Transaction Management

Ramakrishnan & Gehrke, Chapter 14+

Transactions

- Concurrent execution of user requests is essential for good DBMS performance
  - User requests arrive concurrently
  - Because disk accesses are frequent, and relatively slow, it is important to keep the cpu humming by working on several user programs concurrently
- user's program may carry out many operations on data retrieved, but DBMS only concerned about data read/written from/to database
- transaction (TA) := the DBMS's abstract view of a user program: a sequence of (SQL) reads and writes that is executed as a unit

Concurrency in a DBMS

- Users submit TAs, can think of each (trans)action as execution unit
  - Concurrency achieved by DBMS by interleaving TAs
  - TA must leave DB in consistent state
    assuming DB is consistent when TA begins
    - *ICs declared in CREATE TABLE, CHECK constraints, etc.*
- Issues:
  - Effect of interleaving TAs
  - Crashes
  - Performance of concurrency control

Atomicity of Transactions

- Two possible TA endings:
  - commit after completing all its actions – data must be safe in DB
  - abort (by application or DBMS) – must restore original state
- Important property guaranteed by the DBMS: TAs atomic
  - Perception: TA executes all its actions in one step, or none
- Technically: DBMS logs all actions
  - can undo actions of aborted TAs
  - Write-ahead logging (WAL): save record of action before every update

ACID

- TA concept includes four basic properties:
- Atomic
  - all TA actions will be completed, or nothing
- Consistent
  - after commit/abort, data satisfy all integrity constraints
- Isolation
  - any changes are invisible to other TAs until commit
- Durable
  - nothing lost in future; failures occurring after commit cause no loss of data

Transaction Syntax in SQL

- START TRANSACTION start TA
- COMMIT end TA successfully
- ROLLBACK abort TA (undo any changes)
- If none of these TA management commands is present, each statement starts and ends its own TA
  - including all triggers, constraints,…

Anatomy of Conflicts

- Consider two TAs:

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

  - Intuitively, first TA transfers $100 from B's account to A's account
  - second TA credits both accounts with a 6% interest payment

- no guarantee that T1 will execute before T2 or vice-versa, if both are submitted together

- However, net effect must be equivalent to these two TAs running serially in some order

Anatomy of Conflicts (contd.)

- Consider a possible interleaving (schedule):

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

- This is OK. But what about:

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

- The DBMS's view of the second schedule:

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

Anomalies from Interleaved Execution

- Reading uncommitted data (R/W conflicts, “dirty reads”):

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

- Unrepeatable reads (R/W conflicts):

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

- Overwriting uncommitted data (W/W conflicts):

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

Scheduling Transactions: Definitions

- Serial schedule:
  Schedule that does not interleave the actions of different TAs
- Equivalent schedules:
  For any database state, the effect (on the set of objects in the database) of executing the first schedule is identical to the effect of executing the second schedule
- Serializable schedule:
  A schedule equivalent to some serial execution of the TAs
- each TA preserves consistency
  $\Rightarrow$ every serializable schedule preserves consistency

Lock-Based Concurrency Control

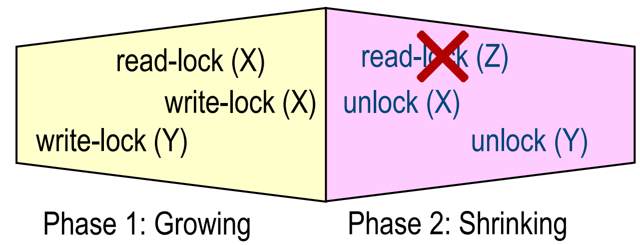
- Core issues: What lock modes? What lock conflict handling policy?
- Common lock modes: SX
  - Each TA must obtain an S (shared) lock before reading, and an X (exclusive) lock before writing

```
  | S X
--+-----
S | + -
X | - -
```

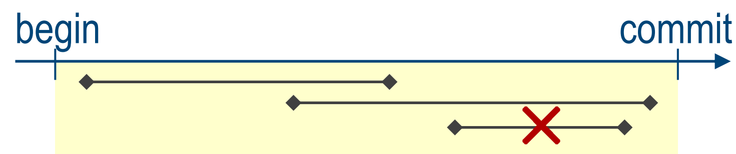
- Lock conflict handling
  - Abort conflicting TA / let it wait / work on previous version
- Locking protocols
  - two-phase locking (strict, non-strict, conservative, …) – *next!*
  - Timestamp based
  - Multi-version based
  - Optimistic concurrency control

Two-Phase Locking Protocol

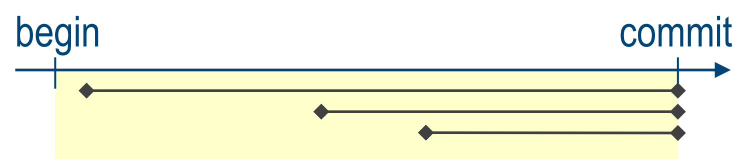
- 2PL
  - All locks acquired before first release
  - cannot acquire locks after releasing first lock



- allows only serializable schedules ☺
  - but complex abort processing



- Strict 2PL
  - Write locks released at TA end
  - Read locks released earlier (more concurrency)



- Strict 2PL simplifies TA aborts ☺☺

2PL Variants

No need to remember

- Basic 2PL
- Conservative 2PL
  - All locks acquired before transaction execution
  - Makes sure TA can get necessary locks
- Strict 2PL
  - Releasing of write-locks only after TA end
  - Avoid cascading abort
- Rigorous 2PL
  - Releasing of all locks only after TA end

Limitations of 2PL

- Some serializable schedules may not be permitted
  - Performance not optimal
- 2PL (and locking in general) may cause deadlocks and starvation
  - Deadlock: no transactions can proceed
  - Starvation: some transaction wait forever

Isolation Levels

- Isolation level directives: summary about TA's intentions, placed before TA
  - SET TRANSACTION READ ONLY
    TA will not write → can be interleaved with other read-only TAs
  - SET TRANSACTION READ WRITE
    (default)
- assists DBMS optimizer
- Example: Choosing seats in airplane
  - *Find available seat, reserve by setting occ to TRUE; if there is none, abort*
  - *Ask customer for approval. If so, commit, otherwise release seat by setting occ to FALSE, goto 1*
  - two "TA"s concurrently: can have dirty reads for occ – uncritical! (why?)

Isolation Levels (contd.)

- Refinement:
  SET TRANSACTION READ WRITE ISOLATION LEVEL…
  - …READ UNCOMMITTED
    allows TA to read dirty data
  - …READ COMMITTED
    forbids dirty reads, but allows TA to issue query several times & get different results (as long as TAs that wrote them have committed)
  - …REPEATABLE READ
    ensures that any tuples will be the same under subsequent reads.
    However a query may turn up new (phantom) tuples
  - …SERIALIZABLE
    default; can be omitted

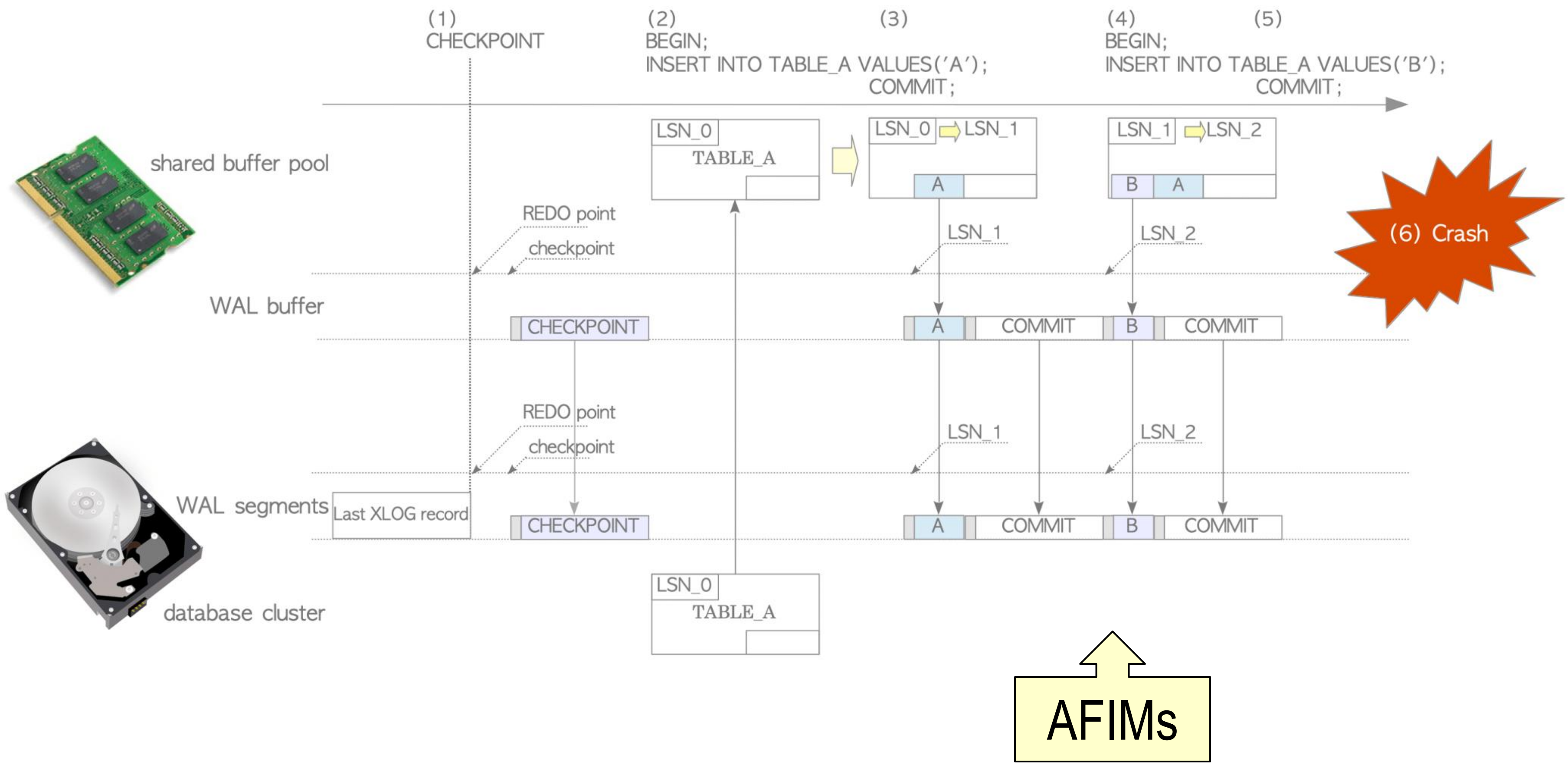
Effects of New Isolation Levels

- Consider seat choosing algorithm:
- If run at level READ COMMITTED
  - seat choice function will not see seats as booked
    if reserved but not committed (roll back if over-booked)
  - Repeated queries may yield different seats (other TAs booking in parallel)
- If run at REPEATABLE READ
  - any seat found in step 1 will remain available in subsequent queries
  - new tuples entering relation (e.g. switching flight to larger plane) seen by new queries

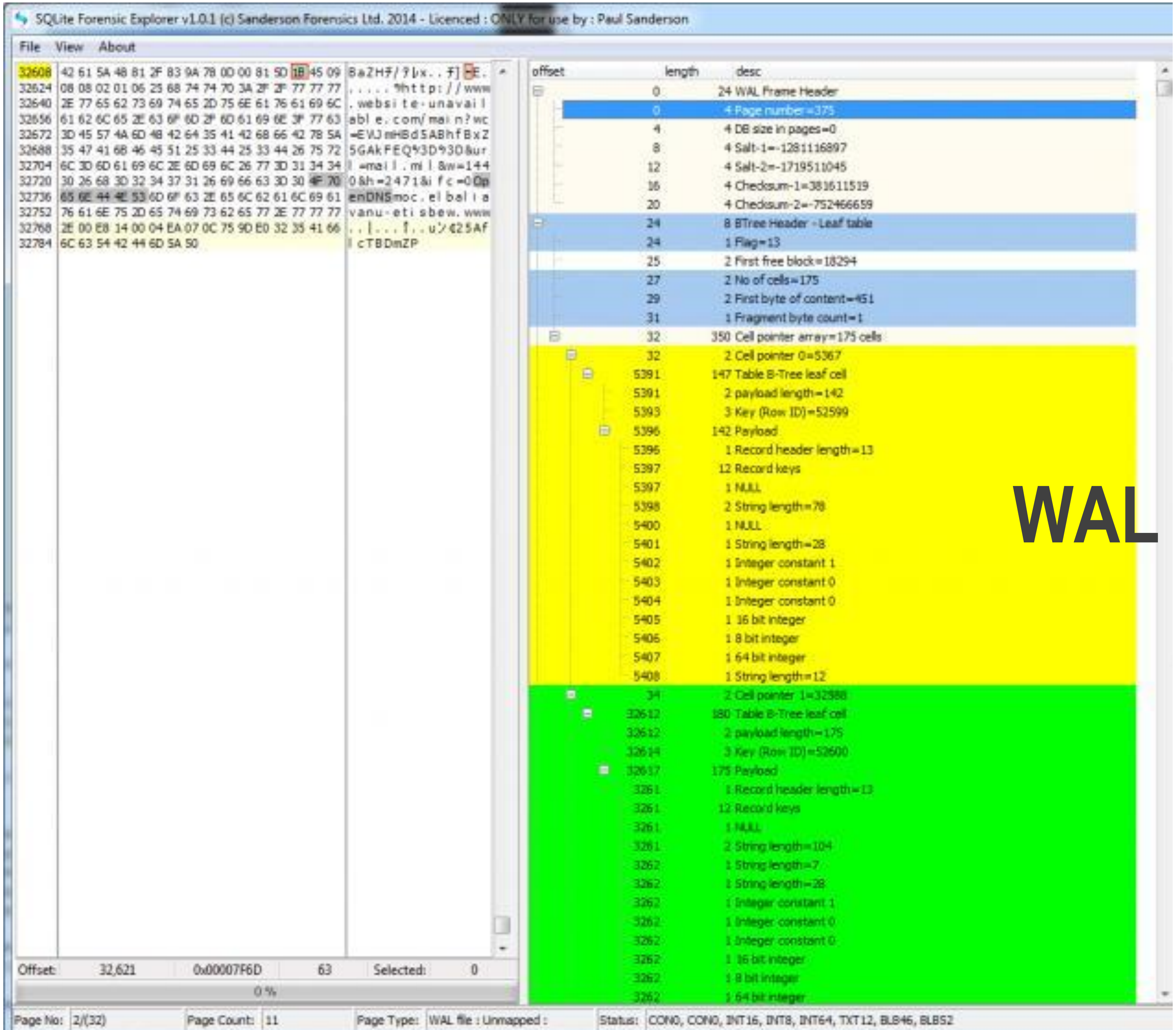
Write-Ahead Logging (WAL)

- All change actions recorded in log file(s)
  - Not single tuples, but complete pages affected
  - Before-Image (BFIM) + After-Image (AFIM) allow choice of redo or undo
  - Ti writes an object: TA identifier + BFIM + AFIM
  - Ti commits/aborts: TA identifier + commit/abort indicator
  - Log records chained by TA id $\rightarrow$ easy to undo specific TA
- Log written before database update = “write ahead”
  - Simply append to log file, so fast
- Log is beating heart of DBMS!
  - Use fast storage
  - often duplexed & archived on stable storage

WAL in Action (PostgreSQL)



[www.interdb.jp]



WAL Inspection

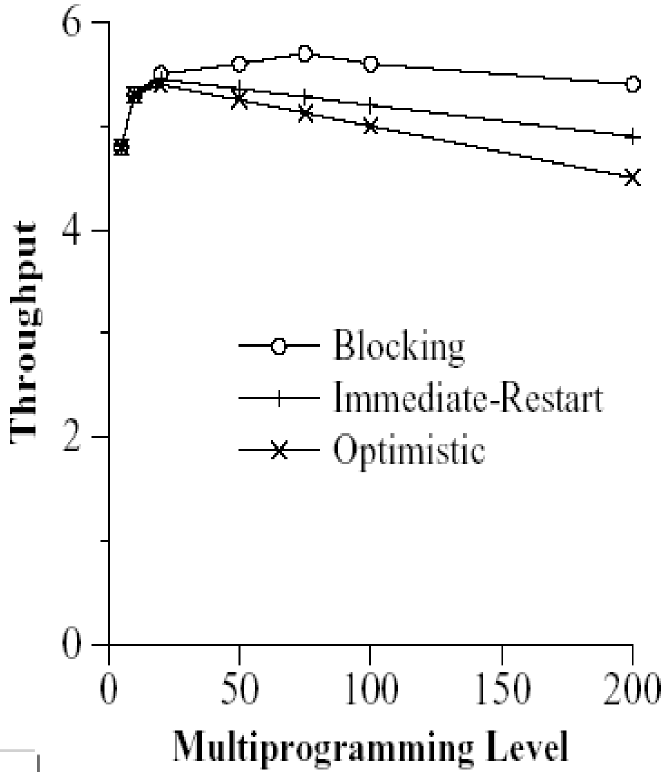
[sqliteforensictoolkit.com]

Crash Recovery

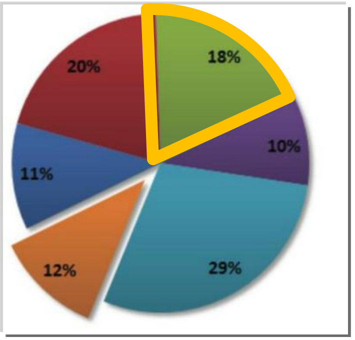
- Log also used to recover from system crashes
  - Abort all TAs active at crash time
  - Re-run changes committed, but not yet permanent at crash time
- Aries recovery algorithm:
  - Analysis: Scan log forward (from most recent checkpoint until crash) to identify
    - *all TAs that were active*
    - *all dirty pages in the buffer pool*
  - Redo: repeat all updates to dirty pages in the buffer pool as needed
    - *to ensure that all logged updates are in fact carried out and written to disk*
  - Undo: nullify writes of all TAs active at crash time working backwards in log
    - *by restoring "before value" of update, which is in log record for update*

Performance Impact

- Lock contention
- Deadlock



- *See NewSQL later!*



Summary

- Concurrency control & recovery: core DBMS functions
- Users need not worry about concurrency
  - System automatically inserts lock/unlocking, schedules TAs, ensures serializability (or what's requested)
- ACID properties!
- Mechanisms:
  - TA scheduling; Strict 2PL !
  - Locks
  - Write-ahead logging (WAL)

Outlook: ACID vs BASE

- BASE (Basically Available Soft-state Eventual Consistency)
  - Prefers availability over consistency
  - Relaxing ACID
- CAP Theorem [proposed: Eric Brewer; proven: Gilbert & Lynch]:
  In a distributed system you can satisfy at most 2 out of the 3 guarantees
  - *Consistency: all nodes have same data at any time*
  - *Availability: system allows operations all the time*
  - *Partition-tolerance: system continues to work in spite of network partitions*
- Comparison:
  - Traditional RDBMSs: Strong consistency over availability under a partition
  - Cassandra: Eventual (weak) consistency, availability, partition-tolerance

Discussion: ACID vs BASE

- Justin Sheely: “eventual consistency in well-designed systems does not lead to inconsistency”
- Daniel Abadi: “If your database only guarantees eventual consistency, you have to make sure your application is well-designed to resolve all consistency conflicts. […] Application code has to be smart enough to deal with any possible kind of conflict, and resolve them correctly”
  - Sometimes simple policies like “last update wins” sufficient
  - other apps far more complicated, can lead to errors and security flaws
  - Ex: ATM heist with 60s window
  - DB with stronger guarantees greatly simplifies application design