The Future of Distributed Databases is Relational

Sumedh Pathak, Co-Founder & VP Engineering, Citus Data

QCon London 2018

@moss_toss | @citusdata

Citus Data co-founders, left-to-right
Ozgun Erdogan, Sumedh Pathak, & Umur Cubukcu
Photo cred: Willy Johnson, Monterey CA, Sep 2017

About Me

- Co-Founder & VP Engineering at **Citus Data**
- Amazon Shopping Cart (former)
- Amazon Supply Chain & Order Fulfillment (former)
- Stanford Computer Science

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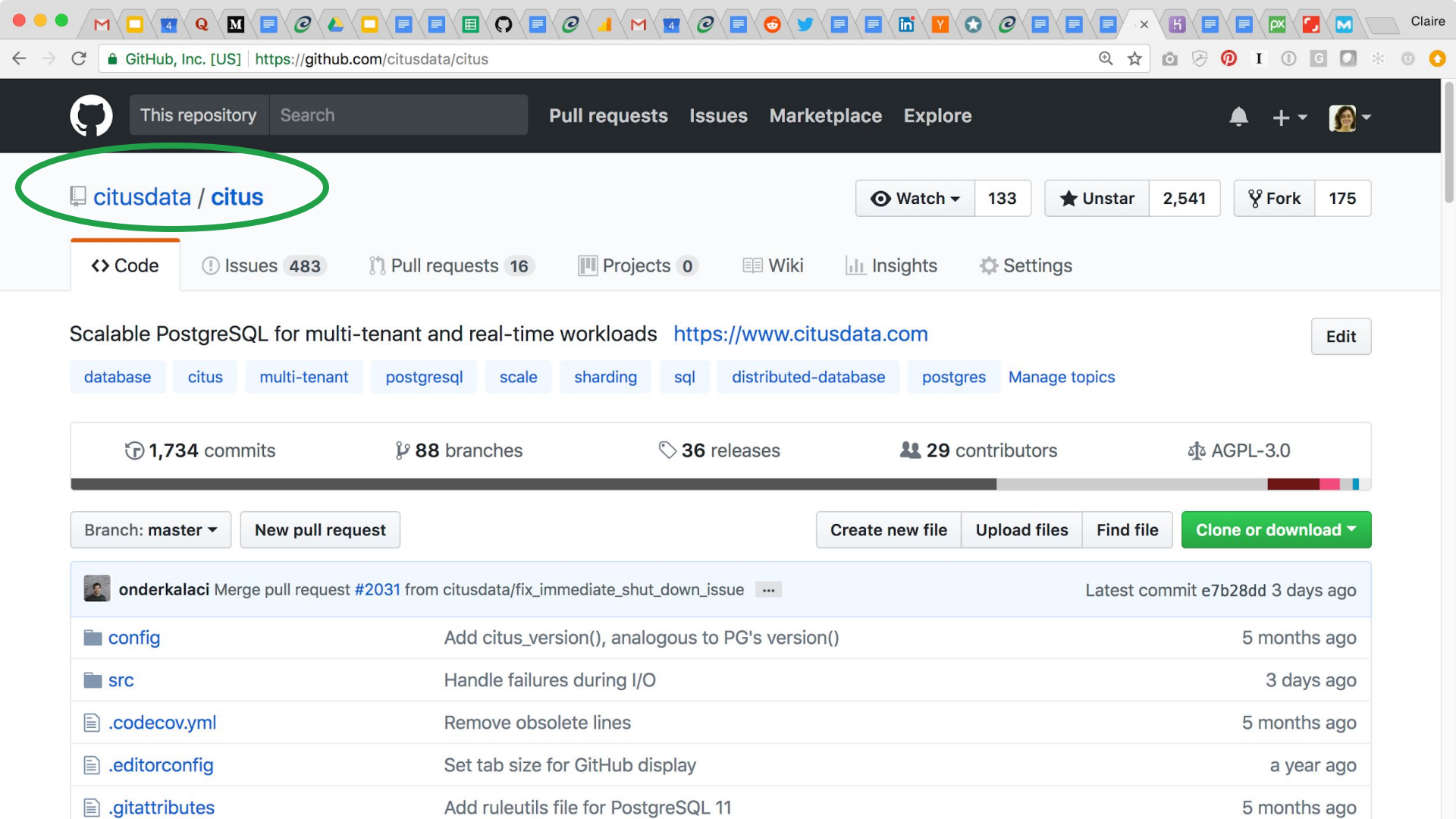
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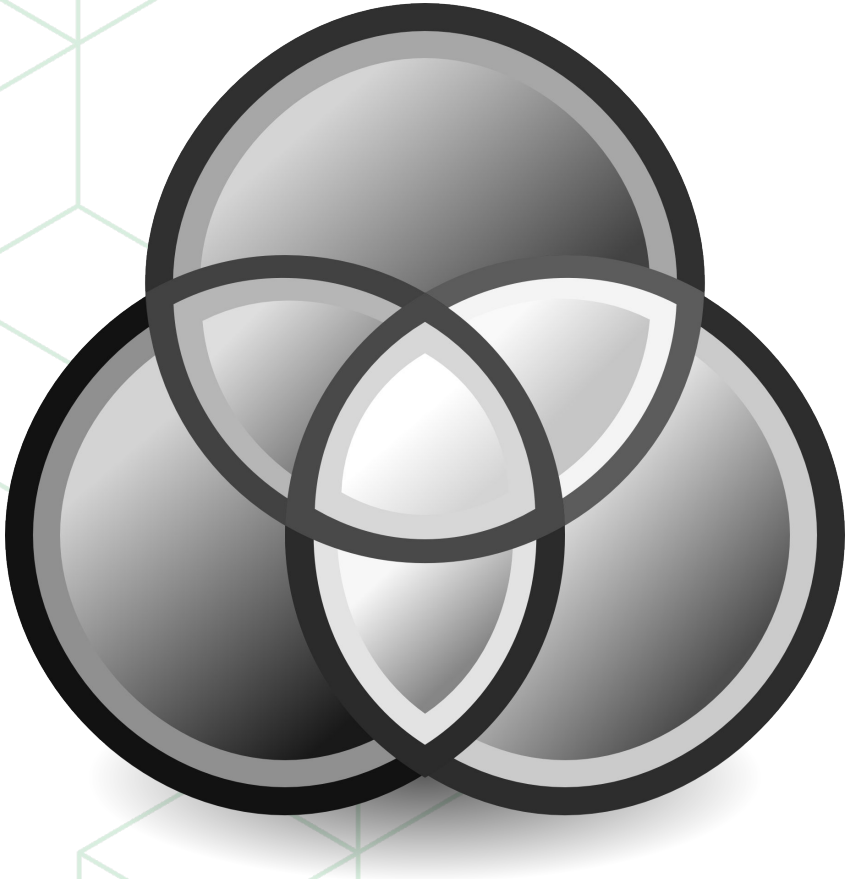
Manage topics
1,734 commits
88 branches
36 releases
29 contributors
AGPL-3.0
Branch: master
New pull request
Create new file
Upload files
Find file
Clone or download
onderkalaci Merge pull request #2031 from citusdata/fix_immediate_shut_down_issue
Latest commit e7b28dd 3 days ago
config
Add citus_version(), analogous to PG's version()
5 months ago
src
Handle failures during I/O
3 days ago
.codecov.yml
Remove obsolete lines
5 months ago
.editorconfig
Set tab size for GitHub display
a year ago
.gitattributes
Add ruleutils file for PostgreSQL 11
5 months ago



Why RDBMS?

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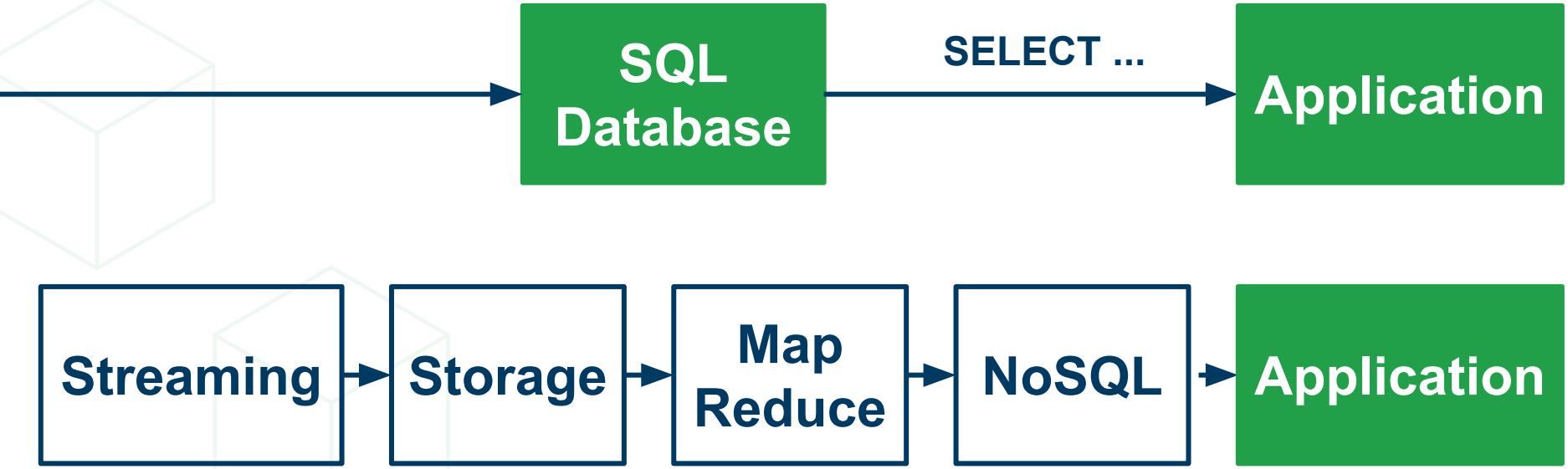
Because your architecture could be simpler



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An RDBMS is a general-purpose data platform

Fast writes **High throughput** **Data consistency**

Real-time & bulk **High concurrency** **Query optimizers**

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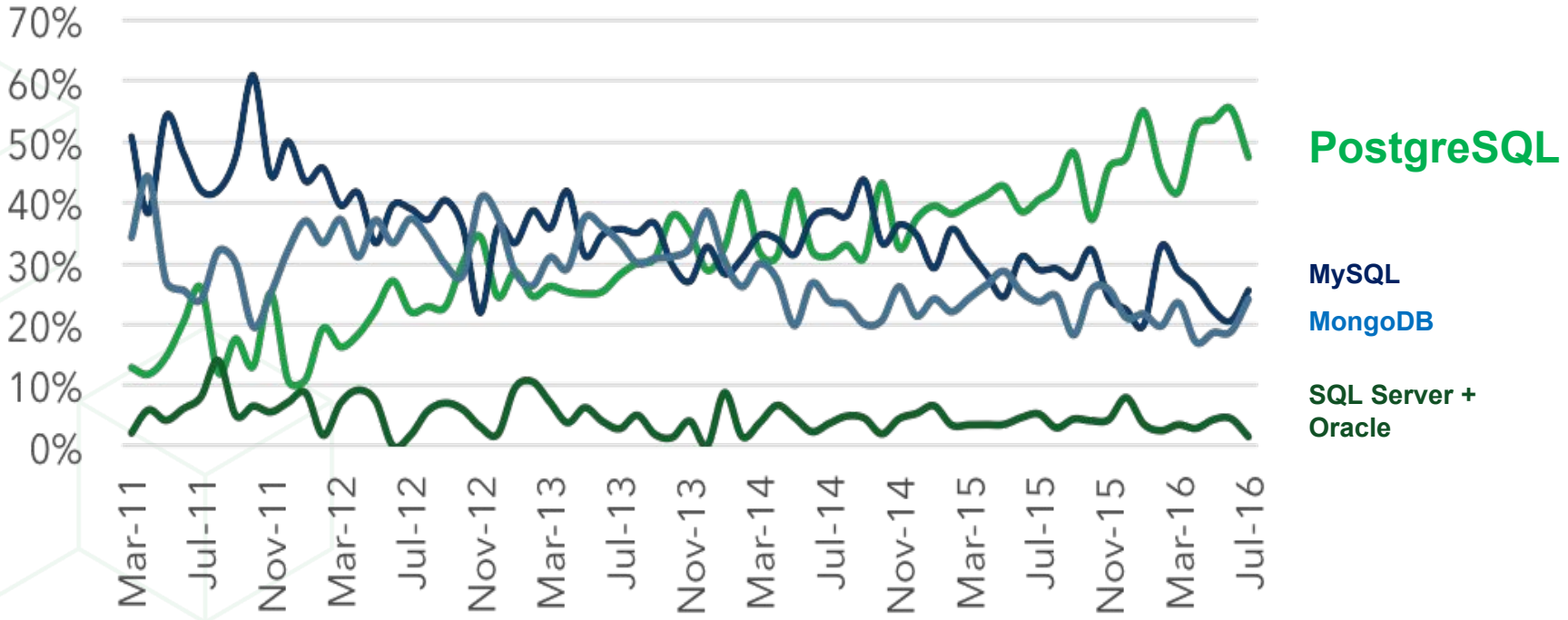
Startups Are Choosing Postgres

% database job posts mentioning each database, across 20K+ job posts



Source: Hacker News, https://news.ycombinator.com

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but RDBMS's don't scale, right?

~~but RDBMS's don't scale~~

RDBMS's are hard to scale

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What exactly needs to Scale?

1. Tables (Data)
   - Partitioning, Co-location, Reference Tables
2. SQL (Reads)
   - How do we express and optimize distributed SQL
3. Transactions (Writes)
   - Cross Shard updates/deletes, Global Atomic Transactions

Scaling Tables

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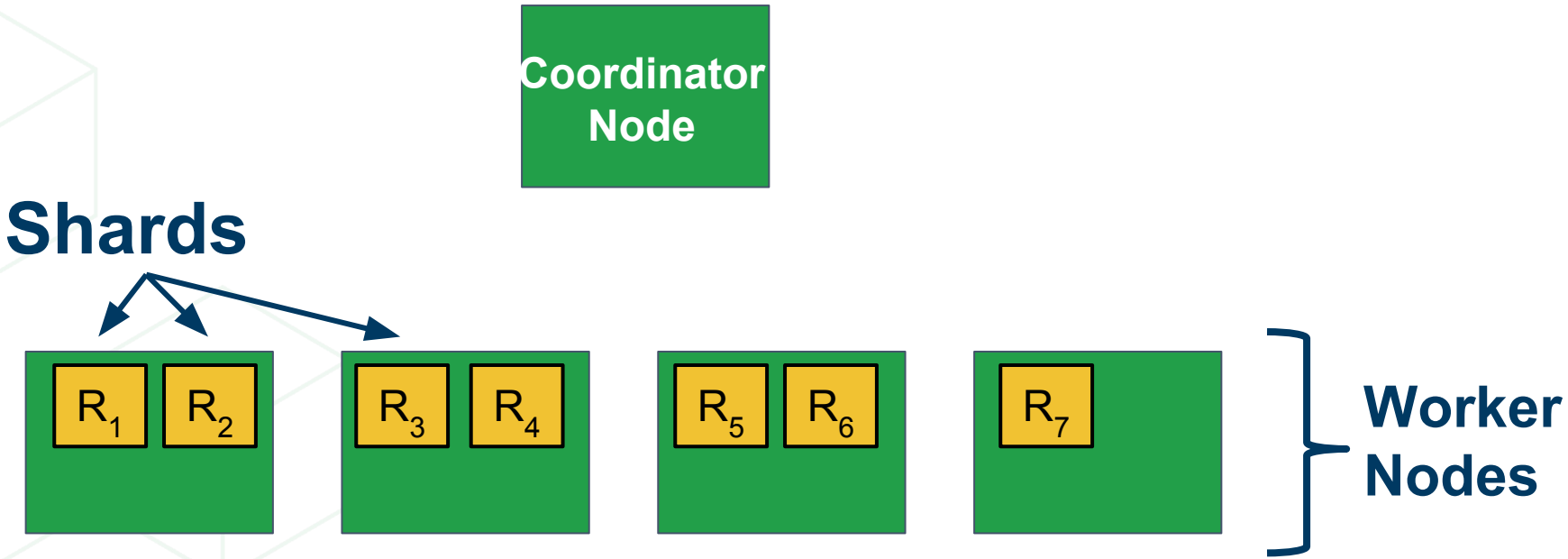
How to partition the data?

- Pick a column
  - Date
  - Id (customer_id, cart_id)
- Pick a method
  - Hash
  - Range

Partition data across nodes



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Worker → RDBMS, Shard → Table

```
postgres=# \d campaigns_102040
                          Table "public.campaigns_102040"
        Column          |            Type             | Collation | Nullable | Default
------------------------+-----------------------------+-----------+----------+---------
 id                     | bigint                      |           | not null |
 company_id             | bigint                      |           | not null |
 name                   | text                        |           | not null |
 cost_model             | text                        |           | not null |
 state                  | text                        |           | not null |
 monthly_budget         | bigint                      |           |          |
 blacklisted_site_urls  | text[]                      |           |          |
 created_at             | timestamp without time zone |           | not null |
 updated_at             | timestamp without time zone |           | not null |
Indexes:
    "campaigns_pkey_102040" PRIMARY KEY, btree (id, company_id)
    "campaigns_name_102040" btree (name)
```

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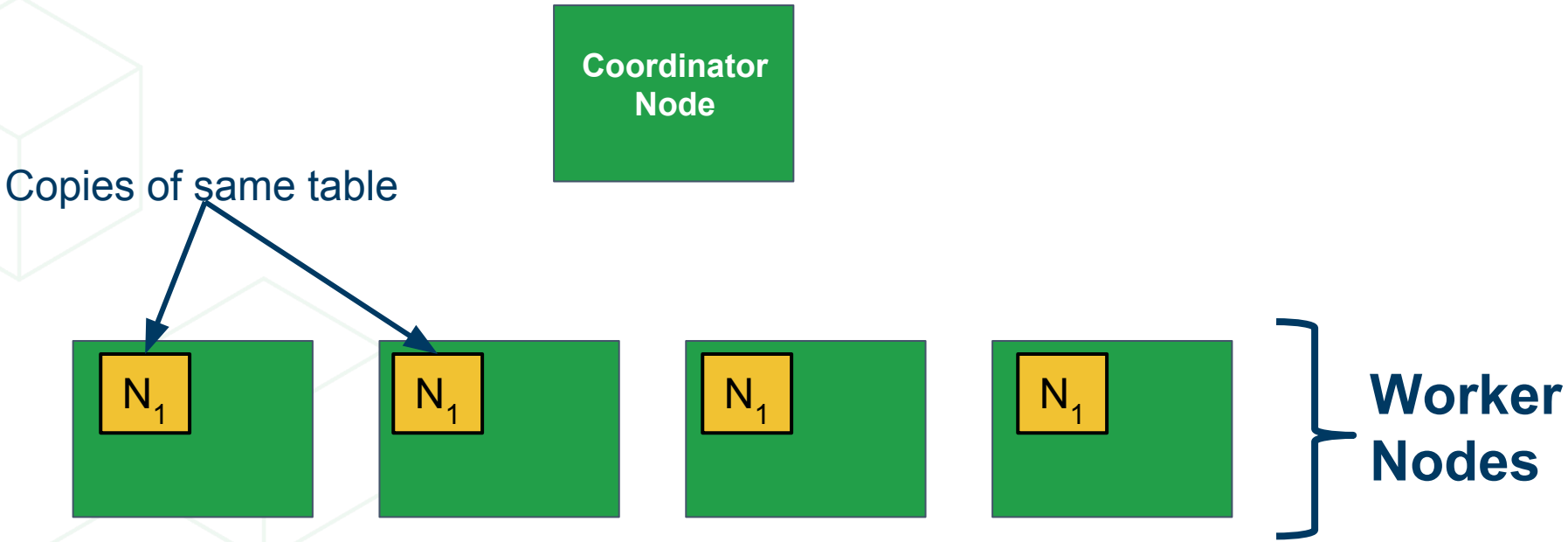
Reference Tables



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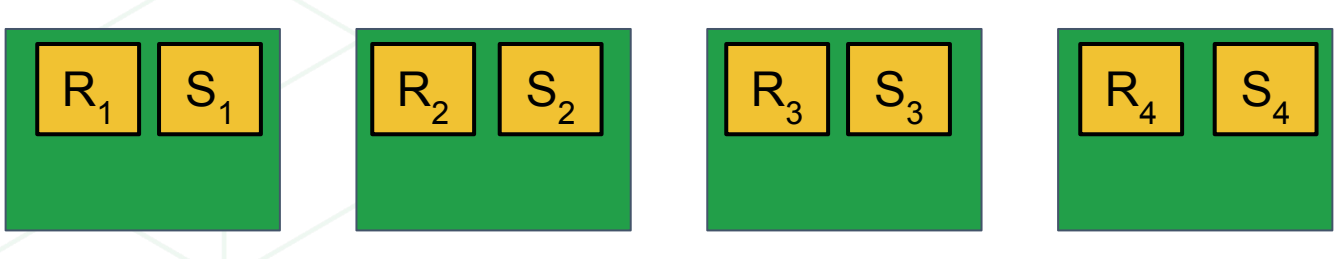
Co-Location

Explicit Co-Location API.
E.g. Partition by Tenant



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What about Foreign Keys?

```
CREATE TABLE campaigns (
  id bigserial PRIMARY KEY,
  company_id bigint REFERENCES companies (id),
  name text NOT NULL,
  cost_model text NOT NULL,
  state text NOT NULL,
  monthly_budget bigint,
  blacklisted_site_urls text[],
  created_at timestamp without time zone NOT NULL,
  updated_at timestamp without time zone NOT NULL
);

CREATE TABLE ads (
  id bigserial PRIMARY KEY,
  campaign_id bigint REFERENCES campaigns (id),
  name text NOT NULL,
  image_url text,
  target_url text,
  impressions_count bigint DEFAULT 0,
  clicks_count bigint DEFAULT 0,
  created_at timestamp without time zone NOT NULL,
  updated_at timestamp without time zone NOT NULL
);
```

```
CREATE TABLE campaigns (
  id bigserial,       -- was: PRIMARY KEY
  company_id bigint REFERENCES companies (id),
  name text NOT NULL,
  cost_model text NOT NULL,
  state text NOT NULL,
  monthly_budget bigint,
  blacklisted_site_urls text[],
  created_at timestamp without time zone NOT NULL,
  updated_at timestamp without time zone NOT NULL,
  PRIMARY KEY (company_id, id) -- added
);

CREATE TABLE ads (
  id bigserial,       -- was: PRIMARY KEY
  company_id bigint,  -- added
  campaign_id bigint, -- was: REFERENCES campaigns (id)
  name text NOT NULL,
  image_url text,
  target_url text,
  impressions_count bigint DEFAULT 0,
  clicks_count bigint DEFAULT 0,
  created_at timestamp without time zone NOT NULL,
  updated_at timestamp without time zone NOT NULL,
  PRIMARY KEY (company_id, id),         -- added
  FOREIGN KEY (company_id, campaign_id) -- added
    REFERENCES campaigns (company_id, id)
);
```

The key to scaling tables...

- Use relational databases as a building block
- Understand semantics of application—to be smart about partitioning
  - Multi-tenant applications

```
1  SELECT list_id, list_name, num_items
2  FROM
3    todo_lists lists
4    JOIN
5    ( SELECT user_id, list_id, count(*
6    USING (user_id, list_id)
7  WHERE  user_id = 1
8  ORDER BY num_items DESC;
9
10  list_id |    list_name    | num_ite
11 ---------+-----------------+--------
12        1 | work things     |
13        2 | personal things |
14 (2 rows)
15
16 Time: 2.014 ms
```

Scaling SQL

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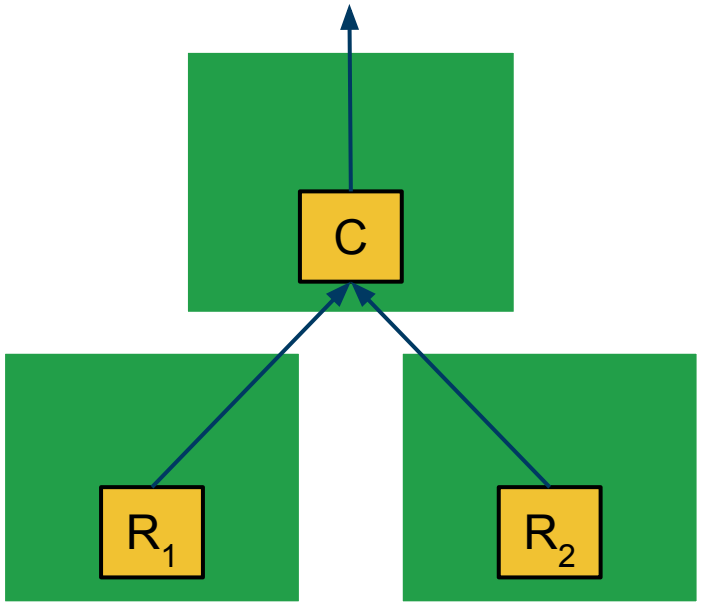
SQL ↔ Relational Algebra

`FROM table`	R
`SELECT x`	$\text{Project}_{x}(R) \rightarrow R'$
`WHERE f(x)`	$\text{Filter}_{f(x)}(R) \rightarrow R'$
`... JOIN ...`	$R \times S \rightarrow R'$

Distributed Relational Algebra

FROM sharded_table Collect(R_1,R_2,...) → R



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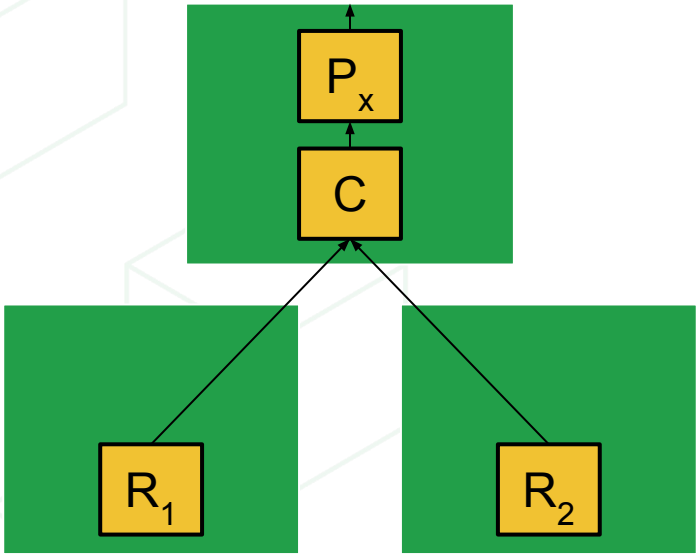
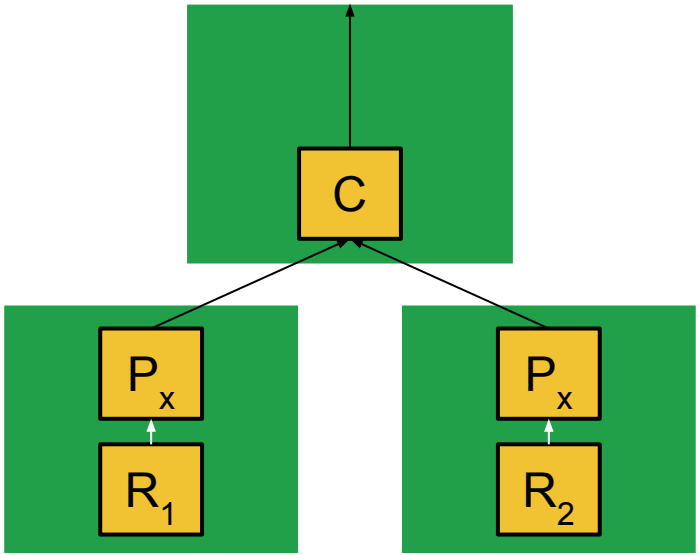
Commutative property

$$Project_x(Collect(R_1, R_2, ...)) = Collect(Project_x(R_1), Project_x(R_2)...)$$





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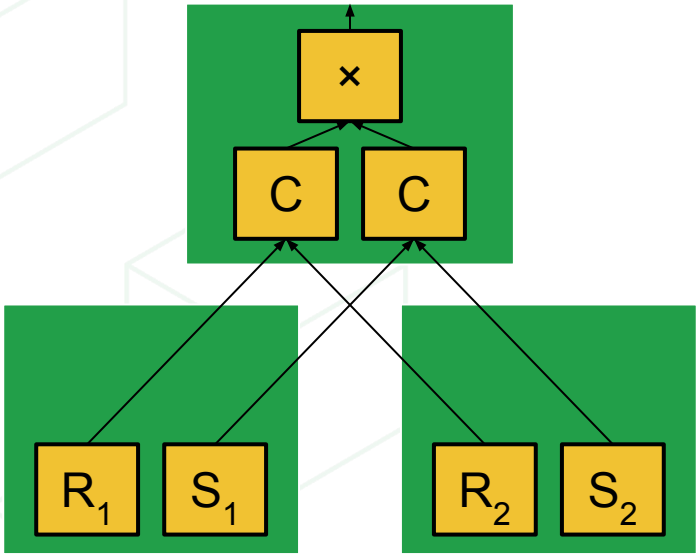
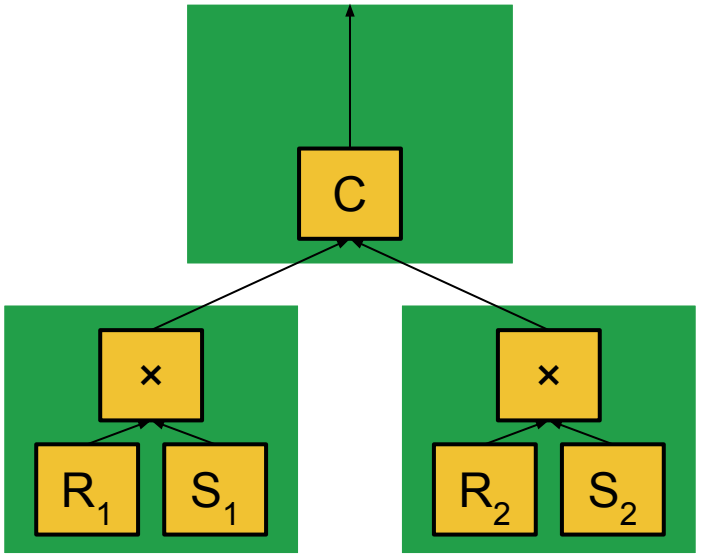
Distributive property

$$Collect(R_1,R_2,...) \times Collect(S_1,S_2,...) = Collect(R_1 \times S_1, R_2 \times S_2, ...)$$





X = Join Operator

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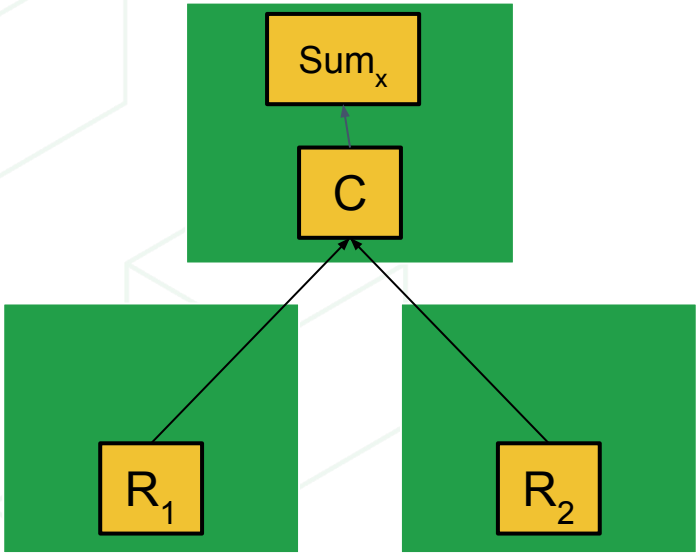
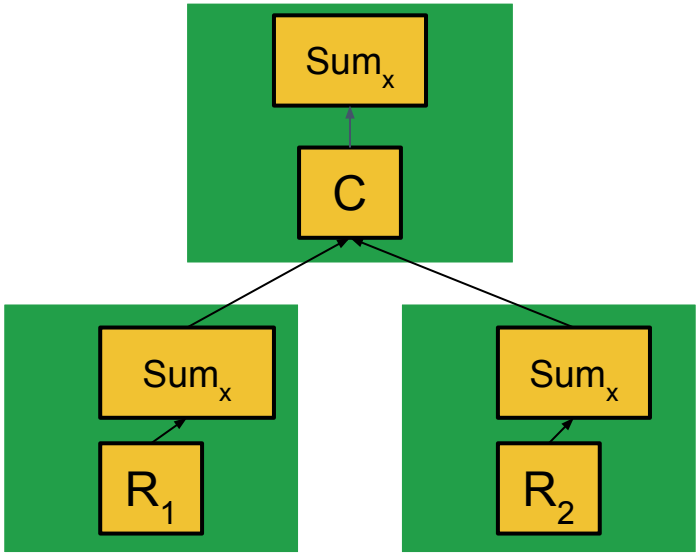
Associative property

$$SUM(x)(Collect(R_1,R_2,...)) = SUM(Collect(SUM(R_1), SUM(R_2)...))$$





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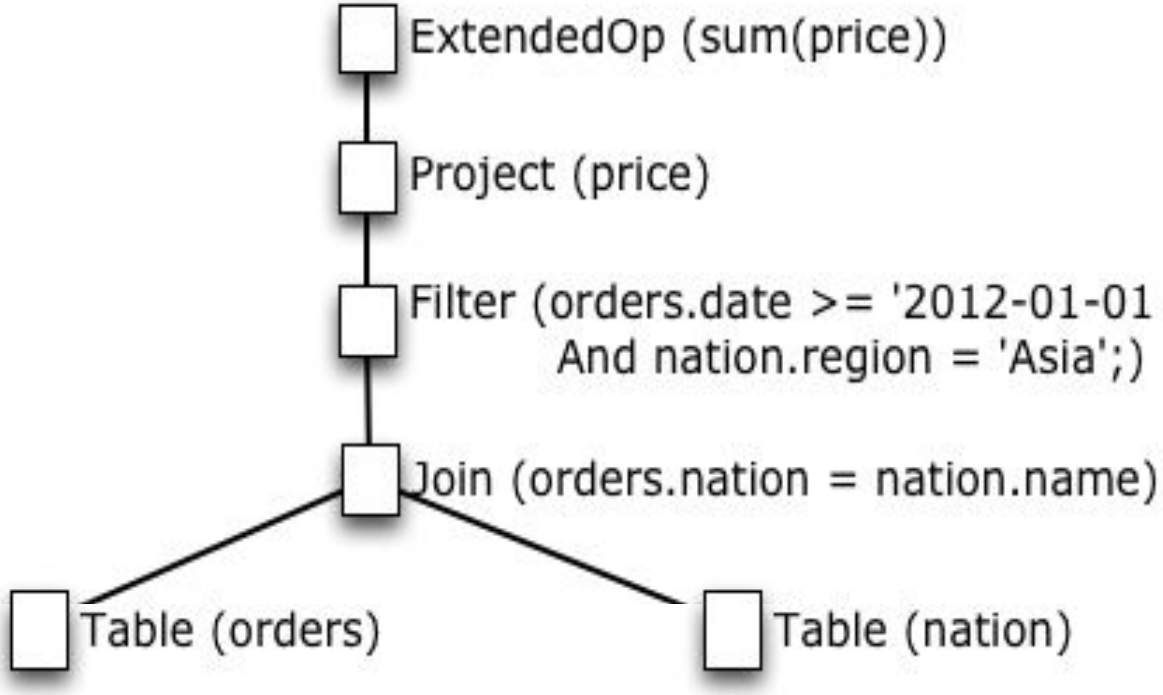
```
SELECT sum(price) FROM orders, nation
WHERE orders.nation = nation.name AND
      orders.date >= '2012-01-01' AND
      nation.region = 'Asia';
```


ExtendedOp (sum(price))
Project (price)
Filter (orders.date >= '2012-01-01
And nation.region = 'Asia';)
Join (orders.nation = nation.name)
Table (orders)
Table (nation)

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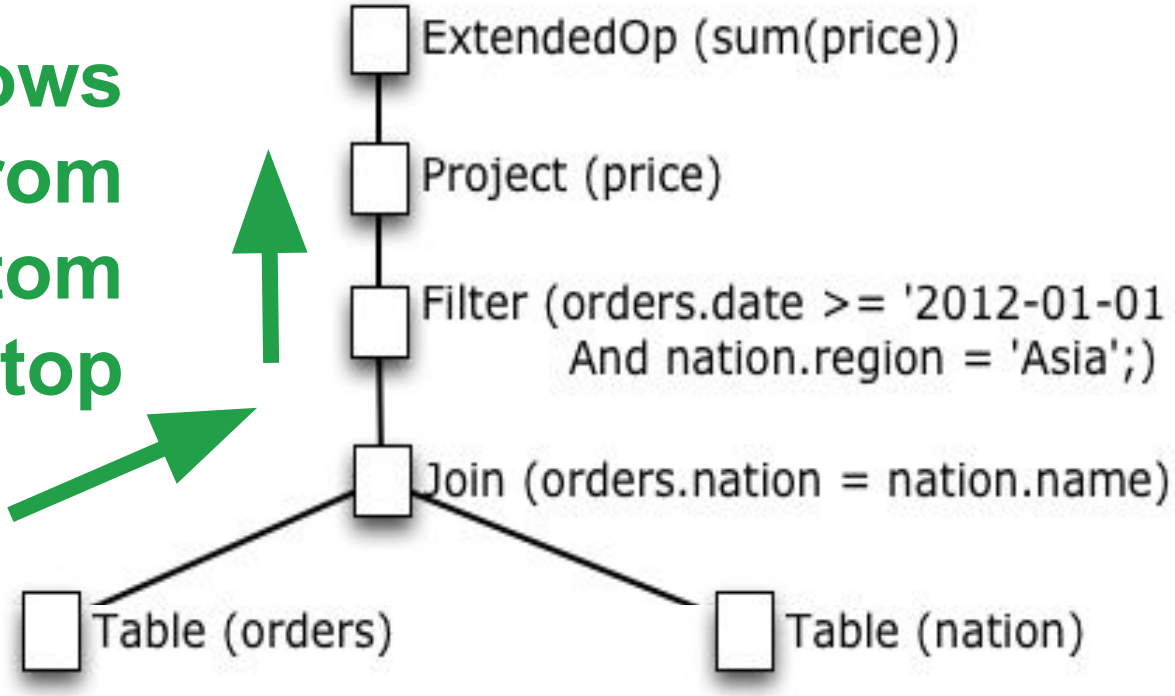
Volcano style processing

Data flows from bottom to top



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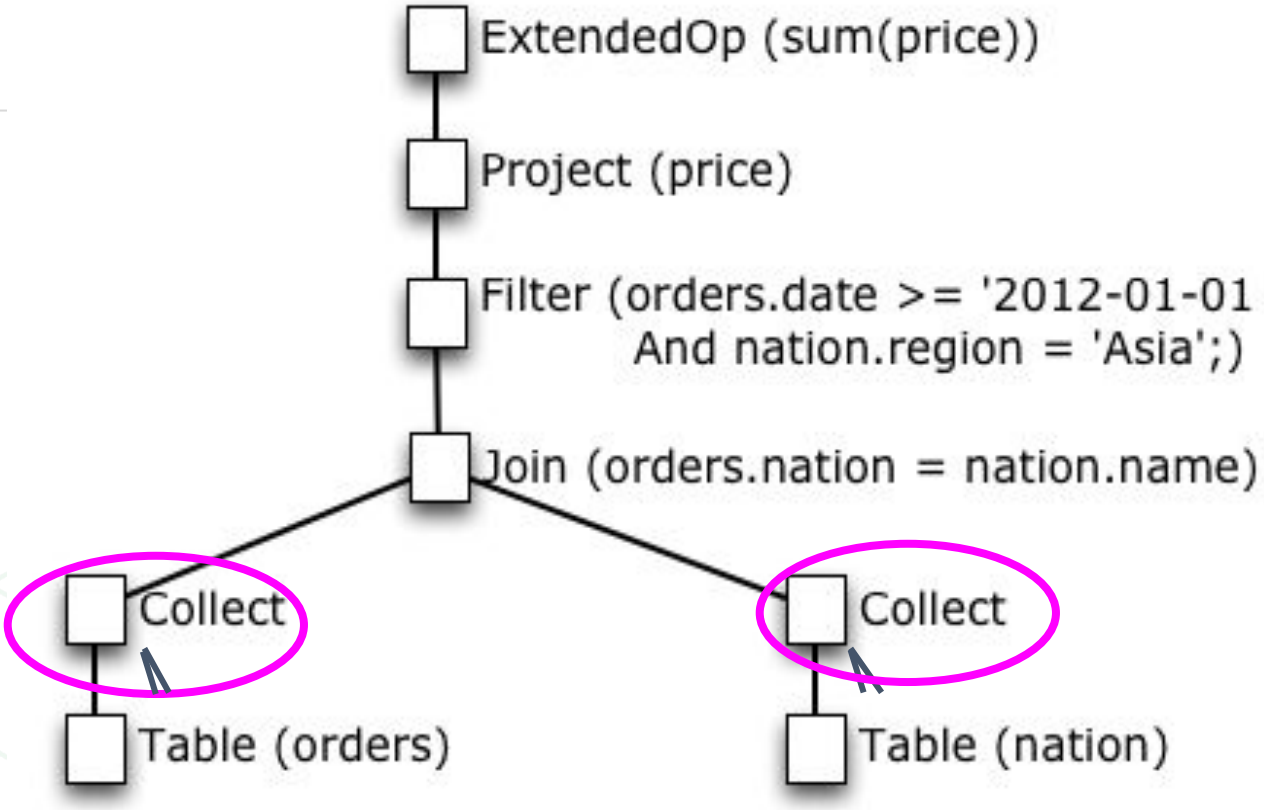
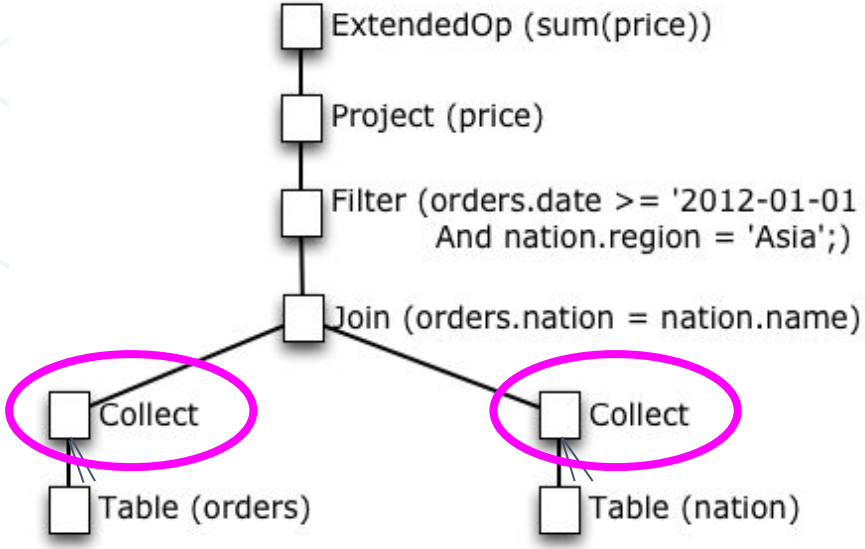
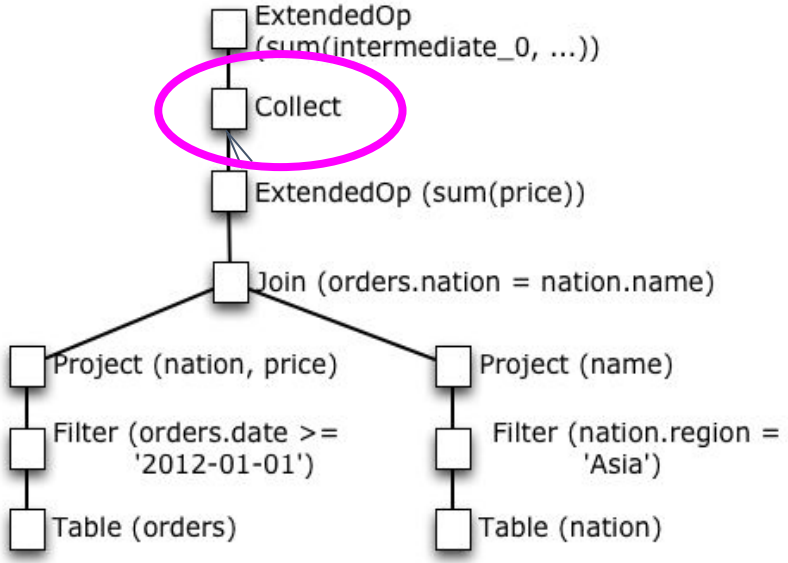

ExtendedOp (sum(price))
Project (price)
Filter (orders.date >= '2012-01-01
And nation.region = 'Asia';)
Join (orders.nation = nation.name)
Collect
Collect
Table (orders)
Table (nation)


ExtendedOp (sum(price))
Project (price)
Filter (orders.date >= '2012-01-01
And nation.region = 'Asia';)
Join (orders.nation = nation.name)
Collect
Collect
Table (orders)
Table (nation)


ExtendedOp
(sum(intermediate_0, ...))
Collect
ExtendedOp (sum(price))
Join (orders.nation = nation.name)
Project (nation, price)
Project (name)
Filter (orders.date >=
'2012-01-01')
Filter (nation.region =
'Asia')
Table (orders)
Table (nation)

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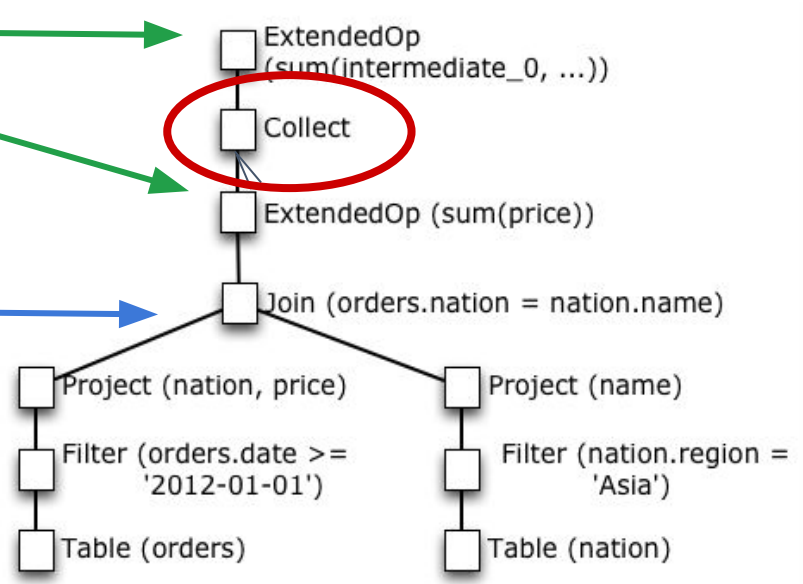
Parallelize Aggregate

Push Joins & Filters below collect. Run in parallel across all nodes

Filters & Projections done before Join



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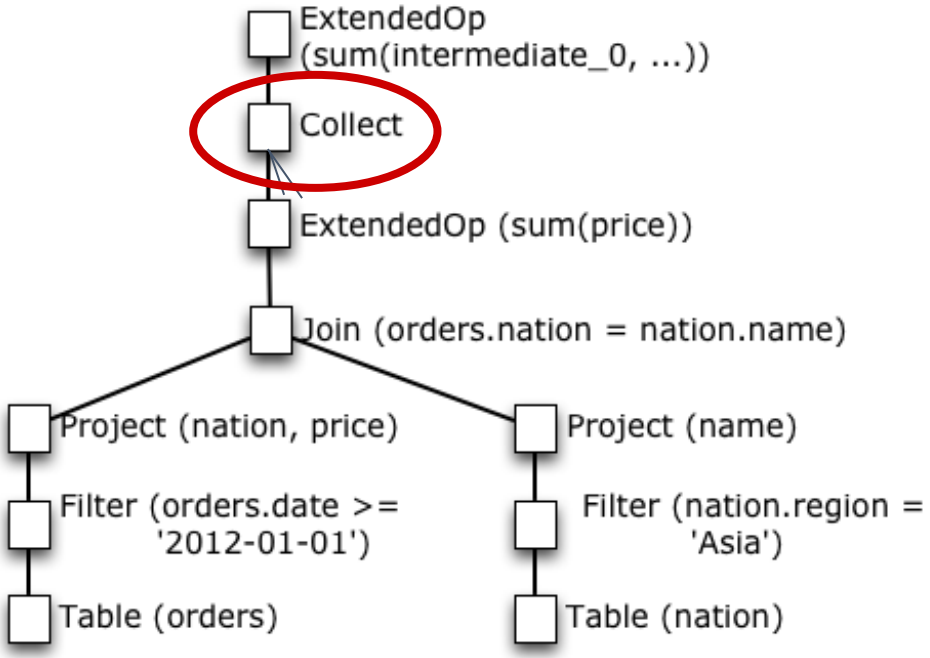


```
SELECT sum(intermediate_col)
FROM <concatenated results>;
```

```
SELECT sum(price)
FROM orders_2 JOIN nation_1
ON (orders_2.name = nation_1.name)
WHERE
  orders_2.date >= '2017-01-01'
AND
  nation_2.region = 'Asia';
```


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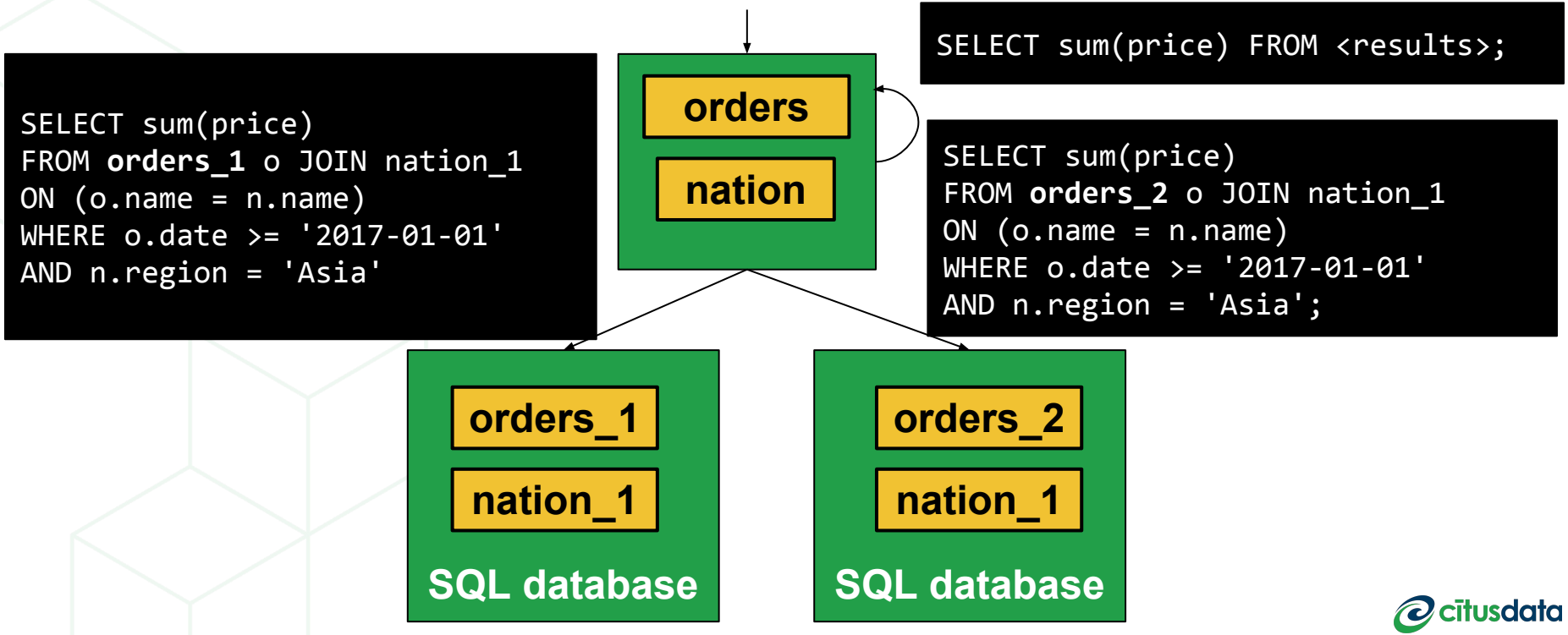
Executing Distributed SQL



The key to scaling SQL...

- New relational algebra operators for distributed processing
- Relational Algebra Properties to optimize tree: **Commutativity, Associativity, & Distributivity**
- Map / Reduce operators

Scaling Transactions

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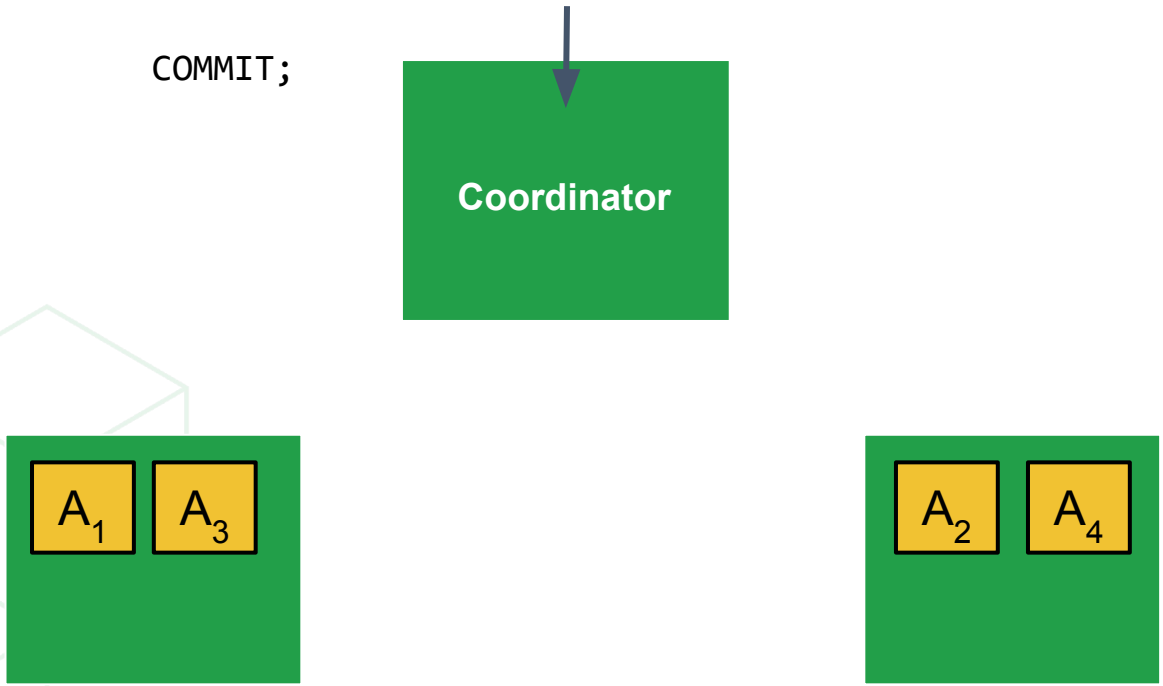
Money Transfer, as an example

```
BEGIN;

UPDATE accounts SET balance = balance -
    WHERE id = ‘ALICE’;

UPDATE accounts SET balance = balance +
    WHERE id = ‘BOB’;

COMMIT;
```

```
BEGIN;

UPDATE accounts SET balance = balance -
100 WHERE id = ‘ALICE’;

UPDATE accounts SET balance = balance +
100 WHERE id = ‘BOB’;

COMMIT;
```



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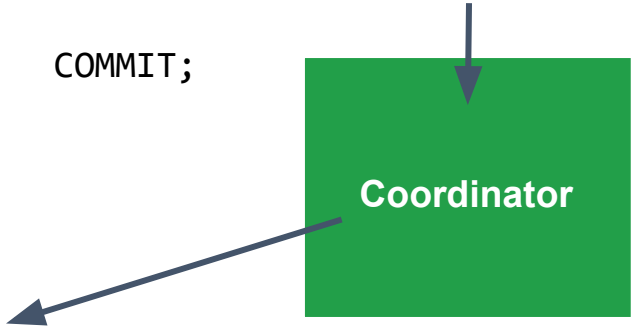
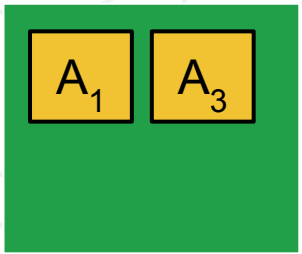
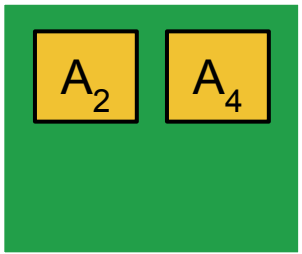
```
BEGIN;

UPDATE accounts SET balance = balance -
100 WHERE id = ‘ALICE’;

UPDATE accounts SET balance = balance +
100 WHERE id = ‘BOB’;

COMMIT;
```




```
BEGIN;

UPDATE accounts SET balance = balance -
100 WHERE id = ‘ALICE’;
```





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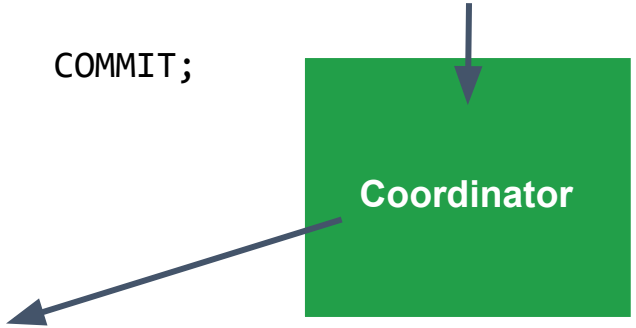
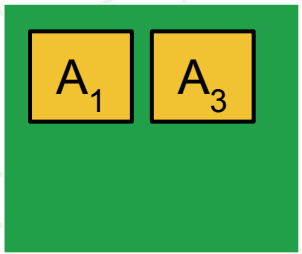
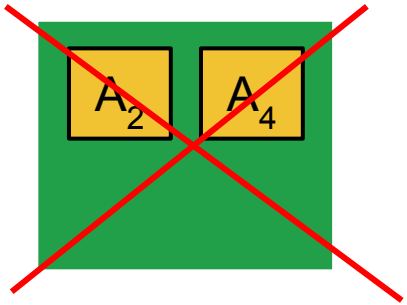
```
BEGIN;

UPDATE accounts SET balance = balance -
100 WHERE id = ‘ALICE’;

UPDATE accounts SET balance = balance +
100 WHERE id = ‘BOB’;

COMMIT;
```

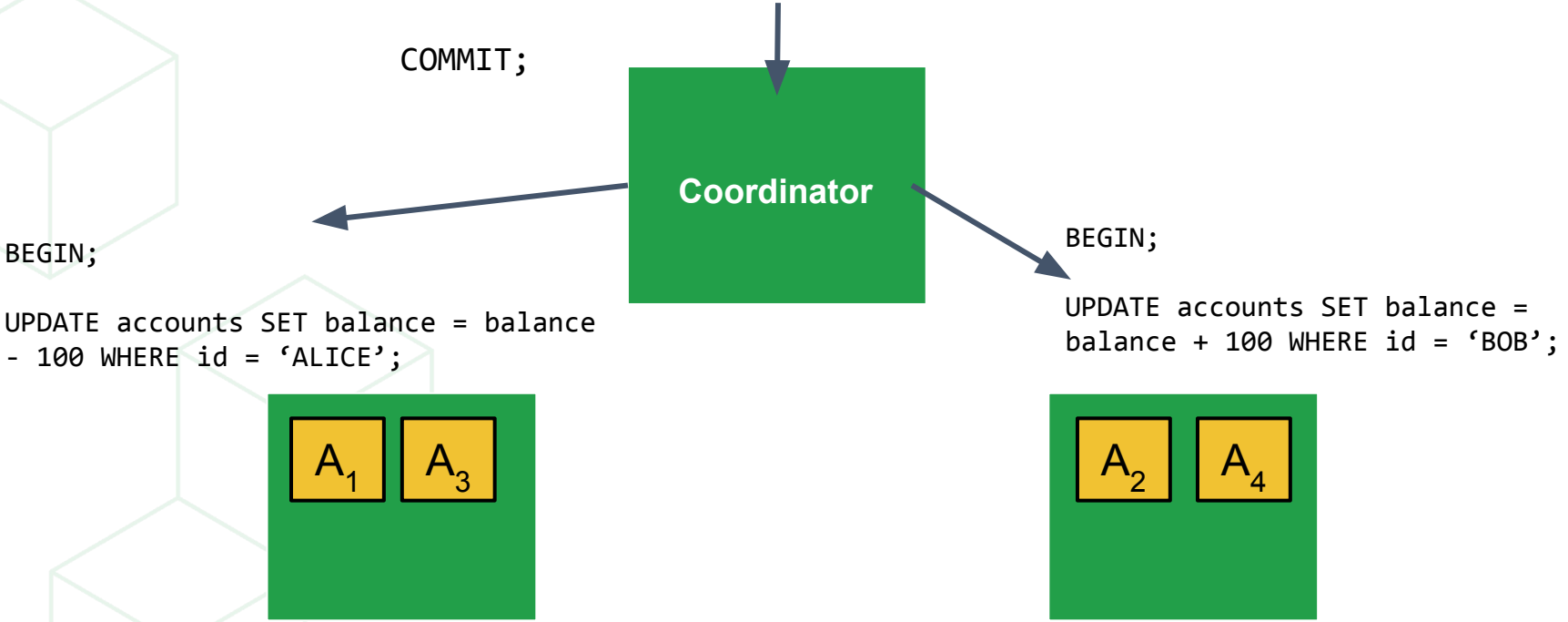



```
BEGIN;

UPDATE accounts SET balance = balance -
100 WHERE id = ‘ALICE’;

COMMIT;
```





```
BEGIN;

UPDATE accounts SET balance = balance -
100 WHERE id = ‘ALICE’;

UPDATE accounts SET balance = balance +
100 WHERE id = ‘BOB’;

COMMIT;
```



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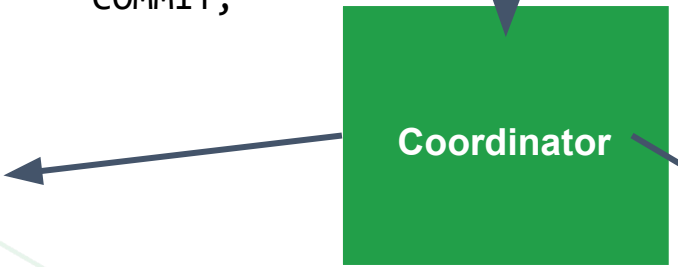
BEGIN;

UPDATE accounts SET balance = balance -
100 WHERE id = ‘ALICE’;

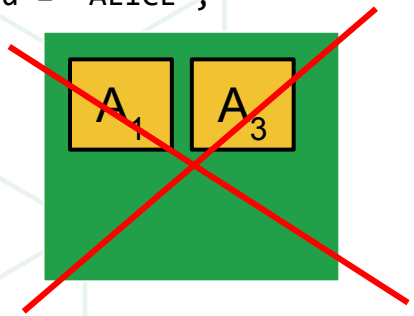
UPDATE accounts SET balance = balance +
100 WHERE id = ‘BOB’;

COMMIT;
```




```
BEGIN;

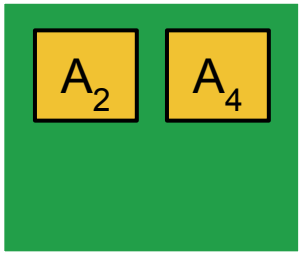
UPDATE accounts SET balance = balance
- 100 WHERE id = ‘ALICE’;
```




```
BEGIN;

UPDATE accounts SET balance =
balance + 100 WHERE id = ‘BOB’;

COMMIT
```



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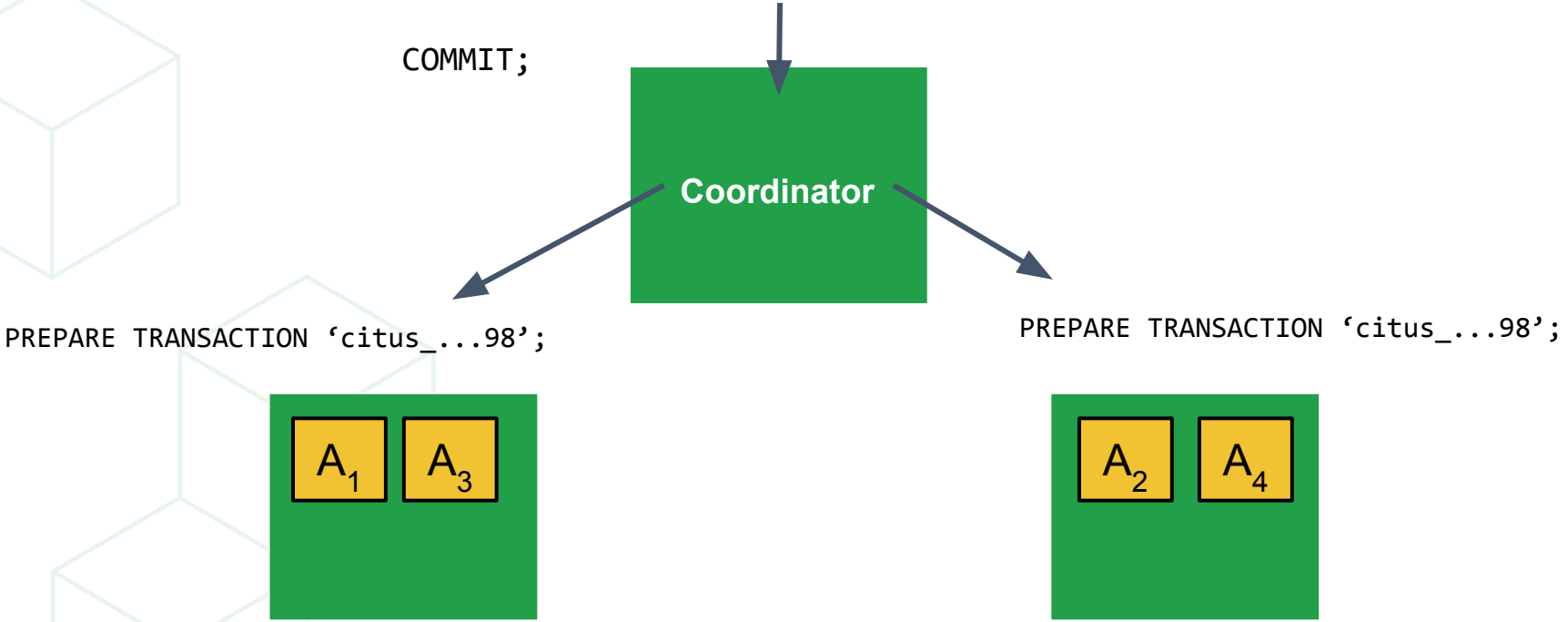
```
BEGIN;

UPDATE accounts SET balance = balance -
100 WHERE id = ‘ALICE’;

UPDATE accounts SET balance = balance +
100 WHERE id = ‘BOB’;

COMMIT;
```



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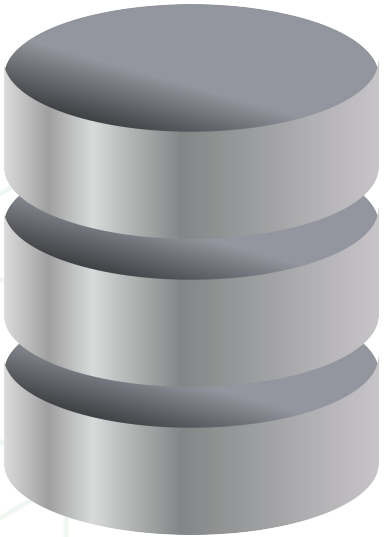
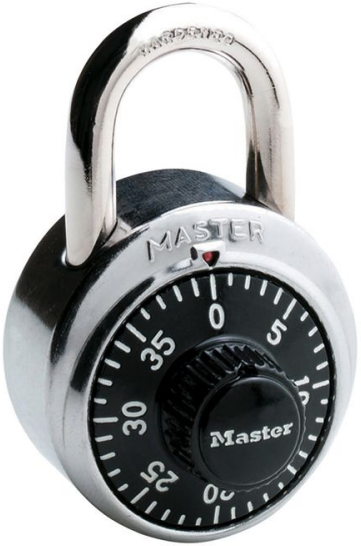
What happens during PREPARE?

State of transaction stored on a durable store



&

Locks are maintained



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UPDATE accounts SET balance = balance +
100 WHERE id = ‘BOB’;

COMMIT;
```
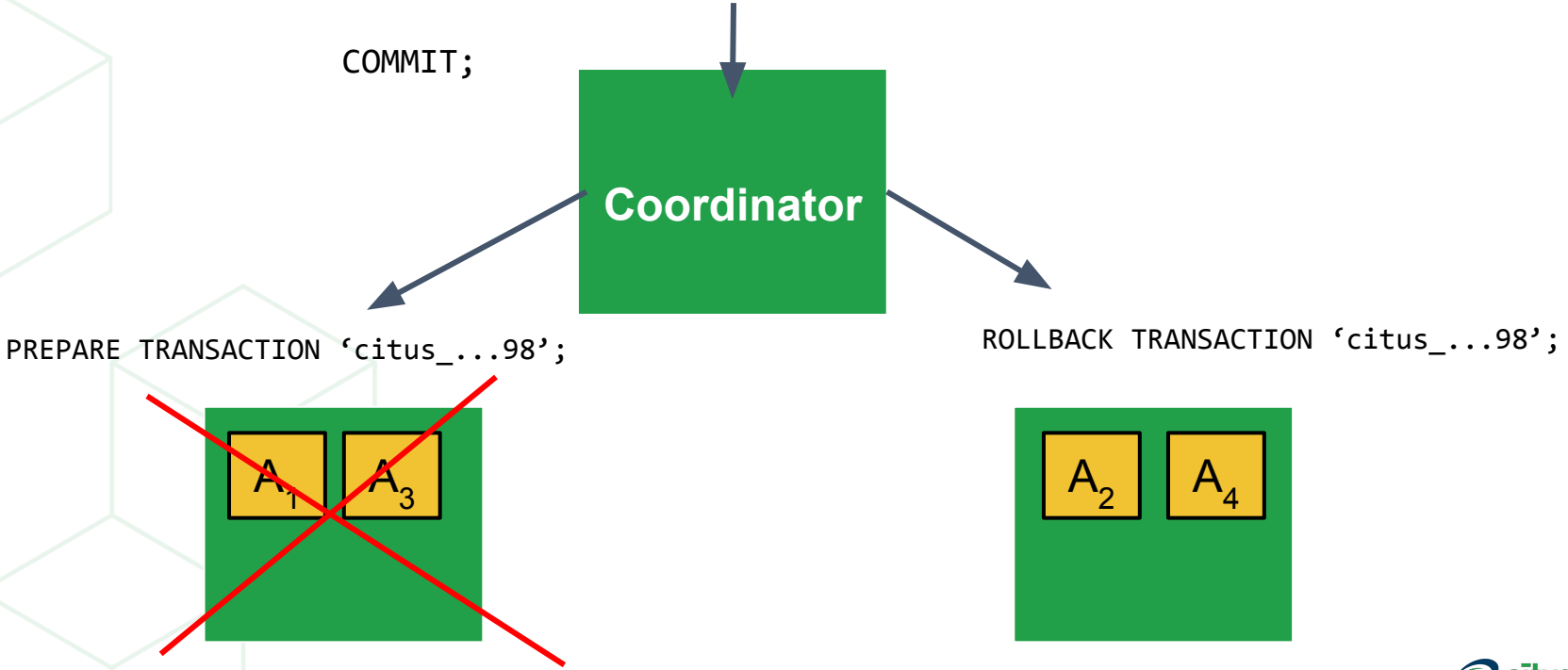
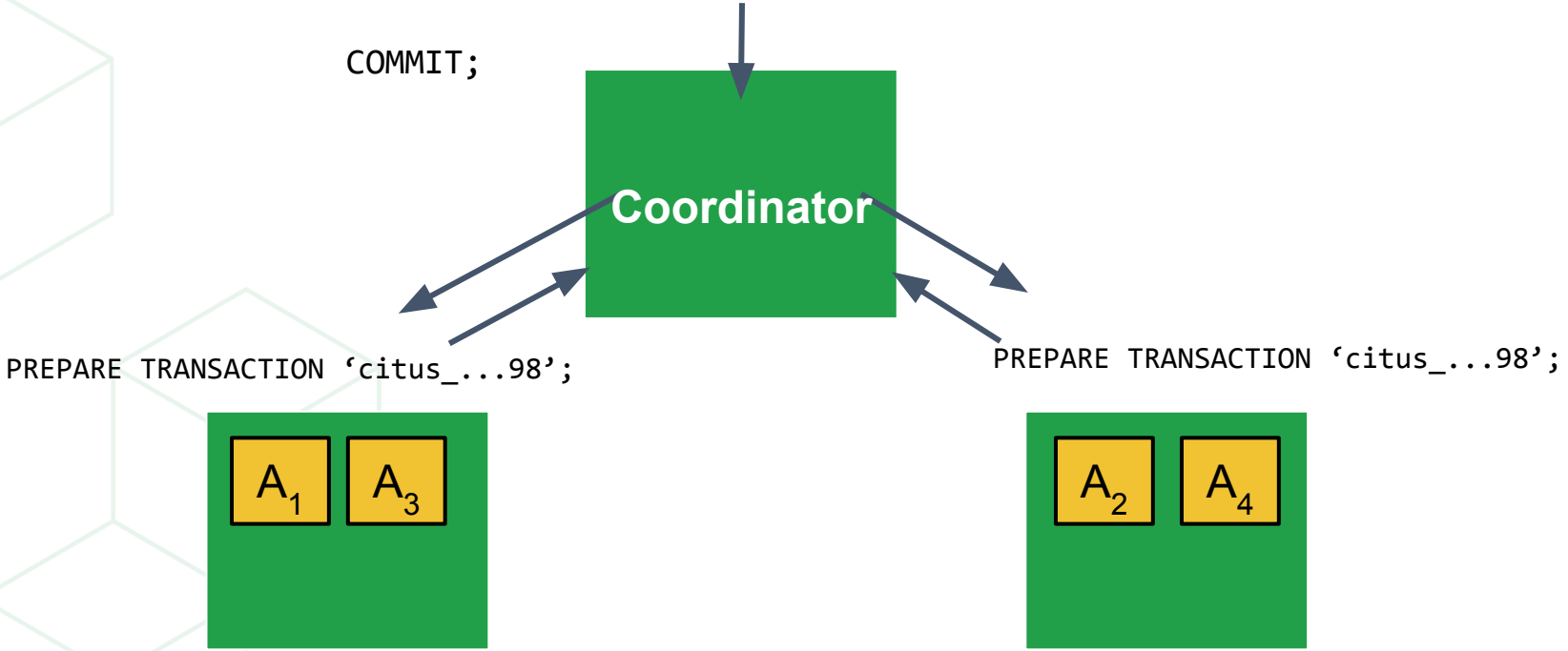



citusdata

```
BEGIN;

UPDATE accounts SET balance = balance -
100 WHERE id = ‘ALICE’;

UPDATE accounts SET balance = balance +
100 WHERE id = ‘BOB’;

COMMIT;
```



citusdata

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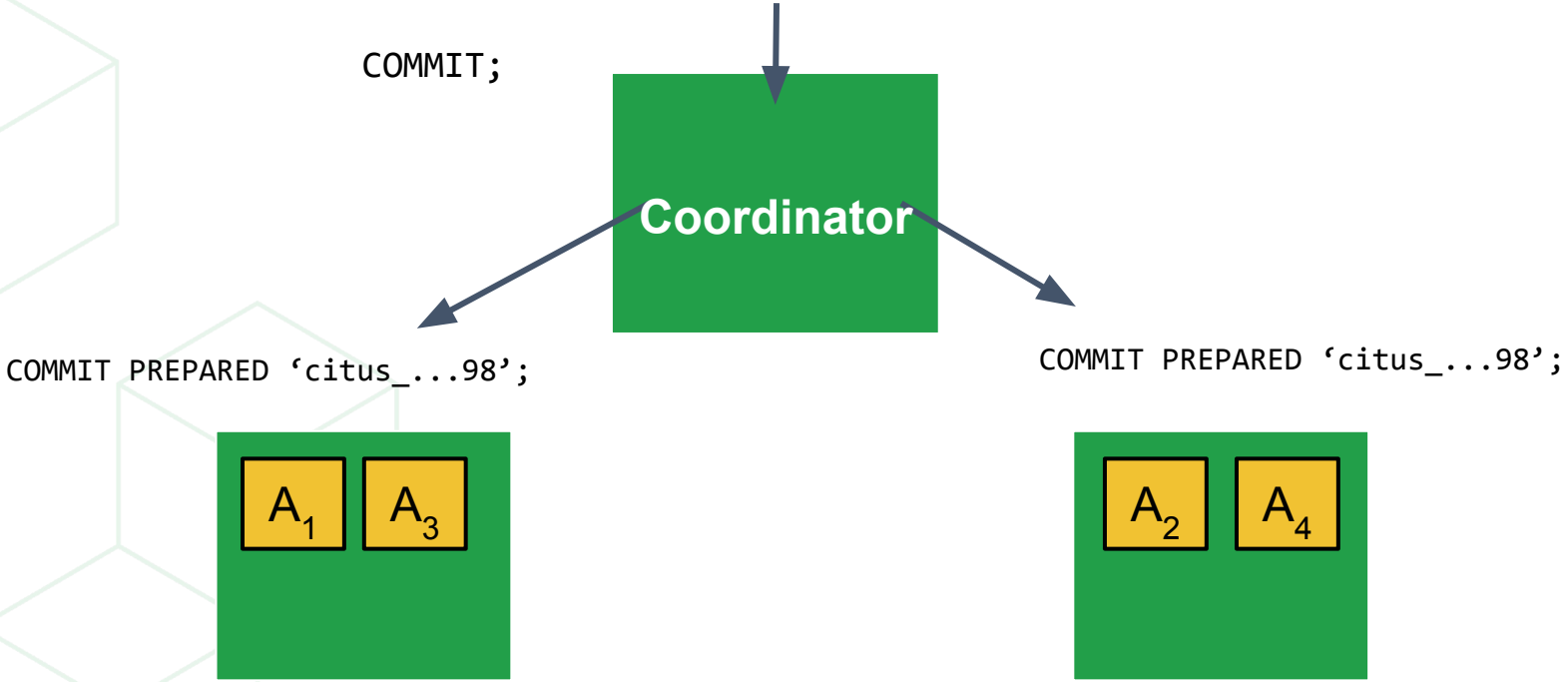

citusdata

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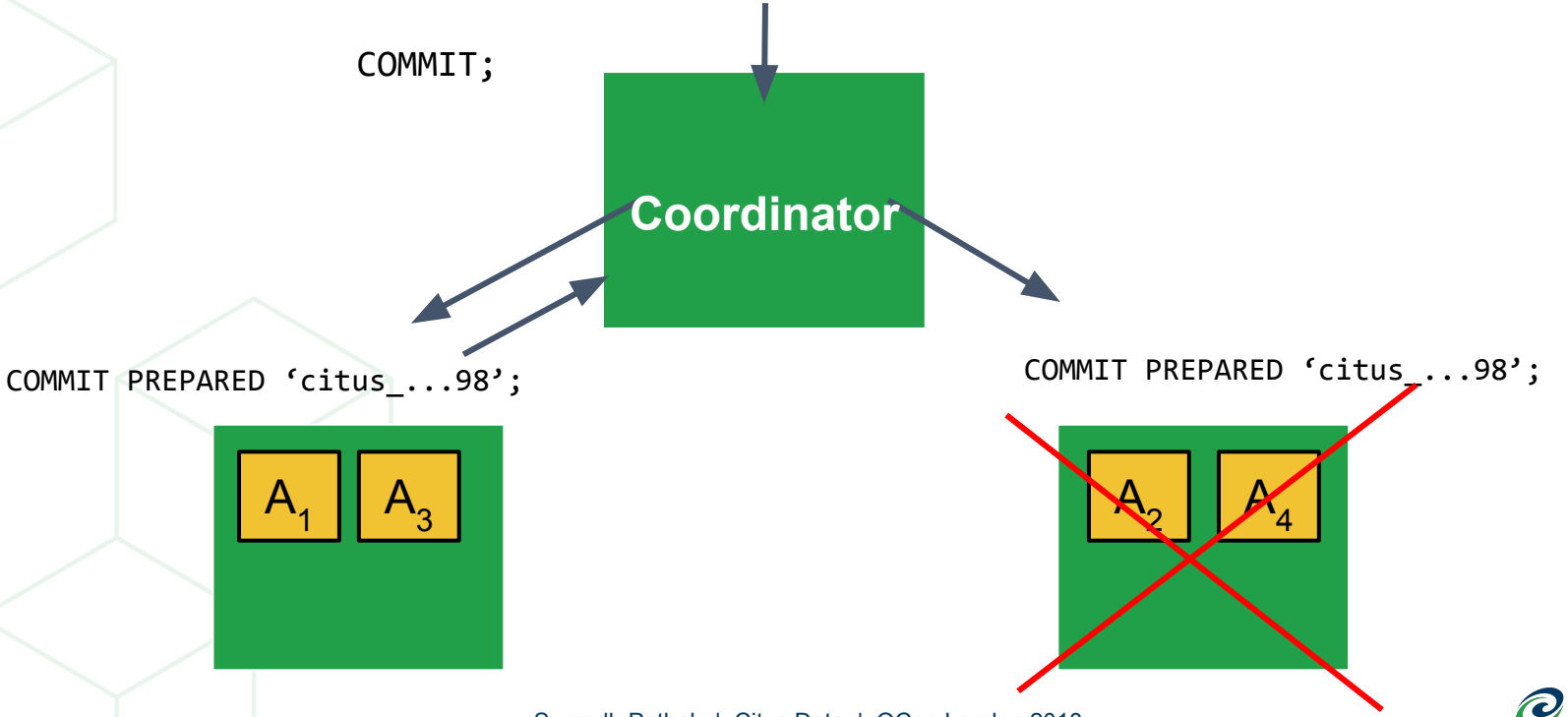
COMMIT;
```



citusdata

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COMMIT;
```

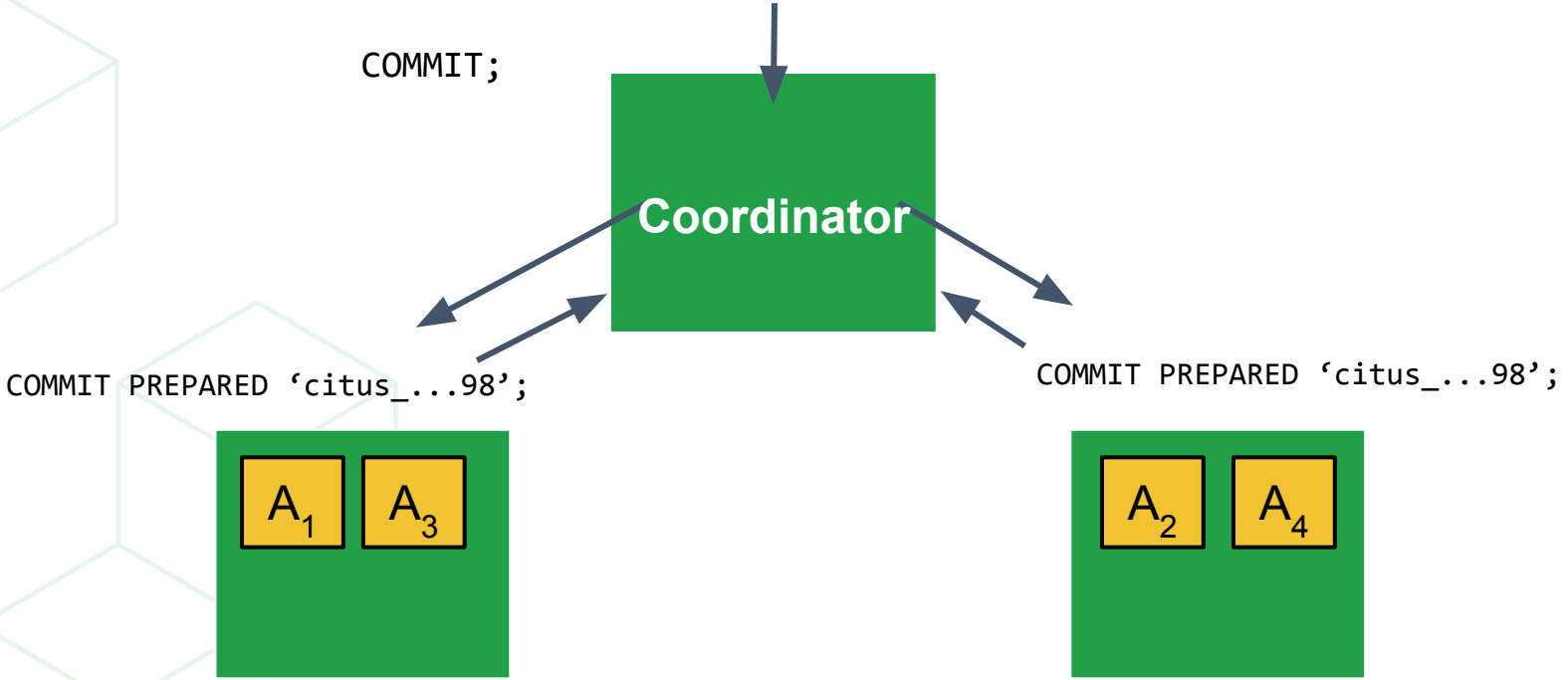

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But.... Deadlocks!

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Example

```
// SESSION 1

BEGIN;
UPDATE accounts SET balance
= balance - 100 WHERE id =
‘ALICE’;
(LOCK on ROW with id
‘ALICE’)
```

```
// SESSION 2
```


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Example

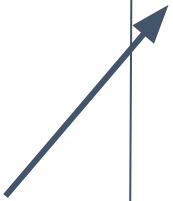
```
// SESSION 1

BEGIN;
UPDATE accounts SET balance = balance - 100 WHERE
id = ‘ALICE’;
(LOCK on ROW with id ‘ALICE’)
```

```
// SESSION 2

BEGIN;
UPDATE accounts SET balance
= balance + 100 WHERE id =
‘BOB’;
(LOCK on ROW with id ‘BOB’)
```

Example

```
// SESSION 1

BEGIN;
UPDATE accounts SET balance = balance - 100 WHERE
id = ‘ALICE’;
(LOCK on ROW with id ‘ALICE’)
```

```
// SESSION 2

BEGIN;
UPDATE accounts SET balance = balance + 100 WHERE
id = ‘BOB’;
(LOCK on ROW with id ‘BOB’)
```

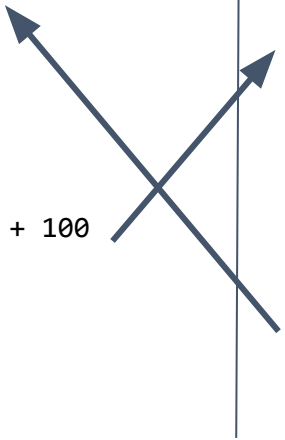


```
UPDATE accounts SET balance
= balance + 100 WHERE id =
‘BOB’;
```

Example

```
// SESSION 1

BEGIN;
UPDATE accounts SET balance = balance - 100 WHERE
id = ‘ALICE’;
(LOCK on ROW with id ‘ALICE’)
```

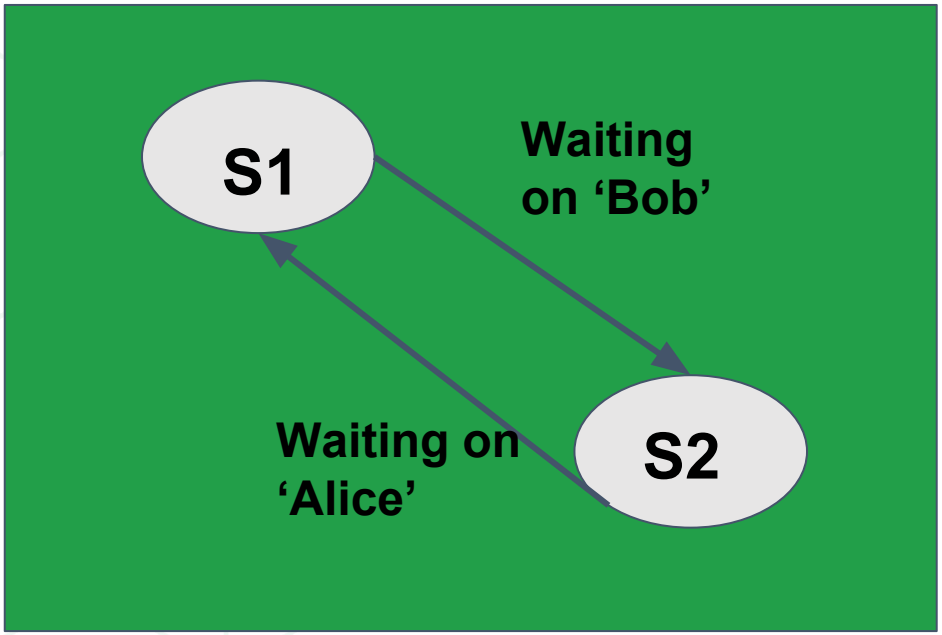
```
// SESSION 2

BEGIN;
UPDATE accounts SET balance = balance + 100 WHERE
id = ‘BOB’;
(LOCK on ROW with id ‘BOB’)
```



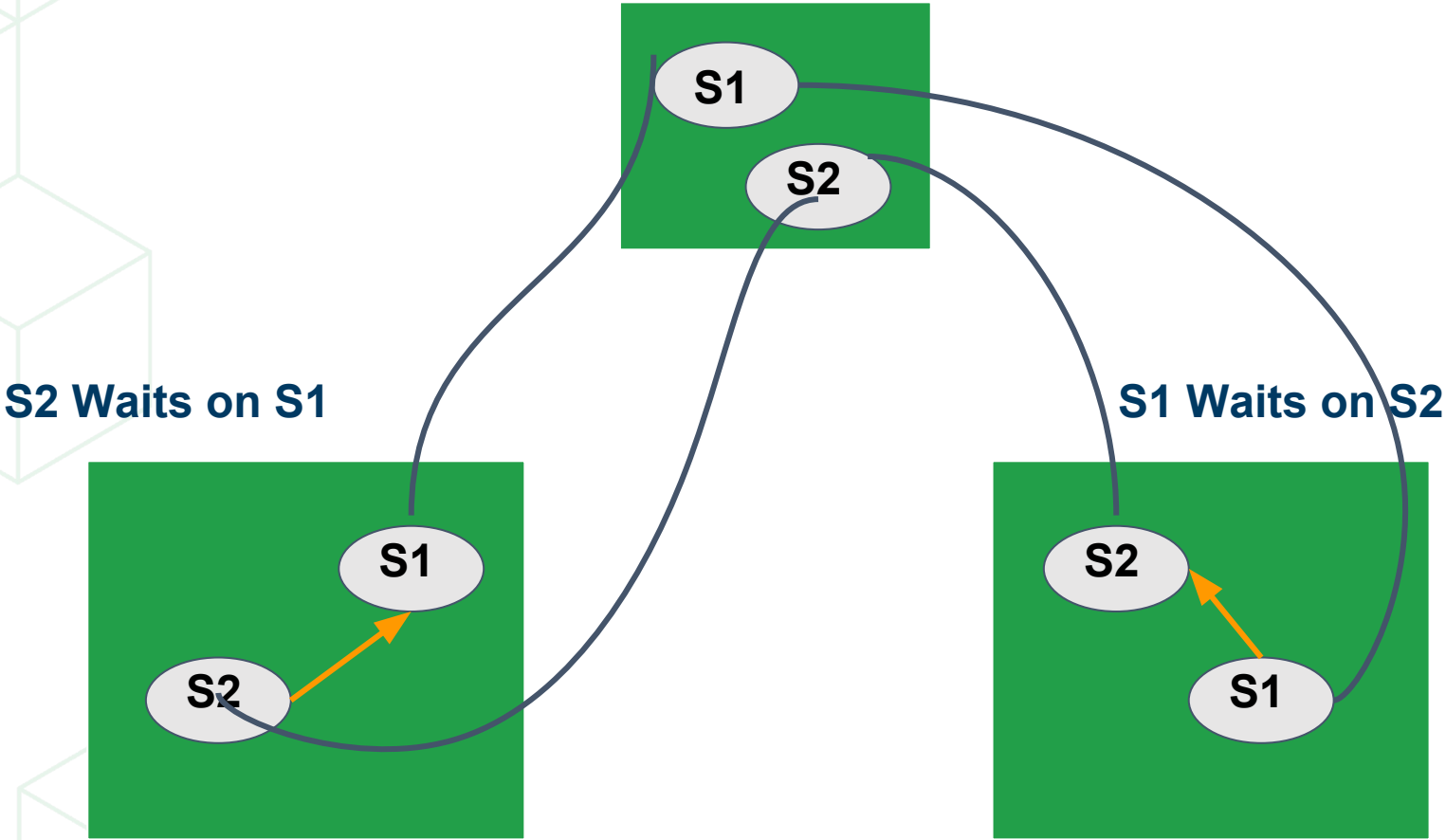
```
UPDATE accounts SET balance = balance + 100
WHERE id = ‘BOB’;
```

```
UPDATE accounts SET balance
= balance - 100 WHERE id =
‘ALICE’
```

How do Relational DB's solve this?



- Construct a Directed Graph
- Each node is a session/transaction
- Edge represents a wait on a lock



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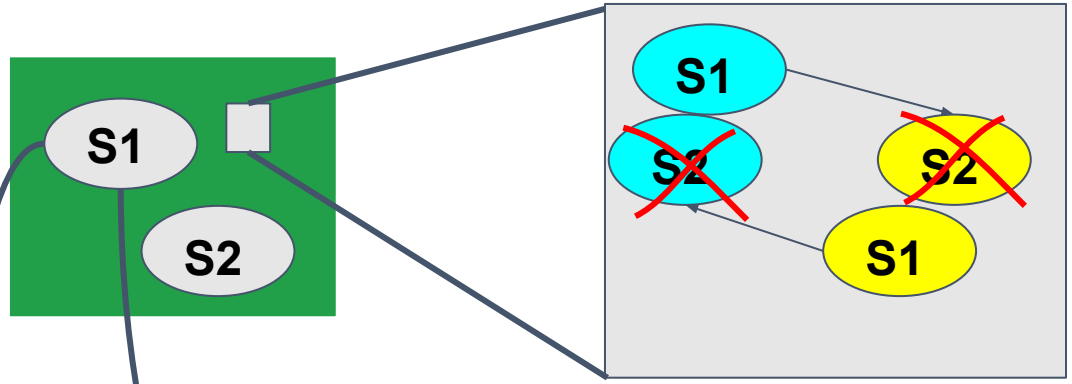
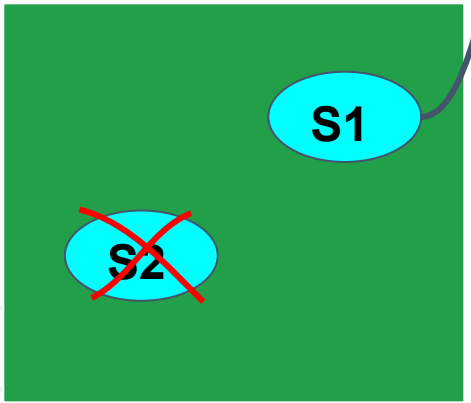
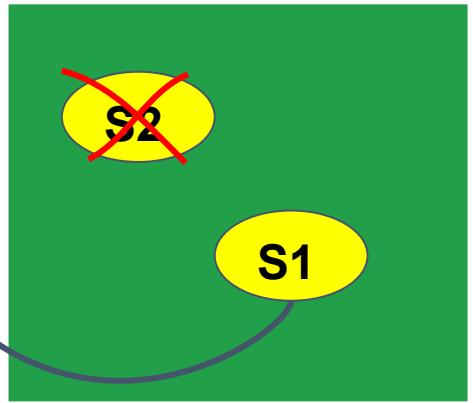
Distributed Deadlock Detector



S2 Waits on S1



S1 Waits on S2



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4 keys to scaling transactions

- 2PC to ensure atomic transactions across nodes
- Deadlock Detection—to scale complex & concurrent transaction workloads
- MVCC
- Failure Handling

It's 2018. Distributed can be Relational

- Scale tables—**via sharding**
- Scale SQL—**via distributed relational algebra**
- Scale transactions—**via 2PC & Deadlock Detection**

Now, how do we implement all of this?

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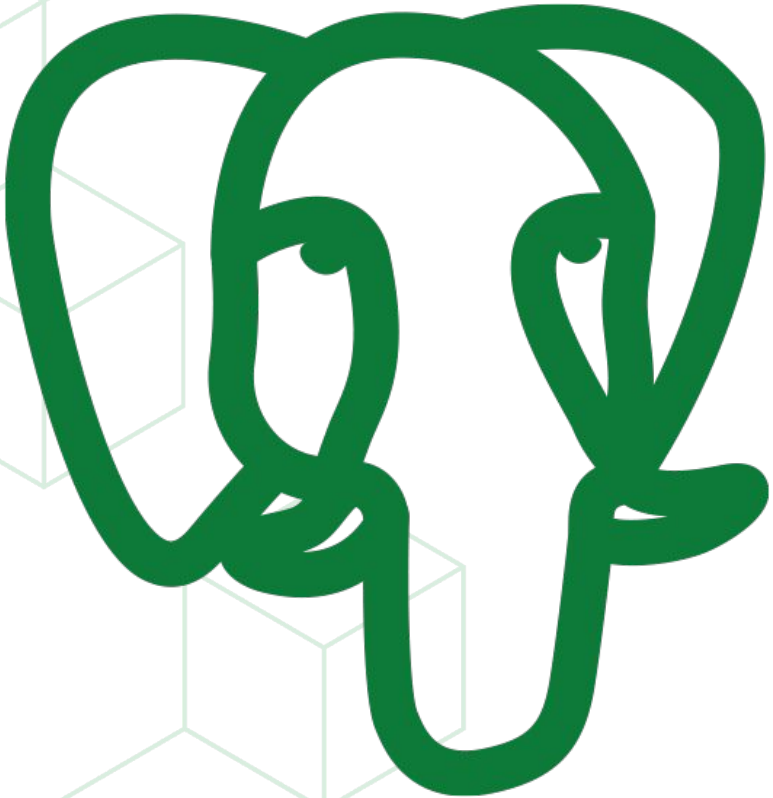

Postgres

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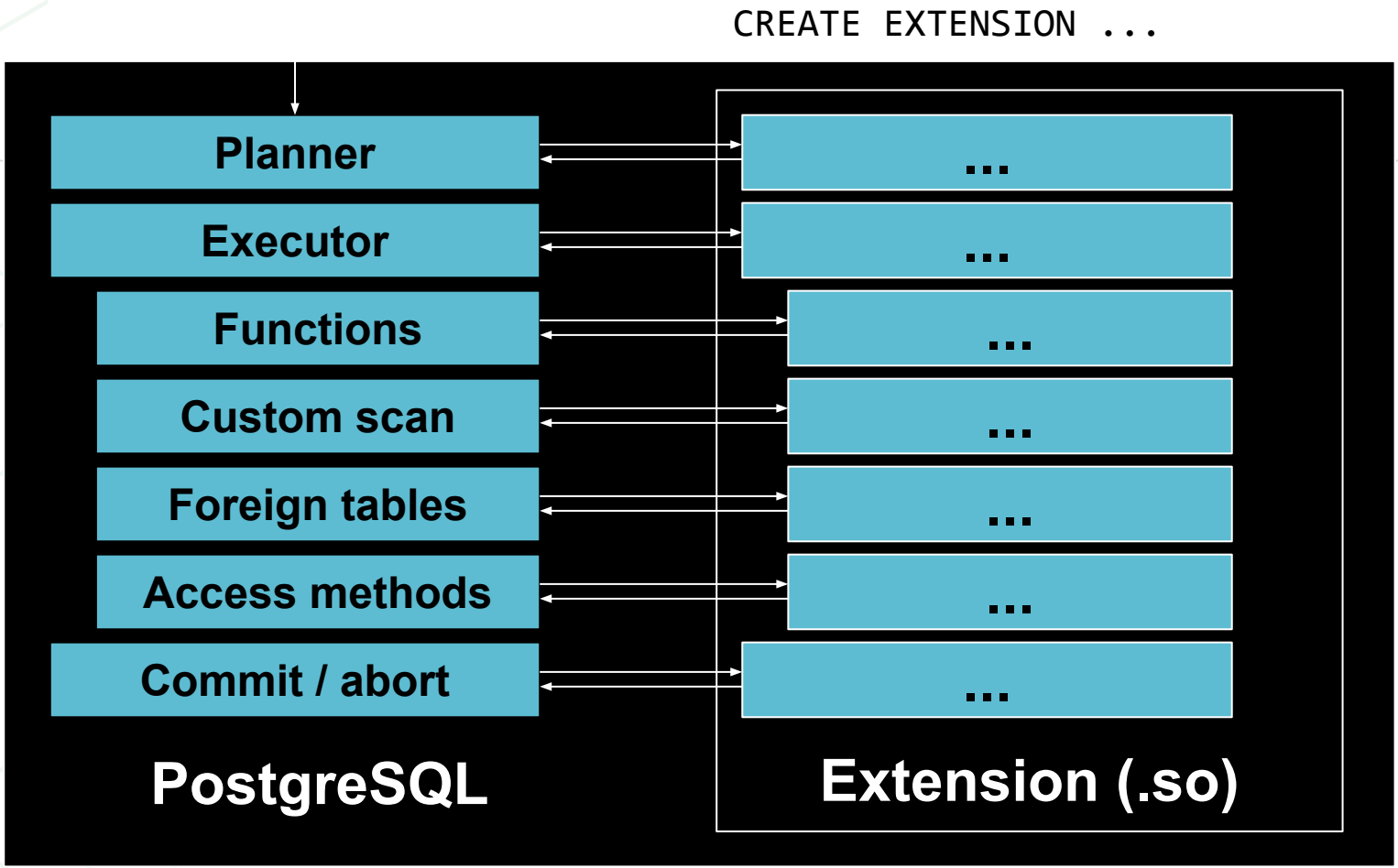
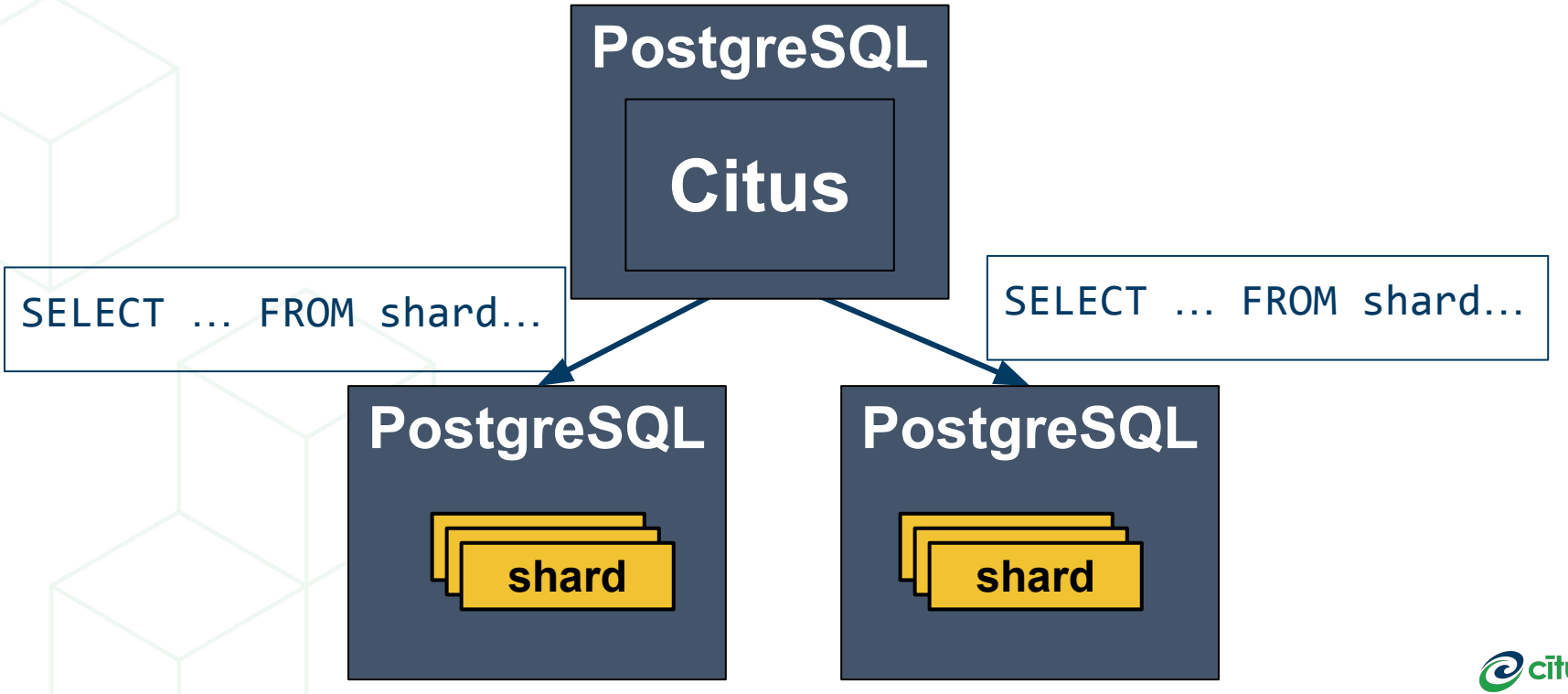

CREATE EXTENSION ...
Planner
Executor
Functions
Custom scan
Foreign tables
Access methods
Commit / abort
...
...
...
...
...
...
PostgreSQL
Extension (.so)

SELECT ... FROM distributed_table ...



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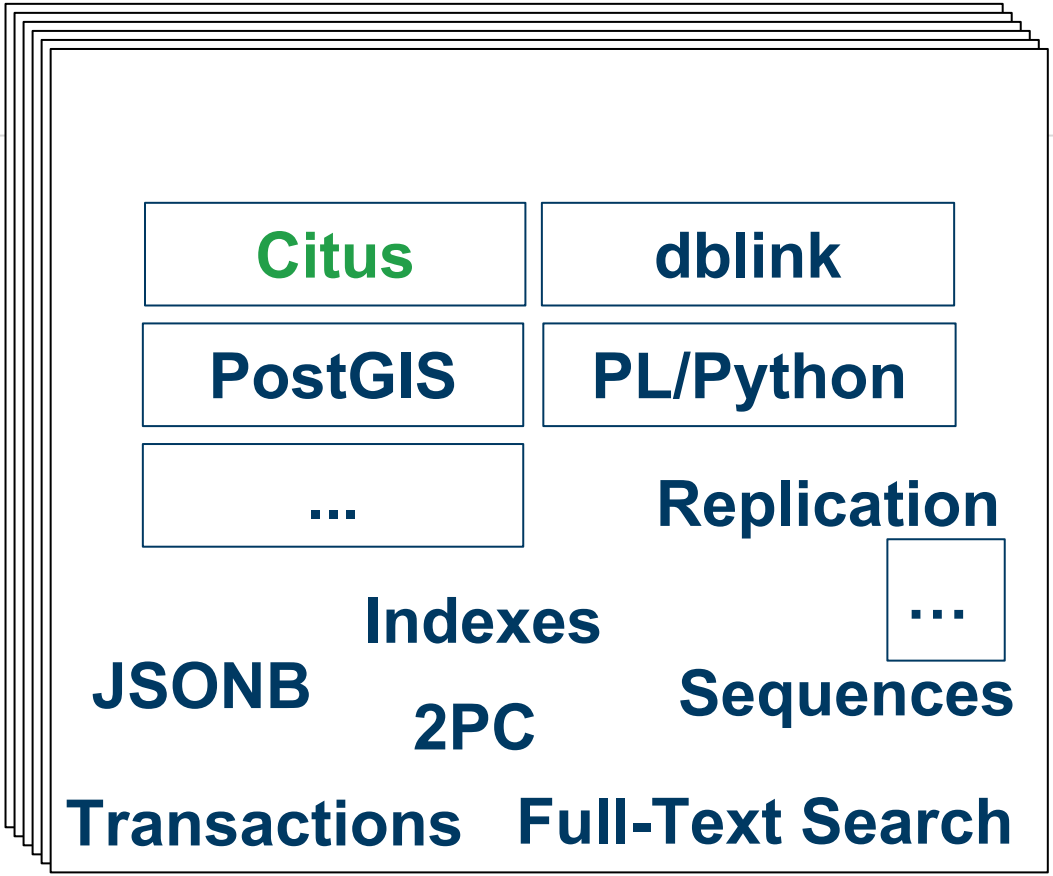
Rich ecosystem of tooling, data types, & extensions in PostgreSQL



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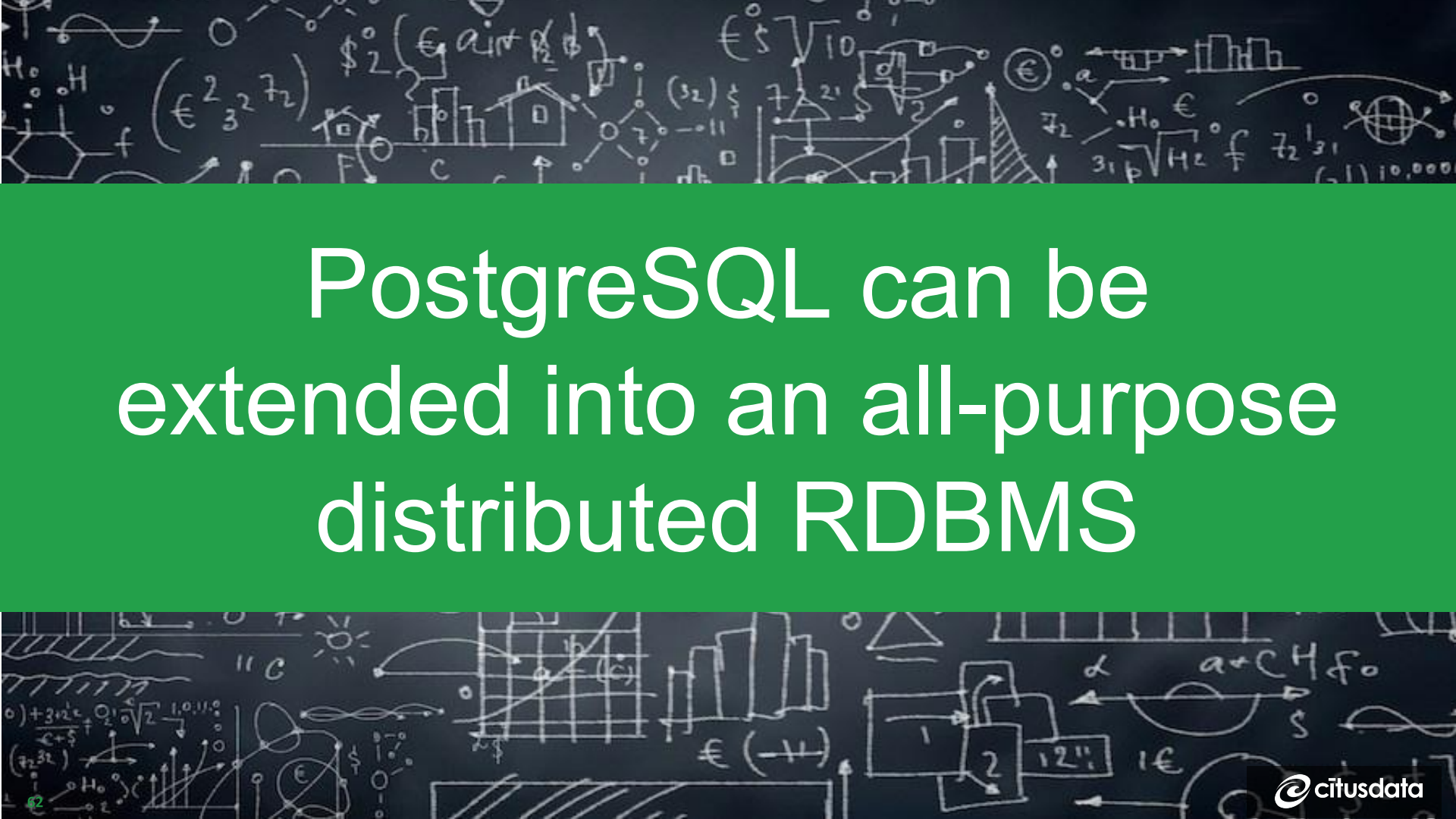
PostgreSQL can be extended into an all-purpose distributed RDBMS
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I believe the future of distributed databases *is* relational.

Thank you!

Sumedh Pathak

sumedh@citusdata.com

@moss_toss | @citusdata | citusdata.com

QCon London 2018 | The Future of Distributed Databases is Relational