Concurrency Control

Why Have Concurrent Processes?

- Better transaction throughput, response time
- Done via better utilization of resources:
  - While one processes is doing a disk read, another can be using the CPU or reading another disk.
- DANGER DANGER! Concurrency could lead to incorrectness!
  - Must carefully manage concurrent data access.
  - There's (much!) more here than the usual OS tricks!

Transactions

- Basic concurrency / recovery concept: a *<u>transaction</u> (Xact).*
  - A sequence of many actions which are considered to be one atomic unit of work.
- DBMS "actions":
  - reads, writes
  - Special actions: commit, abort

The ACID Properties

- A tomicity: All actions in the Xact happen, or none happen.
- C onsistency: If each Xact is consistent, and the DB starts consistent, it ends up consistent.
- I solation: Execution of one Xact is isolated from that of other Xacts.
- Durability: If a Xact commits, its effects persist.

Passing the ACID Test

- Concurrency Control
  - Guarantees Consistency and Isolation, given Atomicity.
- Logging and Recovery
  - Guarantees Atomicity and Durability.
- We'll do C. C. first:
  - What problems could arise?
  - What is acceptable behavior?
  - How do we guarantee acceptable behavior?

Schedules

<u>T1</u>	***<u>T2</u>***
R(A)	
W(A)	
	R(B)
	W(B)
R(C)	
W(C)	

- <u>Schedule</u>: An interleaving of actions from a set of Xacts, where the actions of any 1 Xact are in the original order.
  - Represents some actual sequence of database actions.
  - Example: R_1(A), W_1(A), R_2(B), W_2(B), R_1(C), W_1(C)
  - In a *complete* schedule, each Xact ends in commit or abort.
- Initial State + Schedule → Final State

Acceptable Schedules

- One sensible "isolated, consistent" schedule:
  - Run Xacts one at a time, in a series.
  - This is called a serial schedule.
  - NOTE: Different serial schedules can have different final states; all are "OK" -- DBMS makes no guarantees about the order in which concurrently submitted Xacts are executed.
- Serializable schedules:
  - Final state is what *some* serial schedule would have produced.
  - Aborted Xacts are not part of schedule; ignore them for now (they are made to `disappear' by using logging).

Serializability Violations

- Two actions conflict when 2 xacts access the same item:
  - W-R conflict: T2 reads something T1 wrote; T1 *still active*
  - R-W and W-W conflicts: Similar.
- WR conflict (dirty read):
  - Result is not equal to any serial execution!
  - T2 reads what T1 wrote, but it shouldn't have!!

Database is inconsistent!

transfer $100 from A to B	add 6% interest to A & B
T1	***T2***
R(A)	
W(A)	
	R(A)
	W(A)
	R(B)
	W(B)
	Commit
R(B)	
W(B)	
Commit	

More Conflicts

- RW Conflicts (Unrepeatable Read)
  - T2 overwrites what T1 read.

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

  - Again, not equivalent to a serial execution.
- WW Conflicts (Lost Update)
  - T2 overwrites what T1 wrote.

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

  - Usually occurs with RW or WR anomalies.
    - Unless you have "blind writes" (as here).

Now, Aborted Transactions

- Serializable schedule: Equivalent to a serial schedule of *committed* Xacts.
  - as if aborted Xacts *never happened.*
- Two Issues:
  - How does one undo the effects of an xact?
    - We'll cover this in logging / recovery
  - What if another Xact sees these effects??
    - Must undo that Xact as well!

Cascading Aborts

T1	***T2***
R(A)	
W(A)	
	R(A)
	W(A)
abort	

- Abort of T1 requires abort of T2!
  - Cascading Abort
- What about WW conflicts & aborts?
  - T2 overwrites a value that T1 writes.
  - T1 aborts: its "remembered" values are restored.
  - Lose T2's write! We will see how to solve this, too.
- An ACA (avoids cascading abort) schedule is one in which cascading abort cannot arise.
  - A Xact only reads / writes data from committed Xacts.

Recoverable Schedules

T1	***T2***
R(A)	
W(A)	
	R(A)
	W(A)
	commit
abort	

- Abort of T1 requires abort of T2!
  - But T2 has already committed!
- A recoverable schedule is one in which this cannot happen.
  - i.e. a Xact commits only after all the Xacts it "depends on" (i.e. it reads from or overwrites) commit.
  - Recoverable implies ACA (but not vice-versa!).
- Real systems typically ensure that only recoverable schedules arise (through locking).

Locking: A Technique for C. C.

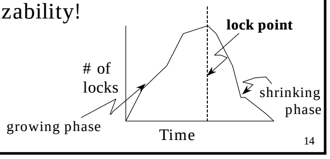
- Concurrency control usually done via locking.
- Lock info maintained by a "lock manager":
  - Stores (XID, RID, Mode) triples.
    - This is a simplistic view; suffices for now.
  - Mode ∈ {S,X}
  - Lock compatibility table:
- If a Xact can't get a lock, it is suspended on a wait queue.

LOCK REQUESTED

LOCK HELD	--	S	X
--	√	√	√
S	√	√	
X	√		

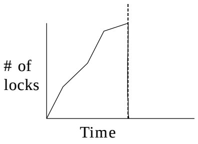
Two-Phase Locking (2PL)

- 2PL:
  - If T wants to read an object, first obtains an S lock.
  - If T wants to modify an object, first obtains X lock.
  - If T releases any lock, it can acquire no new locks!
- Locks are automatically obtained by DBMS.
- *Guarantees* serializability!
  - Why?



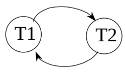
Strict 2PL

- Strict 2PL:
  - If T wants to read an object, first obtains an S lock.
  - If T wants to modify an object, first obtains X lock.
  - Hold all locks until end of transaction.
- Guarantees serializability, and recoverable schedule, too!
  - Thus ensures ACA!



Precedence Graph

- A Precedence (or Serializability) graph:
  - Node for each committed Xact.
  - Arc from Ti to Tj if an action of Ti precedes and conflicts with an action of Tj.
- T1 transfers $100 from A to B, T2 adds 6%
  - R_1(A), W_1(A), R_2(A), W_2(A), R_2(B), W_2(B), R_1(B), W_1(B)



Conflict Serializability

- 2 schedules are conflict equivalent if:
  - they have the same sets of actions, and
  - each pair of conflicting actions is ordered in the same way.
- A schedule is conflict serializable if it is conflict equivalent to a serial schedule.
  - Note: Some serializable schedules are not conflict serializable!

Conflict Serializability & Graphs

- Theorem: A schedule is conflict serializable iff its precedence graph is acyclic.
- Theorem: 2PL ensures that the precedence graph will be acyclic!
- Strict 2PL improves on this by avoiding cascading aborts, problems with undoing WW conflicts; i.e., ensuring recoverable schedules.

Lock Manager Implementation

- Question 1: What are we locking?
  - Tuples, pages, or tables?
  - Finer granularity increases concurrency, but also increases locking overhead.
- Question 2: How do you “lock” something??
- <u>Lock Table:</u> A hash table of Lock Entries.
  - *Lock Entry:*
    - OID
    - Mode
    - List: Xacts holding lock (or a count)
    - List: Wait Queue

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 <u>oldest</u> 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 <u>oldest</u> (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, predicate locking, or table locking.)
- Example shows that conflict serializability guarantees serializability only if the set of objects is fixed!

Summary of Concurrency Control

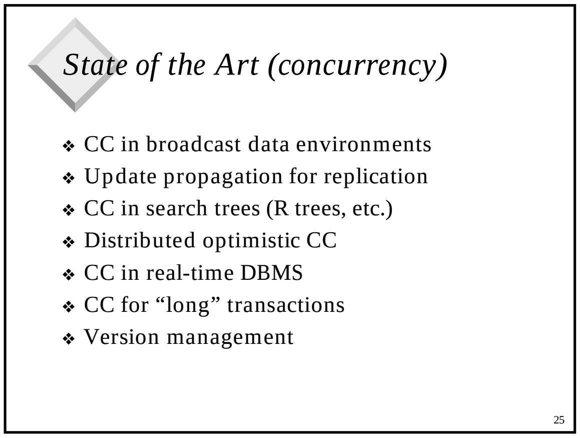
- Concurrency control key to a DBMS.
  - More than just mutexes!
- Transactions and the ACID properties:
  - C & I are handled by concurrency control.
  - A & D coming soon with logging & recovery.
- Conflicts arise when two Xacts access the same object, and one of the Xacts is modifying it.
- Serial execution is our model of correctness.

Summary, cont.

- Serializability allows us to “simulate” serial execution with better performance.
- 2PL: A simple mechanism to get serializability.
  - Strict 2PL also gives us recoverability, ACA
- Lock manager module automates 2PL so that only the access methods worry about it.
  - Lock table is a big main-mem hash table
- Deadlocks are possible, and typically a deadlock detector is used to solve the problem.

Summary, cont.: SQL-92 support

ISOLATION LEVEL	*LOST UPDATE*	*DIRTY READ*	*UNREPEATABLE READ*	*PHANTOM*	*IMPLEMENTATION*
Read Uncommitted (0)	N	Y	Y	Y	No S locks; writers must run at higher levels
Read Committed (1)	N	N	Y	Y	Strict 2PL X locks; S locks released anytime
Repeatable Reads (2)	N	N	N	Y	Strict 2PL on data
Serializable (3)	N	N	N	N	Strict 2PL on data and indices (or predicate locking)



State of the Art (concurrency)

- CC in broadcast data environments
- Update propagation for replication
- CC in search trees (R trees, etc.)
- Distributed optimistic CC
- CC in real-time DBMS
- CC for “long” transactions
- Version management