COMP 3311
DATABASE MANAGEMENT SYSTEMS

LECTURE 22
CONCURRENCY CONTROL:
TIMESTAMP-BASED PROTOCOLS

TIMESTAMPS

Each transaction is issued a fixed timestamp TS(T_i) by the system before it starts execution.

If an old transaction T_i has timestamp TS(T_i), a new transaction T_j is assigned timestamp TS(T_j) such that TS(T_i) < TS(T_j).

☞ **The timestamps determine the serializability order.**

- To implement serializability, two timestamp values are associated with each data item *Q*

WTS(*Q*) (write timestamp) the largest timestamp of any transaction that executed write(*Q*) successfully.

RTS(*Q*) (read timestamp) the largest timestamp of any transaction that executed read(*Q*) successfully.

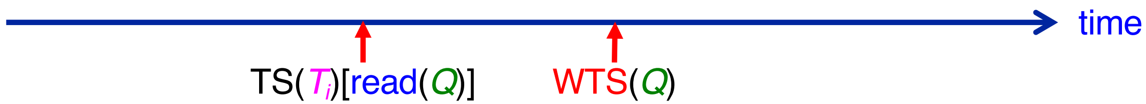
and updated whenever a new read(*Q*) or write(*Q*) instruction is executed.

TIMESTAMP-ORDERING PROTOCOL: READ

The timestamp-ordering protocol ensures that any conflicting read and write operations are executed in timestamp order.

Suppose a transaction T_i issues a read(Q).

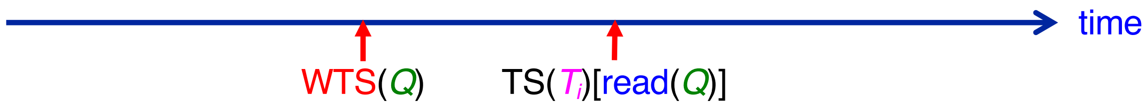
1. If TS(T_i) < WTS(Q), then T_i needs to read a value of Q that was already overwritten.



☞ Reject the read operation and **roll back** T_i.

☞ Restart T_i with a new (larger) timestamp TS′(T_i).

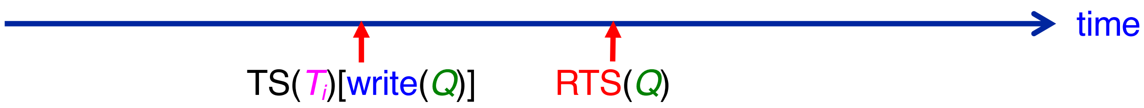
2. If TS(T_i) ≥ WTS(Q), then execute the read operation and set RTS(Q) to the *maximum* of RTS(Q) and TS(T_i).



TIMESTAMP-ORDERING PROTOCOL: WRITE

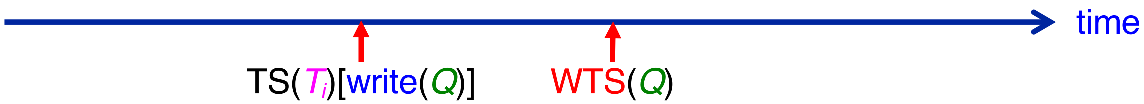
Suppose that transaction T_i issues a write(Q).

1. If TS(T_i) < RTS(Q), then the value of Q that T_i is writing was needed previously and the system assumed that that value would never be written (since a different value was already read).



☞ Reject the write operation and **roll back** T_i.

2. If TS(T_i) < WTS(Q), then T_i is attempting to write an obsolete value of Q.



☞ Reject the write operation and **roll back** T_i.

3. Otherwise, execute the write operation and set WTS(Q) to TS(T_i).

TIMESTAMP-ORDERING PROTOCOL EXAMPLE

A partial schedule for several data items for transactions with timestamps 1, 2, 3, 4, 5. Assume initial R/W timestamp of all items is 0.

RTS(X)=5	WTS(X)=0	RTS(Y)=2	WTS(Y)=3	RTS(Z)=5	WTS(Z)=3

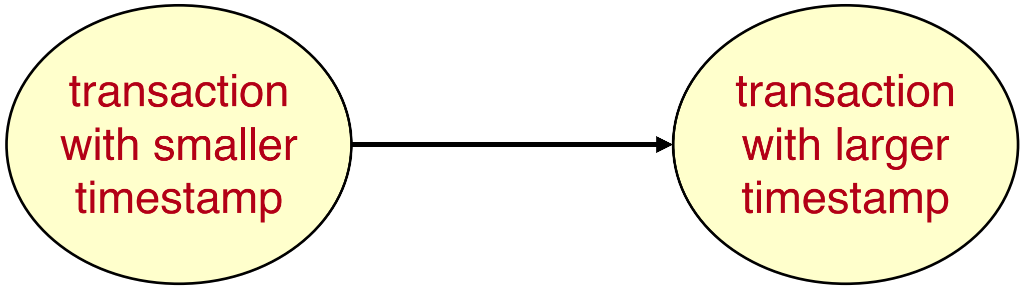
T_1 [TS=1]	T_2 [TS=2]	T_3 [TS=3]	T_4 [TS=4]	T_5 [TS=5]
				read(X) ✓ TS(T_5)=5 ≥ WTS(X)=0; set RTS(X)=5
	read(Y) ✓ TS(T_2)=2 ≥ WTS(Y)=0; set RTS(Y)=2			
read(Y) ✓ TS(T_1)=1 ≥ WTS(Y)=0				
		write(Y) ✓ TS(T_3)=3 ≥ RTS(Y)=2 & ≥ WTS(Y)=0; set WTS(Y)=3		
		write(Z) ✓ TS(T_3)=3 ≥ RTS(Z)=0 & WTS(Z)=0; set WTS(Z)=3		
	read(Z) TS(T_2)=2 < WTS(Z)=3 ⟹ rollback			
				read(Z) ✓ TS(T_5)=5 ≥ WTS(Z)=3; set RTS(Z)=5
read(X) ✓ TS(T_1)=1 ≥ WTS(X)=0				⟹ rollback
		write(Z) TS(T_3)=3 < RTS(Z)=5 ⟹ rollback		
				write(Y)
				write(Z)

Read
If TS(T_i) < WTS(Q) **rollback**
If TS(T_i) ≥ WTS(Q)
RTS(Q) = max(TS(T_i), RTS(Q))

Write
If TS(T_i) < RTS(Q) **rollback**
If TS(T_i) < WTS(Q) **rollback**
Otherwise WTS(Q) = TS(T_i)

TIMESTAMP-ORDERING PROTOCOL CORRECTNESS

- The timestamp-ordering protocol ensures conflict serializability since all the arcs in the precedence graph are of the form:



☞ **Conflicting instructions are processed in timestamp order.**

- Since, there can be no cycles in the precedence graph, the timestamp protocol ensures freedom from deadlock and no transaction ever waits.

- However, starvation of long transactions is possible and a schedule may not be recoverable.

RECOVERABILITY AND CASCADING ROLLBACK

- The problem with the timestamp-ordering protocol:
  - Suppose T_i aborts, but T_j has read a data item written by T_i.
  - Then T_j must abort; if T_j had been allowed to commit before T_i aborted, the schedule is not recoverable.
  - Further, any transaction that has read a data item written by T_j must abort.

☞ **This can lead to cascading rollback.**

Solution

- A transaction is structured such that *all its writes* are performed at the end of its processing.
- All writes of a transaction form an atomic action; no transaction may execute while a transaction is being written.
- A transaction that aborts is restarted with a new timestamp.

THOMAS' WRITE RULE

Read
If TS(T_i) < WTS(Q) **rollback**
If TS(T_i) ≥ WTS(Q)
RTS(Q) = max(TS(T_i), RTS(Q))

Write
If TS(T_i) < RTS(Q) **rollback**
If TS(T_i) < WTS(Q) **rollback**
Otherwise WTS(Q) = TS(T_i)

RTS(Q)=1	WTS(Q)=2

T_1 [TS=1]	T_2 [TS=2]	
read(Q) ✓		TS(T_1)=1 ≥ WTS(Q)=0; set RTS(Q)=1
	write(Q) ✓	TS(T_2)=2 ≥ RTS(Q)=1 & ≥ WTS(Q)=0; set WTS(Q)=2
write(Q)		TS(T_1)=1 < WTS(Q)=2 ⟹ rollback

☞ **Rollback of T_1 is actually unnecessary!**

- Since T_2 has already written Q (with TS=2), the value T_1 is attempting to write (with TS=1) *will never be read*.
  - Any transaction with timestamp less than TS(T_2) that attempts to read Q will be rolled back since its timestamp will be less than WTS(Q).
  - Any transaction with a timestamp greater than TS(T_2) must read the value of Q written by T_2, rather than the one T_1 is attempting to write.

☞ **Ignore write of T_1!**

Read (unchanged)
If TS(T_i) < WTS(Q) **rollback**
If TS(T_i) ≥ WTS(Q)
RTS(Q) = max(TS(T_i), RTS(Q))

Write (Thomas' write rule)
If TS(T_i) < RTS(Q) **rollback**
If TS(T_i) < WTS(Q) **ignore**
Otherwise WTS(Q) = TS(T_i)

VALIDATION-BASED PROTOCOLS

Assumption: Most transactions are read-only.

- Transactions execute in two or three phases:

1. **Read phase**	write data items in temporary, local variables.
2. **Validation phase**	determine whether the transaction can proceed to the write phase; abort transaction if test fails.
3. **Write phase**	apply write operations to database. Read-only transactions omit this phase.

- The system maintains three timestamps for each transaction:
  1. start(T_i) – the time when T_i started execution.
  2. validation(T_i) – the time when T_i finished its read phase and started its validation phase.
  3. finish(T_i) – the time when T_i finished its write phase.

VALIDATION TEST

- For all transactions T_k with $TS(T_k) < TS(T_i)$, one of the following conditions must hold:

  1. finish(T_k) < start(T_i).

     Serializable since T_k completes before T_i started.

  2. data items written by (T_k) ∩ data items read by (T_i) = ∅ and (start(T_i) < finish(T_k) < validation(T_i)) (ensures that the writes of T_k and T_i do not overlap).

     Serializable since the writes of T_k do not affect the read of T_i, and T_i cannot affect the read of T_k.

- Ensures no cascading rollbacks, but starvation of long transactions is possible.

☞ **Optimistic concurrency-control.**

VALIDATION-BASED PROTOCOL EXAMPLE

T_1	T_2
read(B)	
	read(B)
	B := B - 50
	read(A)
	A := A - 50
read(A)	
validate	
display(A+B)	
	validate
	write(B)
	write(A)

- Note that the writes to the actual variables are performed only after the validation phase of T_2.
- Thus, T_1 reads the old values of A and B, and this schedule is serializable.

MULTIVERSION SCHEMES

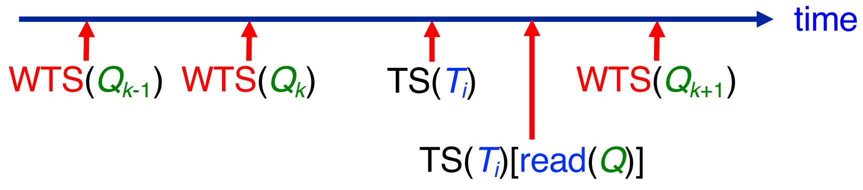
- Multiversion schemes keep old versions of data items, labelled with timestamps, to increase concurrency.
  - Multiversion Timestamp Ordering
  - Multiversion Two-Phase Locking
- Each data item Q has a sequence of versions <Q_1, Q_2, …, Q_m>.
- Each version Q_k contains three data fields:

Content	The value of version Q_k.
WTS(Q_k)	The timestamp of the transaction that created (wrote) version Q_k.
RTS(Q_k)	The largest timestamp of a transaction that successfully read version Q_k.

- Each successful write by a transaction T_i creates a new version Q_k of Q, and sets Q_k's RTS and WTS to TS(T_i).

MULTIVERSION TIMESTAMP ORDERING: READ

Let Q_k be the version of Q whose write timestamp is the largest write timestamp *less than or equal to* TS(T_i).



- If transaction T_i issues a read(Q), then the value returned is the content of version Q_k (i.e., T_i reads the most recent version that comes before it in time).

  ☞ If TS(T_i) > RTS(Q_k), then set RTS(Q_k) = TS(T_i).

☞ **Reads never fail and never wait as an appropriate version can always be found.**

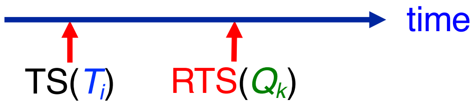
Read
Reads always succeed
set RTS(Q_k) = max(TS(T_i), RTS(Q_k))

MULTIVERSION TIMESTAMP ORDERING: WRITE

Let Q_k be the version of Q whose write timestamp is the largest write timestamp *less than or equal to* TS(T_i).

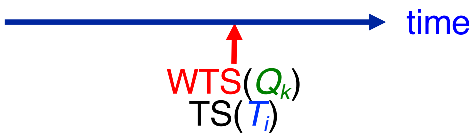
If transaction T_i issues a write(Q), then

a) if TS(T_i) < RTS(Q_k), then **roll back** T_i.

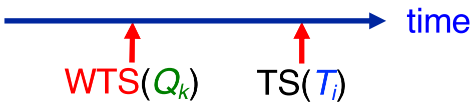


Since some other transaction T_j that should read T_i's write (in the serialization order defined by the timestamp values) has already read a version created by a transaction older than T_i.

b) if TS(T_i) = WTS(Q_k), overwrite the contents of Q_k
$\Longrightarrow$ Q_k was written before also by T_i.



c) if TS(T_i) > WTS(Q_k) create a new version of Q and set R/WTS of new version to TS(T_i).



☞ **Conflicts are resolved through aborting transactions.**

Write

If TS(T_i) < RTS(Q) **rollback**
If TS(T_i) = WTS(Q) **overwrite contents**
If TS(T_i) > WTS(Q) **create new version**
set R/WTS(Q')=TS(T_i)

MULTIVERSION SCHEMES: NOTES

- The schedule of **Exercise 2** will terminate successfully although it is not conflict serializable.
- The concept of conflict serializability does not apply to multi-version protocols, since read operations do not conflict with previous writes (there is always a version to read).

Versions are removed as follows:

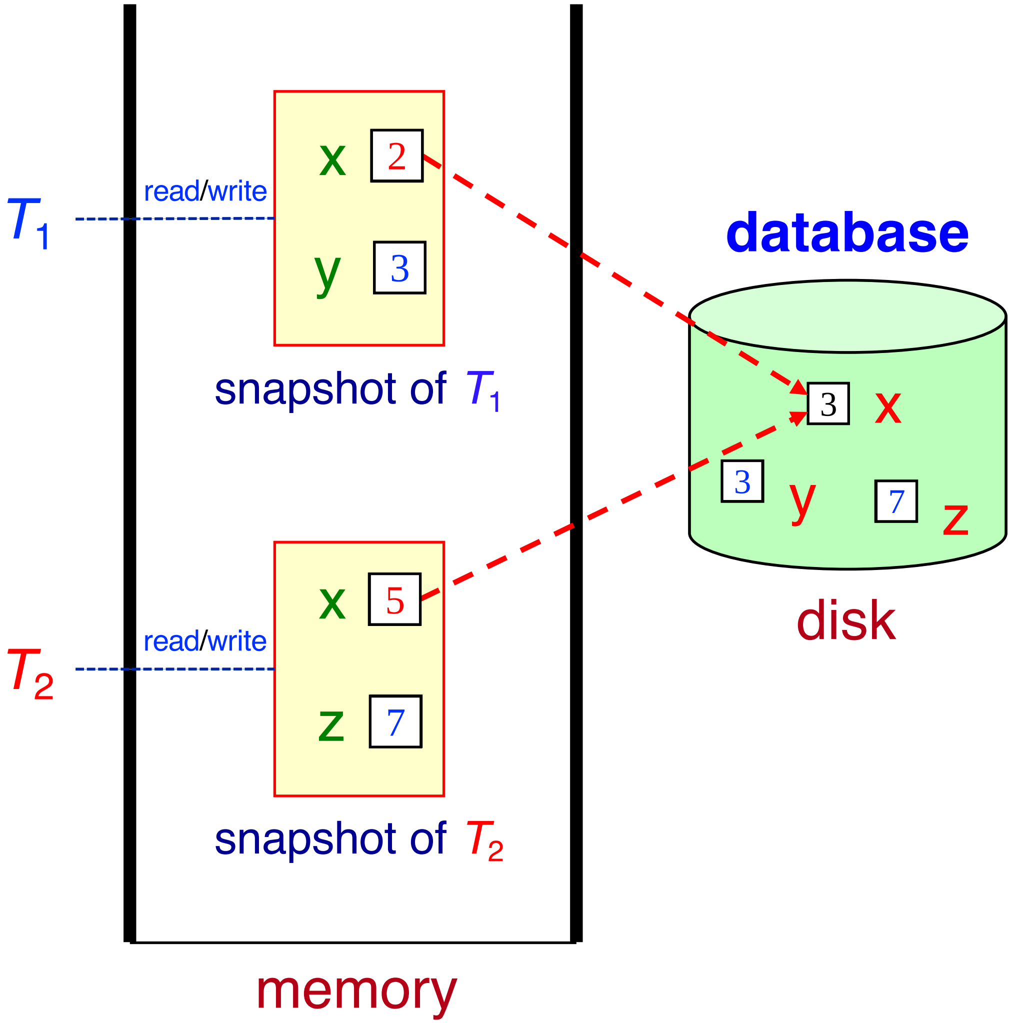
- Suppose that there are two versions Z_1 and Z_2 with timestamps 3 and 1 (as could happen in **Exercise 2**) that both have a smaller timestamp than the oldest transactions (i.e., T_1, T_2 and T_3 have committed and the new transactions have timestamps ≥ 4).
- Then the version Z_2 with timestamp 1 will not be used again and is deleted.
- If any subsequent transaction needs to read Z, it will read Z_1 with timestamp 3.

- In **Exercise 2** it is as if the last write(Z) was never executed, which is OK because T_3 executes a *blind* write(Z) (i.e., write with no previous read).
- If, on the other hand, T_3 had read Z *before* writing it, the schedule would fail at the last write of T_1.

SNAPSHOT ISOLATION

- Each transaction works on its own private copy (snapshot) of the data items it reads and writes.
- If most transactions are read-only or if their updated data items do not overlap, then they cannot conflict with each other.

  ☞ **Results in higher concurrency levels.**
- Concurrency control is only needed if updates conflict.



SNAPSHOT ISOLATION VALIDATION STEPS

First Committer Wins

if a data item that *T* intends to write has already been updated by any concurrent transaction:
then *T* **aborts**;
else *T* **commits** and writes its updates to the database;

First Updater Wins

if *T*'s request for an x-lock on a data item it intends to update is granted:
- **if** the data item has already been updated by any concurrent transaction:
  - **then** *T* **aborts**;
  - **else** *T* **proceeds with its execution** including possibly committing;

else // data item is locked ⟹ wait until transaction holding the lock aborts or commits
- **if** the transaction holding the lock aborts:
  - **then** the lock is released and *T* locks the data item;
  - **if** the data item has already been updated by any concurrent transaction:
    - **then** *T* **aborts**;
    - **else** *T* **proceeds with its execution** including possibly committing;
- **if** the transaction holding the lock commits:
  - **then** *T* **aborts**;

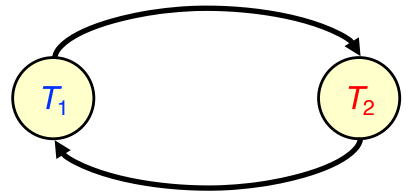
SNAPSHOT ISOLATION: NOTES

- Snapshot isolation is attractive because overhead is low and no abort occurs unless two concurrent transactions update the same data item.

- Snapshot isolation does not ensure serializability!

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

Precedence Graph



  - The schedule is allowed by snapshot isolation since T_1 and T_2 update different data items.
  - However, it is not serializable!

SNAPSHOT ISOLATION: NOTES (CONT'D)

- Although snapshot isolation permits schedules that are not serializable, it is widely used in commercial systems (e.g., Oracle, SQL Server).
  - If database consistency is preserved, then non-serializable executions are OK.
  - Constraints can be used to help ensure database consistency when non-serializable schedules are allowed.

CONCURRENCY CONTROL: SUMMARY

While most protocols discussed ensure correctness,

☞ **A correct schedule may not be permitted by a protocol.**

☞ **The more correct schedules allowed by a protocol, the greater the degree of concurrency.**

- The protocols differ in the way they handle conflicts:
  i. Lock-based protocols make transactions wait (thus, they can result in deadlocks).
  ii. Timestamp-based protocols make transactions abort (thus, there are no deadlocks, but aborting a transaction may be more expensive).

- Recoverability (i.e., no rollback after a commit) is a necessary property of a schedule.

☞ **To ensure recoverability, transaction T_i can commit only after all transactions that wrote items that T_i read have committed.**

CONCURRENCY CONTROL: SUMMARY (CONT'D)

- A cascading rollback happens when an *uncommitted* transaction must be rolled back because it read an item written by a transaction that aborted.

  ☞ **It is desirable to have cascadeless schedules.**

  ☞ **To achieve this property a transaction should only be allowed to read items written by committed operations.**

- If a schedule is cascadeless, it is also recoverable.
  - Strict 2PL ensures cascadeless schedules by releasing all exclusive locks of transaction T_i after T_i commits (therefore other transactions cannot read the items locked by T_i at the same time).
  - Timestamp-based protocols can also achieve cascadeless schedules by performing all the writes at the end of the transaction as an atomic operation.