Course Presentation

Distributed Database Systems

A Critique of ANSI SQL Isolation Levels

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Overview

- ANSI Specifications
- Phenomenon and Anomalies
- Broad v/s Strict Notations
- Isolation Levels
- Locking
- Cursor Stability
- Snapshot Isolation
- Conclusion

ANSI/ ISO-92 specifications

- READ UNCOMMITTED
- READ COMMITTED
- REPEATABLE READ
- SERIALIZABLE

- Above go from *weaker* to *stronger* isolation.
- Stronger isolation implies *less throughput* and *lesser anomalies*.

Phenomenon

Prohibited Action sequences or Phenomenon are action subsequences that may lead to *anomalous behavior*

Primary Types:

- Dirty Read
- Non-Repeatable Read
- Phantom

Serializability Concepts and Terminology

- A *transaction* groups a set of actions that transform the database from one consistent state to another.
- A *history* models the interleaved execution of a set of transactions as a linear ordering of their actions, such as Reads and Writes
- Two actions in a history are said to *conflict* if they are performed by distinct transactions on the same data item and at least one of is a Write action.
- Conflicting actions can also occur on a set of data items, covered by a *predicate lock*, as well as on a single data item
- A particular history gives rise to a *dependency graph* defining the temporal data flow among transactions
- A history is serializable if it is equivalent to a *serial history* — that is, if it has the same dependency graph (inter-transaction temporal data flow) as some history that executes *transactions one at a time in sequence*.

Phenomenon in Detail

- **P1 (Dirty Read)**: Transaction T1 modifies a data item. Another transaction T2 then reads that data item *before* T1 performs a COMMIT or ROLLBACK. If T1 then performs a *ROLLBACK*, T2 has read a data item that was never committed and so never really existed.
- **P2 (Non-repeatable or Fuzzy Read)**: Transaction T1 reads a data item. Another transaction T2 then *modifies or deletes* that data item and commits. If T1 then attempts to reread the data item, it receives a modified value or discovers that the data item has been deleted.
- **P3 (Phantom)**: Transaction T1 reads a set of data items satisfying some <search condition>. Transaction T2 then *creates* data items that satisfy T1's <search condition> and commits. If T1 then repeats its read with the same <search condition>, it gets a set of data items different from the first read.
- **Note:** None of these phenomena could occur in a *serial history.*

Isolation Level	P1 (or A1) Dirty Read	P2 (or A2) Fuzzy Read	P3 (or A3) Phantom
ANSI READ UNCOMMITTED	Possible	Possible	Possible
ANSI READ COMMITTED	Not Possible	Possible	Possible
ANSI REPEATABLE READ	Not Possible	Not Possible	Possible
ANOMALY SERIALIZABLE	Not Possible	Not Possible	Not Possible

Broad v/s Strict Notations (Phenomenon v/s Anomalies)

- **P1**: w1[x]...r2[x]...((c1 or a1) and (c2 or a2) in any order)
- **A1**: w1[x]...r2[x]...(a1 and c2 in any order)
- **P2**: r1[x]...w2[x]...((c1 or a1) and (c2 or a2) in any order)
- **A2**: r1[x]...w2[x]...c2...r1[x]...c1
- **P3**: r1[P]...w2[y in P]...((c1 or a1) and (c2 or a2) any order)
- **A3**: r1[P]...w2[y in P]...c2...r1[P]...c1
- One of the primary goals of the paper is to argue that the *Anomaly (Strict)* notation is not sufficient for real world cases, and the *Phenomenon (Broad)* notation is required

Isolation Levels

- Each isolation level is characterized by the phenomena that a transaction is *forbidden* to experience (broad or strict interpretations).
- SERIALIZABLE isolation level must provide what is “commonly known as *fully serializable execution*.”
- It is a common misconception that *disallowing the three phenomena implies serializability.*
- Picking a broad interpretation of a phenomenon *excludes a larger* set of histories than the strict interpretation.
- Multiple versions of a data item may exist at one time in a *multi-version system*.
    - Any read must be *explicit* about which version is being read.

Locking

- Transactions executing under a locking scheduler *request Read (Share) and Write (Exclusive) locks* on data items or sets of data items they read and write.
- A Read (resp. Write) *predicate* lock on a given <search condition> is effectively a lock on all data items satisfying the <search condition>.
- A transaction has *well-formed writes (reads)* if it requests a Write (Read) lock on each data item or predicate before writing (reading) that data item, or set of data items defined by a predicate.
- A transaction has *two-phase writes (reads)* if it does *not* set a new Write (Read) lock on a data item after releasing a Write (Read) lock.
- The locks requested by a transaction are of *long duration* if they are held until after the transaction commits or aborts.
- *Short locks* are released immediately after the action completes.
- Well-formed two-phase locking *guarantees serializability*.

Locking and Isolation Levels

Consistency Level = Locking Isolation Level	**Read Locks on Data Items and Predicates (the same unless noted)**	**Write Locks on Data Items and Predicates (always the same)**
Degree 0	none required	Well-formed Writes
Degree 1 = Locking READ UNCOMMITTED	none required	Well-formed Writes Long duration Write locks
Degree 2 = Locking READ COMMITTED	Well-formed Reads Short duration Read locks (both)	Well-formed Writes, Long duration Write locks
Cursor Stability (see Section 4.1)	Well-formed Reads Read locks held on current of cursor Short duration Read Predicate locks	Well-formed Writes, Long duration Write locks
Locking REPEATABLE READ	Well-formed Reads Long duration data-item Read locks Short duration Read Predicate locks	Well-formed Writes, Long duration Write locks
Degree 3 = Locking SERIALIZABLE	Well-formed Reads Long duration Read locks (both)	Well-formed Writes, Long duration Write locks

- Isolation level L1 is *weaker* than isolation level L2 (or L2 is stronger than L1), denoted *L1 « L2*, if all non-serializable histories that obey the criteria of L2 also satisfy L1 and there is at least one non-serializable history that can occur at level L1 but not at level L2.
- Two isolation levels are *incomparable*, denoted *L1 »« L2*, when each isolation level allows a non-serializable history that is disallowed by the other.
- Two isolation levels L1 and L2 are *equivalent*, denoted *L1 == L2*, if the sets of non-serializable histories satisfying L1 and L2 are identical.
- Locking READ UNCOMMITTED « Locking READ COMMITTED « Locking REPEATABLE READ « Locking SERIALIZABLE

Analysis of Isolation Levels

- Locking isolation levels are *at least as* isolated as the same-named ANSI levels.
- **P0 (Dirty Write):** Transaction T1 modifies a data item. Another transaction T2 then further modifies that data item before T1 performs a COMMIT or ROLLBACK. If T1 or T2 then performs a ROLLBACK, it is unclear what the correct data value should be.
  - **Broad interpretation: P0:** w1[x]...w2[x]...((c1 or a1) and (c2 or a2) in any order)
- Dirty writes can *violate* database consistency.
  - w1[x] w2[x] w2[y] c2 w1[y] c1, with the constraint x = y
- ANSI SQL isolation should be modified to require P0 for all isolation levels.
- Balance transfer case: $40 transfer between bank balance rows x and y
  - H1: r1[x=50]w1[x=10]r2[x=10]r2[y=50]c2 r1[y=50]w1[y=90]c1
  - T2 reads an inconsistent state with a total balance of *60*, it should be 100
  - H1 does not violate A1, A2, A3. *H1 violates P1.*
  - Hence it is argued that the broad (Phenomenon) interpretation is the correct one, not anomalous one
- For single version histories, it turns out that the P0, P1, P2, P3 *phenomena are disguised versions of locking.*

Cursor Stability

- Designed to prevent the *lost update phenomenon.*
- **P4 (Lost Update)**: The lost update anomaly occurs when transaction T1 reads a data item and then T2 updates the data item (possibly based on a previous read), then T1 (based on its earlier read value) updates the data item and commits. In terms of histories, this is:
  - P4: r1[x]…w2[x]…w1[x]...c1
- Extends READ COMMITTED locking behavior for SQL cursors by adding a new read action for FETCH from a cursor and *requiring that a lock be held* on the current item of the cursor.
- The lock is held until the cursor moves or is *closed,* possibly by a commit.

Snapshot Isolation

- Each transaction reads reads data from a snapshot of the (committed) data as of the time the transaction started, called its *Start-Timestamp*
- The transaction's writes (updates, inserts, and deletes) will be reflected in this snapshot, to be read again if the transaction accesses (i.e., reads or updates) the data a second time.
- Updates by other transactions active after the transaction Start-Timestamp are *invisible* to the transaction
- Snapshot Isolation is a type of *multiversion* concurrency control.
- When the transaction T1 is ready to commit, it gets a *Commit-Timestamp*, which is larger than any existing Start-Timestamp or Commit-Timestamp.
- The transaction *successfully commits only if* no other transaction T2 with a Commit-Timestamp in T1's execution interval [Start- Timestamp, Commit-Timestamp] wrote data that T1 also wrote.
- This feature, called *First-committer-wins* prevents lost updates (P4)
- 40$ transfer case:
  - H1.SI: r1[x0=50] w1[x1=10] r2[x0=50] r2[y0=50] c2 r1[y0=50] w1[y1=90] c1

Data Item Constraint Violation

A5A - Read Skew: Suppose transaction T1 reads x, and then a second transaction T2 updates x and y to new values and commits. If now T1 reads y, it may see an inconsistent state, and therefore produce an inconsistent state as output. In terms of histories, we have the anomaly:

A5A: r1[x]...w2[x]...w2[y]...c2...r1[y]...(c1 or a1)

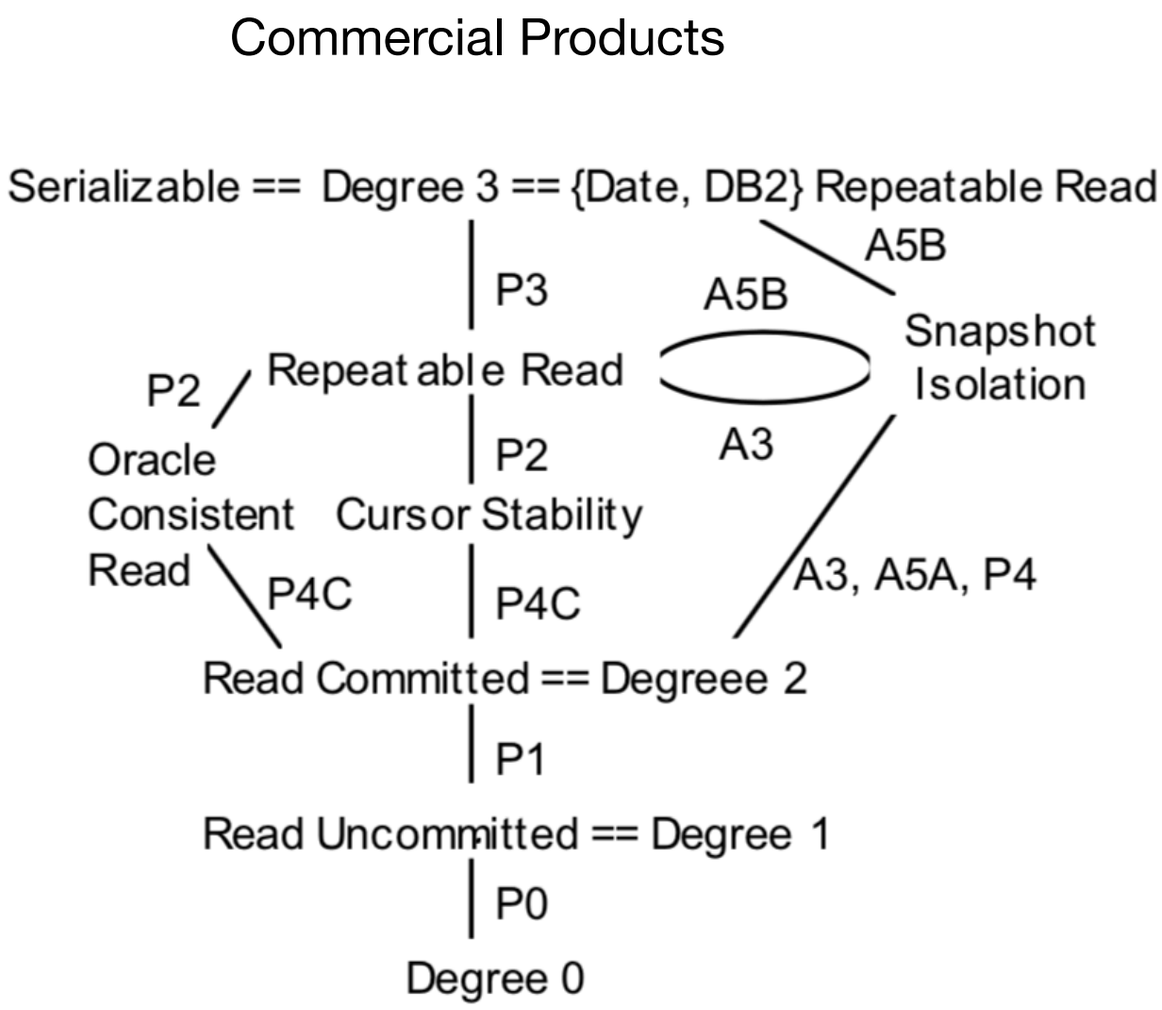
A5B - Write Skew: Suppose T1 reads x and y, which are consistent with C(), and then a T2 reads x and y, writes x, and commits. Then T1 writes y.

A5B: r1[x]...r2[y]...w1[y]...w2[x]...(c1 and c2 occur)

Isolation level	**P0** Dirty Write	**P1** Dirty Read	**P4C** Cursor Lost Update	**P4** Lost Update	**P2** Fuzzy Read	**P3** Phantom	**A5A** Read Skew	**A5B** Write Skew
READ UNCOMMITTED == Degree 1	Not Possible	Possible	Possible	Possible	Possible	Possible	Possible	Possible
READ COMMITTED == Degree 2	Not Possible	Not Possible	Possible	Possible	Possible	Possible	Possible	Possible
Cursor Stability	Not Possible	Not Possible	Not Possible	Sometimes Possible	Sometimes Possible	Possible	Possible	Sometimes Possible
REPEATABLE READ	Not Possible	Not Possible	Not Possible	Not Possible	Not Possible	Possible	Not Possible	Not Possible
Snapshot	Not Possible	Not Possible	Not Possible	Not Possible	Not Possible	Sometimes Possible	Not Possible	Possible
ANSI SQL SERIALIZABLE == Degree 3 == Repeatable Read Date, IBM, Tandem, ...	Not Possible	Not Possible	Not Possible	Not Possible	Not Possible	Not Possible	Not Possible	Not Possible

Conclusion

- There are *serious problems* with the original ANSI SQL definition of isolation levels
  - Dirty Writes (P0) are *not precluded*.
- Many applications avoid lock contention by using *Cursor Stability* or Oracle's Read Consistency isolation.



Thank You!

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