Database Management Systems

Lecture 2

Transactions. Concurrency Control

Conflict Serializability

- *C* – set of transactions
- *Sch(C)* – the set of schedules for *C*
- *Op(C)* – set of operations of the transactions in *C*
- consider schedule $S \in Sch(C)$
- the *conflict relation* of *S* is defined as:
    - *conflict(S)* = $\{(op_1, op_2) \mid op_1, op_2 \in Op(C)$, op_1 occurs before op_2 in S, op_1 and op_2 are in conflict$\}$

Conflict Serializability

- C – set of transactions
- $Sch(C)$ – the set of schedules for C
- two schedules S_1 and $S_2 \in Sch(C)$ are <u>*conflict equivalent*</u>, written $S_1 \equiv_c S_2$, if $conflict(S_1) = conflict(S_2)$, i.e.:
  - S_1 and S_2 contain the same operations of the same transactions and
  - every pair of conflicting operations is ordered in the same manner in S_1 and S_2

Conflict Serializability

S1

T1	T2
Read(A)	
A := A – 100	
Write(A)	
Read(B)	
B := B + 200	
Write(B)	
	Read(A)
	A := A * 0.2
	Write(A)
	Read(B)
	B := B + 300
	Write(B)

S2

T1	T2
Read(A)	
A := A – 100	
Write(A)	
	Read(A)
	A := A * 0.2
	Write(A)
Read(B)	
B := B + 200	
Write(B)	
	Read(B)
	B := B + 300
	Write(B)

conflict(S1) = conflict(S2)

=> S1 $\equiv_c$ S2

conf(S1) = {(Read(T1, A), Write(T2, A)), (Write(T1, A), Read(T2, A)), (Write(T1, A), Write(T2, A)), (Read(T1, B), Write(T2, B)), (Write(T1, B), Read(T2, B)), (Write(T1, B), Write(T2, B))}

Conflict Serializability

S1

T1	T2
Read(A)	
A := A – 100	
Write(A)	
Read(B)	
B := B + 200	
Write(B)	
	Read(A)
	A := A * 0.2
	Write(A)
	Read(B)
	B := B + 300
	Write(B)

S3

T1	T2
	Read(A)
	A := A * 0.2
	Write(A)
	Read(B)
	B := B + 300
	Write(B)
Read(A)	
A := A – 100	
Write(A)	
Read(B)	
B := B + 200	
Write(B)	

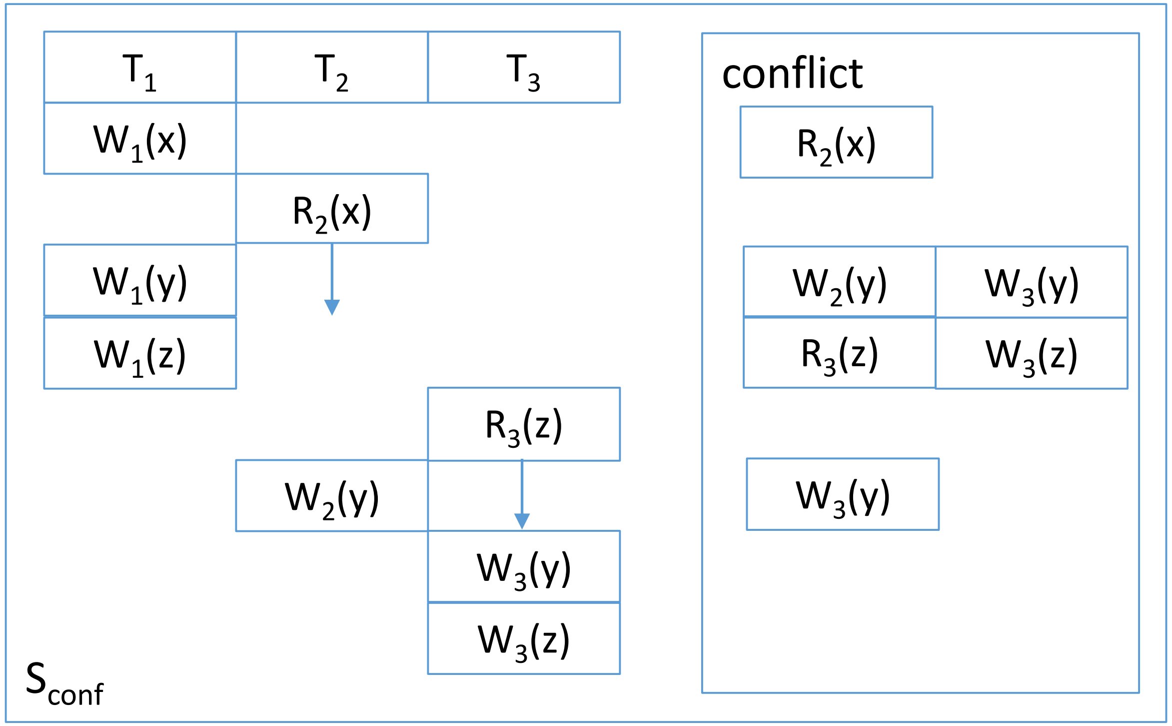
conflict(S1) ≠ conflict(S3)

=> $S1 \not\equiv_c S3$

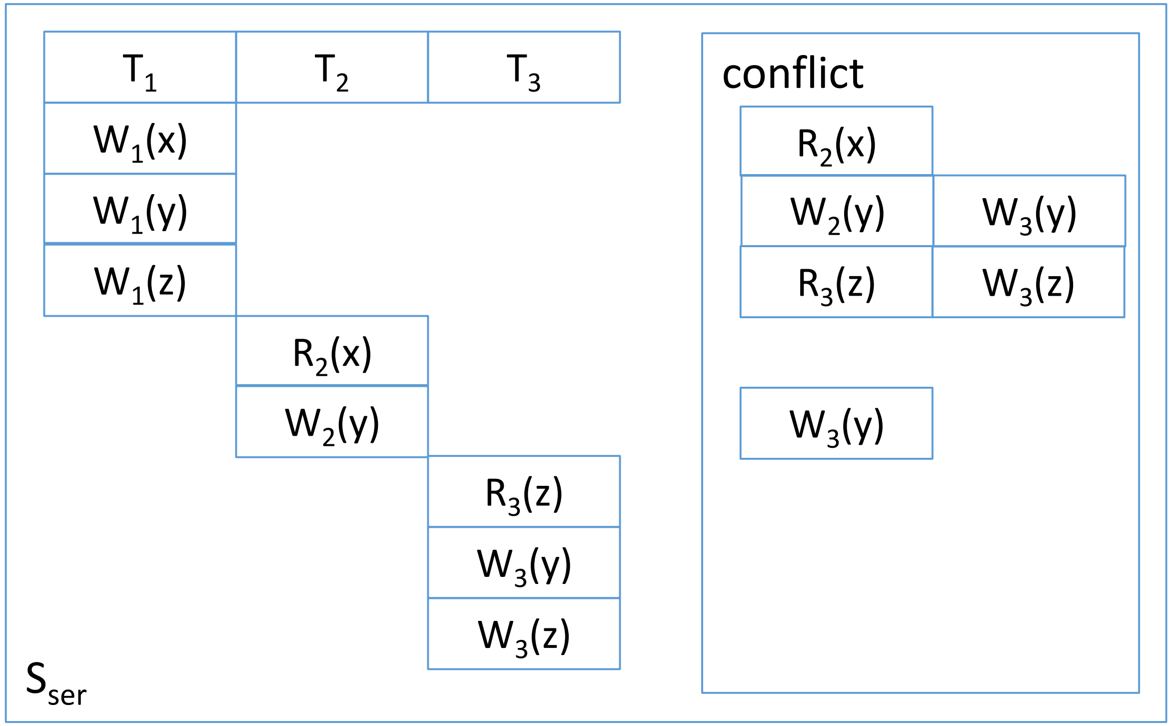
Conflict Serializability

- C – set of transactions
- $Sch(C)$ – the set of schedules for C
- let S be a schedule in $Sch(C)$
- schedule S is *conflict serializable* if there exists a serial schedule $S_0 \in Sch(C)$ such that $S \equiv_c S_0$, i.e., S is conflict equivalent to some serial schedule

Conflict Serializability



conflict serializable schedule



serial schedule

Conflict Serializability - Precedence Graph

- let *S* be a schedule in *Sch(C)*
- the *precedence graph* (*serializability graph*) of *S* contains*:*
  - one node for every committed transaction in *S*
  - an arc from T_i to T_j if an action in T_i precedes and conflicts with one of the actions in T_j

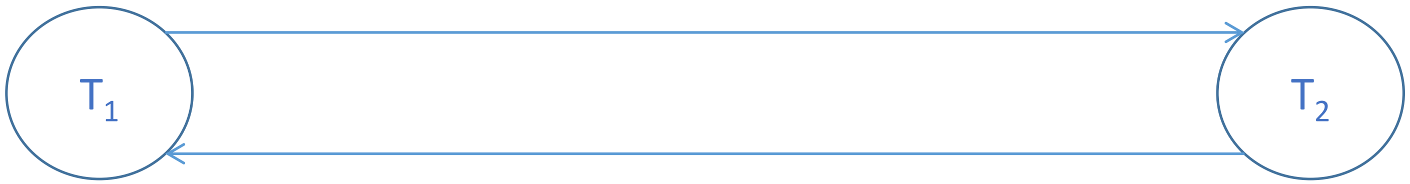
- Theorem:
  - a schedule $S \in Sch(C)$ is conflict serializable if and only if its precedence graph is acyclic

Conflict Serializability - Precedence Graph

- example - a schedule that is not conflict serializable:

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

- the precedence graph has a cycle:



Conflict Serializability - Precedence Graph

- algorithm to test the conflict serializability of a schedule $S \in Sch(C)$

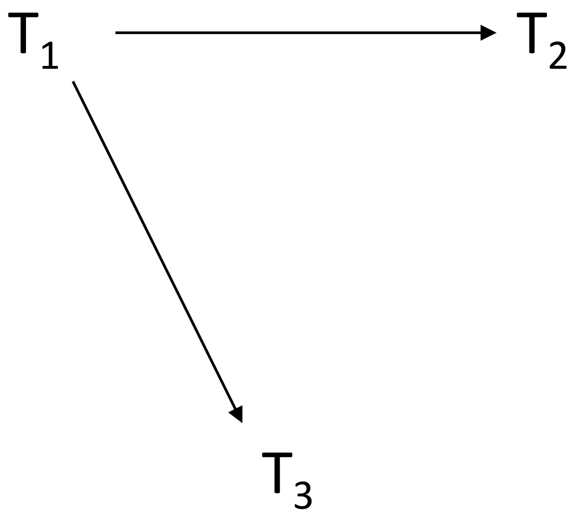
1. create a node labeled T_i in the precedence graph for every committed transaction T_i in the schedule
2. create an arc (T_i,T_j) in the precedence graph if T_j executes a Read(A) after a Write(A) executed by T_i
3. create an arc (T_i,T_j) in the precedence graph if T_j executes a Write(A) after a Read(A) executed by T_i
4. create an arc (T_i,T_j) in the precedence graph if T_j executes a Write(A) after a Write(A) executed by T_i
5. *S* is conflict serializable if and only if the resulting precedence graph has no cycles

Conflict Serializability - Precedence Graph

- examples
- let S_1 be a schedule over $\{T_1, T_2, T_3\}$:

T_1	T_2	T_3
$R_1(x)$		
$R_1(y)$		
	$R_2(y)$	
$W_1(x)$		
		$R_3(x)$
	$W_2(y)$	
		$W_3(x)$

- the precedence graph for S_1:

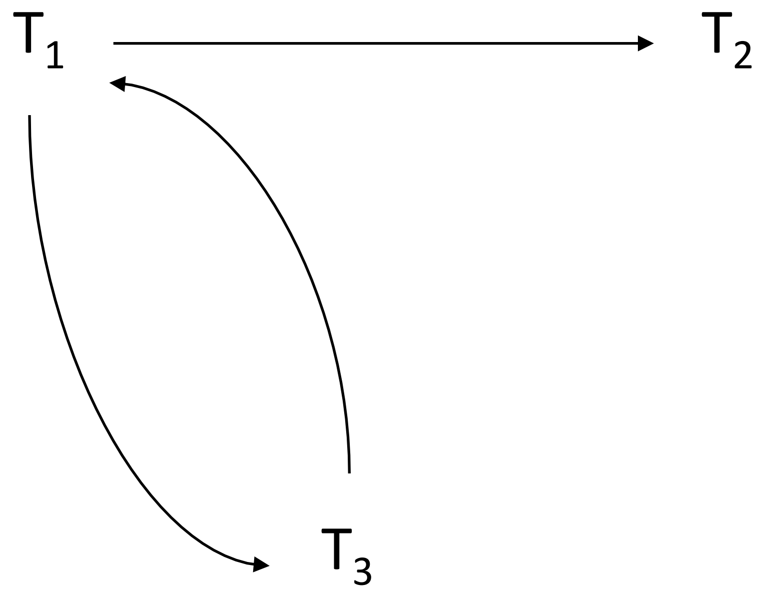


Conflict Serializability - Precedence Graph

- examples
- let S_2 be a schedule over $\{T_1, T_2, T_3\}$:

T_1	T_2	T_3
$R_1(x)$		
$R_1(y)$		
		$R_3(x)$
	$R_2(y)$	
$W_1(x)$		
	$W_2(y)$	
		$W_3(x)$

- the precedence graph for S_2:



Conflict Serializability

- every conflict serializable schedule is serializable (in the absence of inserts / deletes, when items can only be updated)
- there are serializable schedules that are not conflict serializable
- *S* is equivalent to the serial execution of transactions T_1, T_2, T_3 (in this order), but it is not conflict equivalent to this serial schedule (the write operations in T_1 and T_2 are ordered differently)

S

T_1	T_2	T_3
$R_1(A)$		
	$W_2(A)$	
	commit	
$W_1(A)$		
commit		
		$W_3(A)$
		commit

View Serializability

- conflict serializability is a sufficient condition for serializability, but it is not a necessary one
- *view serializability*
  - a more general, sufficient condition for serializability
  - based on *view-equivalence,* a less stringent form of equivalence

View Serializability

- C – set of transactions
- $Sch(C)$ – the set of schedules for C
- let T_i, $T_j \in C$, S_1, $S_2 \in Sch(C)$; S_1 and S_2 are <u>*view equivalent*</u>, written $S_1 \equiv_v S_2$, if the following conditions are met:
  - if T_i reads the initial value of V in S_1, then T_i also reads the initial value of V in S_2;
  - if T_i reads the value of V written by T_j in S_1, then T_i also reads the value of V written by T_j in S_2;
  - if T_i writes the final value of V in S_1, then T_i also writes the final value of V in S_2.
- i.e.:

each transaction performs the same computation in S_1 and S_2

and

S_1 and S_2 produce the same final database state.

View Serializability

S1

T1	T2
Read(A)	
A := A – 100	
Write(A)	
Read(B)	
B := B + 200	
Write(B)	
	Read(A)
	A := A * 0.2
	Write(A)
	Read(B)
	B := B + 300
	Write(B)

S2

T1	T2
Read(A)	
A := A – 100	
Write(A)	
	Read(A)
	A := A * 0.2
	Write(A)
Read(B)	
B := B + 200	
Write(B)	
	Read(B)
	B := B + 300
	Write(B)

$S1 \equiv_v S2$

View Serializability

S1

T1	T2
Read(A)	
A := A – 100	
Write(A)	
Read(B)	
B := B + 200	
Write(B)	
	Read(A)
	A := A * 0.2
	Write(A)
	Read(B)
	B := B + 300
	Write(B)

S3

T1	T2
	Read(A)
	A := A * 0.2
	Write(A)
	Read(B)
	B := B + 300
	Write(B)
Read(A)	
A := A – 100	
Write(A)	
Read(B)	
B := B + 200	
Write(B)	

$$S1 \not\equiv_v S3$$

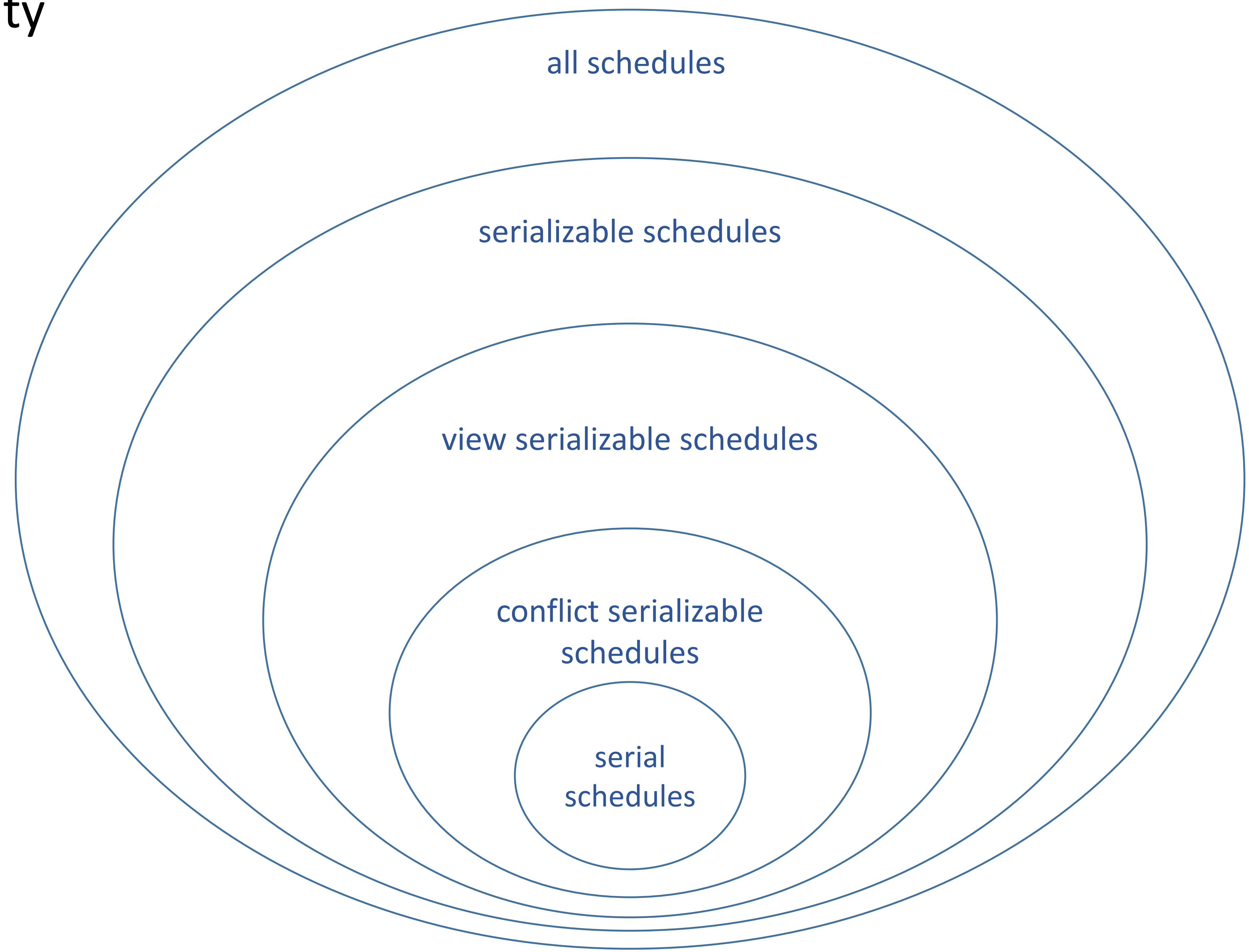
View Serializability

- C – set of transactions
- $Sch(C)$ – the set of schedules for C
- a schedule $S \in Sch(C)$ is ***view serializable*** if there exists a serial schedule $S_0 \in Sch(C)$ such that $S \equiv_v S_0$, i.e., S is view equivalent to some serial schedule

T_1	T_2	T_3
$R_1(A)$		
	$W_2(A)$	
	commit	
$W_1(A)$		
commit		
		$W_3(A)$
		commit

T_1	T_2	T_3
$R_1(A)$		
$W_1(A)$		
commit		
	$W_2(A)$	
	commit	
		$W_3(A)$
		commit

Serializability



Recoverable Schedules

- consider schedule *S* over $\{T_1, T_2\}$

T_1	T_2
Read(x)	
x := x + 10	
Write(x)	
	Read(x)
	x := x * 5
	Write(x)
	Read(y)
	y := y * 5
	Write(y)
	commit
abort	

- T_2 operates on a value of x that shouldn't have been in the database, since T_1 aborted

Recoverable Schedules

T_1	T_2
Read(x)	
x := x + 10	
Write(x)	
	Read(x)
	x := x * 5
	Write(x)
	Read(y)
	y := y * 5
	Write(y)
	commit
abort	

- cannot cascade the abort of T_1, since T_2 has already committed
- schedule *S* is *unrecoverable*

Recoverable Schedules

- recoverable schedule
  - a schedule in which a transaction T commits only after all transactions whose changes T read commit

Avoiding Cascading Aborts

T_1	T_2
Write(x)	
	Read(x)
	Write(y)
abort	
	=> abort

- a schedule in which a transaction T is reading only changes of committed transactions is said to <u>avoid cascading aborts</u>
- avoiding cascading aborts => recoverable schedules

Lock-Based Concurrency Control

- technique used to guarantee serializable, recoverable schedules
- *lock*
  - a tool used by the transaction manager to control concurrent access to data
  - prevents a transaction from accessing a data object while another transaction is accessing the object
- *transaction protocol*
  - a set of rules enforced by the transaction manager and obeyed by all transactions
  - example – simple protocol: before a transaction can read / write an object, it must acquire an appropriate lock on the object
  - locks in conjunction with transaction protocols allow interleaved executions

Lock-Based Concurrency Control

- *transaction protocol*
  - it's impractical for the DBMS to test the serializability of schedules, since the operating system could determine the interleaving of operations
  - instead, the DBMS uses protocols known to produce serializable schedules

Lock-Based Concurrency Control

- *<u>SLock</u>* (*shared* or *read lock*)
  - if a transaction holds an SLock on an object, it can read the object, but it cannot modify it
- *<u>XLock</u>* (*exclusive* or *write lock*)
  - if a transaction holds an XLock on an object, it can both read and write the object
- if a transaction holds an SLock on an object, other transactions can be granted SLocks on the object, but they cannot acquire XLocks on it
- if a transaction holds an XLock on an object, other transactions cannot be granted either SLocks or XLocks on the object

	Shared	Exclusive
Shared	Yes	No
Exclusive	No	No

Lock-Based Concurrency Control

- lock upgrade
  - an SLock granted to a transaction can be upgraded to an XLock
- transactions are issuing lock requests to the lock manager
- locks are held until being explicitly released by transactions
- lock acquire / lock release requests are automatically inserted into transactions by the DBMS (not the user's responsibility)
- locking / unlocking
  - atomic operations

Lock-Based Concurrency Control

- *lock table*
  - structure used by the lock manager to keep track of granted locks / lock requests
  - entry in the lock table (corresponding to one data object):
    - number of transactions holding a lock on the data object
    - lock type (SLock / XLock)
    - pointer to a queue of lock requests

Lock-Based Concurrency Control

- *transactions table*
    - structure maintained by the DBMS
    - one entry / transaction
    - keeps a list of locks held by every transaction

References

- [Ra00] RAMAKRISHNAN, R., GEHRKE, J., Database Management Systems (2nd Edition), McGraw-Hill, 2000
- [Le99] LEVENE, M., LOIZOU, G., A Guided Tour of Relational Databases and Beyond, Springer, 1999
- [Ga08] GARCIA-MOLINA, H., ULLMAN, J., WIDOM, J., Database Systems: The Complete Book, Prentice Hall Press, 2008
- [Ra07] RAMAKRISHNAN, R., GEHRKE, J., Database Management Systems, McGraw-Hill, 2007, http://pages.cs.wisc.edu/~dbbook/openAccess/thirdEdition/slides/slides3ed.html
- [Si10] SILBERSCHATZ, A., KORTH, H., SUDARSHAN, S., Database System Concepts, McGraw-Hill, 2010, http://codex.cs.yale.edu/avi/db-book/
- [Ul11] ULLMAN, J., WIDOM, J., A First Course in Database Systems, http://infolab.stanford.edu/~ullman/fcdb.html