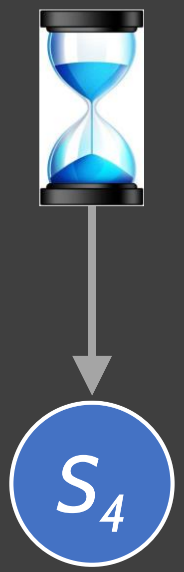
Index *I* is **not used** for reads.

A MapReduce starts to **backfill** index *I*.

All servers maintain index for new rows.

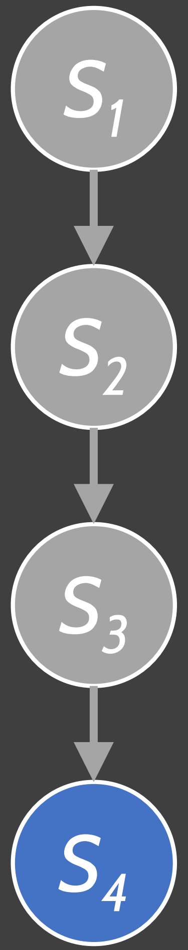


Index add: write only to public



Index *I* is **completely backfilled**.

Index *I* is **public** and **ready to use**.



Adding and dropping **constraints**

Constraint corruption

Change from schema S to S', **making column C unique**.

Problem: servers on schema S can insert duplicates into column C that servers on schema S' don't expect!

Bonus problem: how do we verify that column C only contains unique values?

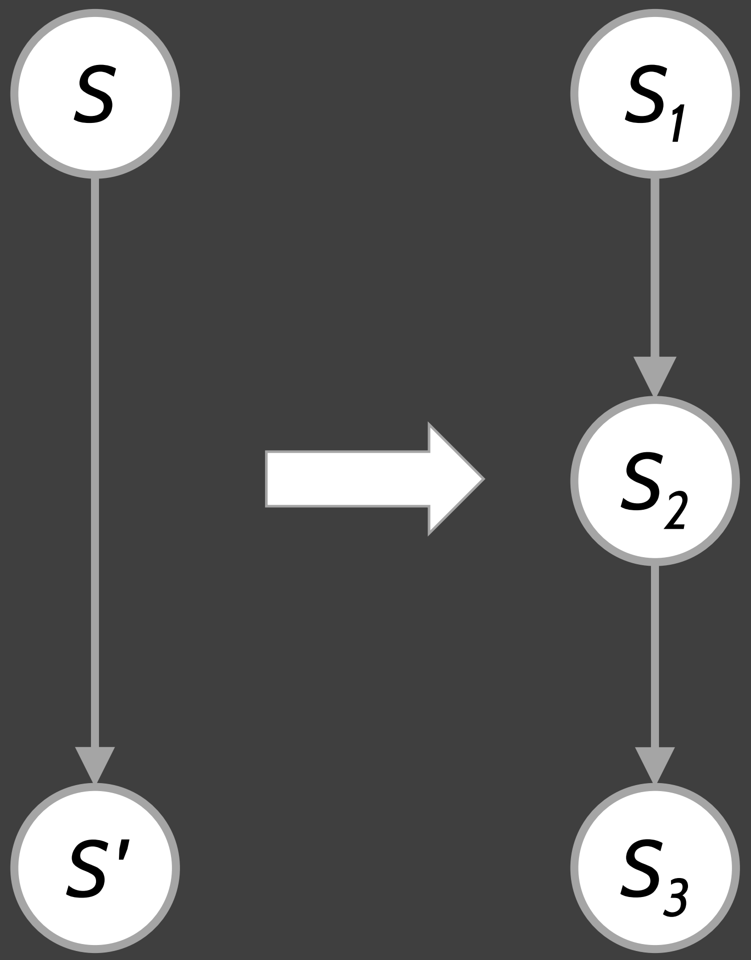
Intermediate states for constraints

Write only

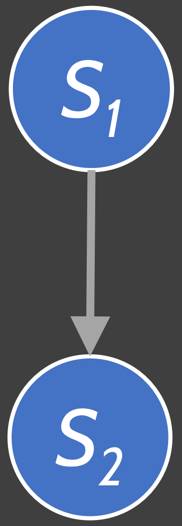
Constraint applies to inserts and updates, but is not guaranteed to hold for reads.

Constraint add revisited

Change from schema S_1 to S_3, **making column C unique**.



Constraint add: absent to write only

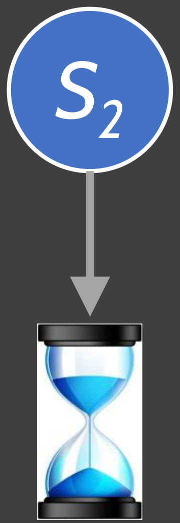


Column *C* is **not unique**.

Column *C* **cannot** have duplicates **inserted**.

Reads **may show duplicates**.

Constraint add: verification



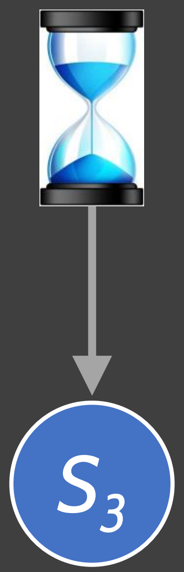
Column C **cannot** have duplicates **inserted**.

Reads **may show duplicates**.

A MapReduce starts to **verify** that column C contains only unique values.

No server allows new duplicates to be inserted.

Constraint add: write only to public



Column *C* is **verified unique**.

Column *C* is unique for **reads and writes**.

Concurrency control

Concurrency corruption

Change from schema S to S', **changing the lock coverage of column C from L_1 to L_2.**

Problem: servers on schema S don't validate writes to column C by servers on schema S'!

Concurrency corruption example

T1: read(C) using S -> read ts_1 from L_1

T2: write(C) using S' -> update L_2 to ts_2

T1: write(C) using S -> validate ts_1 against L_1 (works!)

Corruption!

Intermediate states for lock coverage

Dual coverage

A column is covered by **two locks**.

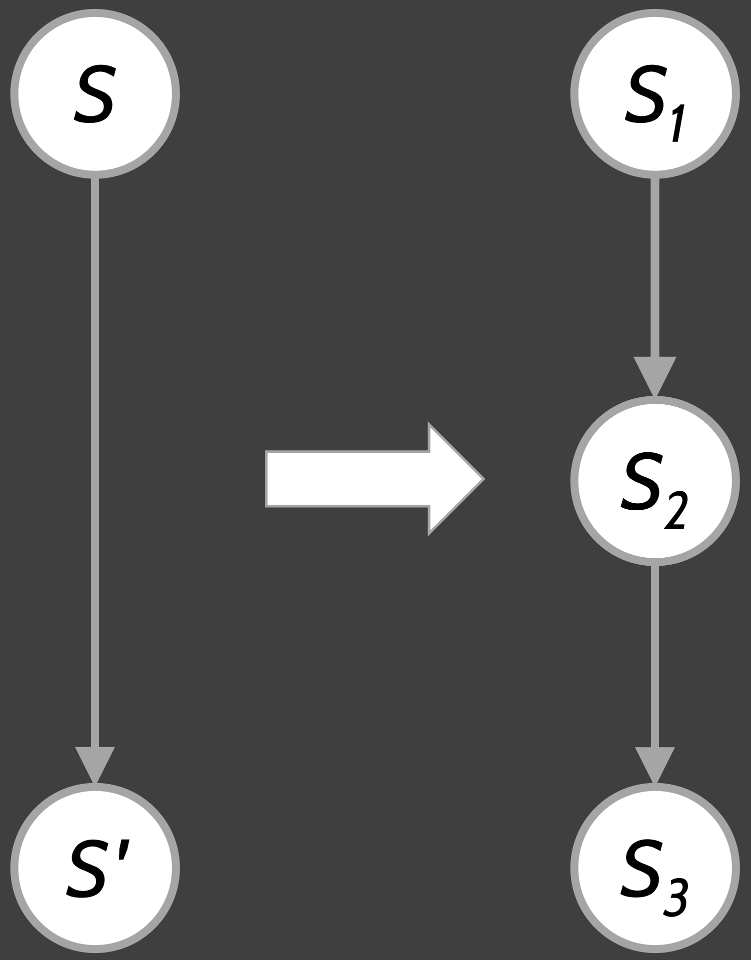
Dual coverage semantics

On a **read**, the timestamp returned is the **maximum** of **both locks**.

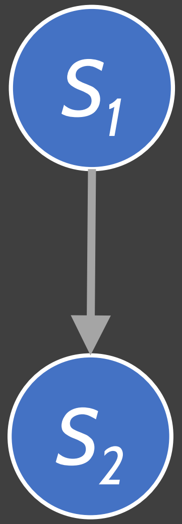
On a **write**, the timestamp is **validated** against **both locks**.

Lock coverage change revisited

Change from schema S_1 to S_3, **changing lock coverage of column C from L_1 to L_2.**



Coverage change: L_1 to dual coverage

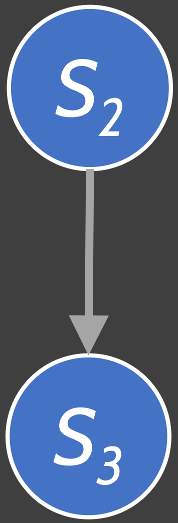


Column C is **covered by L_1**.

Column C **is covered by L_1 and L_2**.

L_1 handles concurrency control.

Coverage change: dual coverage to L_2



Column C is **covered by L_1 and L_2**.

Column C **is covered by L_2**.

L_2 handles concurrency control.

More concurrency corruption

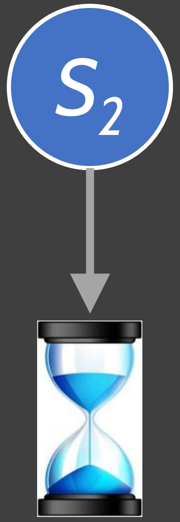
Suppose **both** L_1 and L_2 have the **same timestamp**.

T1: read(C) using S_1 -> read ts_1 from L_1

T2: write(C) using S_1 -> update L_1 to ts_2

T1: write(C) using S_3 -> validate ts_1 against L_2 (works!)

Coverage change: propagation



Column *C* is **covered by L_1 and L_2**.

A MapReduce sets **L_2 = max(L_1, L_2)**.

Timestamps propagate from L_1 to L_2.

Some **implementation** details

Schema leases

Canonical schema file is stored in Spanner.

Once per lease period, F1 servers reload the canonical schema if needed.

If a server cannot read the schema, it terminates and restarts.

Batching

Modifications to the schema are first committed to **source control**, not a live F1 instance.

Schema change process **periodically** applies modifications present in source control as a **batch**.

More details in the paper!

Paper has a lot of other stuff

- Formal model and proofs
- Concurrency control schema changes
- Details on overlapping state transitions
- Discussion of MapReduces needed
- More implementation details
- …

Conclusion

F1 is a globally distributed, fault-tolerant relational database that serves as the main data store for Google AdWords.

Check out the papers for more details:

Shute, J., Vingralek, R., Samwel, B., et al. (2013). "F1: A Distributed Database That Scales," *VLDB*, 6(11).

Rae, I., Rollins, E., Shute, J., et al. (2013). "Online, Asynchronous Schema Change in F1," *VLDB*, 6(11).