Relational Databases and Datawarehousing
Basics of Transaction Management

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What will you learn in this chapter ?

- Transactions, Recovery and Concurrency Control
- The ACID Properties of Transactions
- Transactions and Transaction Management
- Locking
- Isolation levels
- Recovery
- Concurrency Control

Transactions, Recovery and Concurrency control

- Majority of databases are multi user databases
- Concurrent access to the same data may induce different types of anomalies
- Errors may occur in the DBMS or its environment
- DBMS must support ACID (Atomicity, Consistency, Isolation, Durability) properties

Transactions, Recovery and Concurrency control

- Transaction: set of database operations induced by a single user or application, that should be considered as one undividable unit of work
    - E.g., transfer between two bank accounts of the same customer
- Transaction always 'succeeds' or 'fails' in its entirety
- Transaction renders database from one consistent state into another consistent state

Transactions, Recovery and Concurrency control

- Examples of problems: hard disk failure, application/DBMS crash, division by 0, …
- **Recovery**: activity of ensuring that, whichever of the problems occurred, the database is returned to a consistent state without any data loss afterwards
- **Concurrency control**: coordination of transactions that execute simultaneously on the same data so that they do not cause inconsistencies in the data because of mutual interference

ACID Properties of Transactions

- ACID stands for Atomicity, Consistency, Isolation and Durability
- Atomicity guarantees that multiple database operations that alter the database state can be treated as one indivisible unit of work
    - recovery manager can induce rollbacks where necessary, by means of UNDO operations

ACID Properties of Transactions

- Consistency refers to the fact that a transaction, if executed in isolation, renders the database from one consistent state into another consistent state
  - developer is primary responsible
  - also an overarching responsibility of the DBMS’s transaction management system

ACID Properties of Transactions

- Isolation denotes that, in situations where multiple transactions are executed concurrently, the outcome should be the same as if every transaction were executed in isolation
  - responsibility of the concurrency control mechanisms of the DBMS, as coordinated by the scheduler

ACID Properties of Transactions

- Durability refers to the fact that the effects of a committed transaction should always be persisted into the database
  - Responsibility of recovery manager (e.g. by REDO operations or data redundancy)

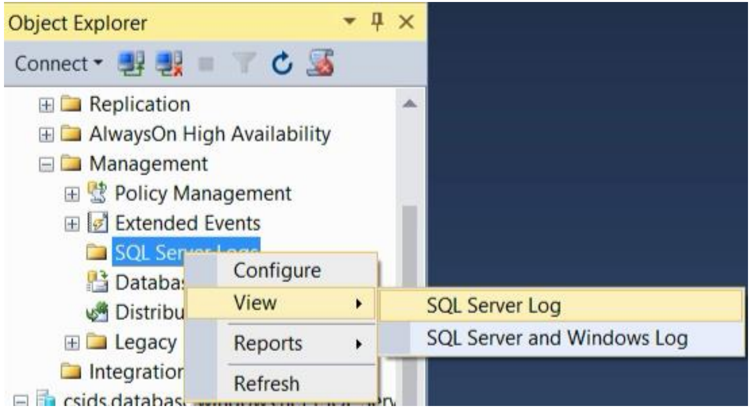
Transactions and Transaction Management

Delineating transactions and the transaction lifecycle
DBMS components involved in transaction management
Logfile

Delineating Transactions and the Transaction Lifecycle

- Transactions boundaries can be specified implicitly or explicitly
  - Explicitly
    - Developer determines when transaction starts and stops or how steps are rolled back to handle faulty situations
    - `begin transaction` and `rollback transaction` / `commit transaction`
  - Implicitly: first executable SQL statement
- Once the first operation is executed, the transaction is active
- If transaction completed successfully, it can be **committed**. If not, it needs to be **rolled back**.

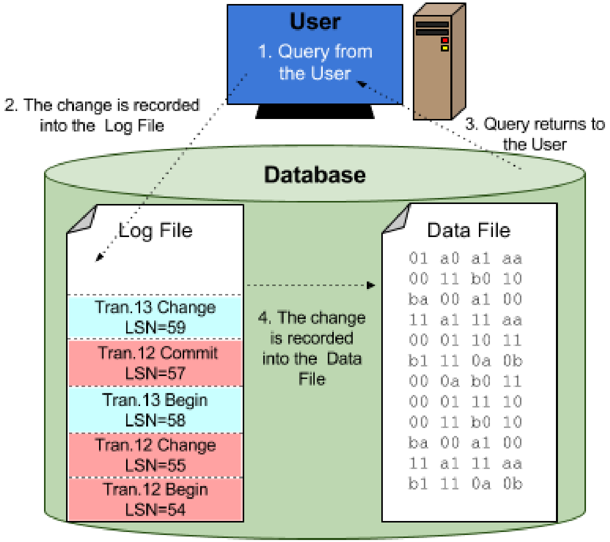
Logfile



- Logfile registers
  - a unique log sequence number
  - a unique transaction identifier
  - a marking to denote the start of a transaction, along with the transaction's start time and indication whether the transaction is read only or read/write
  - identifiers of the database records involved in the transaction, as well as the operation(s) they were subjected to
  - **before images** of all records that participated in the transaction
  - **after images** of all records that were changed by the transaction
  - the current state of the transaction (active, committed or aborted)

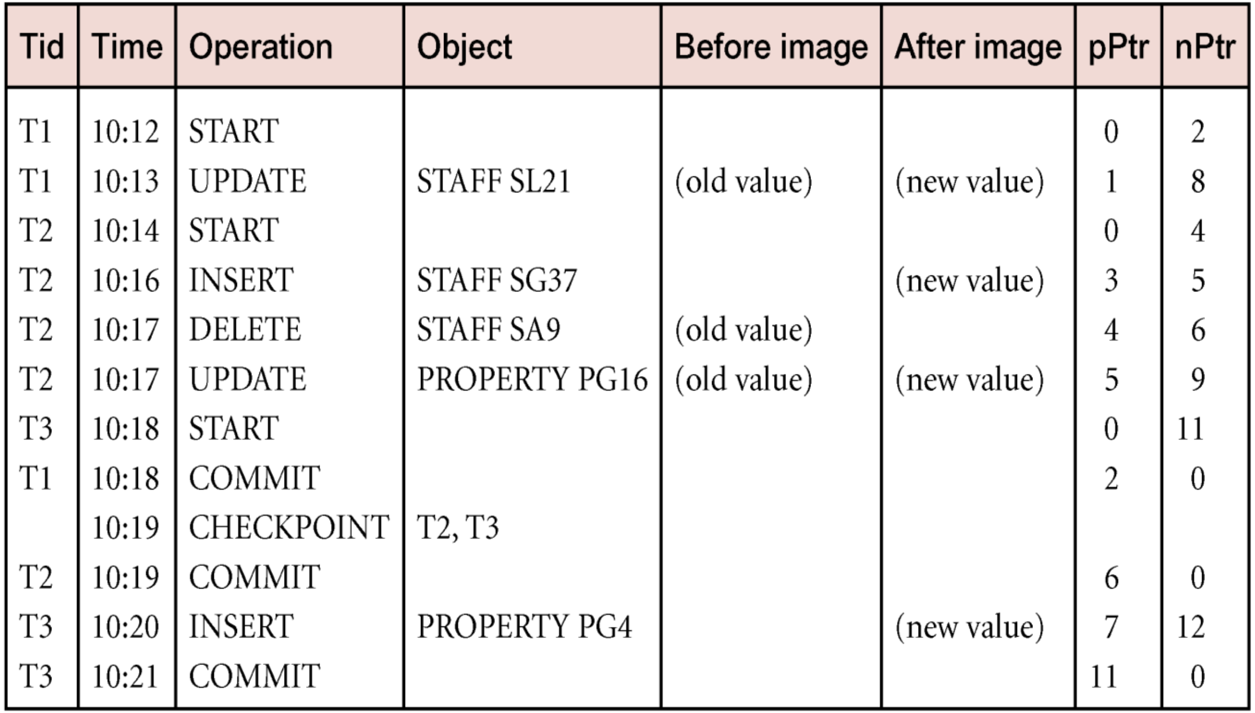
Logfile

- Logfile may also contain checkpoints
  - moments when buffered updates by active transactions, as present in the database buffer, are written to disk at once
- Write ahead log strategy
  - all updates are registered on the logfile before written to disk
  - before images are always recorded on the logfile prior to the actual values being overwritten in the physical database files



```
01 a0 a1 aa
00 11 b0 10
ba 00 a1 00
11 a1 11 aa
00 01 10 11
b1 11 0a 0b
00 0a b0 11
00 01 11 10
00 11 b0 10
ba 00 a1 00
11 a1 11 aa
b1 11 0a 0b
```

Logfile



Tid	Time	Operation	Object	Before image	After image	pPtr	nPtr
T1	10:12	START				0	2
T1	10:13	UPDATE	STAFF SL21	(old value)	(new value)	1	8
T2	10:14	START				0	4
T2	10:16	INSERT	STAFF SG37		(new value)	3	5
T2	10:17	DELETE	STAFF SA9	(old value)		4	6
T2	10:17	UPDATE	PROPERTY PG16	(old value)	(new value)	5	9
T3	10:18	START				0	11
T1	10:18	COMMIT				2	0
	10:19	CHECKPOINT	T2, T3				
T2	10:19	COMMIT				6	0
T3	10:20	INSERT	PROPERTY PG4		(new value)	7	12
T3	10:21	COMMIT				11	0

Recovery

Types of Failures
System Recovery
Media Recovery

Types of Failures

- **Transaction failure** results from an error in the logic that drives the transaction’s operations and/or in the application logic
- **System failure** occurs if the operating system or the database system crashes
- **Media failure** occurs if the secondary storage is damaged or inaccessible

System Recovery

- In case of system failure, 2 types of transactions
  - already reached the committed state before failure
  - still in an active state
- Logfile is essential to take account of which updates were made by which transactions (and when) and to keep track of before images and after images needed for the UNDO and REDO
- Database buffer flushing strategy has impact on UNDO and REDO

System Recovery

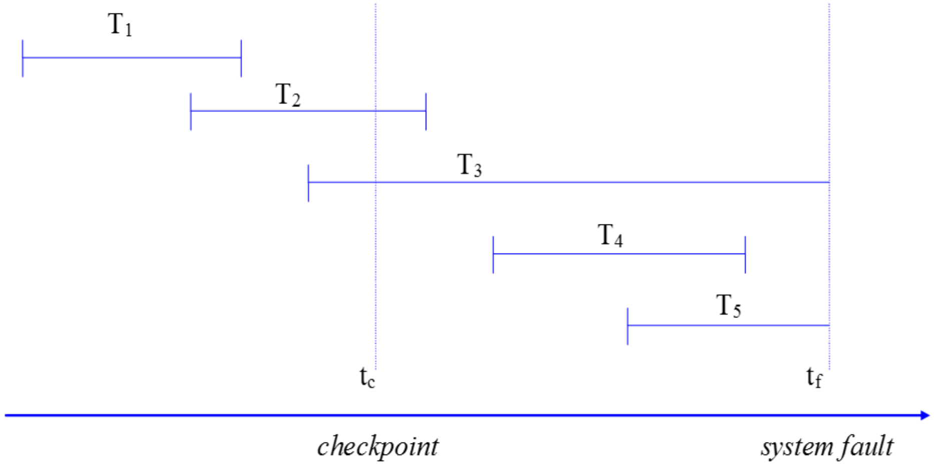
T_1: nothing

T_2: REDO

T_3: UNDO

T_4: REDO

T_5: nothing



Note 1: checkpoint denotes moment the buffer manager last ‘flushed’ the database buffer to disk!

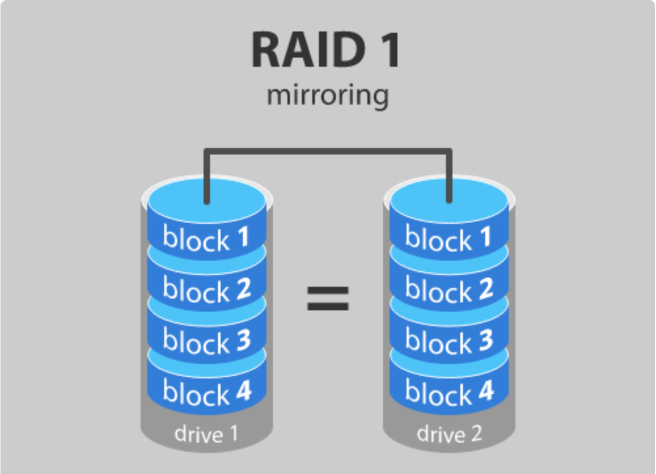
Note 2: similar reasoning can be applied in case of transaction failure (e.g. T_3, T_5)

Media Recovery

- Media recovery is invariably based on some type of data redundancy
  - Stored on offline (e.g., a tape vault) or online media (e.g., online backup hard disk drive)
- Tradeoff between cost to maintain the redundant data and time needed to restore the system
- Two types: disk mirroring and archiving

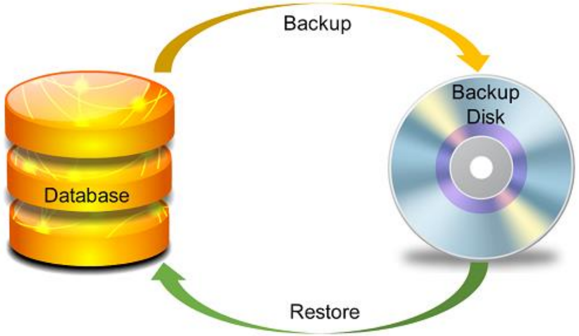
Media Recovery

- Disk mirroring
  - a (near) real time approach that writes the same data simultaneously to 2 or more physical disks
  - limited failover time but often costlier than archiving
  - (limited) negative impact on write performance but opportunities for parallel read access



Media Recovery

- Archiving
  - database files are periodically copied to other storage media (e.g. tape, hard disk)
  - trade-off between cost of more frequent backups and cost of lost data
  - full versus incremental backup



Media Recovery

- Mixed approach: rollfoward recovery
  - Archive database files and mirror logfile such that the backup data can be complemented with (a redo of) the more recent transactions as recorded in the logfile
- Note: NoSQL databases allow for temporary inconsistency, in return for increased performance **(eventual consistency)**

Concurrency Control

Typical Concurrency Problems
Schedules and Serial Schedules
Serializable Schedules
Optimistic and Pessimistic Schedulers
Locking and Locking Protocols

Typical Concurrency Problems

- Scheduler is responsible for planning the execution of transactions and their operations
- Simple serial execution would be very inefficient
- Scheduler will ensure that operations of the transactions can be executed in an interleaved way
- Interference problems could occur
  - lost update problem
  - uncommitted dependency problem
  - inconsistent analysis problem

Typical Concurrency Problems

- **Lost update** problem occurs if an otherwise successful update of a data item by a transaction is overwritten by another transaction that wasn’t ‘aware’ of the first update

time	T_1	T_2	$amount_x$
t_1		begin transaction	100
t_2	begin transaction	read(amount$_x$)	100
t_3	read(amount$_x$)	amount$_x$ = amount$_x$ + 120	100
t_4	amount$_x$ = amount$_x$ - 50	write(amount$_x$)	220
t_5	write(amount$_x$)	commit	50
t_6	commit		50

Typical Concurrency Problems

- If a transaction reads one or more data items that are being updated by another, as yet uncommitted, transaction, we may run into the uncommitted **dependency** (a.k.a. **dirty read**) problem

time	T_1	T_2	*amount$_x$*
t_1		begin transaction	100
t_2		read(amount$_x$)	100
t_3		amount$_x$ = amount$_x$ + 120	100
t_4	begin transaction	write(amount$_x$)	220
t_5	read(amount$_x$)		220
t_6	amount$_x$ = amount$_x$ – 50	rollback	100
t_7	write(amount$_x$)		170
t_8	commit		170

Typical Concurrency Problems

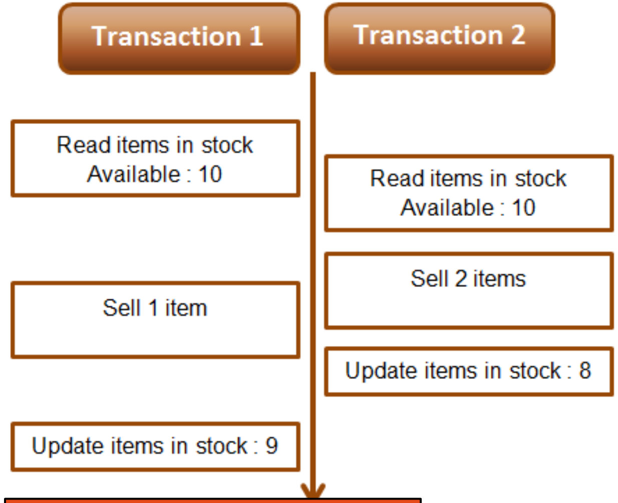
- The **inconsistent analysis** problem denotes a situation where a transaction reads partial results of another transaction that simultaneously interacts with (and updates) the same data items.

time	T_1	T_2	$amount_x$	y	z	*sum*
t_1		begin transaction	100	75	60	
t_2	begin transaction	sum = 0	100	75	60	0
t_3	read($amount_x$)	read($amount_x$)	100	75	60	0
t_4	$amount_x = amount_x – 50$	$sum = sum + amount_x$	100	75	60	100
t_5	write($amount_x$)	read($amount_y$)	50	75	60	100
t_6	read($amount_z$)	$sum = sum + amount_y$	50	75	60	175
t_7	$amount_z = amount_z + 50$		50	75	60	175
t_8	write($amount_z$)		50	75	110	175
t_9	commit	read($amount_z$)	50	75	110	175
t_{10}		$sum = sum + amount_z$	50	75	110	285
t_{11}		commit	50	75	110	285

Typical Concurrency Problems

- **nonrepeatable read (unrepeatable read)** occurs when a transaction T_1 reads the same row multiple times, but obtains different subsequent values, because another transaction T_2 updated this row in the meantime
- **phantom reads** can occur when a transaction T_2 is executing insert or delete operations on a set of rows that are being read by a transaction T_1

Lost update



Transaction 1

Transaction 2

Read items in stock
Available : 10

Read items in stock
Available : 10

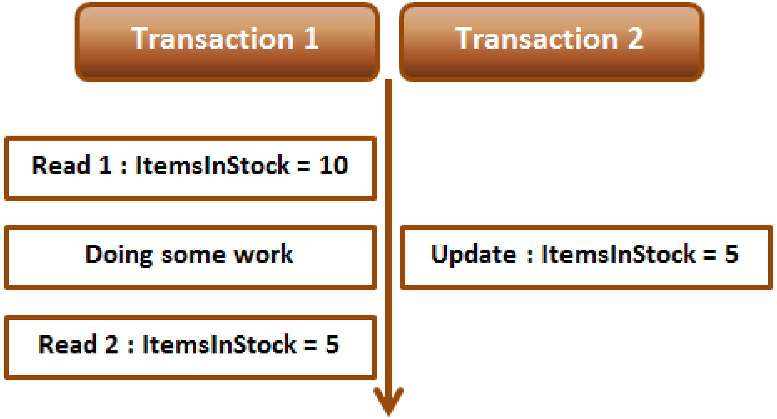
Sell 2 items

Sell 1 item

Update items in stock : 8

Update items in stock : 9

Non repeatable read



Transaction 1

Transaction 2

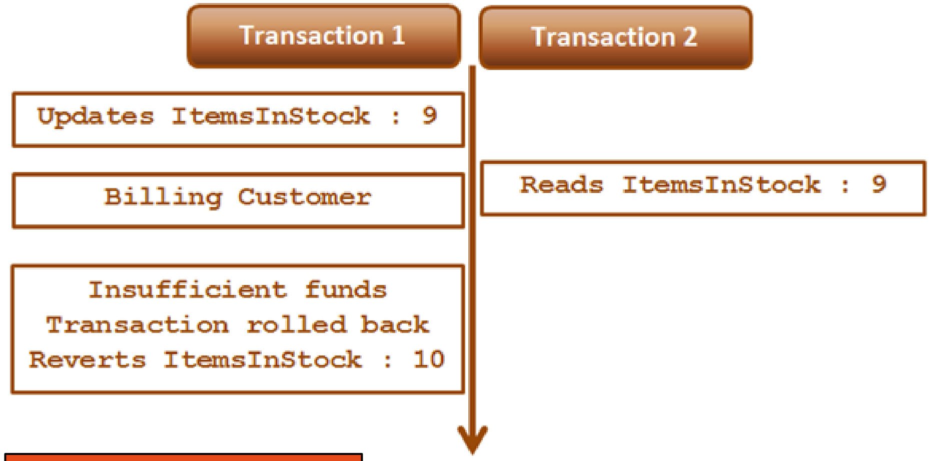
Read 1 : ItemsInStock = 10

Doing some work

Update : ItemsInStock = 5

Read 2 : ItemsInStock = 5

Dirty read



Transaction 1

Transaction 2

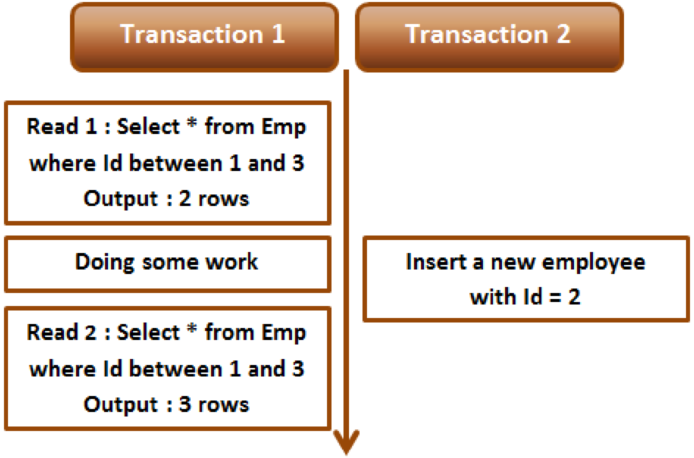
Updates ItemsInStock : 9

Billing Customer

Reads ItemsInStock : 9

Insufficient funds
Transaction rolled back
Reverts ItemsInStock : 10

Phantom read



Transaction 1

Transaction 2

Read 1 : Select * from Emp
where Id between 1 and 3
Output : 2 rows

Doing some work

Insert a new employee
with Id = 2

Read 2 : Select * from Emp
where Id between 1 and 3
Output : 3 rows

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Schedules and Serial Schedules

- A *schedule* S is a set of n transactions, and a sequential ordering over the statements of these transactions, for which the following property holds: *“For each transaction T that participates in a schedule S and for all statements s_i and s_j that belong to the same transaction T: if statement s_i precedes statement s_j in T, then s_i is scheduled to be executed before s_j in S.”*
- Schedule preserves the ordering of the individual statements *within* each transaction but allows an arbitrary ordering of statements between transactions

Schedules and Serial Schedules

- Schedule S is *serial* if all statements si of the same transaction T are scheduled consecutively, without any interleave with statements from a different transaction
- Serial schedules prevent parallel transaction execution
- We need a non-serial, correct schedule!

Optimistic and Pessimistic Schedulers

- Pessimistic protocol
  - it is likely that transactions will interfere and cause conflicts
  - execution of transaction’s operations delayed until scheduler can schedule them in such a way that chance of conflicts is minimized
  - will reduce the throughput to some extent
  - E.g., a serial scheduler

Locking and Locking Protocols

Purposes of Locking
Two-Phase Locking Protocol (2PL)
Cascading Rollbacks
Dealing with Deadlocks
Isolation Levels
Lock Granularity

Purposes of Locking

- Purpose of *locking* is to ensure that, in situations where different concurrent transactions attempt to access the same database object, access is only granted in such a way that no conflicts can occur
- A lock is a variable that is associated with a database object, where the variable's value constrains the types of operations that are allowed to be executed on the object at that time
- Lock manager is responsible for granting locks (*locking*) and releasing locks (*unlocking*) by applying a locking protocol

Purposes of Locking

- An **exclusive lock** (x-lock or write lock) means that a single transaction acquires the sole privilege to interact with that specific database object at that time
  - no other transactions are allowed to read or write it
- A **shared lock** (s-lock or read lock) guarantees that no other transactions will update that same object for as long as the lock is held
  - other transactions may hold a shared lock on that same object as well, however they are only allowed to read it

Purposes of Locking

- If a transaction wants to update an object, an exclusive lock is required
  - only acquired if no other transactions hold any lock on the object
- Compatibility matrix

Type of lock(s) currently held on object

		unlocked	*shared*	*exclusive*
Type of lock requested	*unlock*	-	yes	yes
	shared	yes	yes	no
	exclusive	yes	no	no

Purposes of Locking

- Lock manager implements locking protocol
  - set of rules to determine what locks can be granted in what situation (based on e.g. compatibility matrix)
- Lock manager also uses a lock table
  - which locks are currently held by which transaction, which transactions are waiting to acquire certain locks, etc.
- Lock manager needs to ensure ‘fairness’ of transaction scheduling to, e.g., avoid starvation

Isolation Levels

- Level of transaction isolation offered by 2PL may be too stringent
- Limited amount of interference may be acceptable for better throughput
- Long-term lock is granted and released according to a protocol, and is held for a longer time, until the transaction is committed
- A short-term lock is only held during the time interval needed to complete the associated operation
  - use of short-term locks violates rule 3 of the 2PL protocol
  - can be used to improve throughput!

Isolation Levels

- Reader: statement that reads data using a shared lock (SELECT)
- Writer: statement that writes data, using an exclusive lock (INSERT, UPDATE, DELETE)
- Writers can't be influenced in SQL Server with respect to the locks they claim and the duration of these locks. They always claim an exclusive lock.
  - Readers can be influenced explicitly
  - Using isolation levels

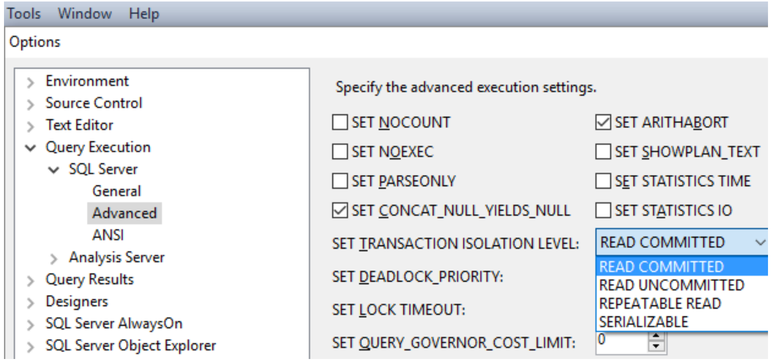
Isolation Levels

- This might have an implicit influence on the behaviour of writers
- Isolation level = setting at session or query level

Isolation Levels in SQL Server

- Based on a pessimistic concurrency control (locking)
  1. READ UNCOMMITTED
  2. READ COMMITTED (default)
  3. REPEATABLE READ
  4. SERIALIZABLE

- locks take longer
- more consistency
- less concurrency



Specify the advanced execution settings.

□ SET NOCOUNT
□ SET NOEXEC
□ SET PARSEONLY
☑ SET CONCAT_NULL_YIELDS_NULL
☑ SET ARITHABORT
□ SET SHOWPLAN_TEXT
□ SET STATISTICS TIME
□ SET STATISTICS IO

SET TRANSACTION ISOLATION LEVEL: READ COMMITTED
READ COMMITTED
READ UNCOMMITTED
REPEATABLE READ
SERIALIZABLE

SET DEADLOCK_PRIORITY:

SET LOCK TIMEOUT:

SET QUERY_GOVERNOR_COST_LIMIT: 0

Isolation Levels

- **Read uncommitted** is the lowest isolation level. Long-term locks are not taken into account; it is assumed that concurrency conflicts do not occur or simply that their impact on the transactions with this isolation level are not problematic. This isolation level is typically only allowed for read-only transactions, which do not perform updates anyway.
- **Read committed** uses long-term write locks, but short-term read locks. In this way, a transaction is guaranteed not to read any data that are still being updated by a yet uncommitted transaction. This resolves the lost update as well as the uncommitted dependency problem. However, the inconsistent analysis problem may still occur with this isolation level, as well as nonrepeatable reads and phantom reads.

Isolation Levels

- **Repeatable read** uses both long-term read locks and write locks. Thus, a transaction can read the same row repeatedly, without interference from insert, update or delete operations by other transactions. Still, the problem of phantom reads remains unresolved with this isolation level.
- **Serializable** is the strongest isolation level and corresponds roughly to an implementation of 2PL. Now, phantom reads are also avoided. Note that in practice, the definition of serializability in the context of isolation levels merely comes down to the absence of concurrency problems, such as nonrepeatable reads and phantom reads.

Isolation Levels

Isolation level	Lost update	Uncommitted dependency	Inconsistent analysis	Nonrepeatable read	Phantom read
Read uncommitted	Yes	Yes	Yes	Yes	Yes
Read committed	No	No	Yes	Yes	Yes
Repeatable read	No	No	No	No	Yes
Serializable	No	No	No	No	No

Read uncommitted

- Lowest isolation level
- Reader doesn't ask for shared lock
- Reader never in conflict with writer (that holds exclusive lock)
- Reader reads uncommitted data (= dirty read)

Read committed

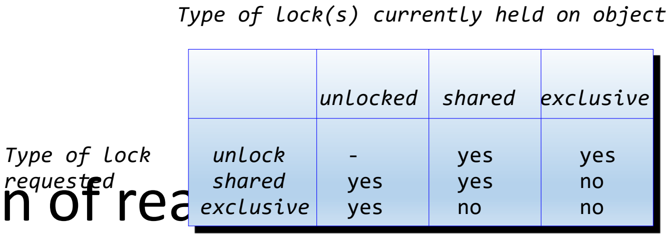
- Default isolation level
- Lowest level that prevents dirty reads
- Reader reads only committed data
- Reader claims shared lock
- If at that moment a writer holds an exclusive lock, reader has to wait for shared lock

Read committed

- Reader keeps shared lock until data is obtained (end of SELECT), not until end of transaction (= short-term lock)
  - Reading again of data in same transaction can give different result
  - = non-repeatable reads or inconsistent analysis
  - Acceptable for many, but not all applications

Repeatable read

- Reader claims shared lock and holds it until end of transaction (= long-term lock)
- Other transaction can't get exclusive lock until end of transaction of rea
- Repeatable read = consistent analysis
- Also avoids lost update (possible in 1 & 2) by claiming shared lock at begin transaction (using SELECT because only readers can be influenced, not writers)



Type of lock(s) currently held on object

Type of lock requested		*unlocked*	*shared*	*exclusive*
	unlock	-	yes	yes
	shared	yes	yes	no
	exclusive	yes	no	no

Serializable

- Repeatable read only locks rows found with first SELECT
- Same SELECT in same transaction can give new row (added by other transactions) = phantoms
- Serializable avoids phantoms
- Locks all keys (current and future) that correspond to WHERE-clause

Dealing with Deadlocks

- A deadlock occurs if 2 or more transactions are waiting for one another’s’ locks to be released
- Example

time	T_1	T_2
t_1	begin transaction	
t_2	x-lock(amount$_x$)	begin transaction
t_3	read(amount$_x$)	x-lock(amount$_y$)
t_4	amount$_x$ = amount$_x$ - 50	read(amount$_y$)
t_5	write(amount$_x$)	amount$_y$ = amount$_y$ - 30
t_6	x-lock(amount$_y$)	write(amount$_y$)
t_7	wait	x-lock(amount$_x$)
t_8	wait	wait

Dealing with Deadlocks

- Deadlock prevention can be achieved by static 2PL
  - transaction must acquire all its locks upon the start
- Detection and resolution
  - wait for graph consisting of nodes representing active transactions and directed edges $T_i \rightarrow T_j$ for each transaction T_i that is waiting to acquire a lock currently held by transaction T_j
  - deadlock exists if the wait for graph contains a cycle
  - victim selection

Lock Granularity

- Database object for locking can be a tuple, a column, a table, a tablespace, a disk block, etc.
- Trade-off between locking overhead and transaction throughput
- Many DBMSs provide the option to have the optimal granularity level determined by the database system

Back-up mechanism

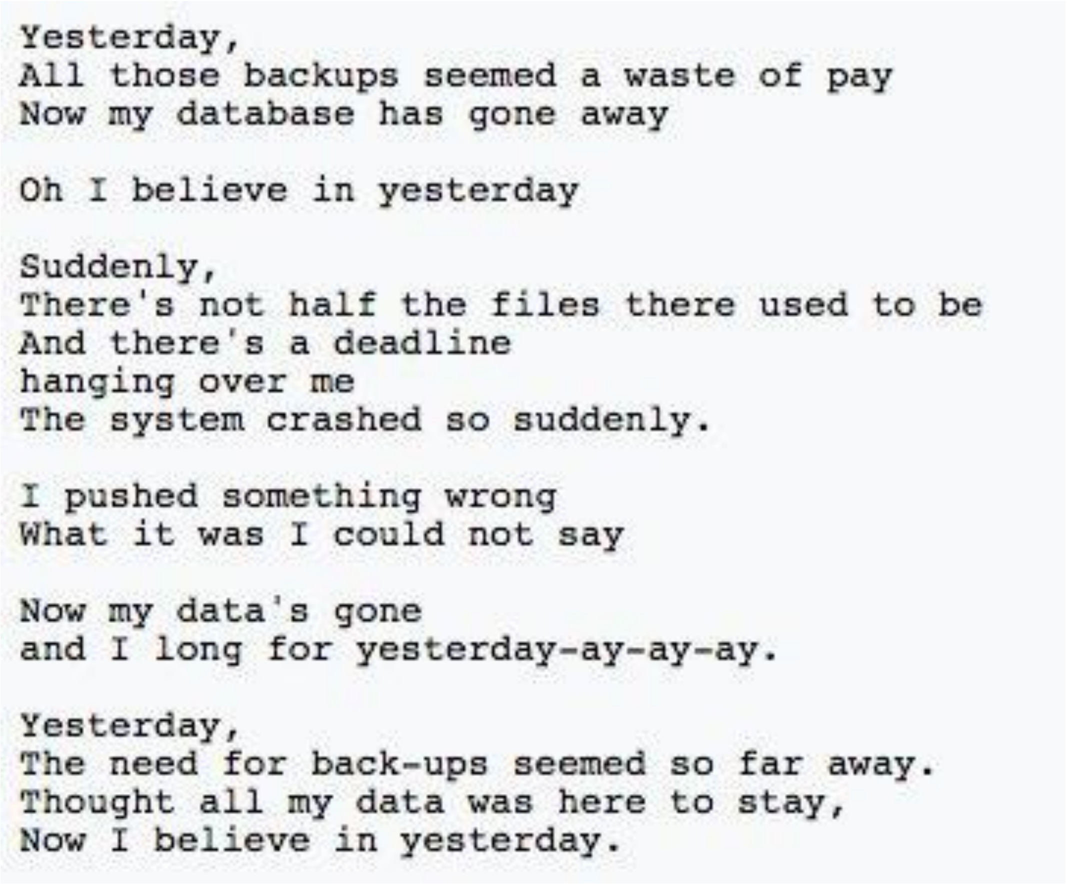
- NEVER use OS backup for a database because
  - Only single or very few database files → incremental backup impossible
  - Data and logfiles are always open
  - Due to running transactions data is inconsistent after restore
  - Use backup tools provided by database vendor: e.g. Microsoft BACKUP command

Back-up mechanism

- On a regular basis the data and logfiles are automatically copied to a safe location
  - Without stopping the system
  - Copies are kept on offline storage
- 2 approaches
  - Complete back-up or Incremental back-up
  - Possible backup strategy: full backup on Sunday night, incremental backup on other nights;
  - Restore: last full backup + subsequent incremental backups, can be very time-consuming => All work of current day is lost!

Back-up

- https://www.youtube.com/watch?v=l7-6m2cE6JM



Yesterday,
All those backups seemed a waste of pay
Now my database has gone away

Oh I believe in yesterday

Suddenly,
There's not half the files there used to be
And there's a deadline
hanging over me
The system crashed so suddenly.

I pushed something wrong
What it was I could not say

Now my data's gone
and I long for yesterday-ay-ay-ay.

Yesterday,
The need for back-ups seemed so far away.
Thought all my data was here to stay,
Now I believe in yesterday.

Source

- Principles of Database Management
  [Wilfried Lemahieu – Seppe Vanden Broucke – Bart Baesens]