TOPSI: Totally-Ordered Prefix Parallel Snapshot Isolation

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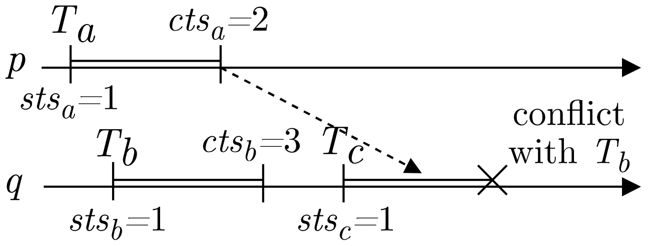
- Applications developers seek transactional and strong consistency guarantees to ease developments;

- However, those guarantees have a greater negative impact on the performance of distributed database systems:
  - Network latencies;
  - Distributed coordination;
  - Fault tolerance;
  - Metadata overhead.

- Relying on weaker consistencies (e.g., eventual) is not viable for a large range of use cases;

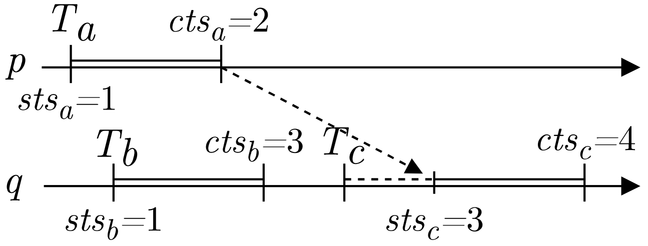
- Snapshot Isolation, widely used in centralized databases, proves to be a performance challenge in a distributed setting:
  - Globally consistent snapshots;
  - Monotonic snapshot evolution.

- ***Generalized Snapshot Isolation* (GSI)** allows transactions to execute over an older snapshot:
  - (+) Reduces blocking;
  - (-) Increases abort probability;
  - (-) A transaction might not be able to read its immediate writes.



T_a : $w(x)$
T_b : $w(y)$
T_c : $w(y), w(z)$

- ***Prefix-Constant Snapshot Isolation* (PCSI)** extends GSI to ensure that a snapshot contains all locally committed transactions:
  - (+) Reduces abort probability;
  - (+) A transaction can read its immediate writes;
  - (-) Increased response time due to blocking.



T_a : $w(x)$
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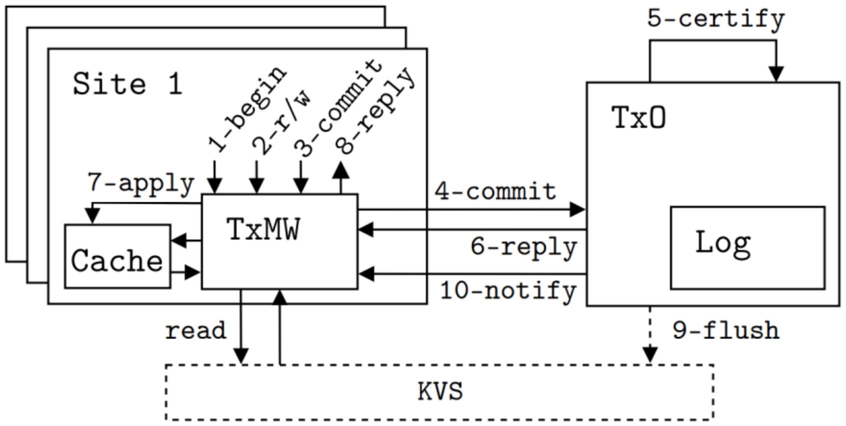
- ***Parallel Snapshot Isolation* (PSI)** allows different sites to apply transactions in different orders, as long as causal dependencies are respected:
  - (+) Reduces blocking;
  - (+) A transaction can read its immediate writes;
  - (+) Reduces abort probability;
  - (-) Independently evolving snapshots might not be viable for strict use cases

- Common implementations of PSI are built under the assumption of data partitioning, by sharding or by restricting an object's writes to a single site;

- Different sites end up with **different views of the transaction history**, meaning they cannot be applied to systems that disaggregate execution from storage;

- Different histories points to a more complex time management, e.g, vector clocks (more expensive snapshot materialization, conflict computation, site's connection and disconnection).

- Ensures PSI;
- Guarantees that the history at different sites **converge to the same totally ordered sequence of transactions**;
- No restrictions on data storage. It can be partitioned, completely replicated, or even shared among sites;
- Optimal timestamp management with low storage and computing overheads. No special coordination is necessary on site connection and disconnection.



- **Key-value store (KVS):**
  - Central component that stores all data;
  - Delivers data to the TxMWs based on the order it was flushed.

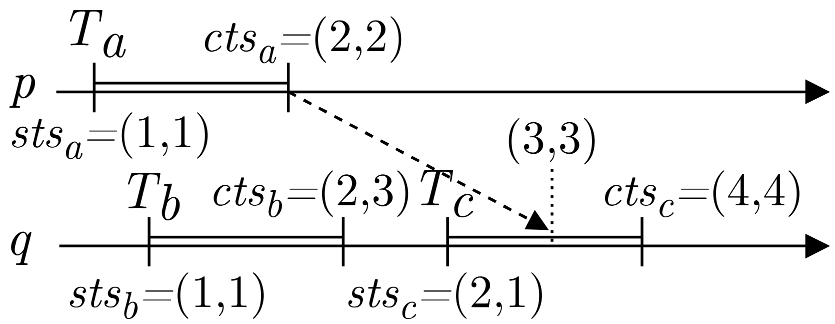
- **Transaction oracle (TxO):**
  - Central component;
  - Processes transactions' certifications and commits;
  - Flushes data based on commit order.

- **Transaction middleware (TxMW):**
  - Embed in every site;
  - Processes transactions' reads and writes; applies them to its local cache.

- ***Global_t:***
  - Monotonically assigned to a transaction when it commits, by the TxO;
  - Mainly used for transaction certification;
  - Unique across all sites.

- ***Local_t:***
  - Assigned to a transaction when it is applied, by the TxMW;
  - Mainly used for snapshot computation;
  - Unique in each site.

- $(local\_t, global\_t)$ pair assigned to each transaction/object.



T_a : $w(x)$
T_b : $w(y)$
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- Reading (k):
  - Look in the transaction's (T) cache for the record (r) with key k;
  - If not found, look in the site's cache for the most recent k where $r.local\_t \leq T.local\_t \wedge T.global\_t \leq r.global\_t$;
  - If not found, look in the KVS for k for the most recent record where $\mathrm{r}.global\_t \leq T.global\_t$.

- Writing (k, v):
  - Add k, v, and the $global\_t$ of the current record in the snapshot with key k to T's cache.

- Certification (T):
  - For each element e in T's write-set, evaluate if there is any record r with the same key where $r.global\_t > e.global\_t$;
  - If none is found, T can commit ($T.global\_t = next(global\_t)$).

- Apply (T):
  - For each element e in T's write-set, set $e.global\_t = T.global\_t$, $e.local\_t = next(local\_t)$, and add e to the TxMW cache;
  - Increment the TxMW's current $local\_t$.

PROBLEM

BACKGROUND

TOPSI OVERVIEW

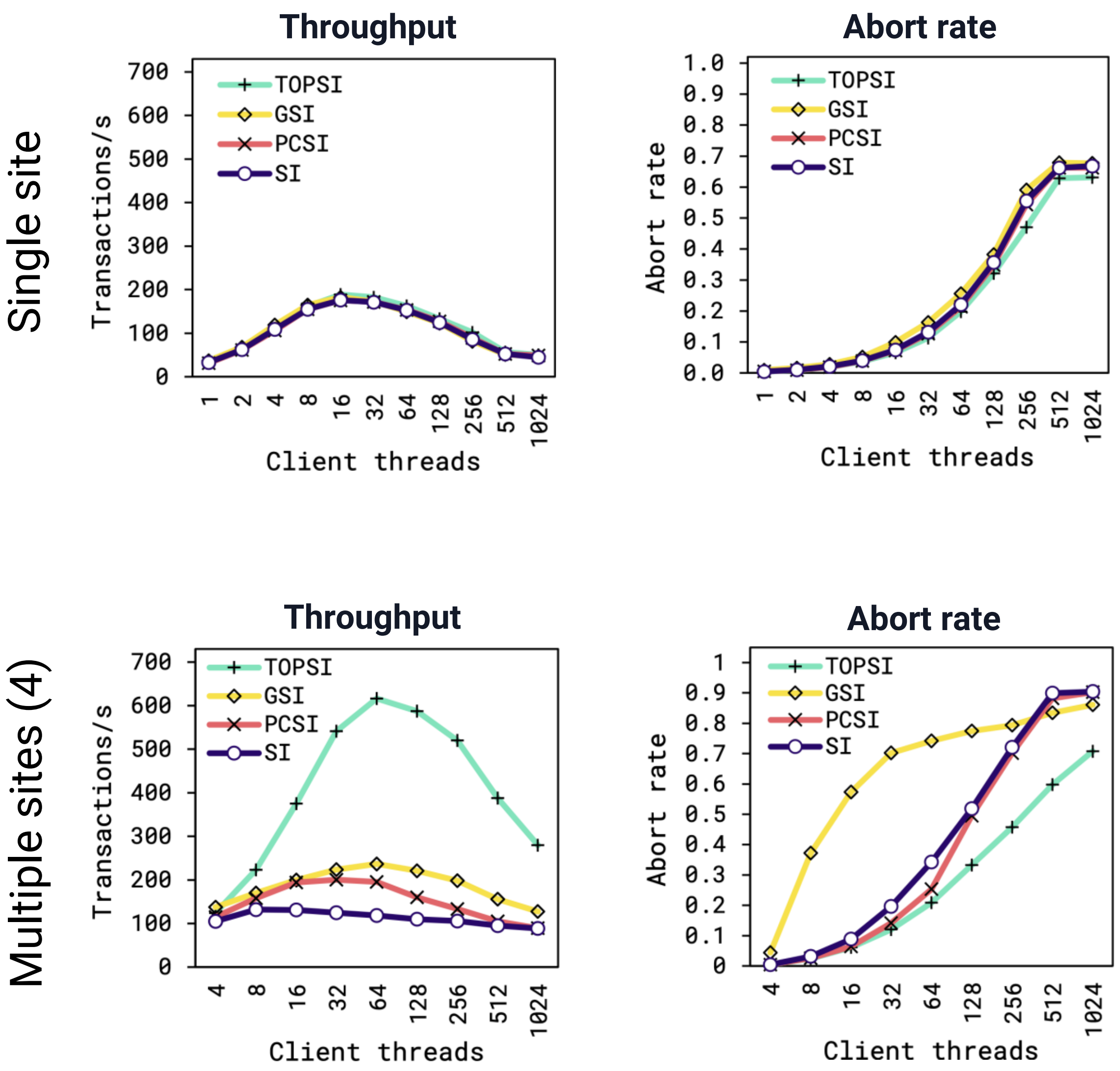
SYSTEM MODEL

TIME MANAGEMENT

TRANSACTION EXECUTION

PRELIMINARY RESULTS

CONCLUSIONS AND FUTURE WORK



- TOPSI presents better scalability than GSI, PCSI and SI;
- The two-timestamp solution ensures low storage and computation overheads;
- Having different sites share the same transaction history means that TOPSI is better suited for the class of systems that disaggregate computation from storage;
- For future work, we aim to create an architecture built with TOPSI that takes full advantage of parallelism to achieve optimal performance.

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