

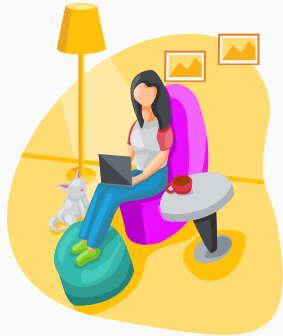
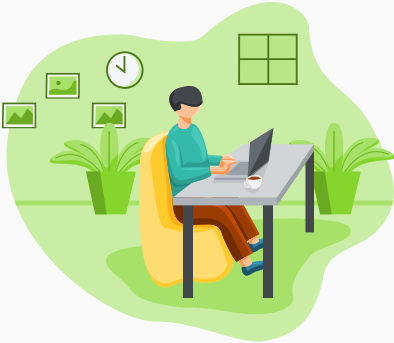
Synql: A CRDT-based Approach for Replicated Relational Databases with Integrity Constraints

Victorien Elvinger



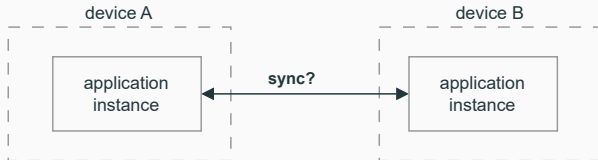
June 2024

Adding collaborative features to applications



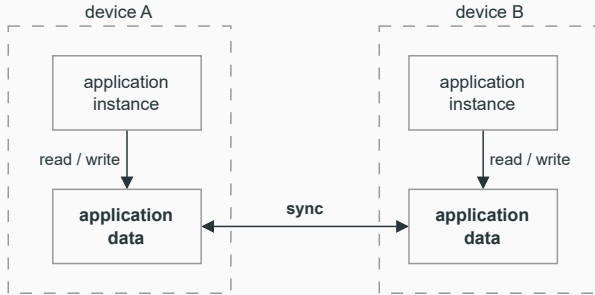
- several persons **modify together** a shared content
 - located at **different places**
 - **simultaneous** modifications or at **distinct time**
- adding collaborative features to applications is hard
 - **sequential** → **concurrent** modifications
 - **offline support**

Adding collaborative features to applications



- replicate the application?
 - require dedicated development

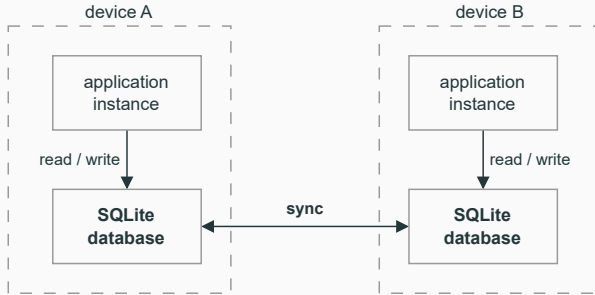
Adding collaborative features to applications



- replicate the application?
 - require dedicated development
- **replicate the application data^a**

^aKleppmann et al., “Local-first software: you own your data, in spite of the cloud”.

Adding collaborative features to applications



- replicate the application?
 - require dedicated development
- **replicate the application data^a**
- SQLite is embedded in many applications

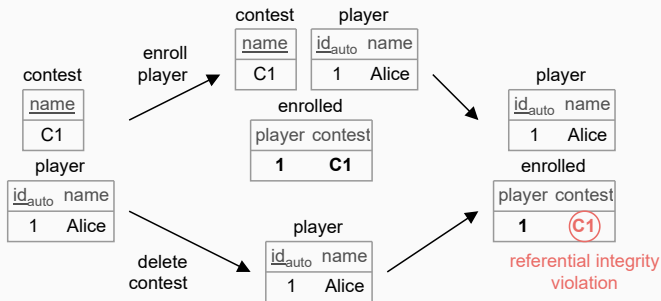
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Referential integrity



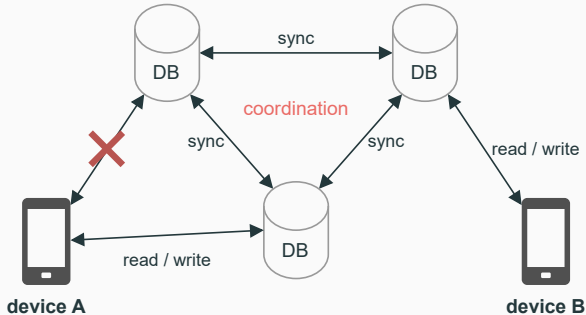
- ensure that the **target of a reference exists**
- the deletion of a reference target can result in
 - the **abortion of the deletion**
 - the **propagation of the deletion** to the reference source

Referential integrity in face of concurrencies



- concurrent deletion and referencing of a row

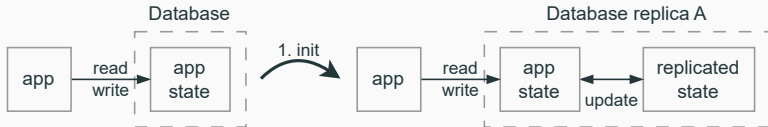
Replicating relational databases: already done?



- **client-server** architecture
- **coordination** to maintain **data integrity**^a

^aBailis et al., “Highly Available Transactions: Virtues and Limitations”.

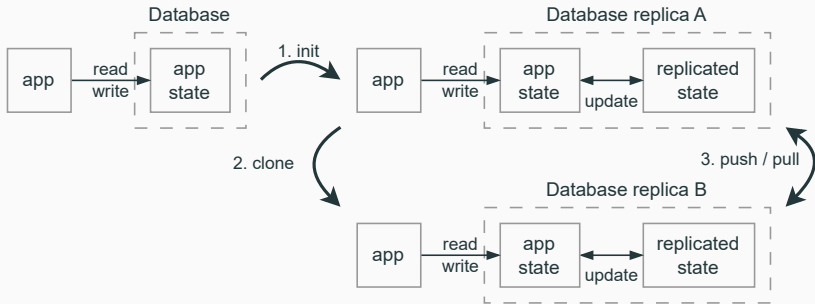
Coordination-less replication of relational databases



- Git-like **coordination-less** replication of relational databases^a
 - based on Conflict-free Replicated Data Types (CRDTs)
- can **break data integrity and user intent**
- **not Strongly Convergent**

^aYu et al., “Conflict-Free Replicated Relations for Multi-Synchronous Database Management at Edge”.

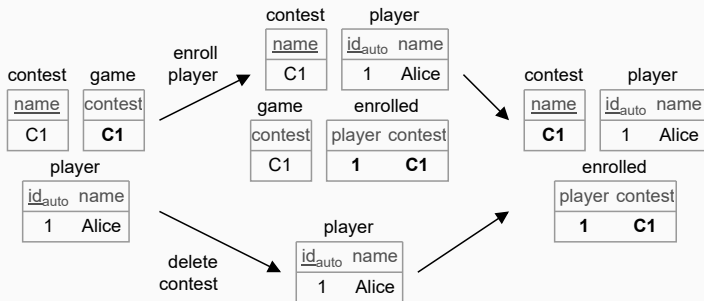
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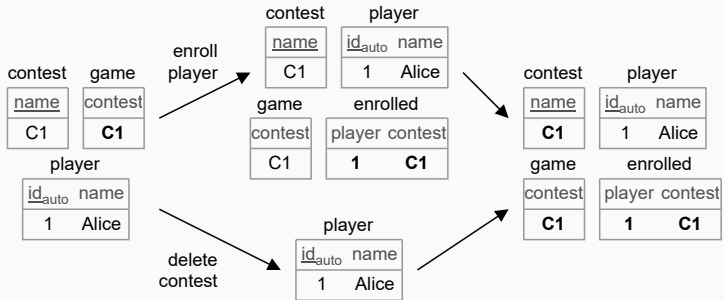
Referential integrity maintenance - state of the art



- writes are compensated^a in order to ensure integrity
- the *contest* is restored
- however, the *game* is not restored

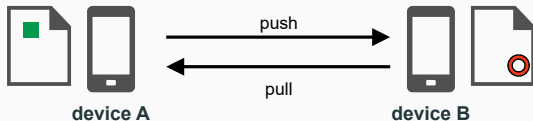
^aBalegas et al., "IPA: Invariant-preserving Applications for Weakly-consistent Replicated Databases".

Referential integrity maintenance - desired output



- the *game* should be restored

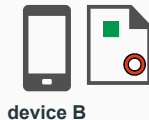
Strong convergence



- property enforced by CRDTs^a
- advantages:
 - **low latency**
 - **no flickering**

^aShapiro et al., "Conflict-Free Replicated Data Types".

Strong convergence

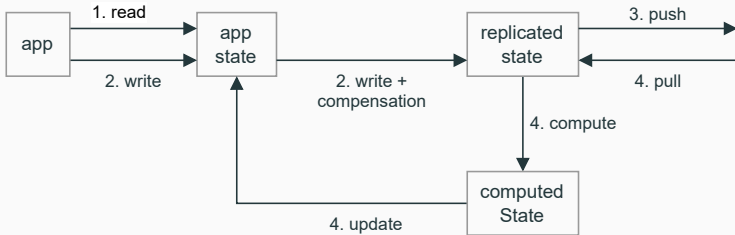


- property enforced by CRDTs^a
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**Can we replicate a relational database without
any coordination that enforces Strong
Convergence and maintains data integrity?**

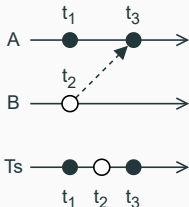
Architecture overview



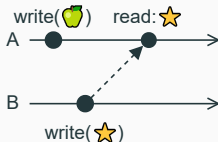
- app read without overhead
- an app write triggers replicated state update
- push / pull in background
- a pull merges the received state and computes app state

Replicated state: composing CRDTs

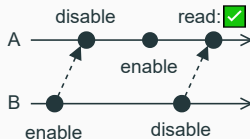
Unique Monotonic Timestamps



Last-Writer-Win Register



Causal-Length Flag

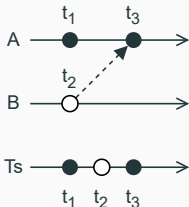


- globally unique and monotonic timestamps
 - monotonic: greater than previously observed timestamps
- Last-Writer-Win (LWW) Register^a keeps the newest value
- state of CLFlag computed from the longest chain

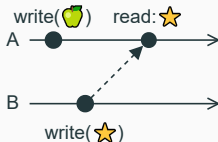
^aJohnson et al., "Maintenance of duplicate databases".

Replicated state: composing CRDTs

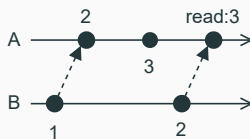
Unique Monotonic Timestamps



Last-Writer-Win Register



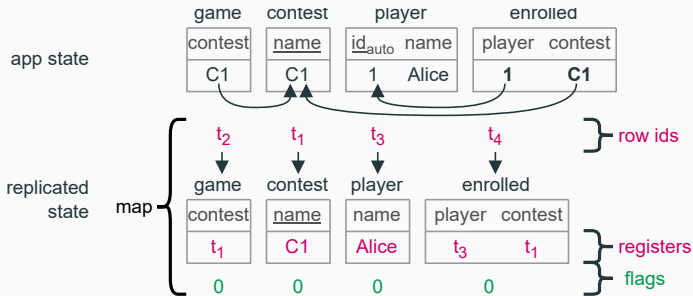
Causal-Length Flag



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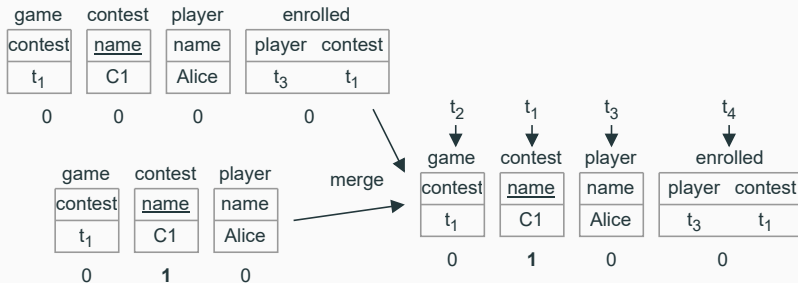
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Replicated state: composing CRDTs



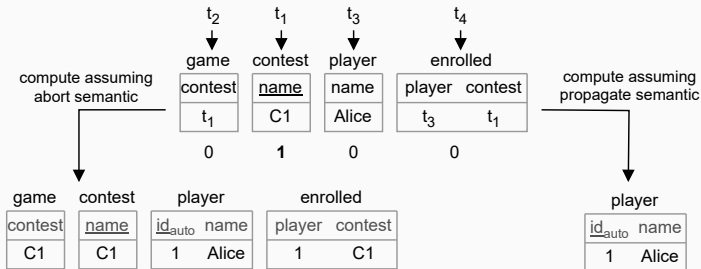
- **timestamps as row identifiers**
- a CL-Flag indicates if a row is removed
- a replicated attribute is a LWW-Register
- row identifiers as values of foreign keys

Replicated state: composing CRDTs



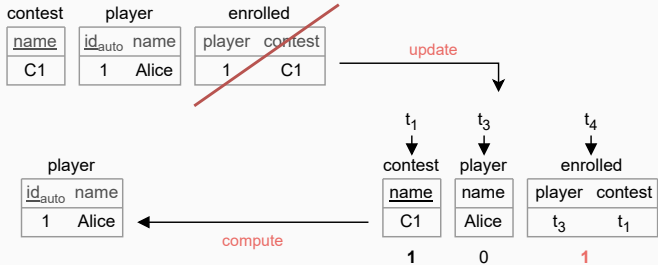
- the replicated state encodes only the app write

Compute app state from replicated state



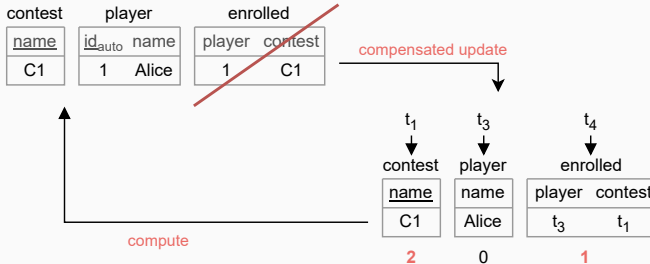
- app state is **derived from the replicated state**
- leverage database schema for selecting **computation semantic**

Compensation of app writes



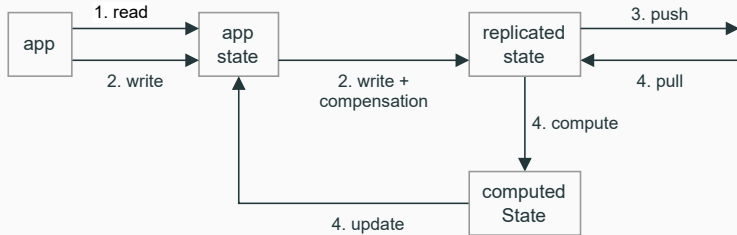
- state computation can result in surprising effect on app writes

Compensation of app writes



- state computation can result in surprising effect on app writes
- **app writes must be compensated** for ensuring user intent

Conclusions



- **coordination-less** replication of relational database
 - maintains data integrity
 - **Strongly Convergent**
- composition of CRDTs + state computation + compensations

