Serializable Snapshot Isolation

Making ISOLATION LEVEL SERIALIZABLE Provide Serializable Isolation

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Overview

Serializable isolation makes it easier to reason about concurrent transactions

In 9.0 and before, SERIALIZABLE was really *snapshot isolation* – allows anomalies

in 9.1: *Serializable Snapshot Isolation (SSI)*

- a new way to ensure true serializability (first implementation in a production DBMS!)

Agenda

- **What is serializability? Why do we want it?**
- Snapshot isolation vs. serializability
- Serializable Snapshot Isolation
- SSI implementation overview
- Using SSI
- Performance results

Transactions

Transactions group related operations:

shouldn't see one operation without the others

- ...even if the system crashes (recoverability)
- ...even if other transactions are executing concurrently (**isolation**)

Isolation

Serializable isolation:
each transaction is guaranteed to behave as though it's the only one running

- makes it easy to reason about each transaction's behavior in isolation

Weaker isolation levels:

- concurrent transactions can cause anomalous behavior

Isolation Levels

SQL Standard

SERIALIZABLE

REPEATABLE
READ

READ
COMMITTED

READ
UNCOMMITTED

Isolation Levels

9.0	**SQL Standard**
snapshot isolation	SERIALIZABLE
	REPEATABLE READ
per-statement snapshots	READ COMMITTED
	READ UNCOMMITTED

Isolation Levels

9.0

SQL Standard

9.1

SERIALIZABLE → ***SSI***

snapshot isolation

REPEATABLE READ → snapshot isolation

per-statement snapshots ← READ COMMITTED → per-statement snapshots

READ UNCOMMITTED

Snapshot Isolation

Each transaction sees a “snapshot” of DB taken at its first query

- implemented using MVCC
- tuple-level write locks prevent concurrent modifications

Still a weaker isolation level than true serializability!

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Goal:

ensure at least one guard always on-duty

guard	on-duty?
Alice	y
Bob	y

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ensure at least one guard always on-duty

```
BEGIN

SELECT count(*)
FROM guards
WHERE on-duty = y

if > 1 {
  UPDATE guards
  SET on-duty = n
  WHERE guard = x
}

COMMIT
```

guard	on-duty?
Alice	y
Bob	y

guard	on-duty?
Alice	y
Bob	y

BEGIN

SELECT count(*)
FROM guards
WHERE on-duty = y
[result = 2]

guard	on-duty?
Alice	y
Bob	y

BEGIN

SELECT count(*)
FROM guards
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[result = 2]

BEGIN

SELECT count(*)
FROM guard
WHERE on-duty = y
[result = 2]

guard	on-duty?
Alice	y
Bob	y

```
BEGIN

SELECT count(*)
FROM guards
WHERE on-duty = y
      [result = 2]

if > 1 {
  UPDATE guards
  SET on-duty = n
  WHERE guard = 'Alice'
}
COMMIT
```

```
BEGIN

SELECT count(*)
FROM guard
WHERE on-duty = y
      [result = 2]
```

guard	on-duty?
Alice	y
Bob	y

```
BEGIN

SELECT count(*)
FROM guards
WHERE on-duty = y
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if > 1 {
   UPDATE guards
   SET on-duty = n
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COMMIT
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```
BEGIN

SELECT count(*)
FROM guard
WHERE on-duty = y
        [result = 2]
```

guard	on-duty?
Alice	~~y~~ n
Bob	y

```
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      [result = 2]

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```

Serializable means: results equivalent to *some* serial ordering of the transactions

Serialization history graph shows dependencies between transactions

- A → B ("wr-dependency")
  if B sees a change made by A
- A → B ("ww-dependency")
  if B overwrites a change by A
- B → A ("rw-conflict")
  if B *doesn't* see a change made by A

Serializable if *no cycle in graph*

```
BEGIN

SELECT count(*)
FROM guards
WHERE on-duty = y
      [result = 2]

if > 1 {
  UPDATE guards
  SET on-duty = n
  WHERE guard = ‘Alice’
}
COMMIT
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SELECT count(*)
FROM guard
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```

rw-conflict:
T1 didn’t see
T2’s UPDATE

```
BEGIN

SELECT count(*)
FROM guard
WHERE on-duty = y
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if > 1 {
  UPDATE guards
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guard	on-duty?
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BEGIN

SELECT count(*)
FROM guards
WHERE on-duty = y
[result = 2]

if > 1 {
UPDATE guards
SET on-duty = n
WHERE guard = 'Alice'
}
COMMIT

rw-conflict:
T1 didn't see
T2's UPDATE

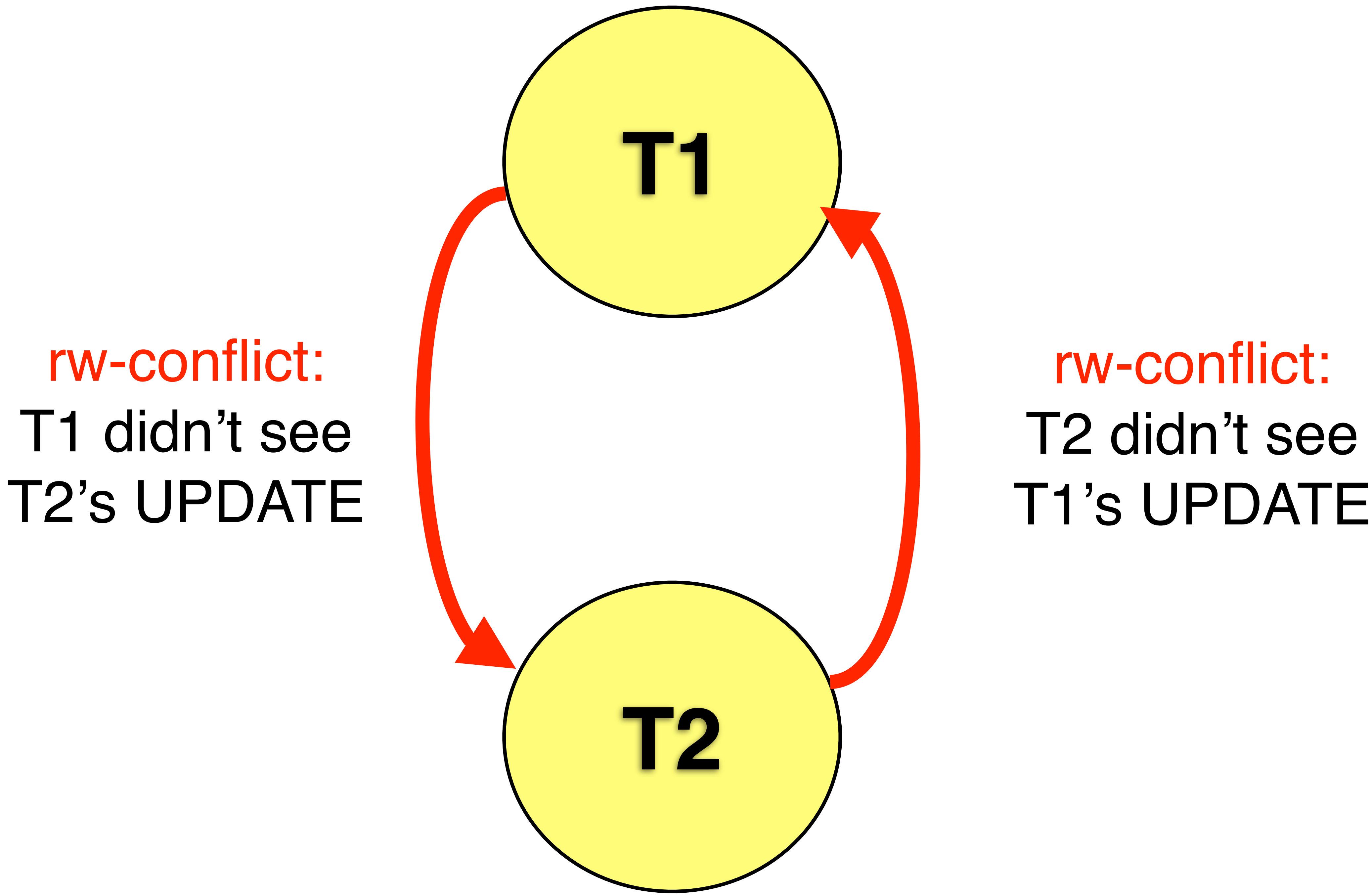
BEGIN

SELECT count(*)
FROM guard
WHERE on-duty = y
[result = 2]

rw-conflict:
T2 didn't see
T1's UPDATE

if > 1 {
UPDATE guards
SET on-duty = n
WHERE guards = 'Bob'
}
COMMIT

guard	on-duty?
Alice	~~y~~ n
Bob	~~y~~ n



cycle means no serial order exists!
T1 before T2 before T1...

Batch Processing Example

- control table just holds current batch #
- receipts table entries tagged w/ batch #

Three transactions:

- read current batch, insert receipt tagged w/ it
- increment current batch #
- read batch, get all receipts for previous batch

Invariant: after we read yesterday’s report, no new receipts for yesterday should appear

T1 **T2**

SELECT batch
FROM control
[result = 5/19]

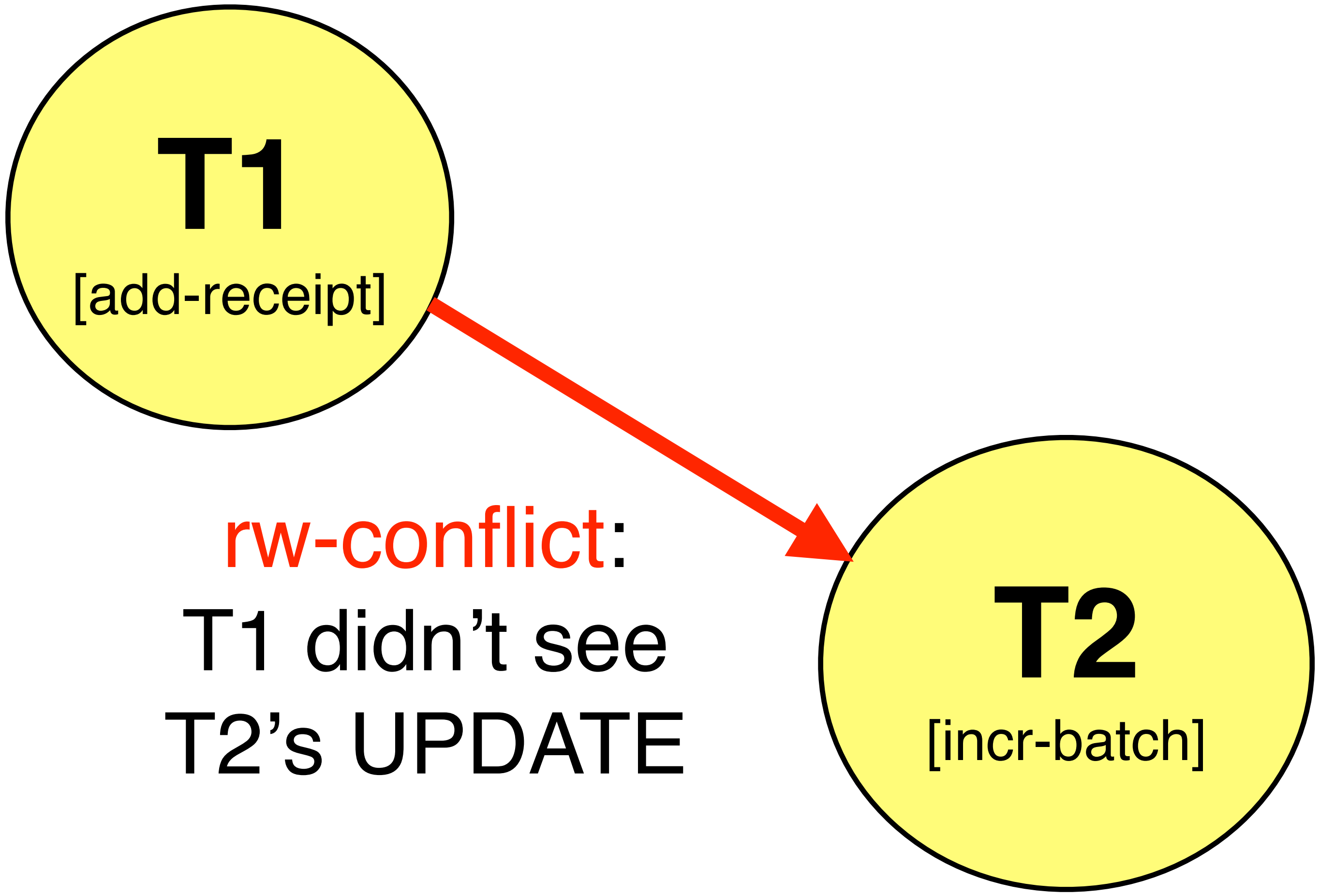
rw-conflict: T1 didn't see T2's UPDATE

UPDATE control
SET batch = 5/20

COMMIT

INSERT receipt
(5/19, …)

COMMIT



Serializable!

Apparent order of execution: T1 before T2

...but T2 committed before T1. That's OK!

T1	**T2**	**T3**
SELECT batch FROM control *[result = 5/19]*		
	UPDATE control SET batch = 5/20	
	COMMIT	
INSERT receipt (5/19, …)		
COMMIT		

T1	**T2**	**T3**
SELECT batch FROM control *[result = 5/19]*		
	UPDATE control SET batch = 5/20	
	COMMIT	
		SELECT batch... *[result = 5/20]*
		SELECT 5/19 receipts [...]
INSERT receipt (5/19, …)		
COMMIT		

T1	**T2**	**T3**
SELECT batch FROM control *[result = 5/19]*		
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	COMMIT	
		SELECT batch... *[result = 5/20]*
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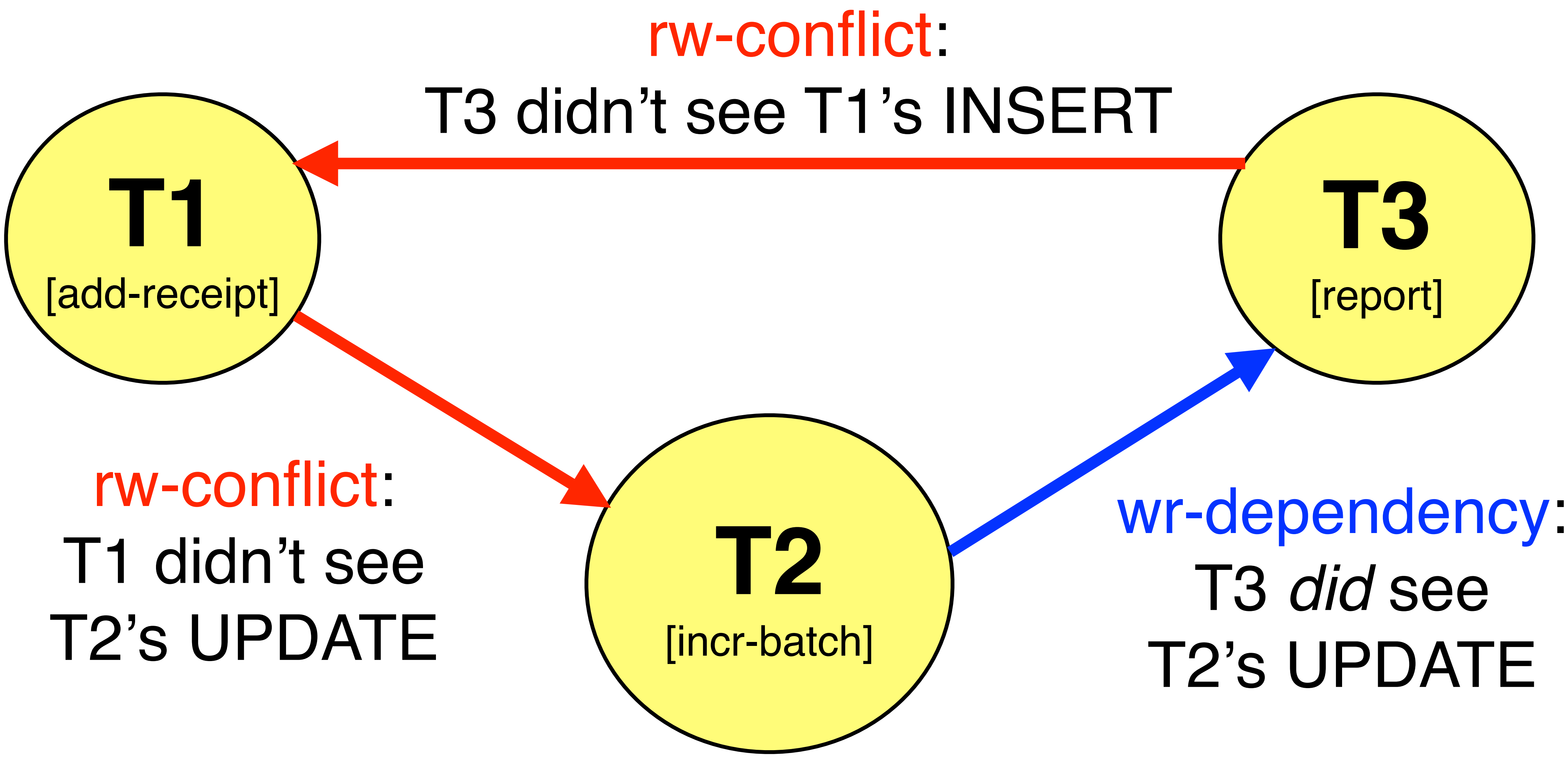
INSERT receipt (5/19, …)		
COMMIT		

rw-conflict

T1	**T2**	**T3**
SELECT batch FROM control *[result = 5/19]*		
	rw-conflict	
	UPDATE control SET batch = 5/20	
	COMMIT	
		wr-dependency
		SELECT batch... *[result = 5/20]*
		SELECT 5/19 receipts [...]
INSERT receipt (5/19, …)		
COMMIT		

T1	**T2**	**T3**
SELECT batch FROM control *[result = 5/19]*		
	rw-conflict	
	UPDATE control SET batch = 5/20	
		wr-dependency
	COMMIT	
		SELECT batch... *[result = 5/20]*
	rw-conflict	SELECT 5/19 receipts [...]
INSERT receipt (5/19, …)		
COMMIT		



Not serializable!

Adding the read-only transaction creates a cycle.

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Existing Approaches to Serializability

- ignore the problem, make the user deal
  - use SELECT FOR UPDATE, LOCK TABLE
  - can be hard to figure out where to put these!
- run one transaction at a time [not practical]
- strict two-phase locking
  - acquire lock on every object read or written
  - causes readers to block writers & vice versa

T1 **T2**

SELECT batch
FROM control
[result = 5/19]

T1 **T2**

SELECT batch
FROM control 
[result = 5/19]

T1

T2

SELECT batch
FROM control 
[result = 5/19]

UPDATE control
SET batch = 5/20
[blocked!]

T1 **T2**

SELECT batch
FROM control 
[result = 5/19]

UPDATE control
SET batch = 5/20
[blocked!]

INSERT receipt
(5/19, …)

COMMIT

SSI Approach (Almost.)

Actually build the dependency graph!

- If a cycle is created,
  abort some transaction to break it

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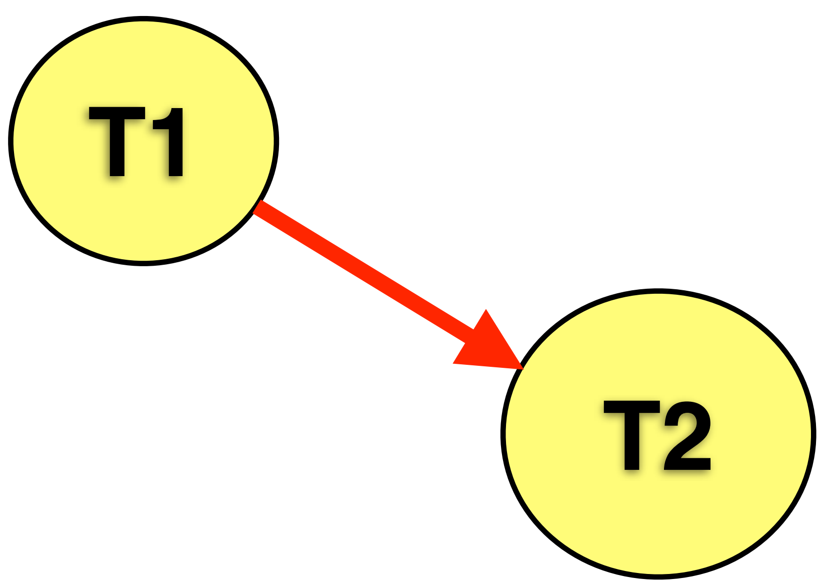

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Actually build the dependency graph!

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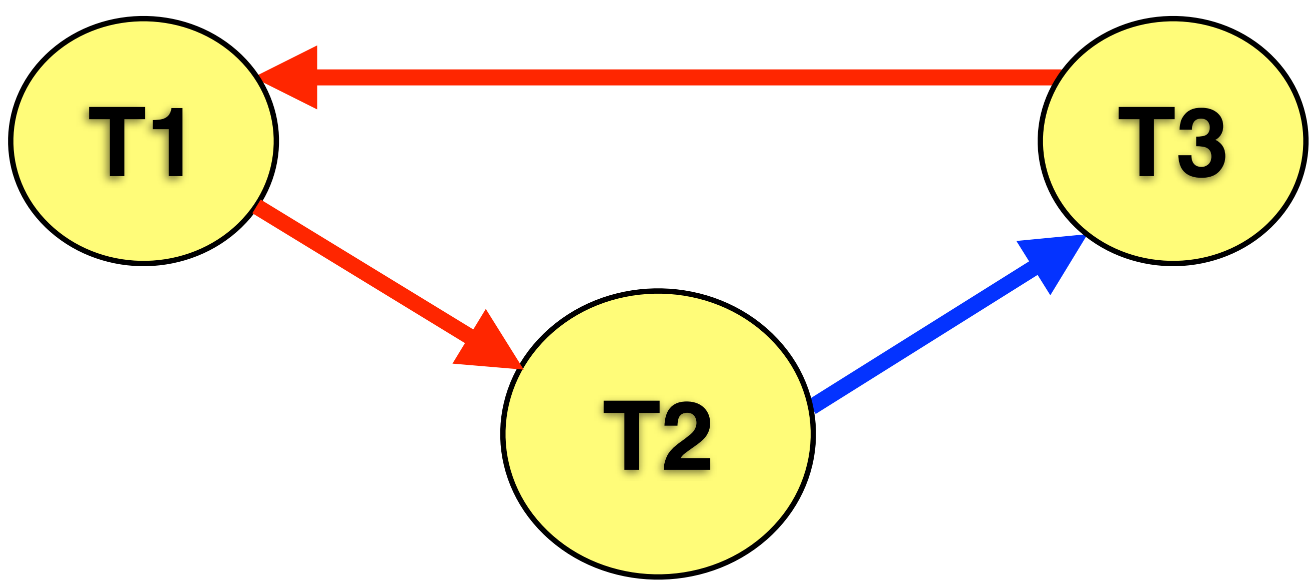

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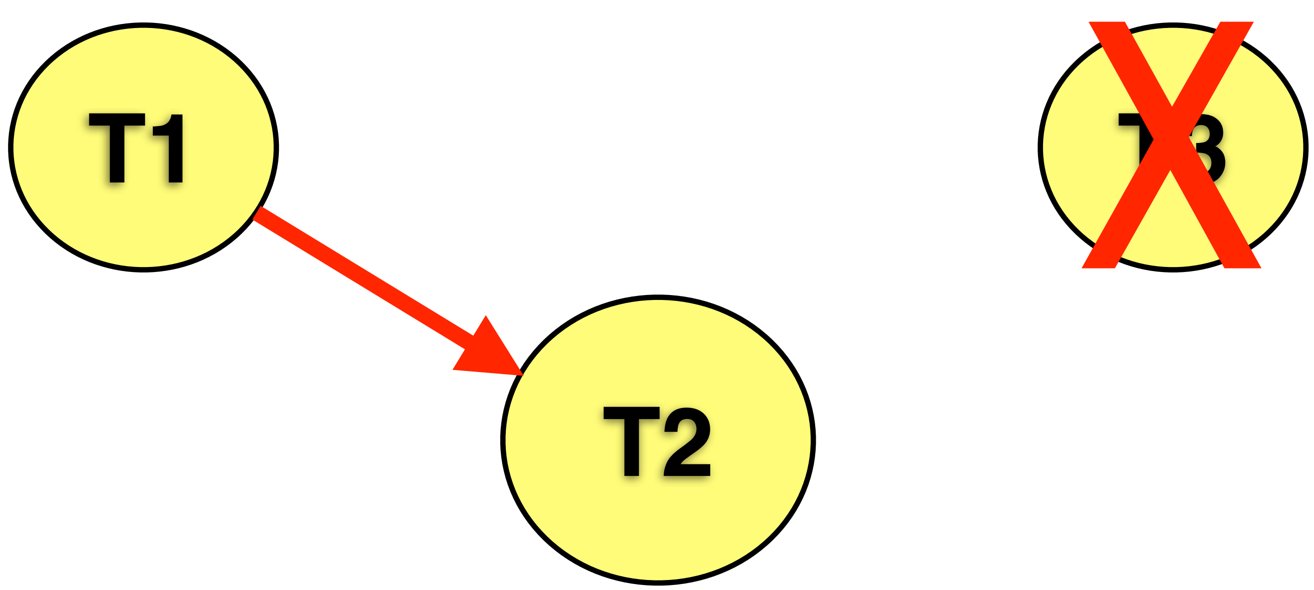

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Actually build the dependency graph!

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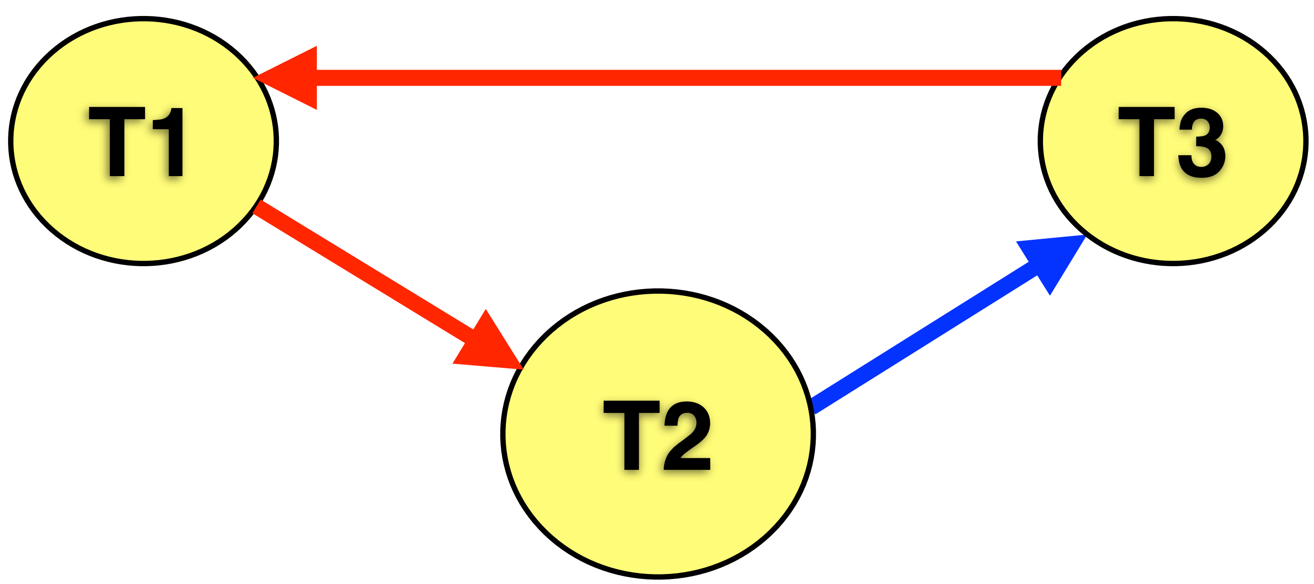

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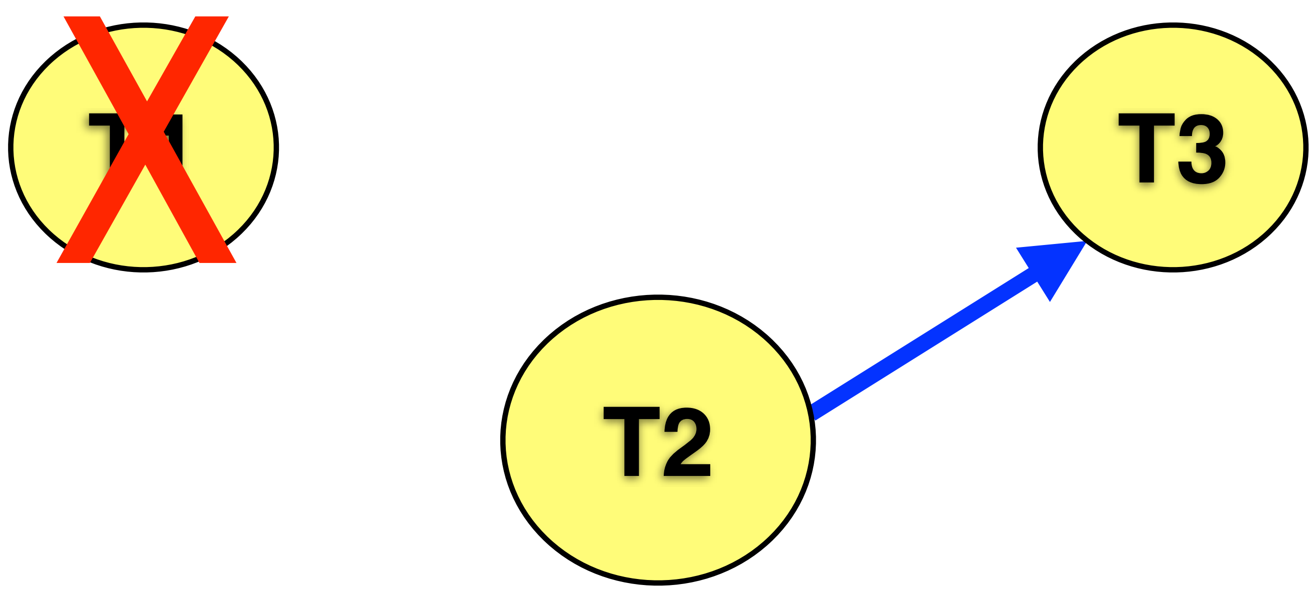

Serializability theory tells us:

- every cycle contains two adjacent rw-conflict edges (where A didn't see B's update)

So we can just look for those

- don't need to track other types of edges
- conservative (occasional false positives)

SSI Rule:

Don't let a transaction have *both* a rw-conflict in and a rw-conflict out!

[Cahill et al. Serializable Isolation For Snapshot Databases, SIGMOD '08]

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Implementing SSI

Need to keep some extra transaction state

- mainly: list of rw-conflicts in and out
- if one transaction has both, abort something
- note: need to keep lists after xact commits, until *all concurrent transactions* commit

But how do we identify a rw-conflict?

Identifying rw-conflicts

Recall: T1 —> T2 if T2 makes a change, and T1's read doesn't see its effects

- If T2's write happens first:
  T1 will see tuple's MVCC data and ignore it

xmin	xmax	data
T2		…

- If T1's read happens first:
  use a "lock" to know that T2's write conflicts

Identifying rw-conflicts

Recall: T1 —> T2 if T2 makes a change, and T1's read doesn't see its effects

- If T2's write happens first:
  T1 will see tuple's MVCC data and ignore it

xmin	xmax	data
T2		…

T2 not in T1's snapshot
=> conflict w/ T1

- If T1's read happens first:
  use a "lock" to know that T2's write conflicts

Tracking Read Dependencies

Acquire a “SIREAD lock” on anything read

Check for SIREAD locks on write, flag conflict

New lock manager — unlike current locks:

- no blocking! (just flag a conflict instead)
- can persist beyond transaction commit
- multi-granularity (relation, page, tuple); promotion
- needs predicate locking

Predicate Locking

Not enough just to lock returned tuples:

SELECT FROM...	INSERT INTO…
WHERE x=42	VALUES (x=42)
[3 results]	*[should conflict; won't]*

Really want predicate locking:
"lock everything where x=42" (but not feasible)

Instead: lock corresponding index page

- if no index, lock entire relation

Other Features

Deferrable read-only transactions

- wait until xact can be executed safely without lock overhead or risk of abort

Dealing with shared memory exhaustion

- promote locks to coarser granularity
- reduce information about committed transactions and push to disk if necessary (SLRU)

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Conflicts may cause transactions to abort

- source of conflict might not be obvious
- will usually succeed if retried
- middleware that automatically retries can help

Performance tips

- declare transactions READ ONLY if possible
- don’t put more into a single transaction than needed
- don’t leave connections dangling “idle in transaction”

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Performance

Two main sources of slowdown

- How much CPU overhead does the SIREAD lock manager add?
  - in-memory pgbench: not much slowdown
- How often are transactions rolled back because of conflicts?
  - depends heavily on workload

Measuring Abort Rate

DBT-2 benchmark (OLTP, like TPC-C)

- modified to retry transactions after serialization failure

Configuration:

- 16-core Xeon E7310, 1.60GHz, 8 GB RAM
- 3x 15K drives for data; 1 for log
- database size ~20 GB

DBT-2 Performance

Approach: use highest scale factor that gives 90% request latency < 5 seconds

REPEATABLE READ (snapshot isolation):

- 160 warehouses, 1941 new order transactions/minute
- 1.5% transactions retried due to serialization failure

SERIALIZABLE (SSI):

- 157 warehouses, 1923 NOTPM (< 2% slowdown)
- 3.1% transactions retried due to serialization failure
  - no aborts of read-only transactions
  - 15% abort rate for “delivery” xacts (4% of workload)

Summary

True serializable transactions are here!

- avoiding snapshot isolation anomalies can simplify applications
- implemented using a novel technique
- reuses existing snapshot isolation mechanisms
- performance cost is reasonable