Serializable Snapshot Isolation

Making ISOLATION LEVEL SERIALIZABLE
Provide Serializable Isolation

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Wisconsin Court System
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

snapshot isolation

per-statement snapshots

SQL Standard

SERIALIZABLE

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Isolation Levels

SQL Standard

9.0

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9.1

snapshot isolation

SSI

snapshot isolation

per-statement snapshots

Saturday, May 21, 2011
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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• **Snapshot isolation vs. serializability**
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Goal:
ensure at least one guard always on-duty

<table>
<thead>
<tr>
<th>guard</th>
<th>on-duty?</th>
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<tbody>
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Goal: ensure at least one guard always on-duty

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

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

COMMIT
<table>
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BEGIN

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

[result = 2]

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```
SELECT count(*)
FROM guards
WHERE on-duty = y
[result = 2]
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SELECT count(*)
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Saturday, May 21, 2011
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Serializable means: results equivalent to some serial ordering of the transactions

Serialization history graph shows dependencies between transactions

- $A \rightarrow B$ ("wr-dependency") if B sees a change made by A
- $A \rightarrow B$ ("ww-dependency") if B overwrites a change by A
- $B \rightarrow A$ ("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
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if > 1 {
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BEGIN

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

if > 1 {
  UPDATE guards
  SET on-duty = n
  WHERE guards = 'Bob'
}
COMMIT
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SELECT count(*)
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[result = 2]

if > 1 {
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FROM guards
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COMMIT

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

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

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**

SELECT batch
FROM control
[result = 5/19]

**T2**

UPDATE control
SET batch = 5/20

COMMIT

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

INSERT receipt
(5/19, ...)

COMMIT
T1 didn’t see T2’s UPDATE

**rw-conflict:**

T2 [incr-batch]

---

**Serializable!**

Apparent order of execution: T1 before T2

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

SELECT batch
FROM control
[result = 5/19]

T2

UPDATE control
SET batch = 5/20

COMMIT

T3

INSERT receipt
(5/19, ...)

COMMIT
**T1**

SELECT batch
FROM control
[result = 5/19]

**T2**

UPDATE control
SET batch = 5/20

COMMIT

**T3**

SELECT batch...
[result = 5/20]

SELECT
5/19 receipts
[...]

Saturday, May 21, 2011
T1

SELECT batch
FROM control
[result = 5/19]

T2

UPDATE control
SET batch = 5/20

COMMIT

T3

SELECT batch...
[result = 5/20]

SELECT
5/19 receipts
[...]

rw-conflict

INSERT receipt
(5/19,  ...)

COMMIT
SELECT batch
FROM control
[result = 5/19]

UPDATE control
SET batch = 5/20
COMMIT

INSERT receipt
(5/19, …)
COMMIT

SELECT batch...
[result = 5/20]
SELECT
5/19 receipts
[...]
```
SELECT batch
FROM control
[result = 5/19]

UPDATE control
SET batch = 5/20

COMMIT

INSERT receipt
(5/19,   …)

COMMIT
```

---

```
SELECT batch...
[result = 5/20]

SELECT
5/19 receipts
[...]
```

---

```
rw-conflict
```

---

```
wr-dependency
```

---

```
rw-conflict
```

---

```
Saturday, May 21, 2011
```
T1 didn’t see T2’s UPDATE

rw-conflict:
T3 didn’t see T1’s INSERT

T1
[add-receipt]

T3
[report]

T2
[incr-batch]

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

wr-dependency:
T3 did see T2’s UPDATE

Not serializable!
Adding the read-only transaction creates a cycle.
Agenda

• What is serializability? Why do we want it?
• Snapshot isolation vs. serializability
• **Serializable Snapshot Isolation**
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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
SELECT batch
FROM control
[\text{result} = 5/19]
SELECT batch
FROM control

[result = 5/19]
T1

SELECT batch
FROM control
[result = 5/19]

T2

UPDATE control
SET batch = 5/20
[blocked!]
**T1**

SELECT batch
FROM control
[result = 5/19]

**T2**

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
SSI Approach (Almost.)

Actually build the dependency graph!

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SSI Approach (Almost.)

Actually build the dependency graph!

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

<table>
<thead>
<tr>
<th>xmin</th>
<th>xmax</th>
<th>data</th>
</tr>
</thead>
</table>
| T2   |      |    ...

- If T1’s read happens first:
  use a “lock” to know that T2’s write conflicts
Identifying rw-conflicts

Recall: T1 $\rightarrow$ 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

- If T1’s read happens first:
  use a “lock” to know that T2’s write conflicts

T2 not in T1’s snapshot

=> conflict w/ T1
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...
WHERE x=42
[3 results]
```

```
INSERT INTO...
VALUES (x=42)
[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