Concurrency Control: Serializability, Schedules, Advanced Topics

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Do-it-yourself-recap: Locking Solutions for Isolation in ACID Transactions

	S	X
S	Yes	No
X	No	No

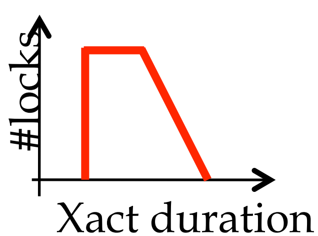
Why two phases? Deadlocks? Cascading aborts?

Solution 4

1) Get exclusive locks on data items that are modified and get shared locks on data items that are read
2) Execute transaction and release locks on objects no longer needed *during execution*

- Greater concurrency
- Conservative Two Phase Locking (2PL)

realease once not be needed anymore



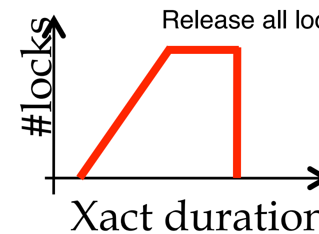
- Problems?

Solution 5

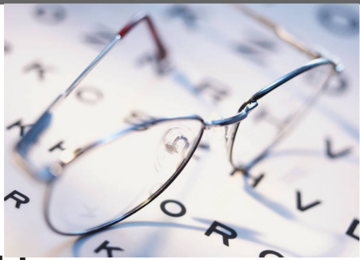
1) Get exclusive locks on data items that are modified and get shared locks on data items that are read, but do this *during execution* of transaction (as needed)
2) Release all locks

- Greater concurrency
- Strict Two Phase Locking (2PL)

Release all locks at once



- Problems?



What should we learn today?

- Discuss the definition of serializability and the notion of anomalies
- Apply the conflict-serializability test using a precedence graph to transaction schedules
- Discuss the difference between conflict-serializability and view-serializability
- Explain deadlock prevention and detection techniques
- Apply deadlock detection using a waits-for graph to transaction schedules
- Explain the optimistic concurrency control and multi-version concurrency control models
- Predict validation decisions under optimistic concurrency control

Is Strict 2PL correct? (assuming database is **not** dynamic)

- We will formalize now **serializability** and argue that Strict 2PL is correct
  - Full proof is left as homework ☺
- Strict 2PL can however deadlock
  - We will see how to handle deadlock automatically

Schedules

- Consider a possible interleaving (*schedule*):

```
T1:    A=A+100,                                B=B-100
T2:                A=1.06*A, B=1.06*B
```

- The system's view of the schedule:

```
T1:    R(A),W(A),                                R(B),W(B)
T2:                R(A),W(A),R(B),W(B)
```

Source: Ramakrishnan & Gehrke (partial)

Scheduling Transactions

- *Serial schedule:* Schedule that does not interleave the actions of different transactions.
- *Equivalent schedules*: For any database state
  - The effect (on the set of objects in the database) of executing the schedules is the same
  - The values read by transactions is the same in the schedules
    - Assume no knowledge of transaction logic
- *Serializable schedule*: A schedule that is equivalent to some serial execution of the transactions.

(Note: If each transaction preserves consistency, every serializable schedule preserves consistency.)

Source: Ramakrishnan & Gehrke (partial)

Anomalies with Interleaved Execution

- Reading Uncommitted Data (WR Conflicts, "dirty reads"):

```
T1:   R(A), W(A),                    R(B), W(B), Abort
T2:               R(A), W(A), C
```

- Unrepeatable Reads (RW Conflicts):

```
T1:   R(A),                        R(A), W(A), C
T2:          R(A), W(A), C
```


Source: Ramakrishnan & Gehrke (partial)

Anomalies (contd.)

- Overwriting Uncommitted Data (WW Conflicts):

```
T1:   W(A),                     W(B), C
T2:            W(A), W(B), C
```


Source: Ramakrishnan & Gehrke (partial)

Conflict Serializable Schedules

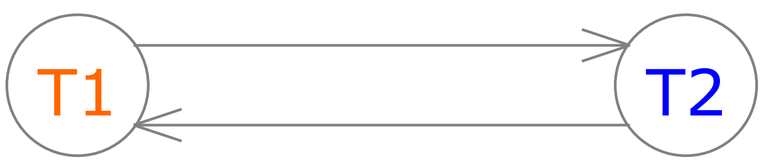
- Two schedules are conflict equivalent if:
  - Involve the same actions of the same transactions
  - Every pair of conflicting actions is ordered the same way
- Schedule S is conflict serializable if S is conflict equivalent to some serial schedule

Source: Ramakrishnan & Gehrke (partial)

Example

- A schedule that is not conflict serializable:

```
T1:    R(A), W(A),                                R(B), W(B)
T2:                R(A), W(A), R(B), W(B)
```



Precedence graph

- The cycle in the graph reveals the problem. The output of T1 depends on T2, and vice-versa.

Source: Ramakrishnan & Gehrke (partial)

Precedence Graph

- *Precedence graph*: One node per Xact; edge from T_i to T_j if operation in T_j conflicts with earlier operation in T_i.
- Theorem: Schedule is conflict serializable if and only if its precedence graph is acyclic
- Strict 2PL only allows conflict serializable schedule
  - Precedence graph is always acyclic

Source: Ramakrishnan & Gehrke (partial)

Are the following schedules conflict-serializable?

- Build the precedence graph for each of the following transaction schedules

```
T1: R(A)           W(B)                  C
T2:      R(B)           R(A)        R(C)    C
T3:           R(B)            W(C)             C
```

Note: C alone stands for commit

```
T1: R(A)      W(B)                       C
T2:      R(B)           R(A)        R(C)    C
T3:                R(B)        W(C)            C
```

Returning to Definition of Serializability

- A schedule S is serializable if there exists a serial order SO such that:
  - The **state of the database** after S is the **same** as the state of the database after SO
  - The **values read** by each transaction in S are the **same** as that returned by each transaction in SO
    - Database does not know anything about the internal structure of the transaction programs

- **Under this definition, certain serializable executions are not conflict serializable!**

Source: Ramakrishnan & Gehrke (partial)

Is this schedule serializable?

```
T1: R(A)          W(A)
T2:         W(A)
T3:                        W(A)
```

```
T1: R(A),W(A)
T2:                  W(A)
T3:                          W(A)
```


Source: Ramakrishnan & Gehrke (partial)

View Serializability

- Schedules S1 and S2 are view equivalent if:
  - If Ti reads initial value of A in S1, then Ti also reads initial value of A in S2
  - If Ti reads value of A written by Tj in S1, then Ti also reads value of A written by Tj in S2
  - If Ti writes final value of A in S1, then Ti also writes final value of A in S2

```
T1: R(A)        W(A)
T2:        W(A)
T3:                   W(A)
```

```
T1: R(A),W(A)
T2:                 W(A)
T3:                        W(A)
```


Source: Ramakrishnan & Gehrke (partial)

Deadlocks

- Deadlock: Cycle of transactions waiting for locks to be released by each other.
- Two ways of dealing with deadlocks:
  - Deadlock prevention
  - Deadlock detection

Source: Ramakrishnan & Gehrke (partial)

Deadlock Prevention

- Assign priorities based on timestamps. Assume Ti wants a lock that Tj holds. Two policies are possible:
  - Wait-Die: It Ti has higher priority, Ti waits for Tj; otherwise Ti aborts
  - Wound-wait: If Ti has higher priority, Tj aborts; otherwise Ti waits
- If a transaction re-starts, make sure it has its original timestamp

Source: Ramakrishnan & Gehrke (partial)

Deadlock Detection

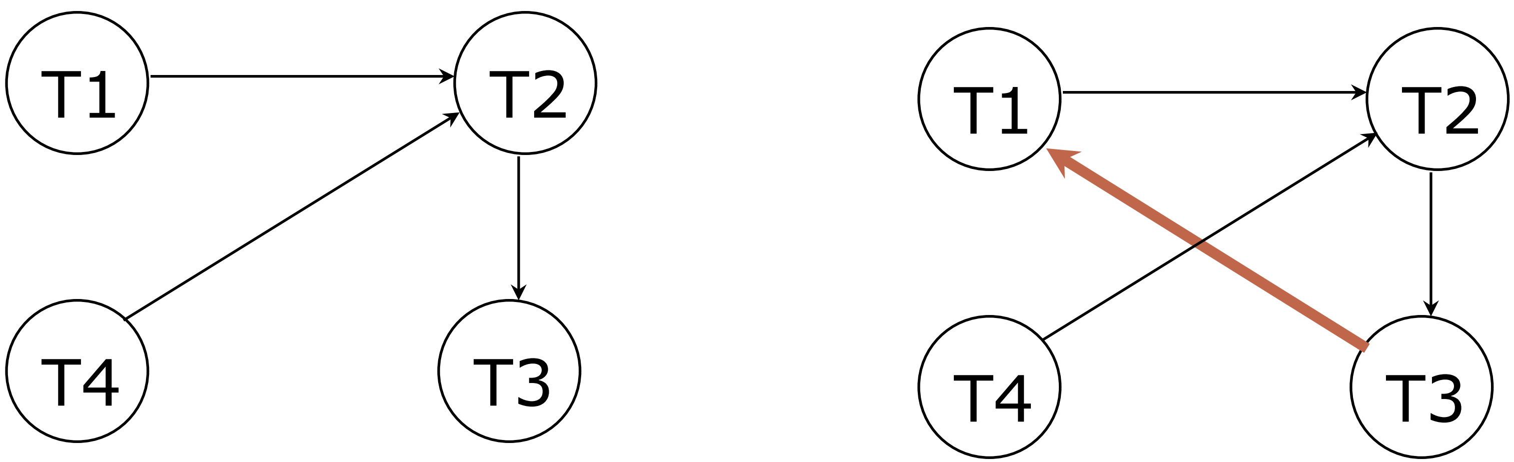
- Create a waits-for graph:
  - Nodes are transactions
  - There is an edge from Ti to Tj if Ti is waiting for Tj to release a lock
- Periodically check for cycles in the waits-for graph

Source: Ramakrishnan & Gehrke

Deadlock Detection

- **Example**

```
T1:  S(A), R(A),          S(B)
T2:            X(B),W(B)              X(C)
T3:                     S(C), R(C)           X(A)
T4:                                     X(B)
```



Source: Ramakrishnan & Gehrke

Do the following schedules lead to deadlock?

- Build the waits-for graph for each of the following transaction schedules

```
T1: S(A)                X(D)      X(C)   C
T2:            X(A)                             X(B)
T3:     S(B)                                           S(C)
```

Note: we only show locking operations for brevity!
C alone denotes commit, all locks released

```
T1:                  S(C) S(A)               X(D)
T2: S(B)                           X(C)
T3:         S(D) X(B)
```

Questions so far?

The Problems with Locking

- Locking is a pessimistic approach in which conflicts are prevented. Disadvantages:
  - Lock management overhead.
  - Deadlock detection/resolution.
  - Lock contention for heavily used objects.
- Remember: We must devise a way to enforce serializability, without destroying concurrency
- Two approaches:
  - Prevent violations → locking
  - Fix violations → aborts

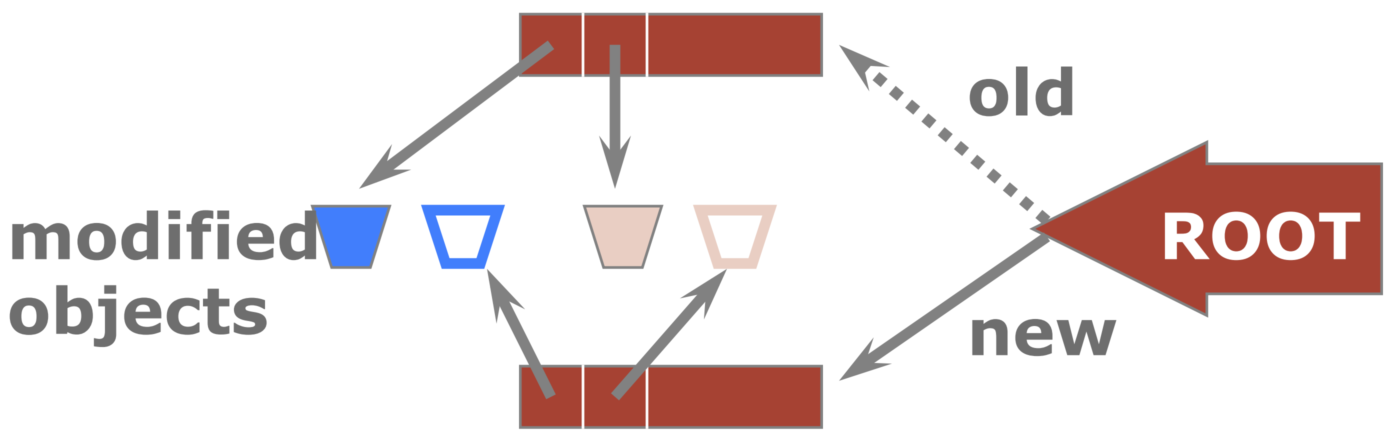
How can we design a protocol based on aborts instead of locks?

Source: Ramakrishnan & Gehrke (partial)

Optimistic CC: Kung-Robinson Model

- Xacts have three phases

- READ: Xacts read from the database, but make changes to private copies of objects.
- VALIDATE: Check for conflicts.
- WRITE: Make local copies of changes public.



Source: Ramakrishnan & Gehrke (partial)

Validation

- Test conditions that are sufficient to ensure that no conflict occurred.
- Each Xact is assigned a numeric id.
  - Just use a **timestamp**.
- Xact ids assigned at end of READ phase, just before validation begins. (Why then?)
- ReadSet(Ti): Set of objects read by Xact Ti.
- WriteSet(Ti): Set of objects modified by Ti.

Source: Ramakrishnan & Gehrke (partial)

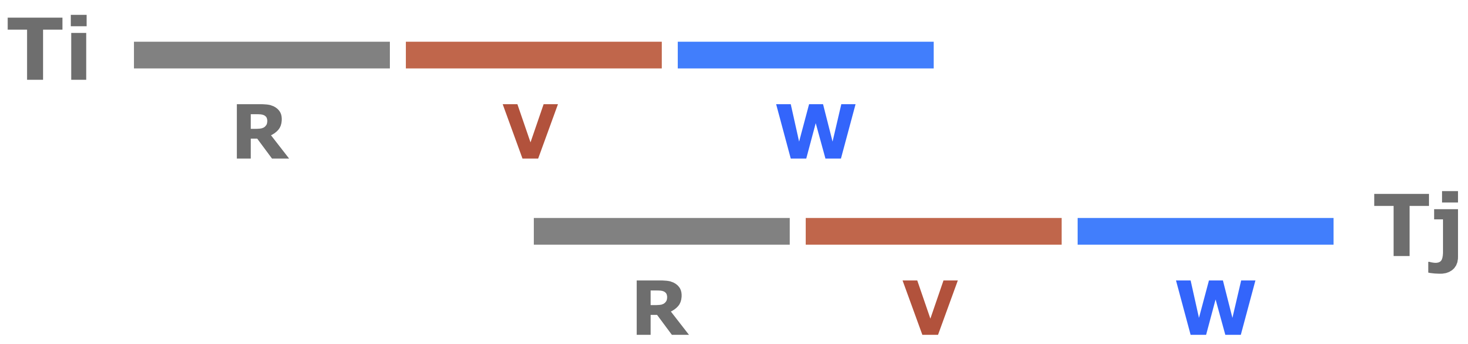
Test 1

- For all i and j such that Ti < Tj, check that Ti completes before Tj begins.

Source: Ramakrishnan & Gehrke (partial)

Test 2

- For all i and j such that Ti < Tj, check that:
  - Ti completes before Tj begins its Write phase **+**
  - WriteSet(Ti) $\cap$ ReadSet(Tj) is empty.

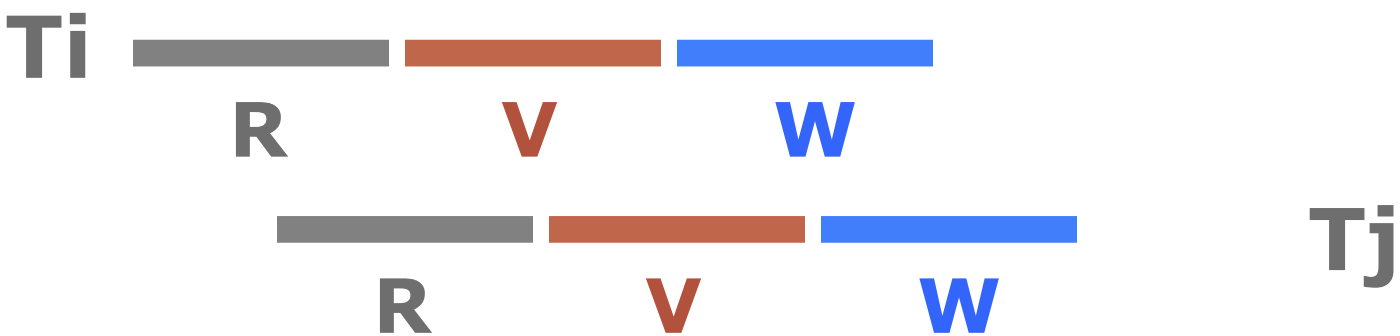


Does Tj read dirty data?

Source: Ramakrishnan & Gehrke (partial)

Test 3

- For all i and j such that Ti < Tj, check that:
  - Ti completes Read phase before Tj does **+**
  - WriteSet(Ti) ∩ ReadSet(Tj) is empty **+**
  - WriteSet(Ti) ∩ WriteSet(Tj) is empty.



Does Tj read dirty data? Does Ti overwrite Tj's writes?

Source: Ramakrishnan & Gehrke (partial)

Validation Example

- Predict whether T3 will be allowed to commit, given the transactions below

```
T1: RS(T1) = {1, 2, 3},    WS(T1) = {4},
      T1 completes before T3 begins with its write phase.
T2: RS(T2) = {6, 7, 8},    WS(T2) = {8},
      T2 completes read phase before T3 does.
T3: RS(T3) = {3, 5, 6, 7}, WS(T3) = {4},
      allow commit or roll back?
```

Overheads in Optimistic CC

- Must record read/write activity in ReadSet and WriteSet per Xact.
  - Must create and destroy these sets as needed.
- Must check for conflicts during validation, and must make validated writes "global".
  - Critical section can reduce concurrency.
  - Scheme for making writes global can reduce clustering of objects.
- Optimistic CC restarts Xacts that fail validation.
  - Work done so far is wasted; requires clean-up.

- Still, optimistic techniques widely used in software transactional memory (STM), main-memory databases

Source: Ramakrishnan & Gehrke (partial)

Multiversion Concurrency Control (MVCC)

- This approach maintains a number of **versions** of a data item and allocates the **right version to a read operation** of a transaction. Thus unlike other mechanisms a **read operation in this mechanism is never rejected**.
- Side effect:
    - Significantly more storage (RAM and disk) is required to maintain multiple versions. To check unlimited growth of versions, a **garbage collection** is run when some criteria is satisfied
- Many commercial database systems implement a combination of MVCC and S2PL
- See compendium for more details

Source: Elmasri & Navathe, 2007 (partial)

Snapshot Isolation

- Often databases implement properties that are **weaker** than serializability
- **Snapshot isolation**
  - **Snapshots:** Transactions see snapshot as of beginning of their execution
  - **First Committer Wins:** Conflicting writes to same item lead to aborts
- May lead to **write skew**
  - Database must have at least one doctor on call
  - Two doctors on call concurrently examine snapshot and see exactly each other on call
  - Doctors update their own records to being on leave
    - No write-write conflicts: different records!
  - After commits, database has no doctors on call

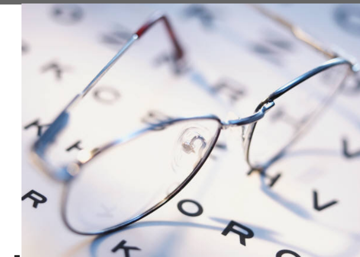
Transaction Support in SQL-92

- Each transaction has an access mode, a diagnostics size, and an isolation level.

Problem with SQL standard: snapshot isolation satisfies all requirements!

Isolation Level	**Dirty Read**	**Unrepeatable Read**	**Phantom Problem**
Read Uncommitted	Maybe	Maybe	Maybe
Read Committed	No	Maybe	Maybe
Repeatable Reads	No	No	Maybe
Serializable	No	No	No

Source: Ramakrishnan & Gehrke



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