COMP 3311
DATABASE MANAGEMENT SYSTEMS

TUTORIAL 10
TRANSACTIONS & CONCURRENCY CONTROL

REVIEW: TRANSACTIONS

- A ***transaction*** is a collection of operations that forms *a single logical unit* of work.

- The main purpose of a transaction is to ensure that the database remains in a consistent state in the presence of multiple and concurrent operations.

- **ACID** properties of transactions:
  Atomicity: either all operations succeed, or none succeed.
  Consistency: preserve database consistency.
  Isolation: transactions are unaware of each other.
  Durability: results of operations persist.

- Two main issues to deal with:
  - Concurrent execution of multiple transactions.
  - Various kinds of failures, such as hardware failures and system crashes.

REVIEW: SERIALIZABILITY

Schedule: chronological execution order of transaction operations.

- Must include all read and write operations of a transaction.
- Must preserve the order of operations for each transaction.

Serializability

Conflict equivalent schedules: transforming a schedule *S* into a schedule *S′* by a series of swaps of non-conflicting operations.

Conflict serializable schedule: a schedule that is conflict equivalent to a serial schedule.

Testing for Serializability

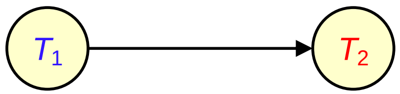
Precedence graph — a directed graph where the vertices are the transactions (names) and there is an edge from T_i to T_j if they conflict on a data item and T_i accessed the data item earlier than T_j.

☞ A schedule is conflict-serializable *if and only if* its precedence graph of committed transactions does not have a cycle.

EXAMPLE: SERIALIZABILITY

Schedule 1

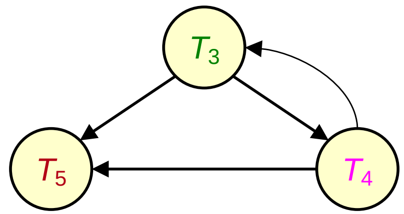
T_1	T_2
read(A)	
write(A)	
read(B)	
	read(A)
	write(A)
write(B)	



Precedence Graph

Schedule 2

T_3	T_4	T_5
read(Q)		
	write(Q)	
write(Q)		
		write(Q)



Precedence Graph

Is it conflict serializable?

Yes Equivalent to T_1, T_2.

Is it conflict serializable?

No There is a cycle in the precedence graph.

REVIEW: RECOVERABILITY

Recoverable Schedule

– If a transaction T_j reads a data item previously written by a transaction T_i, then the commit operation of T_i must appear before the commit operation of T_j.

Non-recoverable Schedule

– The following schedule is not recoverable if T_2 commits immediately after read(A). **Why?**

T_1	T_2
write(A)	
	read(A)
	commit
read(B)	
abort	

T_2 reads data item A written by T_1 and then T_1 aborts. Therefore, the data item read by T_2 is not valid.

EXAMPLE: RECOVERABILITY

Cascading Rollback

- A single transaction failure leads to a series of transaction rollbacks.
- Can lead to the undoing of a significant amount of work.

☞ **It is highly desirable for a schedule to be cascadeless.**

T_1	T_2	T_3
read(A)		
write(A)		
	read(A)	
	write(A)	
		read(A)
abort		
	commit	
		commit

If T_1 fails, T_2 and T_3 must be rolled back.

➡

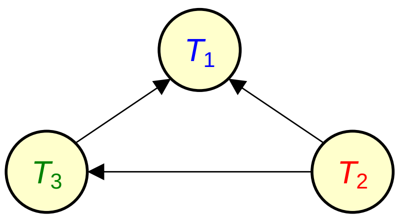
T_1	T_2	T_3
read(A)		
write(A)		
commit		
	read(A)	
	write(A)	
	commit	
		read(A)
		commit

Cascadeless $\Rightarrow$ If transactions commit *before* other transactions access what they have written.

EXERCISE 1

For the following schedule, state whether it is serializable, recoverable and cascadeless. Justify your answers.

T_1	T_2	T_3
		read(Y)
		read(Z)
read(X)		
	read(Y)	
read(Y)		
	read(Z)	
write(Y)		
		write(Z)
write(X)		



Precedence Graph

<u>Serializable?</u>

Yes The precedence graph has no cycle. The equivalent serial schedule is: T_2, T_3, T_1.

<u>Recoverable?</u>

Yes No transaction reads a data item *previously* written by another transaction.

<u>Cascadeless?</u>

Yes No transaction reads a data item *previously* written by another transaction.

REVIEW: CONCURRENCY CONTROL PROTOCOLS

Locking: Shared and exclusive locks prevent multiple transactions from simultaneously accessing the same data item.

2PL (2-phase locking) idea:

Phase 1: request locks.

Phase 2: release locks.

After you unlock any data item, you cannot lock any more data items.

Timestamps: Unique ids (timestamps) assign different priorities to transactions based on the time of their submission.

TS ordering idea:

a) A read will fail if the write-TS of the data item is larger than that of the transaction.

b) A write will fail if the timestamp of the transaction is smaller than either the read-TS or the write-TS of the data item being written.

REVIEW: CONCURRENCY CONTROL PROTOCOLS

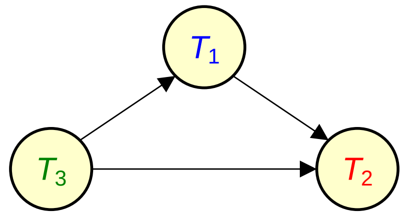
- **Multi-version protocols** use different versions of the same data.
  - A read never fails because a transaction can always find an appropriate version of the data item.
  - A write fails if the read-TS of the appropriate version is larger than that of the transaction meaning that the value that we are trying to write has already been read by a subsequent transaction. Therefore, the write is not valid.

☞ **Multi-version timestamp ordering allows more schedules than simple timestamp ordering.**

EXERCISE 2

Show that the following schedule is conflict serializable and give the timestamp-ordering, serializable schedule (i.e., assign timestamps to T_1, T_2 and T_3 so that the schedule is serializable).

T_1	T_2	T_3
		read(Y)
		read(Z)
read(X)		
write(X)		
		write(Y)
		write(Z)
	read(Z)	
read(Y)		
write(Y)		
	read(Y)	
	write(Y)	
	read(X)	
	write(X)	



Precedence Graph

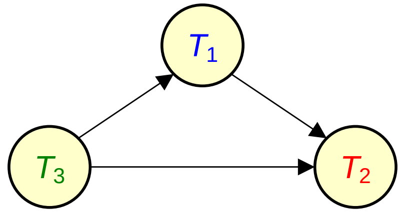
The equivalent serial schedule is: T_3, T_1 , T_2.

EXERCISE 2 (CONT'D)

Timestamp (TS) ordering serializable schedule:

T_1[TS=2], T_2[TS=3], T_3[TS=1]

T_1 [TS=2]	T_2 [TS=3]	T_3 [TS=1]
		read(Y) RTS(Y)=1
		read(Z) RTS(Z)=1
read(X) RTS(X)=2		
write(X) WTS(X)=2		
		write(Y) WTS(Y)=1
		write(Z) WTS(Z)=1
	read(Z) RTS(Z)=3	
read(Y) RTS(Y)=2		
write(Y) WTS(Y)=2		
	read(Y) RTS(Y)=3	
	write(Y) WTS(Y)=3	
	read(X) RTS(X)=3	
	write(X) WTS(X)=3	



Precedence Graph

The equivalent serial schedule is: T_3, T_1 ,T_2.

EXERCISE 2 (CONT'D)

Timestamp (TS) ordering non-serializable schedule.

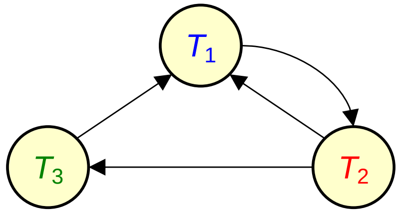
Although the schedule is serializable, only the equivalent serial order T_3, T_1, T_2 is allowed by the timestamp-ordering algorithm. Any other order (e.g., T_1, T_2, T_3) will fail as shown below.

T_1 [TS=1]	T_2 [TS=2]	T_3 [TS=3]
		read(Y) RTS(Y)=3
		read(Z) RTS(Z)=3
read(X) RTS(X)=1		
write(X) WTS(X)=1		
		write(Y) WTS(Y)=3
		write(Z) WTS(Z)=3
	read(Z) **rollback** TS(T_2)[2] < WTS(Z)[3]	
read(Y) **rollback** TS(T_1)[1] < WTS(Y)[3]		
write(Y)		
	read(Y)	
	write(Y)	
	read(X)	
	write(X)	

EXERCISE 3

Is the following schedule conflict serializable? If yes, give the equivalent serial schedule. If no, show, using 2PL, how and where the schedule fails.

T_1	T_2	T_3
	read(Z)	
	read(Y)	
	write(Y)	
		read(Y)
		read(Z)
read(X)		
write(X)		
		write(Y)
		write(Z)
	read(X)	
read(Y)		
write(Y)		
	write(X)	



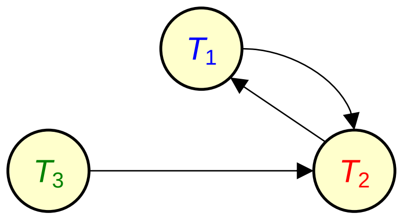
Precedence Graph

Is it conflict serializable?

No There is a cycle in precedence graph.

EXERCISE 3 (CONT'D)

T_1	T_2	T_3
	lock-s(Z)	
	read(Z)	
	lock-s(Y)	
	read(Y)	
	lock-x(Y)	
	write(Y)	
		lock-s(Y) → **WAIT** for T_2
		read(Y)
		read(Z)
lock-s(X)		
read(X)		
lock-x(X)		
write(X)		
		write(Y)
		write(Z)
	lock-s(X) → **WAIT** for T_1	
	read(X)	
lock-s(Y) – **WAIT** for T_2		
read(Y)		
write(Y)		
	write(X)	



Wait-for Graph

T_3 waiting for T_2
T_2 waiting for T_1
T_1 waiting for T_2

☞ **Deadlock!**

EXERCISE 4

Consider the following schedule consisting of transactions T_1, T_2, T_3 and T_4 (note: r_1 means T_1 read, w_1 means T_1 write and so on):

Schedule: $r_1(X)$, $w_1(X)$, $r_2(X)$, $r_3(Y)$, $w_3(Y)$, $w_2(X)$, $r_4(Y)$, $w_1(Y)$

a) Show that the schedule is conflict serializable by constructing the precedence graph.

b) What is the equivalent serial schedule?

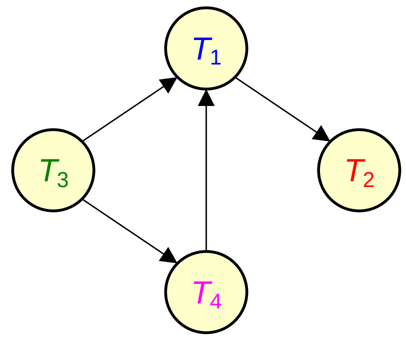
c) Can the schedule be rewritten so it becomes recoverable, <u>but not</u> cascadeless by adding commit operations in the appropriate locations in the schedule? Explain.

d) Can the schedule be rewritten so it becomes <u>both</u> recoverable, <u>and</u> cascadeless by adding commit operations in the appropriate locations in the schedule? Explain.

EXERCISE 4 (CONT'D)

a) Show that the schedule is conflict serializable by constructing the precedence graph.

T_1	T_2	T_3	T_4
read(X)			
write(X)			
	read(X)		
		read(Y)	
		write(Y)	
	write(X)		
			read(Y)
write(Y)			



Precedence Graph

b) What is the equivalent serial schedule? T_3, T_4, T_1, T_2

EXERCISE 4 (CONT'D)

c) Can the schedule be rewritten so it becomes recoverable, <u>but not</u> cascadeless by adding commit operations in the appropriate locations in the schedule? Explain.

Recall: A schedule is recoverable if the commit of a transaction T_j that reads data items *previously written* by a transaction T_i appears <u>after</u> the commit operation of T_i.

T_2 reads X written by T_1
$\Longrightarrow$ T_2 must commit after T_1.
T_4 reads Y written by T_3
$\Longrightarrow$ T_4 must commit after T_3.

<u>Schedule</u>:

$r_1(X)$, $w_1(X)$, $r_2(X)$, $r_3(Y)$, $w_3(Y)$, $w_2(X)$, $r_4(Y)$, $w_1(Y)$, c_1, c_2, c_3, c_4
or
$r_1(X)$, …, c_3, c_4, c_1, c_2
or
$r_1(X)$, …, c_3, c_1, c_4, c_2

T_1	T_2	T_3	T_4
read(X)			
write(X)			
	read(X)		
		read(Y)	
		write(Y)	
	write(X)		
			read(Y)
write(Y)			

EXERCISE 4 (CONT'D)

d) Can the schedule be rewritten so it becomes both recoverable, and cascadeless by adding commit operations in the appropriate locations in the schedule? Explain.

Recall: A schedule is cascadeless if, for each pair of transactions T_i, T_j such that T_j reads a data item previously written by T_i, the commit operation of T_i appears *before* the read operation of T_j.

- The commit of T_1 must appear *before* the read(X) of T_2.
- The commit of T_3 must appear *before* the read(Y) of T_4.

T_1	T_2	T_3	T_4
read(X)			
write(X)			
	read(X)		
		read(Y)	
		write(Y)	
	write(X)		
			read(Y)
write(Y)			

The schedule cannot be made cascadeless as written.

To make the schedule cascadeless, the write(Y) of T_1 must be moved after the write(X) of T_1 so that T_1 can commit before the read(X) of T_2.