Database Systems

Concurrency

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Topics

Transactions

- a group of operations may have to be carried out together
- finishing some operations while failing on others might cause inconsistency
- transaction: a logical unit of work
- no guarantee that multiple operations will all be finished
- at least return to the state before the changes

Transaction Example

- transfer money from one bank account to another

```
UPDATE ACCOUNTS SET BALANCE = BALANCE - 100
  WHERE ACCOUNTID = 123

UPDATE ACCOUNTS SET BALANCE = BALANCE + 100
  WHERE ACCOUNTID = 456
```


Transaction Properties

- Atomicity: all or nothing
- Consistency: move from one consistent state to another
- Isolation: whether operations of an unfinished transaction affect other transactions or not
- Durability: when a transaction is finished, its changes are permanent even if there is a system failure

SQL Transactions

- starting a transaction

```
BEGIN [ WORK | TRANSACTION ]
```

- finishing a transaction

```
COMMIT [ WORK | TRANSACTION ]
```

- cancelling a transaction

```
ROLLBACK [ WORK | TRANSACTION ]
```


Transaction Example

```
  BEGIN TRANSACTION
  ON ERROR GOTO UNDO
  UPDATE ACCOUNTS SET BALANCE = BALANCE - 100
    WHERE (ACCOUNTID = 123)
  UPDATE ACCOUNTS SET BALANCE = BALANCE + 100
    WHERE (ACCOUNTID = 456)
  COMMIT
  ...

UNDO:
  ROLLBACK
```

Recovery

- consider a system failure during a transaction
- buffer cache has not been flushed to the disk
- how to guarantee durability?
- derive the data from other sources in the system

Transaction Log

- log: values of every affected tuple
  before and after every operation
- write-ahead log rule:
  log must be flushed before the transaction is committed
- accessing records in the log is sequential by nature

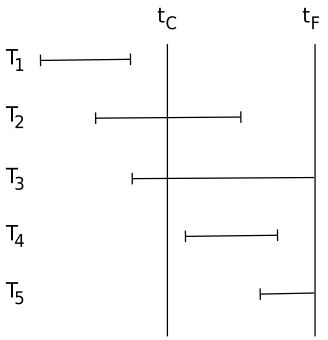
Checkpoints

- create checkpoints at certain intervals:
- flush buffer cache to the physical medium
- note the checkpoint
- note the continuing transactions

Recovery Lists

- after the failure: which transactions will be undone,
  which transactions will be made permanent?
- create two lists: *undo* (U), *redo* (R)
- t_C: last checkpoint in the log
- add the transactions which are active at t_C to U
- scan records from t_C to end of log
- add any starting transaction to U
- move any finishing transaction to R

Recovery Example



- t_C:
  $U = [T_2, T_3]$ $R = []$
- T_4 started:
  $U = [T_2, T_3, T_4]$ $R = []$
- T_2 finished:
  $U = [T_3, T_4]$ $R = [T_2]$
- T_5 started:
  $U = [T_3, T_4, T_5]$ $R = [T_2]$
- T_4 finished:
  $U = [T_3, T_5]$ $R = [T_2, T_4]$

Recovery Process

- scan records backwards from end of log
- undo the changes made by the transactions in U
- scan records forwards
- redo the changes made by the transactions in R

Two-Phase Commit

- different source managers
- different undo / redo mechanisms
- modifications on data on different source managers
- either commit in all or rollback in all
- coordinator

Protocol

- coordinator → participants:
  flush all data regarding the transaction
- coordinator → participants:
  start transaction and report back the result
- all participants succeeded: success
- otherwise: failure
- if success, coordinator → participants: commit
- if failure, coordinator → participants: rollback

References

Required Reading: Date

- Chapter 15: Recovery

Concurrency

- problems that might arise due to simultaneuous transactions:
- lost update
- uncommitted dependency
- inconsistent analysis

Lost Update

Transaction A	Transaction B
...	...
RETRIEVE p	...
...	...
...	RETRIEVE p
...	...
UPDATE p	...
...	...
...	UPDATE p
...	...

Uncommitted Dependency

Transaction A	Transaction B
...	...
...	UPDATE p
...	...
RETRIEVE p	...
...	...
...	ROLLBACK
...	

Inconsistent Analysis

- compute sum of accounts: acc1=40, acc2=50, acc3=30

Transaction A	Transaction B
...	...
RETRIEVE acc1 (40)	...
RETRIEVE acc2 (90)	...
...	...
...	UPDATE acc3 (30 → 20)
...	UPDATE acc1 (40 → 50)
...	COMMIT
...	...
RETRIEVE acc3 (110)	
...	

Conflicts

- A reads, B reads: no problem
- A reads, B writes: non-repeatable read (inconsistent analysis)
- A writes, B reads: dirty read (uncommitted dependency)
- A writes, B writes: dirty write (lost update)

Locking

- let transactions lock the tuples they work on
- shared lock (S)
- exclusive lock (X)

Lock Requests

lock type compatibility matrix

	S	X
-	Y	Y
S	Y	N
X	N	N

- existing shared lock: only shared lock requests are allowed
- existing exclusive lock: all lock requests are denied

Locking Protocol

- transaction requests lock depending on operation
- promote a shared lock to an exclusive lock
- if request denied, it starts waiting
- it continues when the transaction that holds the lock releases it
- starvation

Lost Update

Transaction A	Transaction B
...	...
RETRIEVE p (S+)	...
...	...
...	RETRIEVE p (S+)
...	...
UPDATE p (X-)	...
wait	...
wait	UPDATE p (X-)
wait	wait

Uncommitted Dependency

Transaction A	Transaction B
...	...
...	UPDATE p (X+)
...	...
RETRIEVE p (S-)	...
wait	...
wait	ROLLBACK
RETRIEVE p (S+)	
...	

Inconsistent Analysis

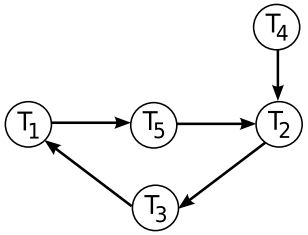
Transaction A	Transaction B
...	...
RETRIEVE acc1 (S+)	...
RETRIEVE acc2 (S+)	...
...	...
...	UPDATE acc3 (X+)
...	UPDATE acc1 (X-)
...	wait
RETRIEVE acc3 (S-)	wait
wait	wait

Deadlock

- deadlock: transactions waiting for each other to release the locks
- almost always between two transactions
- detect and solve
- prevent

Solving Deadlocks

Example



- wait graph
- choose a victim and kill it

Preventing Deadlocks

- every transaction has a starting timestamp
- if A's request conflicts with B's lock:
- wait-die: A waits if older than B, otherwise it dies
  A is rolled back and restarted
- wound-wait: A waits if younger than B, otherwise it wounds B
  B is rolled back and restarted
- timestamp of restarted transaction is not changed

Lock Statements

- shared lock

  ```
  SELECT query FOR SHARE
  ```

- exclusive lock

  ```
  SELECT query FOR UPDATE
  ```

Isolation Levels

- if isolation is decreased, concurrency can be increased
- various isolation levels
- serializable
- repeatable read
- read committed
- read uncommitted

Serializability

- *serial execution*: a transaction starts only after another is finished
- serializable: result of concurrent execution is always the same as one of the serial executions

Example

- $x = 10$
- transaction A: $x = x + 1$
- transaction B: $x = 2 * x$
- first A, then B: $x = 22$
- first B, then A: $x = 21$

Two-Phase Locking Protocol

- two-phase locking:
  after any lock is released, no more new lock requests
- expansion phase: gather locks
- contraction phase: release locks
- two-phase strict locking:
  all locks are released at the end of the transaction
- *If all transactions obey the two-phase locking protocol, all concurrent executions are serializable.*

Read Committed

- read committed: only X locks are held until end of transaction

Transaction A	Transaction B
...	...
RETRIEVE p (S+)	...
...	...
release lock	...
...	...
...	UPDATE p (X+)
...	COMMIT
RETRIEVE p (S+)	

Phantoms

- phantom: when the query is executed again, new tuples appear

Example

- A computes the average of a customer's account balances: $\frac{100+100+100}{3} = 100$
- B creates new account (200) for the same customer
- A computes again: $\frac{100+100+100+200}{4} = 125$

Isolation Levels

- setting an isolation level

```
SET TRANSACTION ISOLATION LEVEL
  [ SERIALIZABLE | REPEATABLE READ |
    READ COMMITTED | READ UNCOMMITTED ]
```


Isolation Level Problems

	dirty read	non-repeatable read	phantom
READ UNCOMMITTED	Y	Y	Y
READ COMMITTED	N	Y	Y
REPEATABLE READ	N	N	Y
SERIALIZABLE	N	N	N

Locking Granularity

- lock relations instead of tuples
- even the entire database
- granularity: unit of locking
- if granularity is increased, concurrency is decreased
- hard to find locks on tuples
  → first, get intent locks on relation variables

Intent Locks

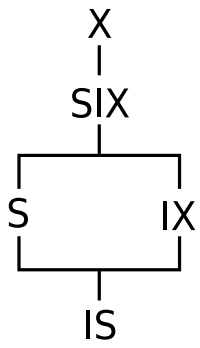
- Intent Shared (IS):
  transaction intends to read some tuples
- Intent Exclusive (IX):
  IS + transaction intends to write some tuples
- Shared (S):
  concurrent readers are allowed but no concurrent writers
- Shared + Intent Exclusive (SIX)
- Exclusive (X):
  no concurrency allowed on this relation

Lock Requests

lock compatibility matrix

	IS	IX	S	SIX	X
-	Y	Y	Y	Y	Y
IS	Y	Y	Y	Y	N
IX	Y	Y	N	N	N
S	Y	N	Y	N	N
SIX	Y	N	N	N	N
X	N	N	N	N	N

Lock Precedence



- for an S on a tuple,
  at least an IS on the relation
- for an X on a tuple,
  at least an IX on the relation

Locking Statements

- lock a table

```
LOCK [ TABLE ] table_name
     [ IN lock_mode MODE ]
```

- lock modes:
  - `ACCESS SHARE`
  - `ROW SHARE`
  - `ROW EXCLUSIVE`
  - `SHARE UPDATE EXCLUSIVE`
  - `SHARE`
  - `SHARE ROW EXCLUSIVE`
  - `EXCLUSIVE`
  - `ACCESS EXCLUSIVE`

References

Required Reading: Date

- Chapter 16: Concurrency