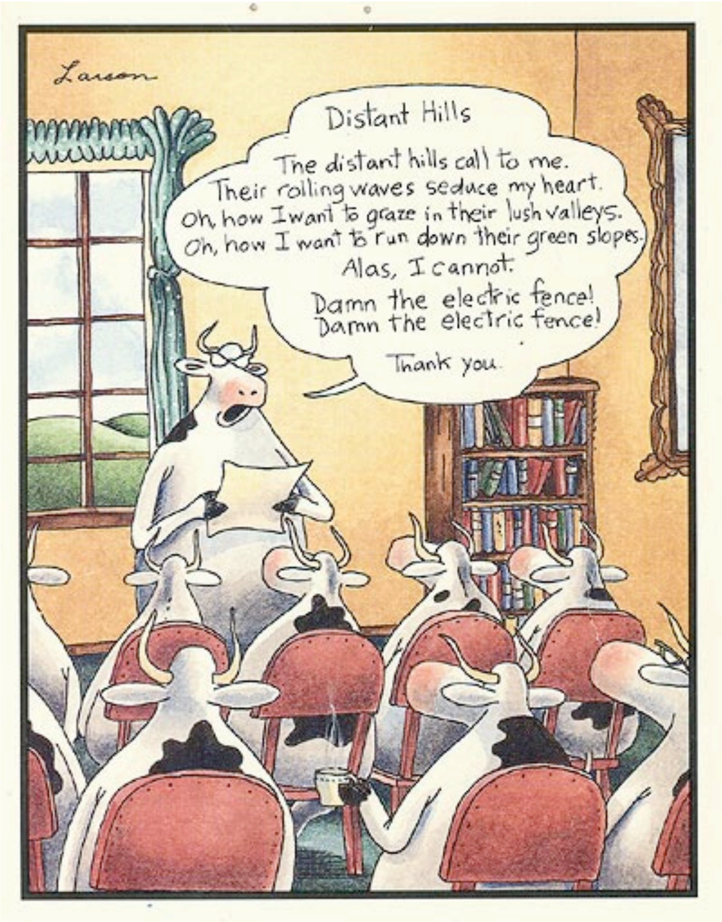
Concurrency Control

Chapter 17



Cow poetry

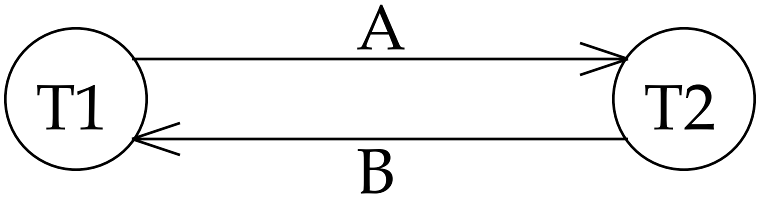
Conflict Serializable Schedules

- Recall *conflicts (WR, RW, WW)* were the cause of sequential inconsistency
- Two schedules are conflict equivalent if:
  - Involve the same actions over the same transactions
  - Every pair of conflicting actions is ordered the same way
- A schedule is conflict serializable if it is *conflict equivalent* to some serializable schedule

Example 1

- A non-serializable schedule that is also not conflict serializable:

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



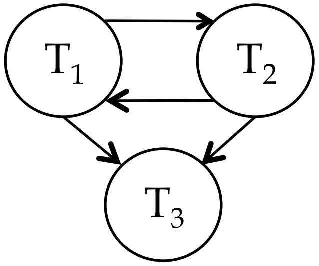
Precedence graph

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

Example 2

- A serializable schedule that is not conflict serializable:

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



- Serializable because it is equiv to

  T1, T2, T3, or T2, T1, T3
- Not conflict serializable, because the ordering:

  $R_1(A),W_2(A),W_1(A),W_3(A)$

  is not consistent with any ordering
- Importance of this distinction is that it can be proven that *Strict 2PL* permits only conflict serializable schedules

Review: **Strict 2PL**

- *Strict Two-phase Locking (Strict 2PL) Protocol*:
  - Each Xact must obtain a S (*shared*) lock on object before reading, and an X (*exclusive*) lock on object before writing.
  - *All locks held by a transaction are released when the transaction completes*
  - If an Xact holds an X lock on an object, no other Xact can get a lock (S or X) on that object.
- Strict 2PL allows only schedules whose precedence graph is acyclic (a DAG)

Two-Phase Locking (2PL)

- Two-Phase Locking Protocol
  - Each Xact must obtain a S (*shared*) lock on object before reading, and an X (*exclusive*) lock on object before writing.
  - *A transaction can release its locks once it has performed its desired operation (R or W). A transaction cannot request additional locks once it releases any locks.*
  - If an Xact holds an X lock on an object, no other Xact can get a lock (S or X) on that object.
- Note: locks can be released before Xact completes (commit/ abort), thus relaxing Strict 2PL. 2PL starts with a "growing" phase, where locks are requested followed by a "shrinking" phase, where locks are released

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)

- Enforcing view serializabiliy is expensive, thus mainly of theoretical interest

Lock Management

- Lock and unlock requests are handled by the lock manager
- Lock table entry (per table, record, or index):
  - Number of transactions currently holding a lock
  - Type of lock held (shared or exclusive)
  - Pointer to queue of lock requests
- Locking and unlocking must be atomic
- *Lock upgrades*: transaction that holds a shared lock can be upgraded to hold an exclusive lock

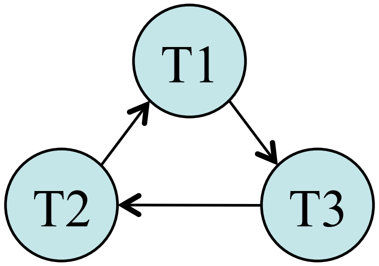
Deadlocks

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

Deadlock Detection

- Create a waits-for graph:
  - Nodes are transactions
  - Edge from Ti to Tj indicates Ti is waiting for Tj to release a lock
- DBMS periodically checks for cycles in the waits-for graph
- ex: T1: A = f(B), T2: B = g(C) , T3: C = h(A), arriving T1,T3,T2

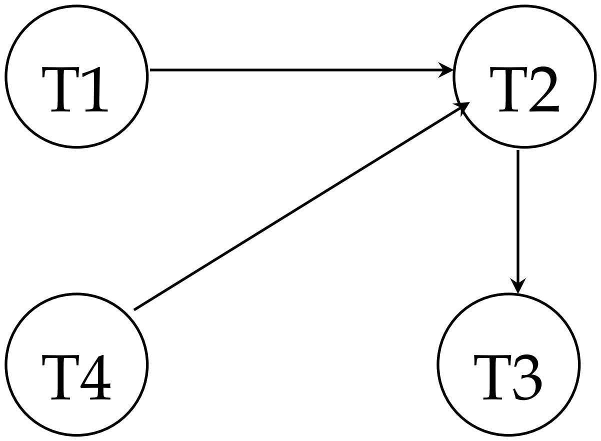
T1:	S(B),R(B),		X(A),…		
T2:				S(C),R(C),X(B),…	
T3:		S(A),R(A),			X(C),…

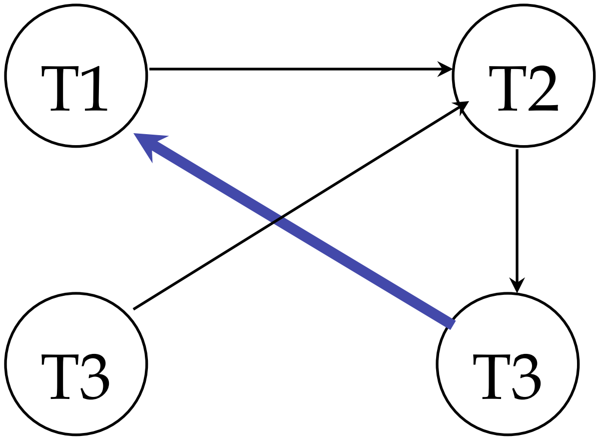


Deadlock Detection (Continued)

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)…





Deadlock Prevention

- When there is high contention for locks, detection and aborting can hurt performance
- Assign priorities (eg. 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 abort Ti
  - *Wound-wait*: If Ti has higher priority, abort Tj; otherwise Ti waits
- When Ti re-starts, it retains its original timestamp, thus moving up the priority list

Multi-Granularity Locks

- Hard to decide what granularity to lock (tuples vs. pages vs. tables).
- Shouldn’t have to decide!
- Data “containers” are nested:

contains ↓

Database
↓
Tables
↓
Pages
↓
Tuples

Solution: New Lock Modes, Protocol

- Allow Xacts to lock at each level, but with a special protocol using new "intention" locks:
- Before locking an item, Xact must set "intention locks" on all its ancestors.
- For unlock, go from specific to general (i.e., bottom-up).
- SIX mode: Like holding the S & IX locks at the same time.

Grant request rules

	--	IS	IX	S	X
--	√	√	√	√	√
IS	√	√	√	√	
IX	√	√	√		
S	√	√		√	
X	√				

Multiple Granularity Lock Protocol

- Each Xact starts from the root of the hierarchy.
- To get S or IS lock on a node, must first hold an IS or IX lock on the node's.
- To get X or IX or SIX on a node, must hold IX or SIX on parent node.
- Must release locks in bottom-up order.

Protocol is correct in that it is equivalent to directly setting locks at the leaf levels of the hierarchy.

Examples

- T1 scans R, and updates a few tuples:
  - T1 gets an SIX lock on R, then repeatedly gets an S lock on tuples of R, and occasionally upgrades to X on the tuples.
- T2 uses an index to read only part of R:
  - T2 gets an IS lock on R, and repeatedly gets an S lock on tuples of R.
- T3 reads all of R:
  - T3 gets an S lock on R.
  - OR, T3 could behave like T2; can use lock escalation to decide which.

	--	IS	IX	S	X
--	√	√	√	√	√
IS	√	√	√	√	
IX	√	√	√		
S	√	√		√	
X	√				

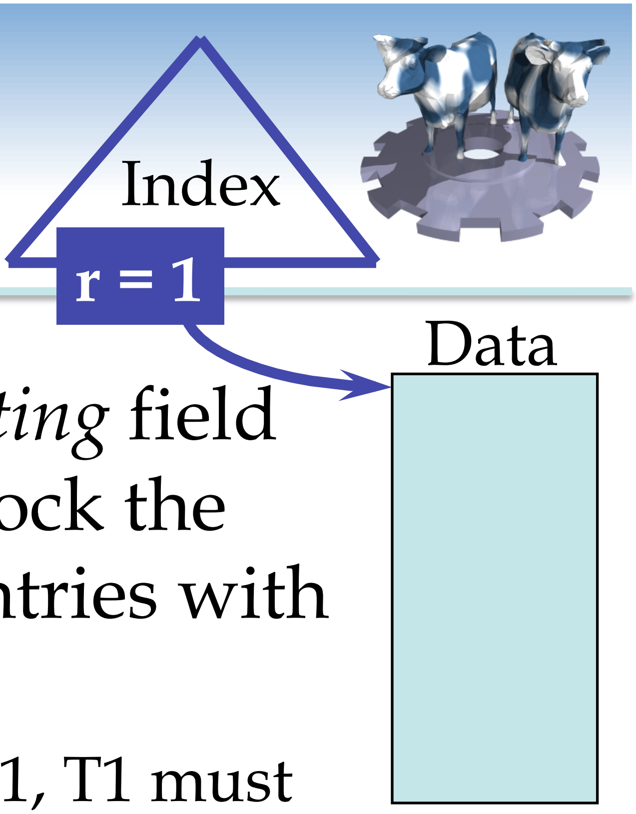
Dynamic Databases

- If we relax the assumption that the DB is a fixed collection of objects, even Strict 2PL will not assure serializability:
  - T1 locks all pages containing sailor records with *rating* = 1, and finds oldest sailor (say, *age* = 71).
  - Next, T2 inserts a new sailor; *rating* = 1, *age* = 96.
  - T2 also deletes oldest sailor with rating = 2 (and, say, *age* = 80), and commits.
  - T1 now locks all pages containing sailor records with *rating* = 2, and finds oldest (say, *age* = 63).
- No consistent DB state where T1 is "correct"!

The Problem

- T1 implicitly assumes that it has locked the set of all sailor records with *rating* = 1.
  - Assumption only holds if no sailor records are added while T1 is executing!
  - Need some mechanism to enforce this assumption. (Index locking and predicate locking.)
- Example shows that conflict serializability guarantees serializability only if the set of objects is fixed!

Index Locking



- If there is a dense index on the *rating* field using Alternative (2), T1 should lock the index page containing the data entries with *rating* = 1.
  - If there are no records with *rating* = 1, T1 must lock the index page where such a data entry *would* be, if it existed!
- If there is no suitable index, T1 must lock all pages, and lock the file/table to prevent new pages from being added, to ensure that no new records with *rating* = 1 are added.

Predicate Locking

- Grant lock on all records that satisfy some logical predicate, e.g. $age > 2*salary$.
- Index locking is a special case of predicate locking for which an index supports efficient implementation of the predicate lock.
  - What is the predicate in the sailor example?
- In general, predicate locking has a lot of locking overhead.

Locking in B+ Trees

- How can we efficiently lock a particular leaf node?
- One solution: Ignore the tree structure, just lock pages while traversing the tree, following 2PL.
- This has terrible performance!
  - Root node (and many higher level nodes) become bottlenecks because every tree access begins at the root.

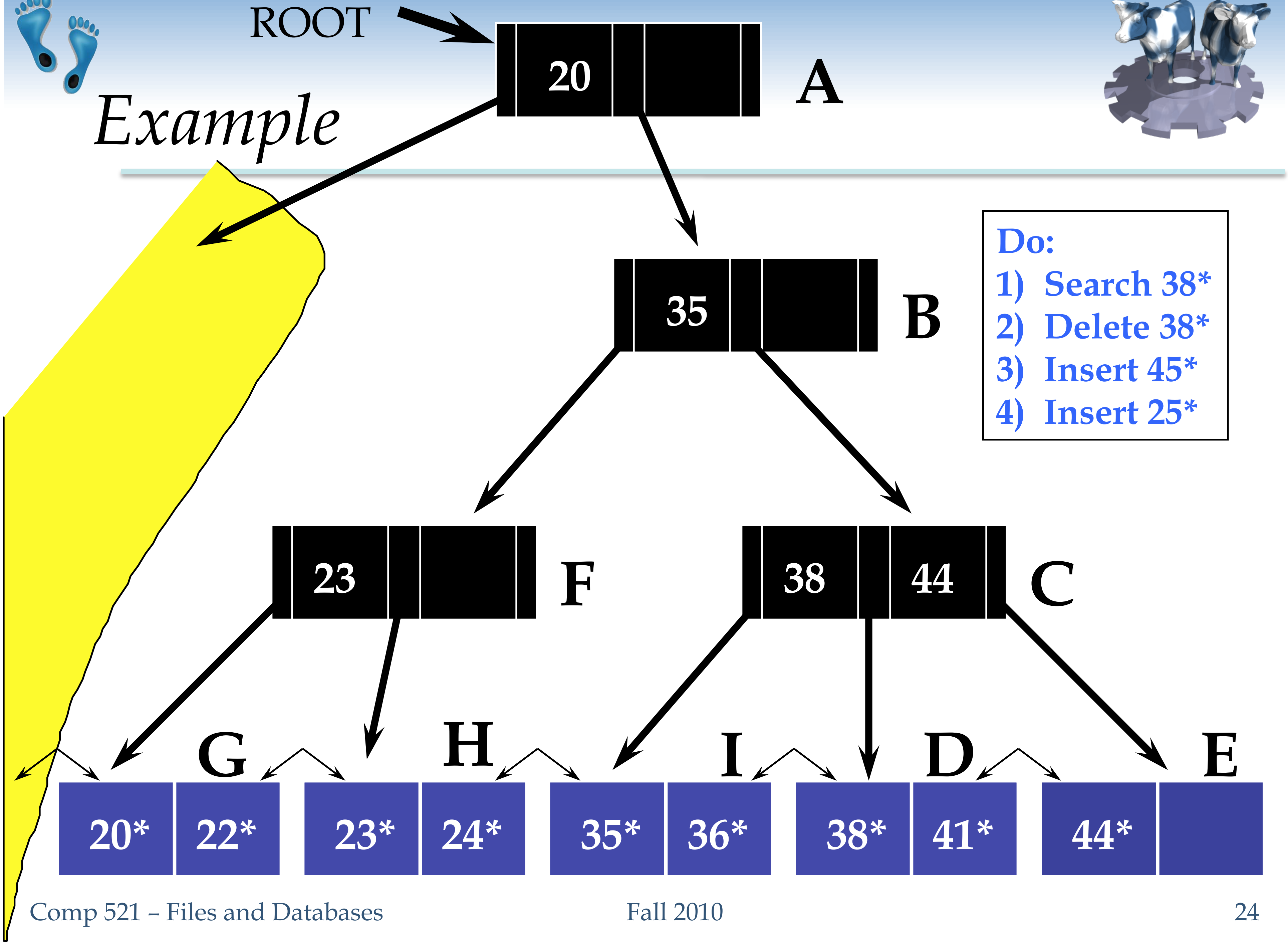
Two Useful Observations

- Higher levels of the tree only direct searches for leaf pages.
- For inserts, a node on a path from root to modified leaf must be locked (in X mode), only if a split can propagate up to it from the modified leaf. (Similar point holds w.r.t. deletes.)
- We can exploit these observations to design efficient locking protocols that guarantee serializability *even though they violate 2PL.*

A Simple Tree Locking Algorithm

- Search: Start at root and go down; repeatedly, S lock child then unlock parent.
- Insert/Delete: Start at root and go down, obtaining X locks as needed. Once child is locked, check if it is safe:
  - If child is safe, release all locks on ancestors.
- Safe node: Node such that changes will not propagate up beyond this node.
  - Inserts: Node is not full.
  - Deletes: Node is not half-empty.

Example



Do:

1) Search 38*
2) Delete 38*
3) Insert 45*
4) Insert 25*

“Optimistic” 2PL

- Basic premise: Most Xacts do not contend for the same object
- Idea: Make a local modified copy, and get locks when ready to commit
- Modified Algorithm:
  - Obtain S locks as usual.
  - Make changes to private copies of objects.
  - Obtain all X locks at end of Xact, make local writes global, then release all locks.

Timestamp CC

- **Idea:** Give each object 2 timestamps and each transaction a timestamp:
  - read-timestamp (RTS), when it was last read
  - write-timestamp (WTS), when it was last written
  - give each Xact a timestamp (TS) when it begins:
- If action ai of Xact Ti conflicts with action aj of Xact Tj, and TS(Ti) < TS(Tj), then ai must occur before aj. Otherwise, abort violating Xact.

When Xact T wants to read Object O

- If TS(T) < WTS(O), this violates timestamp order of T w.r.t. writer of O.
  - So, abort T and restart it with a new, larger TS. (If restarted with same TS, T will fail again! Contrast use of timestamps in 2PL for ddlk prevention.)
- If TS(T) > WTS(O):
  - Allow T to read O.
  - Reset RTS(O) to max(RTS(O), TS(T))
- Change to RTS(O) on reads must be written to disk! This and restarts represent overheads.

When Xact T wants to Write Object O

- If TS(T) < RTS(O), this violates timestamp order of T w.r.t. writer of O; abort and restart T.
- If TS(T) < WTS(O), violates timestamp order of T w.r.t. writer of O.
  - **Thomas Write Rule: We can safely ignore such outdated writes; need not restart T! (T's write is effectively followed by another write, with no intervening reads.) Allows some serializable but non conflict serializable schedules:**
- Else, allow T to write O.

T1	T2
R(A)	
	W(A)
	Commit
~~W(A)~~	
Commit	

Same result as T1; T2

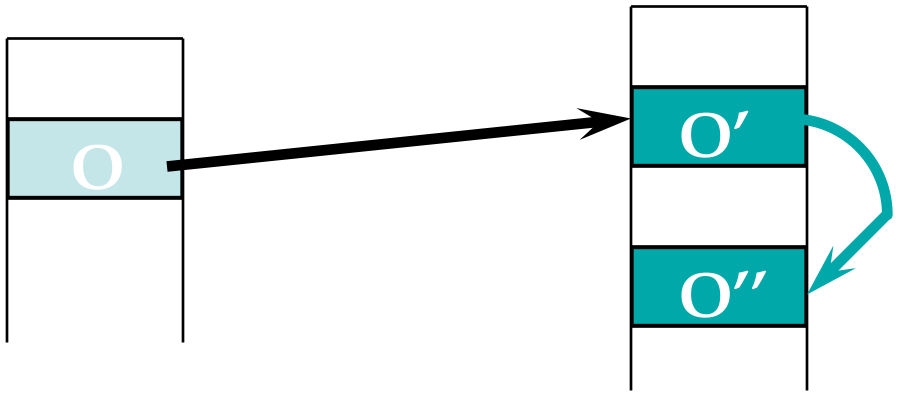
Timestamp CC and Recoverability

T1	**T2**
W(A)	
	R(A)
	W(B)
	Commit

- Unfortunately, unrecoverable schedules are allowed:
- Timestamp CC can be modified to allow only recoverable schedules:
  - Buffer all writes until writer commits (but update WTS(O) when the write is allowed.)
  - Block readers T (where TS(T) > WTS(O)) until writer of O commits.
- Similar to writers holding X locks until commit, but still not quite 2PL.

Multiversion Timestamp CC

- **Idea:** Let writer make a "new" copy while readers use an appropriate "old" copies:



MAIN SEGMENT (Current versions of DB objects)

VERSION POOL (Older versions that may be useful for some active readers.)

- Readers are always allowed to proceed.
  - But may be blocked until writer commits.

Multiversion CC (Contd.)

- Each version of an object has its writer's TS as its WTS, and the TS of the Xact that most recently read this version as its RTS.
- Versions are chained backward; we can discard versions that are "too old to be of interest".
- Each Xact is classified as Reader or Writer.
  - Writer *may* write some object; Reader never will.
  - Xact declares whether it is a Reader when it begins.

Summary

- There are several lock-based concurrency control schemes (Strict 2PL, 2PL). Conflicts between transactions can be detected in the dependency graph
- The lock manager keeps track of the locks issued. Deadlocks can either be prevented or detected.
- Naïve locking strategies may have the phantom problem

Summary (Contd.)

- Index locking is common, and affects performance significantly.
  - Needed when accessing records via index.
  - Needed for locking logical sets of records (index locking/predicate locking).
- Tree-structured indexes:
  - Straightforward use of 2PL very inefficient.
- In practice, better techniques now known; do record-level, rather than page-level locking.

Summary (Contd.)

- Multiple granularity locking reduces the overhead involved in setting locks for nested collections of objects (e.g., a file of pages); should not be confused with tree index locking!
- Optimistic CC aims to minimize CC overheads in an ”optimistic” environment where reads are common and writes are rare.
- Optimistic CC has its own overheads however; most real systems use locking.

Summary (Contd.)

- Timestamp CC is another alternative to 2PL; allows some serializable schedules that 2PL does not (although converse is also true).
- Ensuring recoverability with Timestamp CC requires ability to block Xacts, which is similar to locking.
- Multiversion Timestamp CC is a variant which ensures that read-only Xacts are never restarted; they can always read a suitable older version. Additional overhead of version maintenance.