CSE 444: Database Internals

Section 6:
Transactions

Today

- Serializability and Conflict Serializability
  - Precedence graph
- Two-Phase Locking
  - Strict two phase locking
- Lab 3 Intro

Problem 1: Serializability and Locking

- Is this schedule conflict serializab

What is
- Serializability
- Conflict Serializability?

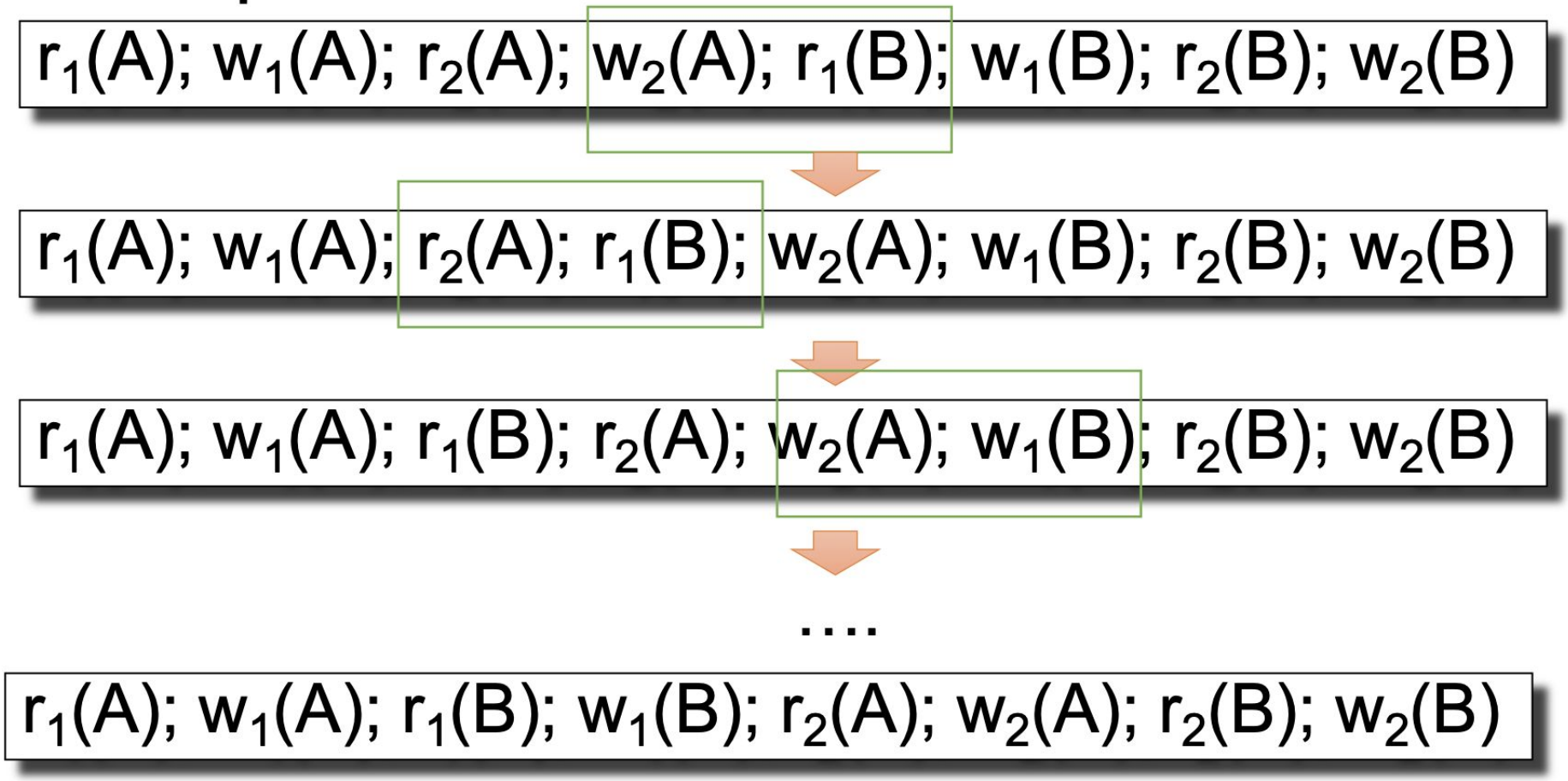
T_0	T_1
$R_0(A)$	
$W_0(A)$	
	$R_1(A)$
	$R_1(B)$
	C_1
$R_0(B)$	
$W_0(B)$	
C_0	

Review: (Conflict) Serializable Schedule

- A schedule is ***serializable*** if it is equivalent to a serial schedule

- A schedule is ***conflict serializable*** if it can be transformed into a serial schedule by a series of swappings of adjacent non-conflicting actions

Example:

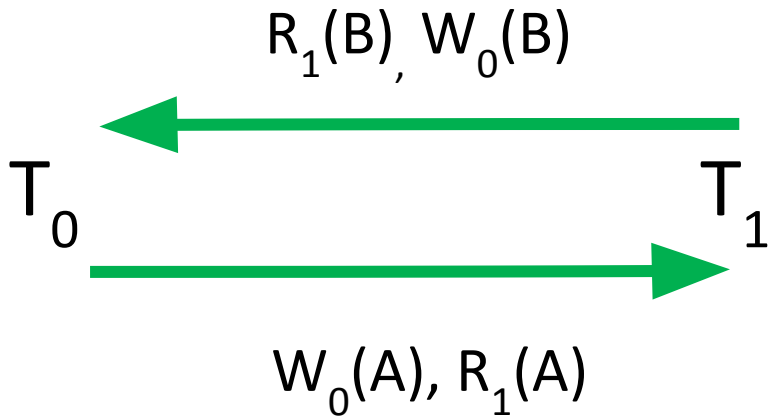

$r_1(A); w_1(A); r_2(A); w_2(A); r_1(B); w_1(B); r_2(B); w_2(B)$
$r_1(A); w_1(A); r_2(A); r_1(B); w_2(A); w_1(B); r_2(B); w_2(B)$
$r_1(A); w_1(A); r_1(B); r_2(A); w_2(A); w_1(B); r_2(B); w_2(B)$
....
$r_1(A); w_1(A); r_1(B); w_1(B); r_2(A); w_2(A); r_2(B); w_2(B)$

Problem 1: Serializability and Locking

- Is this schedule conflict serializable?

T_0	T_1
$R_0(A)$	
$W_0(A)$	
	$R_1(A)$
	$R_1(B)$
	C_1
$R_0(B)$	
$W_0(B)$	
C_0	

- No.
- The **precedence graph** contains a cycle



- So, use 2PL ...
  - ❑ Original schedule below

T_0	T_1
$R_0(A)$	
$W_0(A)$	
	$R_1(A)$
	$R_1(B)$
	C_1
$R_0(B)$	
$W_0(B)$	
C_0	

- So, use 2PL ...
  - ❑ Original schedule below

What is
- Two Phase Locking
- Strict Two Phase Locking?

T_0	T_1
$R_0(A)$	
$W_0(A)$	
	$R_1(A)$
	$R_1(B)$
	C_1
$R_0(B)$	
$W_0(B)$	
C_0	

Review:
(Strict) Two Phase Locking (2PL)

The 2PL rule:

In every transaction, all lock requests must precede all unlock requests

Strict 2PL:

All locks held by a transaction are released when the transaction is completed

- Ensures that schedules are recoverable
  - Transactions commit only after all transactions whose changes they read also commit
- Avoids cascading rollbacks

- How can 2PL can ensure a conflict-serializable schedule?
  - ❑ Original schedule below

T_0	T_1
$R_0(A)$	
$W_0(A)$	
	$R_1(A)$
	$R_1(B)$
	C_1
$R_0(B)$	
$W_0(B)$	
C_0	

T_0	T_1
$L_0(A)$	
$R_0(A)$	
$W_0(A)$	

T_0	T_1
$L_0(A)$	
$R_0(A)$	
$W_0(A)$	
	$L_1(A)$: Block

T_0	T_1
$L_0(A)$	
$R_0(A)$	
$W_0(A)$	
	$L_1(A)$: Block
$L_0(B)$	
$R_0(B)$	
$W_0(B)$	
$U_0(A)$	
$U_0(B)$	
C_0	

T_0	T_1
$L_0(A)$	
$R_0(A)$	
$W_0(A)$	
	$L_1(A)$: Block
$L_0(B)$	
$R_0(B)$	
$W_0(B)$	
$U_0(A)$	
$U_0(B)$	
C_0	
	$L_1(A)$: Granted
	$R_1(A)$
	$L_1(B)$
	$R_1(B)$
	$U_1(A)$
	$U_1(B)$
	C_1

T_0	T_1
$L_0(A)$	
$R_0(A)$	
$W_0(A)$	
	$L_1(A)$: Block
$L_0(B)$	
$R_0(B)$	
$W_0(B)$	
$U_0(A)$	
$U_0(B)$	
C_0	
	$L_1(A)$: Granted
	$R_1(A)$
	$L_1(B)$
	$R_1(B)$
	$U_1(A)$
	$U_1(B)$
	C_1

Is this strict 2PL?

No, release locks after commit

Lab 3 - Transactions

- NO STEAL / FORCE buffer management policy
  - you shouldn't evict dirty (updated) pages from the buffer pool if they are locked by an uncommitted transaction. (this is NO STEAL)
  - on transaction commit, you should force dirty pages to disk (e.g., write the pages out) (this is FORCE)
- Recommend - locking at page level
  - you can acquire and release locks in BufferPool.getPage(), instead of adding calls to each of your operators
  - Might have to change previous implementations to access pages using BufferPool.getPage()

Lab 3 - Transactions (contd.)

- You need to implement **shared** and **exclusive** locks
  - Before read, it must have a shared lock
  - Before write, it must have an exclusive lock
  - Multiple transactions can have a shared lock
  - Only one transaction may have an exclusive lock on an object
  - If transaction t is the only transaction holding a shared lock on an object o, t may upgrade its lock on o to an exclusive lock

- You need to implement **strict two-phase locking**
  - transactions should acquire the appropriate type of lock on any object before accessing that object

  - transaction shouldn't release any locks until after the transaction commits.

Lab 3 - Transactions (contd.)

- You will need to implement a **LockManager class** that will hold data structures to keep track of which locks each transaction holds and that check to see if a lock should be granted to a transaction when it is requested.
- Read about **Synchronization** in Java, and use the **synchronized** keyword in appropriate places in **LockManager**
- You will have to also throw appropriate exceptions like **TransactionAbortedException**

Lab 3 - Transactions (contd.)

- Handling deadlocks
  - implement a simple timeout policy that aborts a transaction if it has not completed after a given period of time
  - implement a cycle-detection in a dependency graph data structure, if cycle exists when granting a new lock abort something.

- Design Choices:
  - Locking Granularity: page-level vs tuple-level (our tests assume page-level)
  - Deadlock Detection: timeout vs dependency graphs
  - Deadlock Resolution: aborting yourself vs aborting others

- Read the spec carefully for more details about various methods and edge cases.

Problem 2: Timestamp-based Concurrency Control

Timestamp-based Concurrency Control

- Some transaction, T.
- Some element (tuple/page), X.

- **TS**(T) - timestamp for transaction T
  - Stays constant for all of T's operations

- **WT**(X) – latest write timestamp for X
  - Set WT(X) = TS(T)

- **RT**(X) – latest read timestamp for X
  - Set RT(X) = TS(T)

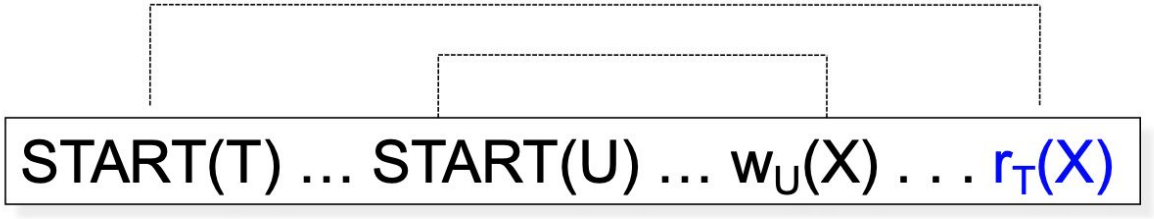
- **C**(X) – X's value has been committed
  - 1 if true, 0 if not

Timestamp-based Concurrency Control

- **Actions for transaction T**
  - **Grant** a read/write request for a transaction
  - **Abort** (in case T violates physical reality – late actions)
  - **Delay** (make the Grant or Abort decision later)
    - When writing, the change is always tentative until we decide to commit. For this, we use a commit bit C to keep track if the transaction that last wrote X has committed
  - **Ignore *Thomas Write Rule*** – ignore outdated writes

Timestamp-based Concurrency Control - Four Rules

- **Rule 1**: **Read** request on X by T

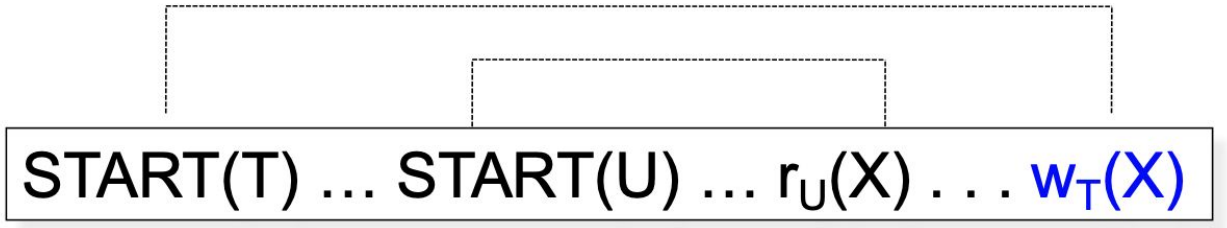


  - TS(T) < WT(X), **abort**, (read too late)

  - TS(T) >= WT(X), physically realizable
    - If C = 1, **grant**, update RT(X)
    - If C = 0, **delay** T

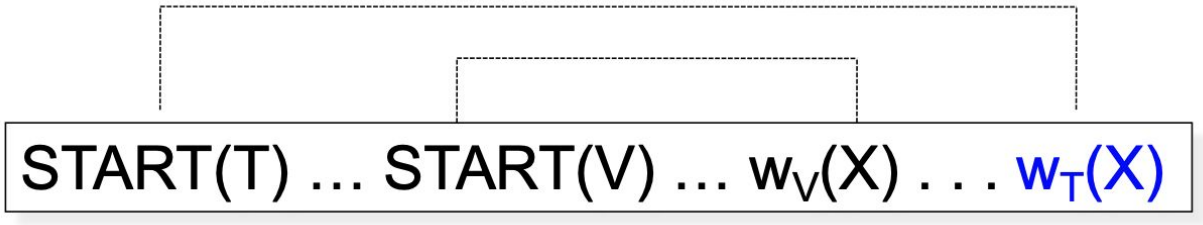
Timestamp-based Concurrency Control - Four Rules

- **Rule 2**: **Write** request on X by T



  - TS(T) < RT(X) (write too late)
    - **Abort**

- TS(T) >= RT(X), physically realizable
  - TS(T) >= WT(X)
    - then **grant**, update WT(X), set C = 0 (as it's not committed yet)



  - TS(T) < WT(X)
    - If C = 1, **don't write X at all!** (***Thomas Write Rule*** – ignore outdated writes)
    - If C = 0, **delay**

Timestamp-based Concurrency Control - Four Rules

- **Rule 3**: **Commit** request by T
  - Set C = 1 for all X written by T
  - Allow waiting transactions to proceed
- **Rule 4**: **Abort** transaction T
  - Check if the waiting transactions can proceed now.

Summary

Transaction wants to READ element X

If WT(X) > TS(T) then ROLLBACK
Else If C(X) = false, then WAIT
Else READ and update RT(X) to larger of TS(T) or RT(X)

Transaction wants to WRITE element X

If RT(X) > TS(T) then ROLLBACK
Else if WT(X) > TS(T)
Then If C(X) = false then WAIT
else IGNORE write (Thomas Write Rule)
Otherwise, WRITE, and update WT(X)=TS(T), C(X)=false

Timestamp-based Concurrency Control

Two transactions get started.

- $Start(T_1)$ -> $Start(T_2)$

Timestamp-based Concurrency Control

What will happen at the last request?

- $S_{tart}(T_1)$ -> $S_{tart}(T_2)$ -> $R_{T1}(A)$ -> $R_{T2}(A)$ -> $W_{T1}(B)$ -> **$W_{T2}(B)$**

Timestamp-based Concurrency Control

What will happen at the last request?

- $Start(T_1)$ -> $Start(T_2)$ -> $R_{T1}(A)$ -> $R_{T2}(A)$ -> $W_{T1}(B)$ -> **$W_{T2}(B)$**
  - **ACCEPTED**

Timestamp-based Concurrency Control

What will happen at the last request?

- $Start(T_1)$ -> $Start(T_2)$ -> $R_{T1}(A)$ -> $R_{T2}(A)$ -> $W_{T1}(B)$ -> **$W_{T2}(B)$**
  - **ACCEPTED**

- $Start(T_1)$ -> $Start(T_2)$ -> $R_{T2}(A)$ -> $Commit_{T2}$ -> $R_{T1}(A)$ -> **$W_{T1}(A)$**

Timestamp-based Concurrency Control

What will happen at the last request?

- $Start(T_1)$ -> $Start(T_2)$ -> $R_{T1}(A)$ -> $R_{T2}(A)$ -> $W_{T1}(B)$ -> **$W_{T2}(B)$**
  - **ACCEPTED**

- $Start(T_1)$ -> $Start(T_2)$ -> $R_{T2}(A)$ -> $Commit_{T2}$ -> $R_{T1}(A)$ -> **$W_{T1}(A)$**
  - **ABORT** T_1 because $R_{T2}(A)$ precedes

Problem 2: Timestamp-based Concurrency Control

T1	T2	T3	T4	X	Y	Z
1	2	3	4	RT = 0, WT = 0, C = 1	RT = 0, WT = 0, C = 1	RT = 0, WT = 0, C = 1
$R_1(X)$						

T1	T2	T3	T4	X	Y	Z
1	2	3	4	RT = 0, WT = 0, C = 1	RT = 0, WT = 0, C = 1	RT = 0, WT = 0, C = 1
$R_1(X)$				RT=1		
	$R_2(X)$					

T1	T2	T3	T4	X	Y	Z
1	2	3	4	RT = 0, WT = 0, C = 1	RT = 0, WT = 0, C = 1	RT = 0, WT = 0, C = 1
$R_1(X)$				RT=1		
	$R_2(X)$					

1. Physically realizable:
$TS(T_1) >= WT(X)$

2. C = 1: grant request

3. Update RT : $TS(T_1) > RT(X)$

T1	T2	T3	T4	X	Y	Z
1	2	3	4	RT = 0, WT = 0, C = 1	RT = 0, WT = 0, C = 1	RT = 0, WT = 0, C = 1
$R_1(X)$				RT=1		
	$R_2(X)$			RT=2		
	$W_2(X)$					

T1	T2	T3	T4	X	Y	Z
1	2	3	4	RT = 0, WT = 0, C = 1	RT = 0, WT = 0, C = 1	RT = 0, WT = 0, C = 1
$R_1(X)$				RT=1		
	$R_2(X)$			RT=2		
	$W_2(X)$					

1. Physically realizable:
$TS(T_2) >= WT(X)$

2. C = 1: grant request

3. Update WT

T1	T2	T3	T4	X	Y	Z
1	2	3	4	RT = 0, WT = 0, C = 1	RT = 0, WT = 0, C = 1	RT = 0, WT = 0, C = 1
$R_1(X)$				RT=1		
	$R_2(X)$			RT=2		
	$W_2(X)$			WT=2, C=0		
$W_1(X)$						

T1	T2	T3	T4	X	Y	Z
1	2	3	4	RT = 0, WT = 0, C = 1	RT = 0, WT = 0, C = 1	RT = 0, WT = 0, C = 1
$R_1(X)$				RT=1		
	$R_2(X)$			RT=2		
	$W_2(X)$			WT=2, C=0		
$W_1(X)$: **abort**						

T1	T2	T3	T4	X	Y	Z
1	2	3	4	RT = 0, WT = 0, C = 1	RT = 0, WT = 0, C = 1	RT = 0, WT = 0, C = 1
$R_1(X)$				RT=1		
	$R_2(X)$			RT=2		
	$W_2(X)$			WT=2, C=0		
$W_1(X)$: **abort**						

1. **NOT** Physically realizable:
$TS(T_1) < RT(X)$

Abort/rollback

T1	T2	T3	T4	X	Y	Z
1	2	3	4	RT = 0, WT = 0, C = 1	RT = 0, WT = 0, C = 1	RT = 0, WT = 0, C = 1
$R_1(X)$				RT=1		
	$R_2(X)$			RT=2		
	$W_2(X)$			WT=2, C=0		
$W_1(X)$: **abort**						
		$W_3(Y)$				

T1	T2	T3	T4	X	Y	Z
1	2	3	4	RT = 0, WT = 0, C = 1	RT = 0, WT = 0, C = 1	RT = 0, WT = 0, C = 1
$R_1(X)$				RT=1		
	$R_2(X)$			RT=2		
	$W_2(X)$			WT=2, C=0		
$W_1(X)$: **abort**						
		$W_3(Y)$			WT=3, C=0	

1. Physically realizable:
$TS(T_3)$ >= RT(Y) and $TS(T_3)$ >= WT(Y)

2. Update WT and C (not committed yet)

T1	T2	T3	T4	X	Y	Z
1	2	3	4	RT = 0, WT = 0, C = 1	RT = 0, WT = 0, C = 1	RT = 0, WT = 0, C = 1
$R_1(X)$				RT=1		
	$R_2(X)$			RT=2		
	$W_2(X)$			WT=2, C=0		
$W_1(X)$: **abort**						
		$W_3(Y)$			WT=3, C=0	
	$W_2(Y)$					

T1	T2	T3	T4	X	Y	Z
1	2	3	4	RT = 0, WT = 0, C = 1	RT = 0, WT = 0, C = 1	RT = 0, WT = 0, C = 1
$R_1(X)$				RT=1		
	$R_2(X)$			RT=2		
	$W_2(X)$			WT=2, C=0		
$W_1(X)$: **abort**						
		$W_3(Y)$			WT=3, C=0	
	$W_2(Y)$: **delay**					

T1	T2	T3	T4	X	Y	Z
1	2	3	4	RT = 0, WT = 0, C = 1	RT = 0, WT = 0, C = 1	RT = 0, WT = 0, C = 1
$R_1(X)$				RT=1		
	$R_2(X)$			RT=2		
	$W_2(X)$			WT=2, C=0		
$W_1(X)$: **abort**						
		$W_3(Y)$			WT=3, C=0	
	$W_2(Y)$: **delay**					

1. Physically realizable:
$TS(T_2)$ >= RT(Y) although $TS(T_2) < WT(Y)$
2. We could not apply Thomas' write rule **(ignore $W_2(Y)$)** since C=0

T1	T2	T3	T4	X	Y	Z
1	2	3	4	RT = 0, WT = 0, C = 1	RT = 0, WT = 0, C = 1	RT = 0, WT = 0, C = 1
$R_1(X)$				RT=1		
	$R_2(X)$			RT=2		
	$W_2(X)$			WT=2, C=0		
$W_1(X)$: **abort**						
		$W_3(Y)$			WT=3, C=0	
	$W_2(Y)$: **delay**					
		C_3				

T1	T2	T3	T4	X	Y	Z
1	2	3	4	RT = 0, WT = 0, C = 1	RT = 0, WT = 0, C = 1	RT = 0, WT = 0, C = 1
$R_1(X)$				RT=1		
	$R_2(X)$			RT=2		
	$W_2(X)$			WT=2, C=0		
$W_1(X)$: **abort**						
		$W_3(Y)$			WT=3, C=0	
	$W_2(Y)$: **delay**					
		C_3			C=1	

T1	T2	T3	T4	X	Y	Z
1	2	3	4	RT = 0, WT = 0, C = 1	RT = 0, WT = 0, C = 1	RT = 0, WT = 0, C = 1
$R_1(X)$				RT=1		
	$R_2(X)$			RT=2		
	$W_2(X)$			WT=2, C=0		
$W_1(X)$: **abort**						
		$W_3(Y)$			WT=3, C=0	
	$W_2(Y)$: **delay**					
		C_3			C=1	

A later write by T_3 has been committed!

T1	T2	T3	T4	X	Y	Z
1	2	3	4	RT = 0, WT = 0, C = 1	RT = 0, WT = 0, C = 1	RT = 0, WT = 0, C = 1
$R_1(X)$				RT=1		
	$R_2(X)$			RT=2		
	$W_2(X)$			WT=2, C=0		
$W_1(X)$: **abort**						
		$W_3(Y)$			WT=3, C=0	
	$W_2(Y)$: **delay**					
		C_3			C=1	
	Ignore $W_2(Y)$ and proceed					

T1	T2	T3	T4	X	Y	Z
1	2	3	4	RT = 0, WT = 0, C = 1	RT = 0, WT = 0, C = 1	RT = 0, WT = 0, C = 1
	Ignore $W_2(Y)$ and **proceed**					
			$W_4(Z)$			

T1	T2	T3	T4	X	Y	Z
1	2	3	4	RT = 0, WT = 0, C = 1	RT = 0, WT = 0, C = 1	RT = 0, WT = 0, C = 1
	Ignore $W_2(Y)$ and **proceed**					
			$W_4(Z)$			WT=4, C = 0

1. Physically realizable:
$TS(T_4)$ >= RT(Z) and $TS(T_4)$ >= WT(Z)

2. Update WT and C (not committed yet)

T1	T2	T3	T4	X	Y	Z
1	2	3	4	RT = 0, WT = 0, C = 1	RT = 0, WT = 0, C = 1	RT = 0, WT = 0, C = 1
	Ignore $W_2(Y)$ and **proceed**					
			$W_4(Z)$			WT=4, C = 0
			C_4			C=1

T1	T2	T3	T4	X	Y	Z
1	2	3	4	RT = 0, WT = 0, C = 1	RT = 0, WT = 0, C = 1	RT = 0, WT = 0, C = 1
	Ignore $W_2(Y)$ and **proceed**					
			$W_4(Z)$			WT=4, C = 0
			C_4			C=1
	$R_2(Z)$					

1. **NOT** Physically realizable: $TS(T_2) < WT(Z)$

Abort/rollback

			T4	X	Y	Z
			4	RT = 0, WT = 0, C = 1	RT = 0, WT = 0, C = 1	RT = 0, WT = 0, C = 1
	d **proceed**					
			$W_4(Z)$			WT=4, C = 0
			C_4			C=1
	$R_2(Z)$: **abort**					

Timestamp-based Concurrency Control

Questions?

Multiversion Concurrency Control

- Maintains **old** versions of database elements in addition the current version in the database itself.

- The idea is to allow reads that would otherwise result in an abort (as the current version was written by future transaction)

Problem with Timestamp-Based Scheduling

T1	T2	T3	T4	A
150	200	175	225	RT = 0 WT = 0
$R_1(A)$				RT = 150
$W_1(A)$				WT = 150
	$R_2(A)$			RT = 200
	$W_2(A)$			WT = 200
		$R_3(A)$		
		Abort		
			$R_4(A)$	RT = 225

Had to abort because WT(A) is greater than my own timestamp

Would have been useful if I had access to an old version of A (from 150)…

Multiversion Timestamps

T1	T2	T3	T4	A_0	A_{150}	A_{225}
150	200	175	225	RT = 0 WT = 0		
$R_1(A)$				RT = 150		
$W_1(A)$					Create	
	$R_2(A)$				RT=200	
	$W_2(A)$					Create
		$R_3(A)$			RT=175	
			$R_4(A)$			RT=225

Don't have to abort

Just read a previous value of A