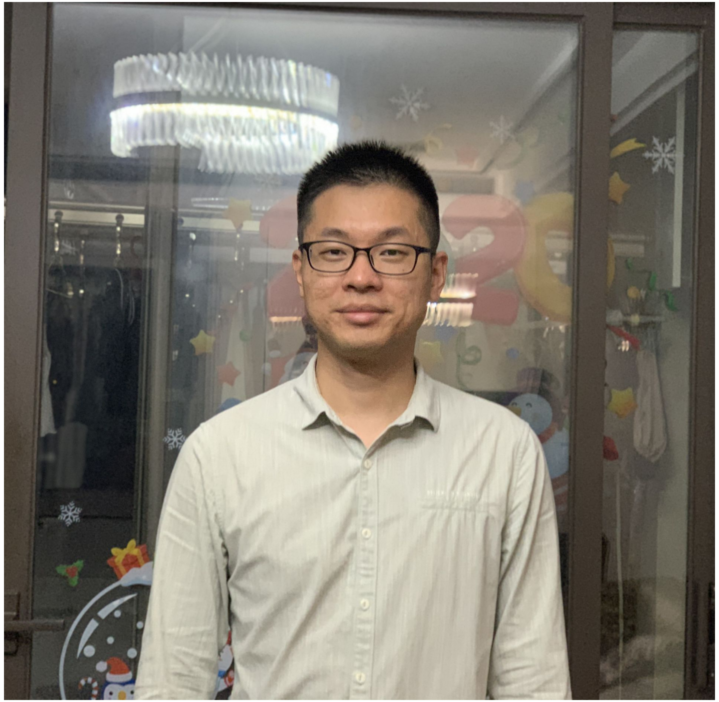
How we built a Geo-Distributed Database with low latency

About Me



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Agenda

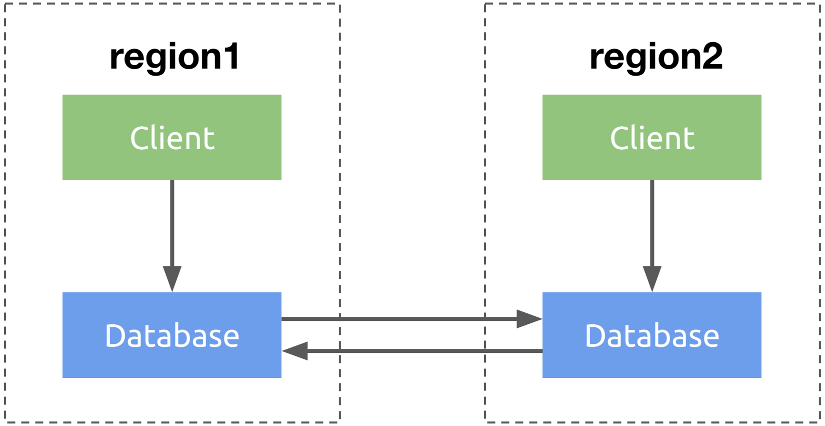
- The geographic problem in databases
- What is TiDB?
- How does Geo-Distribution work in TiDB?
- Q&A

The geographic problem in databases

Multiple Geographic Regions

Why multiple geographic regions?

- Improve access locality to achieve lower latency
- Tolerate the failure of an available zone (AZ) or an entire region



Multiple Geographic Regions

Tradeoff

- Latency
- Consistency level

MySQL Replication

- Asynchronous replication: low latency & lower consistency level
- Semisynchronous replication: high latency & higher consistency level
- Group replication: not optimized for multiple geographic regions

What is TiDB

What is TiDB

Open-source distributed NewSQL database for hybrid transactional and analytical processing (HTAP) which speaks MySQL protocol

Horizontal Scalability

Transparent scale-out without architectural complexity

High Availability

Auto-failover and self-healing to ensure business continuity

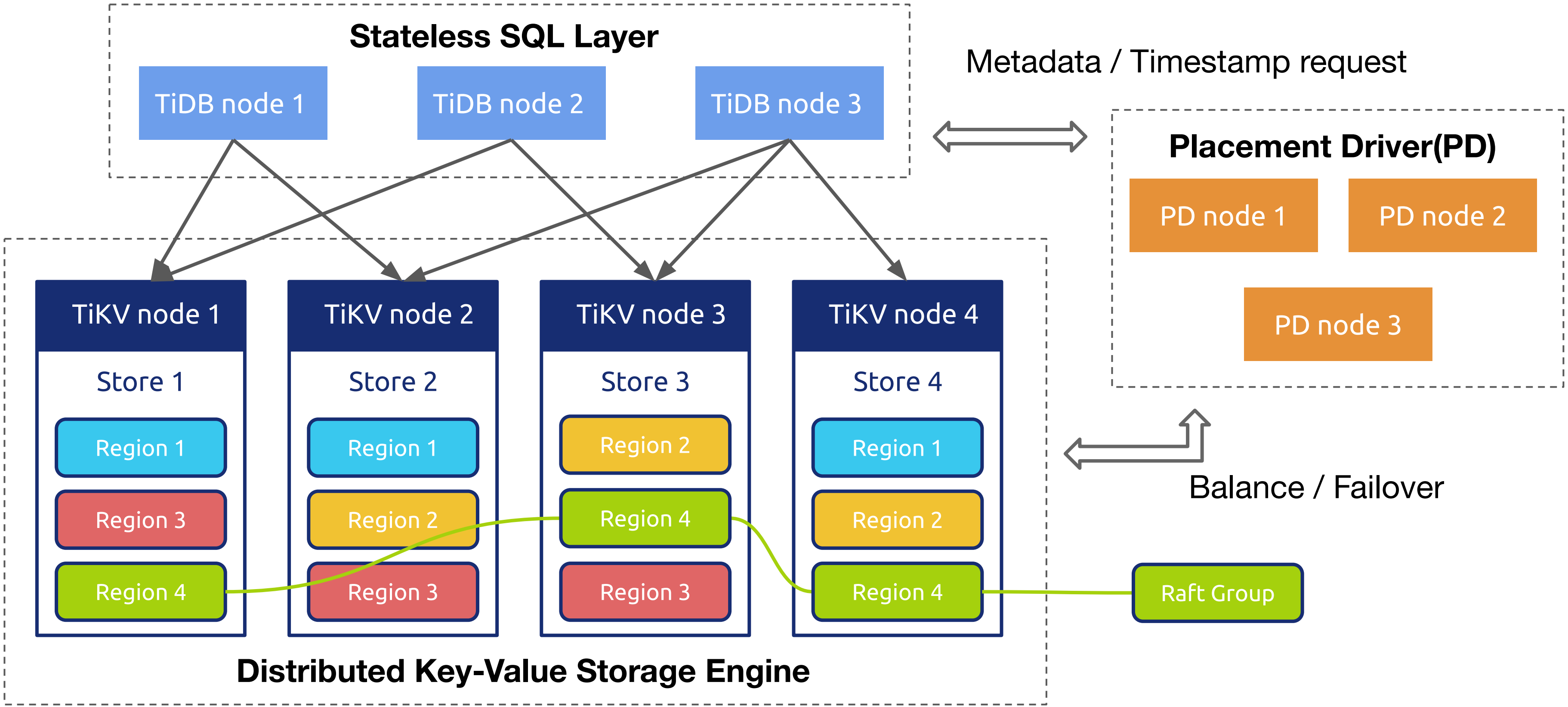
Strongly Consistent

Full ACID transactions at scale in distributed environments

MySQL Compatibility

Without changing MySQL application code in most cases

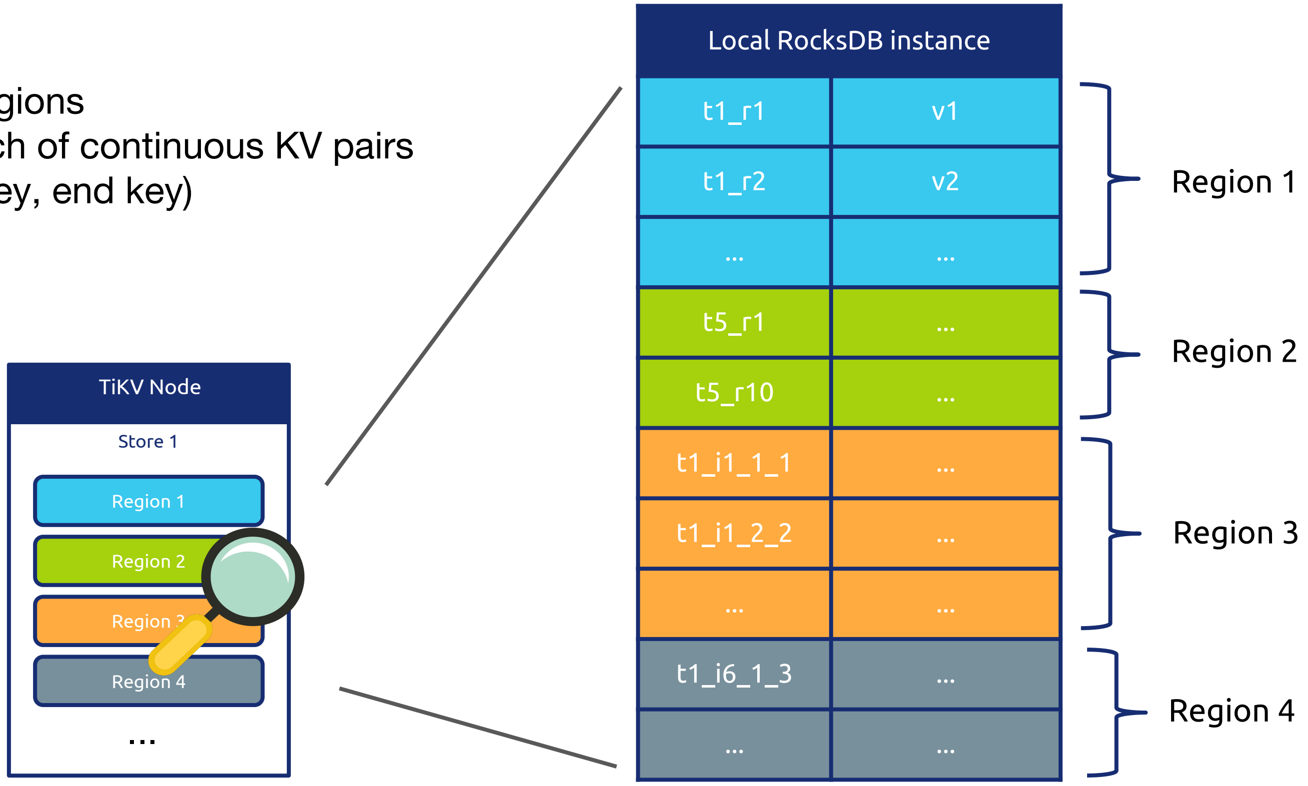
TiDB OLTP Architecture



Data organization

What is a region?

- A table is split into regions
- Each region is a bunch of continuous KV pairs
- Region meta: [start key, end key)



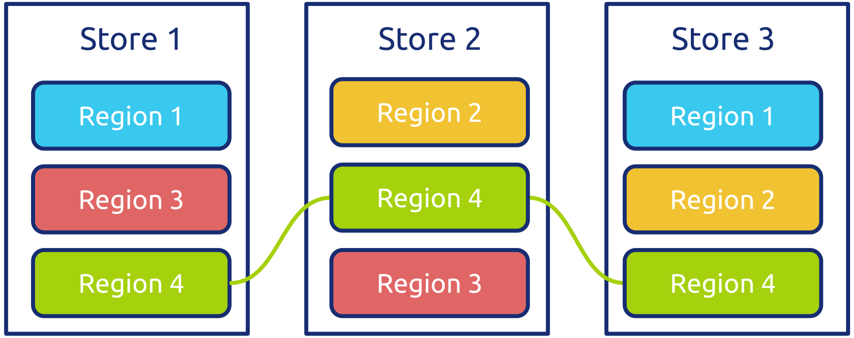
Write and Read

Raft group

- All replicas of a region form a raft group

Raft roles

- Leader (only one)
- Follower
- Learner (optional)



Write

- Data is written to the leader as logs
- The leader replicates logs to followers and learners
- Logs replicated to the majority of voters are committed

Read

- Read from the leader

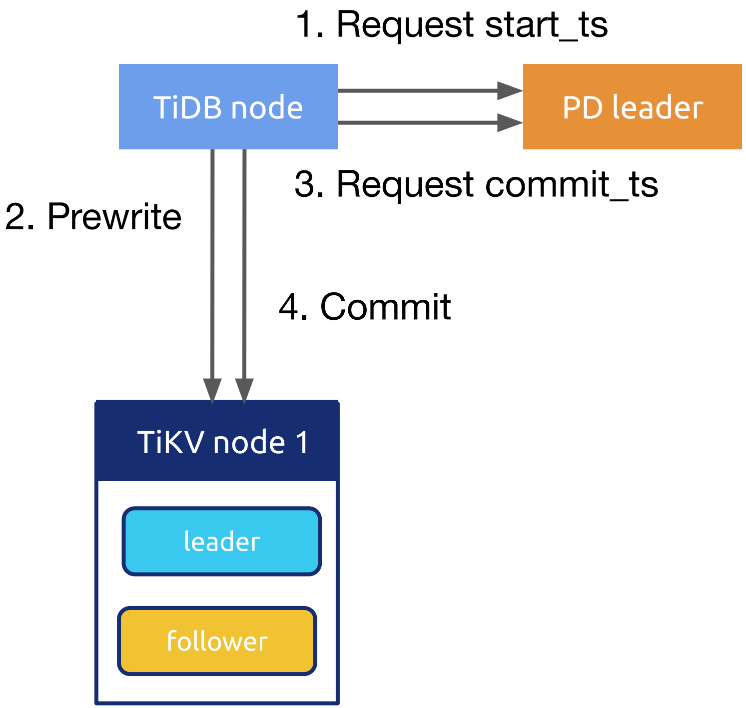
Transaction Model

Two-phase commit (2PC)

1. TiDB requests a start timestamp as the identifier of the transaction: start_ts
2. TiDB prewrites data to TiKV
3. TiDB requests a commit timestamp for the transaction before commit: commit_ts
4. TiDB commits data on TiKV with commit_ts

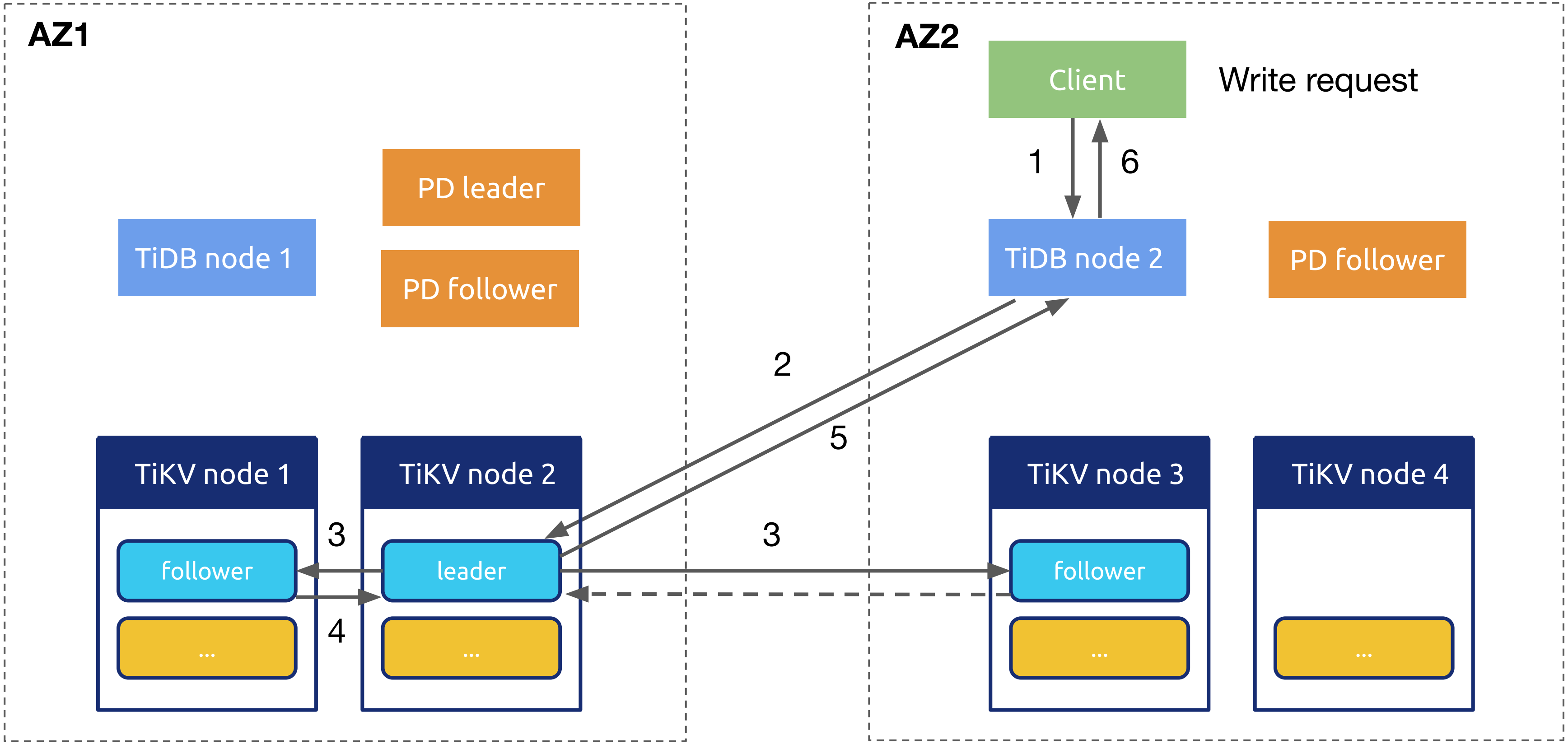
MVCC

- commit_ts is attached to each version of data
- Snapshot isolation

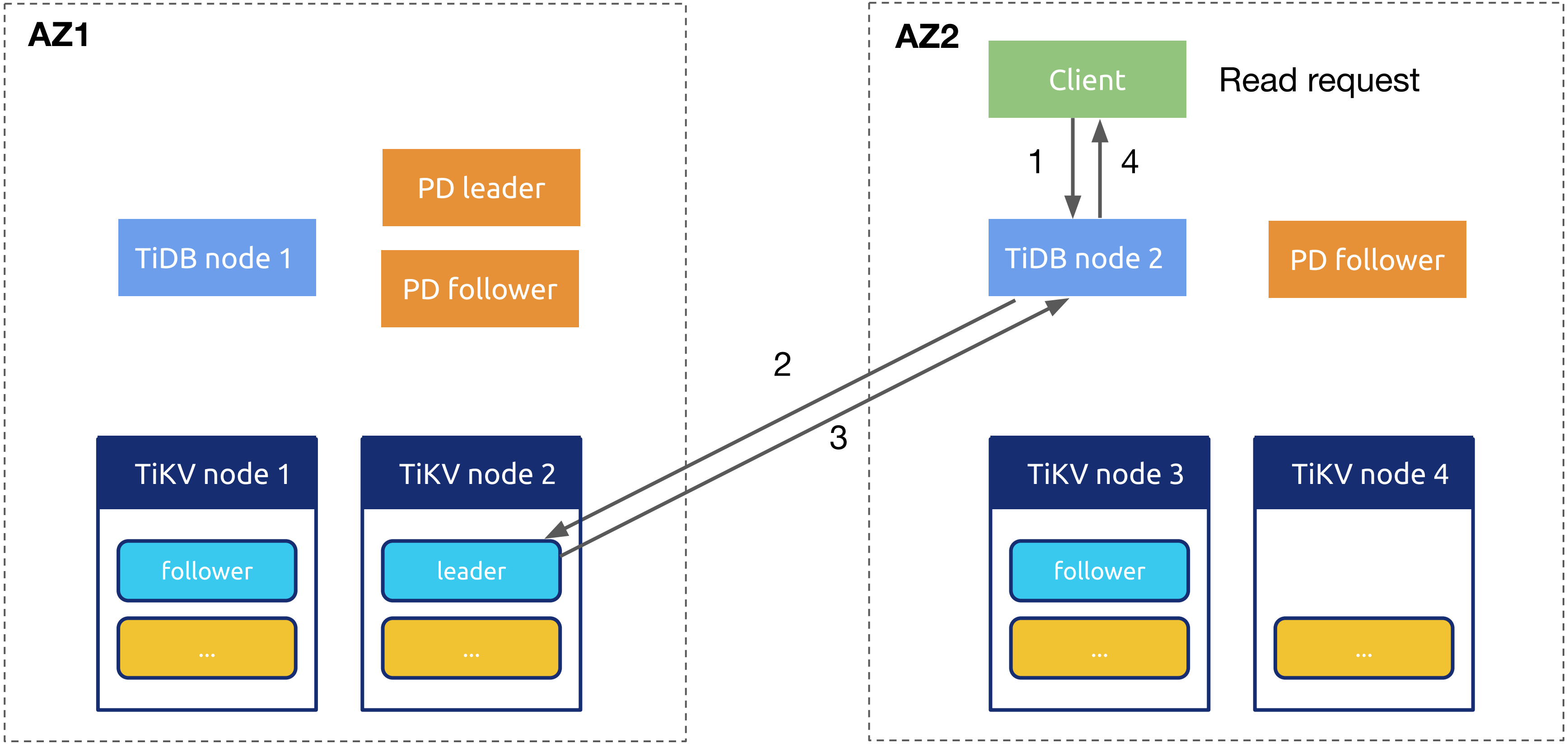


How does Geo-Distribution work in TiDB

Geographic Problems in TiDB



Geographic Problems in TiDB



Geographic Problems in TiDB

Bidirectional replication

- Split the system into seperate TiDB clusters, which reside in different AZ
- Clusters replicate to each other by synchronization tools
- Suffer from maintaining multiple clusters

What do we want?

- Maintain only one TiDB cluster
- Write and read with low latency
- High availability

Placement Policy

What is placement policy

- Define the placement and replica count of raft roles through SQL

Scenarios

- Place data across regions to improve access locality
- Limit data within its national border to guarantee data sovereignty
- Place latest data to SSD and history data to HDD
- Place the leader of hot data to a high-performance TiKV instance
- Increase the replica count of more important data

Placement Policy

A use case

- A user management system
- Users are distributed over the world
- Users visit their own information through the system

Deployment

- Two data centers located in two AZ
- Applications connect to the nearest data center
- Users typically connect to the nearest application

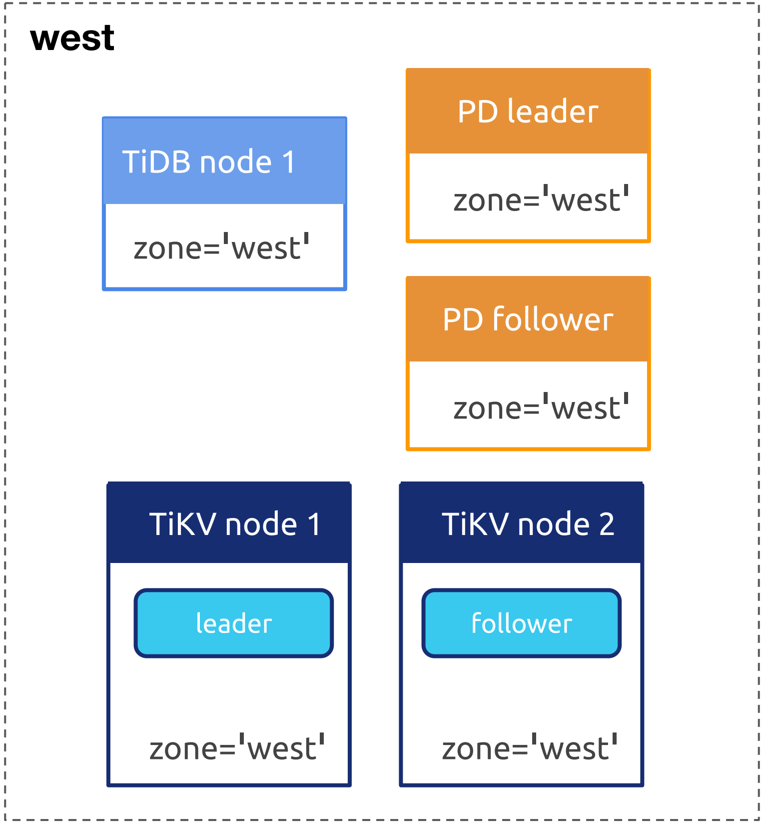
Solution

- Store each user information in the nearest data center according to their location
- Applications request user information from the local data center

Placement Policy

Configuration

- Group components by AZ
- Mark instances with the same `zone` label



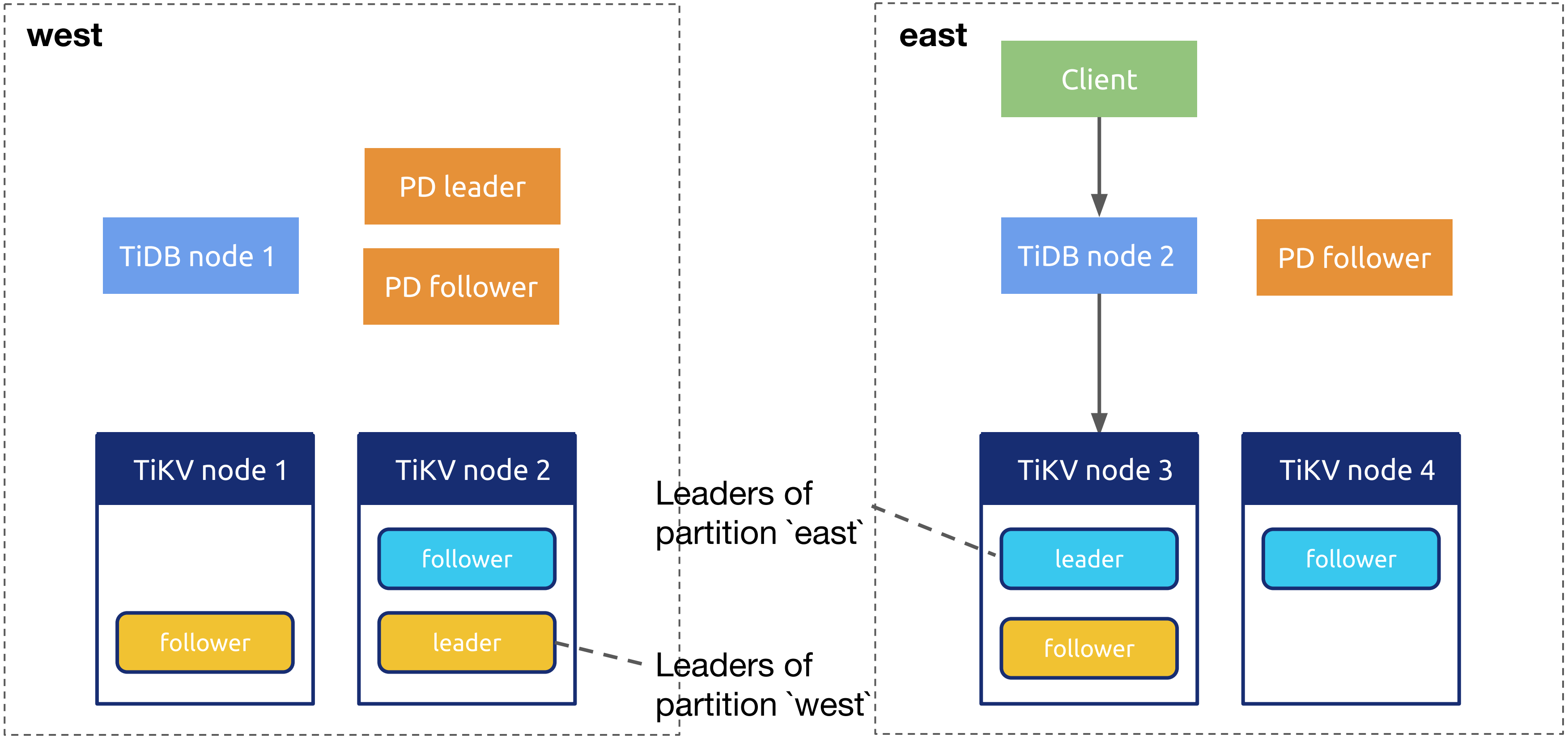
Placement Policy

Statements

```
CREATE TABLE user (id BIGINT AUTO_INCREMENT,
                   name VARCHAR(100), country VARCHAR(100),
                   PRIMARY KEY(country, id))
PARTITION BY LIST COLUMNS(country) (
    PARTITION east VALUES IN('china', 'japan', 'singapore'),
    PARTITION west VALUES IN('usa', 'canada', 'england', 'france')
);

ALTER TABLE user ALTER PARTITION east
    ALTER PLACEMENT POLICY ROLE=leader CONSTRAINTS='["+zone=east"]';
ALTER TABLE user ALTER PARTITION west
    ALTER PLACEMENT POLICY ROLE=leader CONSTRAINTS='["+zone=west"]';
```

Placement Policy



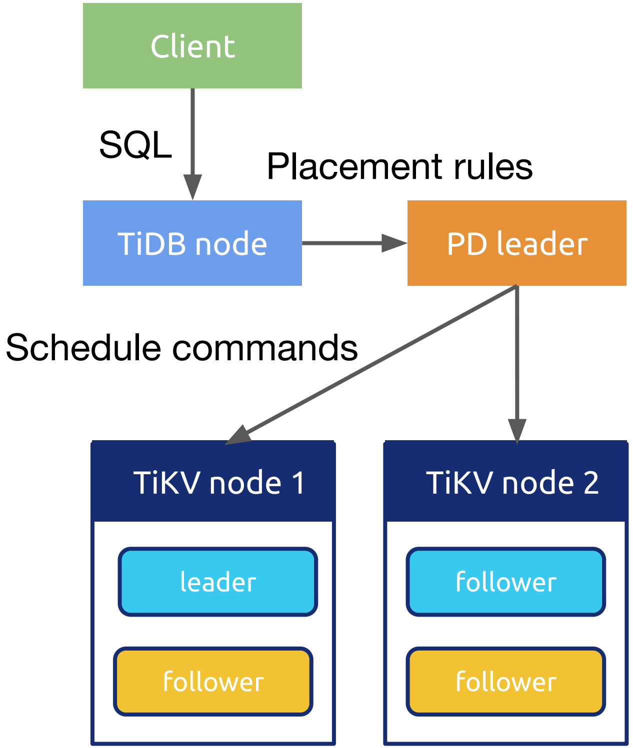
Placement Policy

How does it work

- User defines the placement policies by SQL
- TiDB generates placement rules and send them to PD
- PD schedules data according to the placement rules

Each rule mainly contains:

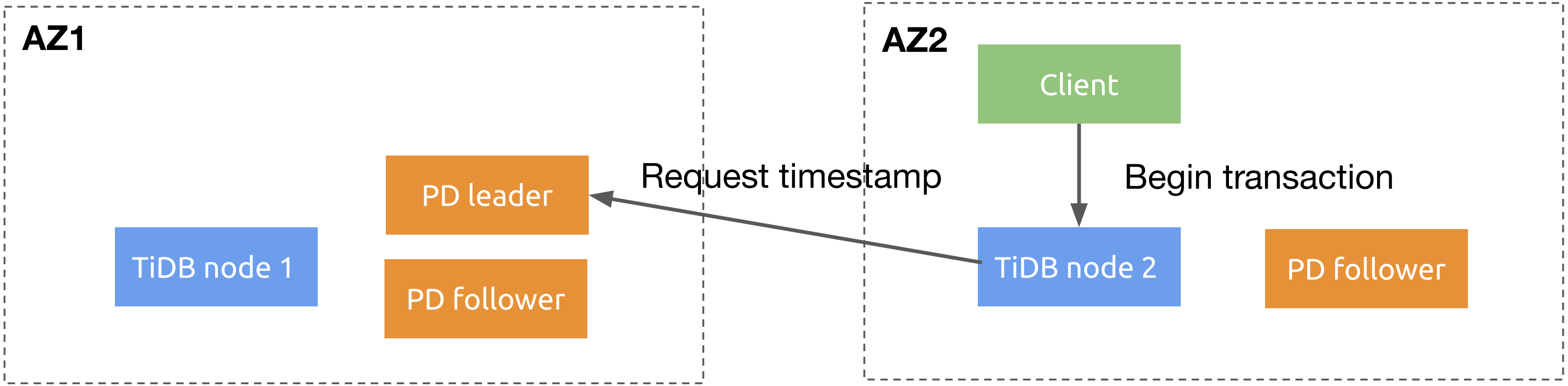
- Key range: the data range of a table or partition
- Raft role: the raft role to be placed
- Constraints: the labels which TiKV instances match



Local Transaction

Problems of requesting timestamps

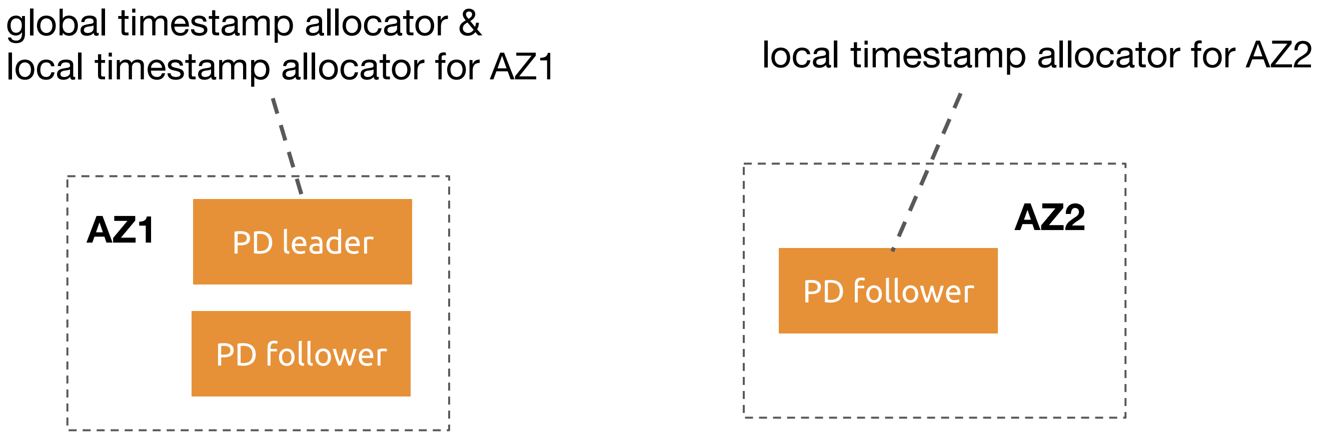
- Request timestamps from the PD leader
- The request crosses different AZ
- Request 2 timestamps for each transaction: start_ts & commit_ts



Local Transaction

Timestamp allocators

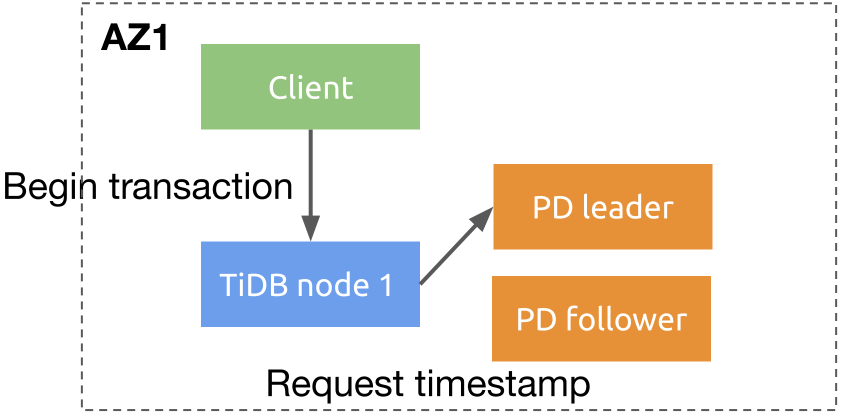
- Elect a local timestamp allocator (PD leader or PD follower) for each AZ
- PD leader is the global timestamp allocator

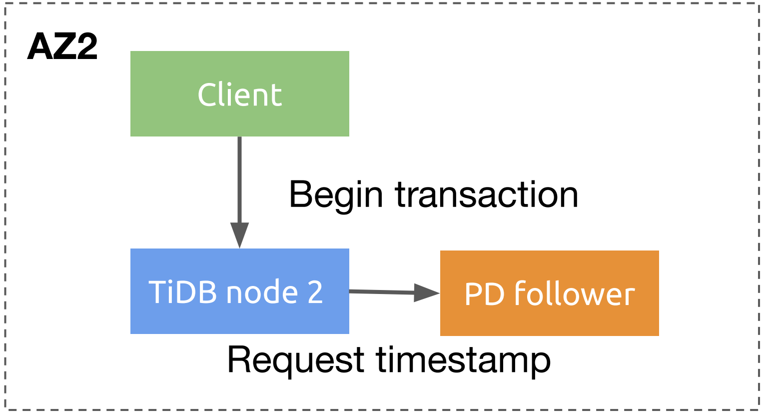


Local Transaction

What are local transactions?

- Local transactions request timestamps from the local timestamp alloator
- Avoid crossing AZ latency





Global Transaction

Limitations of local transactions

- Clock bias exists among local timestamp allocators, so accessing the same data violates linearizability
- Local transactions can only visit local data
- Data placement is defined through placement policies

Why global transactions?

- When a transaction crosses different AZ
- When a transaction accesses global data, such as metadata

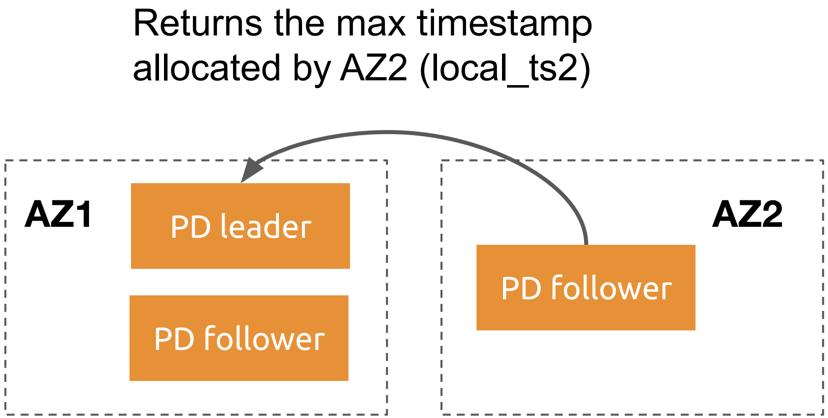
What are global transactions?

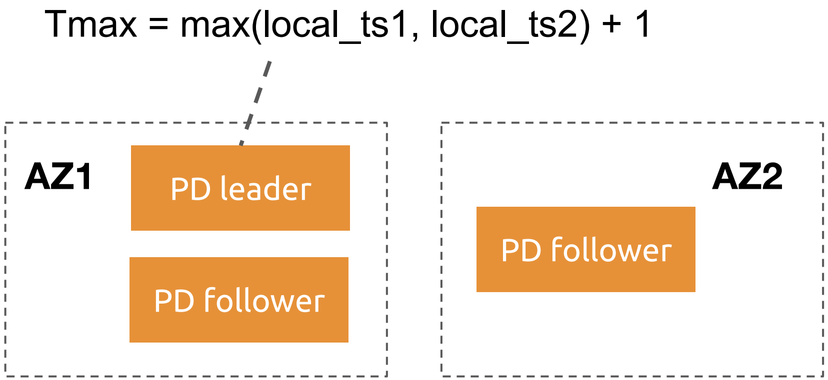
- Global timestamp is allocated from the global timestamp allocator
- Conform to linearizability: previous local timestamp < global timestamp < later local timestamp

Global Transaction

How do global transactions work?

1. The global timestamp allocator collects max timestamps allocated by all local timestamp allocators (local_ts)
2. The global timestamp allocator calculates Tmax: Tmax = max (local_ts, ...) + 1

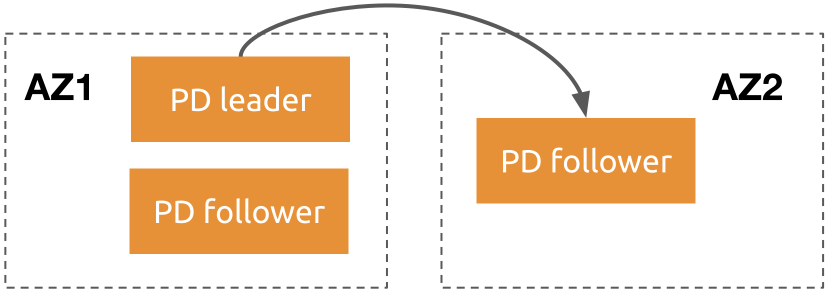


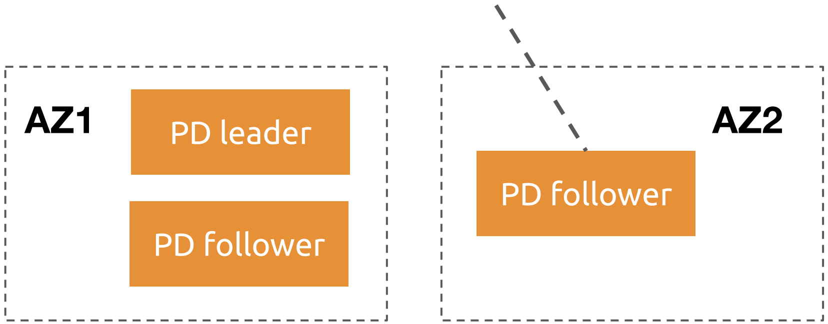


Global Transaction

How do global transactions work?

3. The global timestamp allocator broadcasts Tmax to all local timestamp allocators
4. Local timestamp allocators update their local timestamp starting points local_ts

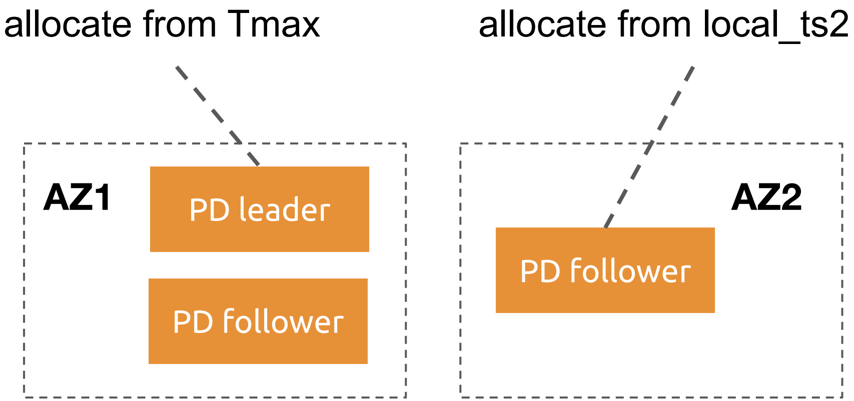




Global Transaction

How do global transactions work?

5. The global timestamp allocator allocates timestamps from Tmax
6. Local timestamp allocators allocate timestamps from local_ts2



Local & Global Transaction

Local transaction limitations

- Data must be bound to one AZ
- A local transaction can only read / write the data from the current AZ

Global transaction limitations

- Able to access any data
- Cross region 3 times for allocating a global timestamp
- Typically only used for accessing data that not bound to any AZ, such as metadata

Local Stale Read

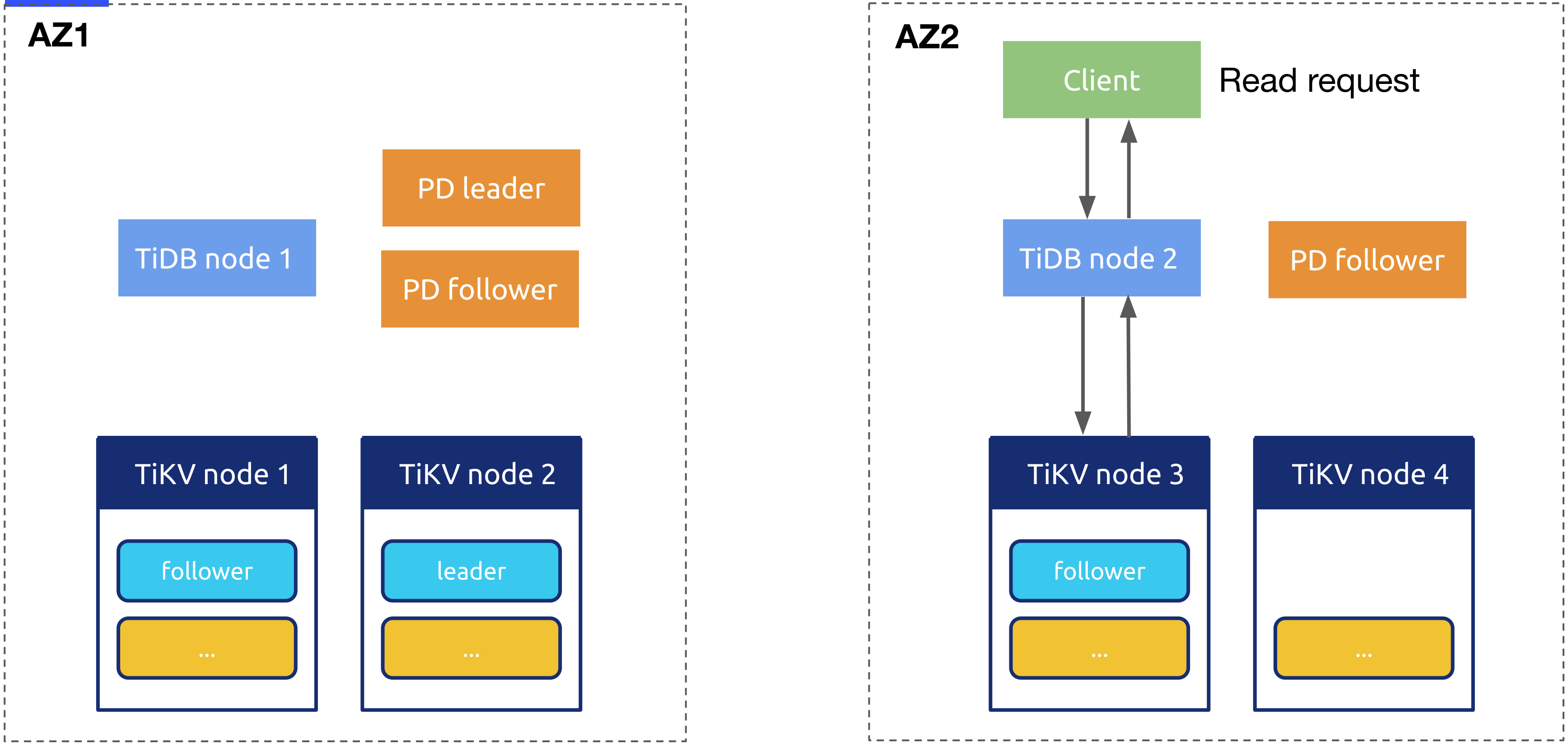
Why local stale read?

- When data is not bound to AZ, placement policies and local transactions are not appliable
- Followers can also be read
- Sometimes strong consistency is not a must

What is local stale read?

- Read the local replica, including followers
- Read stale data, thus do not guarantee linearizability
- Guarantee snapshot isolation

Local Stale Read



Local Stale Read

Example

```
SELECT * FROM users JOIN orders WHERE users.id=orders.user_id
        AS OF TIMESTAMP '2021-05-01 12:00:00';
```

Semantic

- The transaction reads local replicas
- The transaction reads the same snapshot of `users` and `orders`
- The snapshot is no staler than '2021-05-01 12:00:00'
- Read as new data as the local AZ has

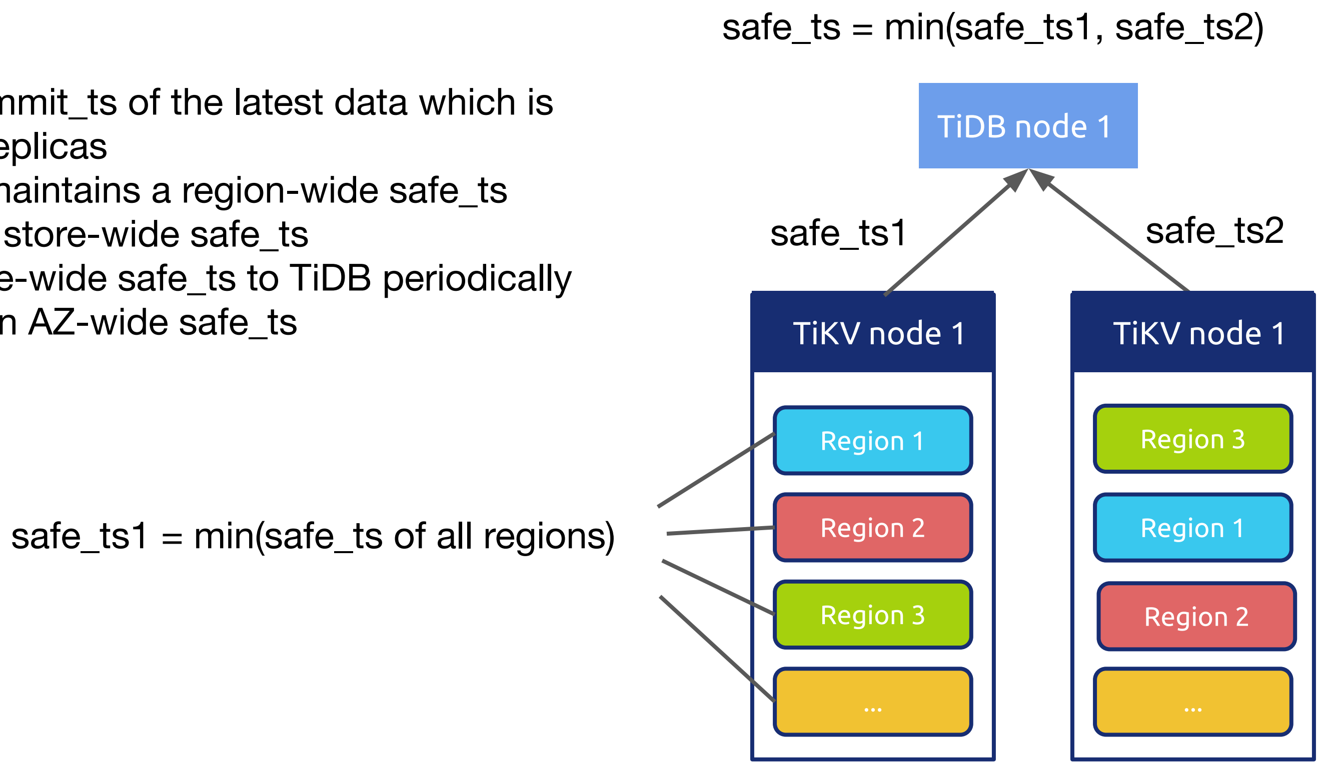
Restriction of start_ts

- All data for the snapshot has been replicated to the current AZ
- No inflight commits which will update the snapshot later

Local Stale Read

Maintain safe_ts

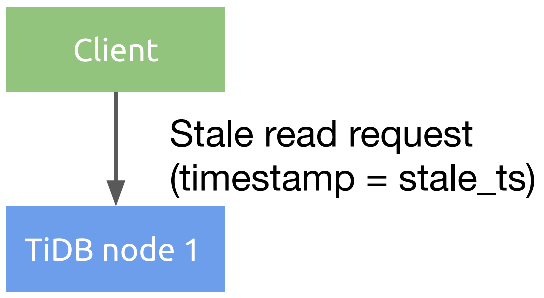
- safe_ts is the commit_ts of the latest data which is replicated to all replicas
- Each raft group maintains a region-wide safe_ts
- TiKV maintains a store-wide safe_ts
- TiKV reports store-wide safe_ts to TiDB periodically
- TiDB maintains an AZ-wide safe_ts



Local Stale Read

Determine start_ts

- TiDB determines start_ts locally
- start_ts is no staler than the user-specified timestamp
- start_ts is no staler than the AZ-wide safe_ts



start_ts = max(safe_ts, stale_ts)

Summary

When data is bound to AZ

- Use placement policy to define placement of data
- Use local transactions to access local data
- Use global transactions to access global data

When data is not bound to AZ & not need strong consistency

- Use local stale read to read local data

More Resources

- Website: https://pingcap.com/
- GitHub: https://github.com/pingcap/tidb
- Twitter: https://twitter.com/PingCAP
- Slack: #everyone on Slack

PingCAP

Make Growth Easier.

About Us

PingCAP is a software service provider committed to delivering one-stop enterprise-grade database solutions.

TiDB is an open-source, distributed New SQL database for elastic scale and real-time analytics.

Thank You!
Q & A