CSE 444: Database Internals

Section 6:
Optimistic Concurrency Control

Today

- Timestamp-based Concurrency Control
- Multiversion Concurrency Control
- Extra help on lab 3

Problem 1: 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  - **Ignore** ***Thomas Write Rule*** – ignore outdated writes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      - If C = 1, **ignore** (***Thomas Write Rule*** – ignore outdated writes)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.

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?

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

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** [no need to check C(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** [no need to check C(B)]

- 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** [no need to check C(B)]

- 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

- TS_1 -> TS_2 -> TS_3 -> TS_4 -> $R_1(X)$ -> $R_2(X)$ -> $W_2(X)$ -> $W_1(X)$ -> $W_3(Y\ )$ -> $W_2(Y\ )$ -> C_3 -> $W_4(Z)$ -> C_4 -> $R_2(Z)$

- Remember!
  - Note changes to RT, WT, A and C bit for each element
  - Apply four rules

ST_1 -> ST_2 -> ST_3 -> ST_4 -> $R_1(X)$ -> $R_2(X)$ -> $W_2(X)$ -> $W_1(X)$ -> $W_3(Y)$ -> $W_2(Y)$ -> C_3 -> $W_4(Z)$ -> C_4 -> $R_2(Z)$

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
$R_1(X)$						

ST_1 -> ST_2 -> ST_3 -> ST_4 -> $R_1(X)$ -> $R_2(X)$ -> $W_2(X)$ -> $W_1(X)$ -> $W_3(Y\ )$ -> $W_2(Y\ )$ -> C_3 -> $W_4(Z)$ -> C_4 -> $R_2(Z)$

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
$R_1(X)$				RT=1		
	$R_2(X)$					

ST_1 -> ST_2 -> ST_3 -> ST_4 -> $R_1(X)$ -> $R_2(X)$ -> $W_2(X)$ -> $W_1(X)$ -> $W_3(Y)$ -> $W_2(Y)$ -> C_3 -> $W_4(Z)$ -> C_4 -> $R_2(Z)$

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
$R_1(X)$				RT=1		
	$R_2(X)$					

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

2. C = 1: grant request

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

ST_1 -> ST_2 -> ST_3 -> ST_4 -> $R_1(X)$ -> $R_2(X)$ -> $W_2(X)$ -> $W_1(X)$ -> $W_3(Y)$ -> $W_2(Y)$ -> C_3 -> $W_4(Z)$ -> C_4 -> $R_2(Z)$

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
$R_1(X)$				RT=1		
	$R_2(X)$			RT=2		
	$W_2(X)$					

ST_1 -> ST_2 -> ST_3 -> ST_4 -> $R_1(X)$ -> $R_2(X)$ -> $W_2(X)$ -> $W_1(X)$ -> $W_3(Y)$ -> $W_2(Y)$ -> C_3 -> $W_4(Z)$ -> C_4 -> $R_2(Z)$

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
$R_1(X)$				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

ST_1 -> ST_2 -> ST_3 -> ST_4 -> $R_1(X)$ -> $R_2(X)$ -> $W_2(X)$ -> $W_1(X)$ -> $W_3(Y)$ -> $W_2(Y)$ -> C_3 -> $W_4(Z)$ -> C_4 -> $R_2(Z)$

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
$R_1(X)$				RT=1		
	$R_2(X)$			RT=2		
	$W_2(X)$			WT=2, C=0		
$W_1(X)$						

ST_1 -> ST_2 -> ST_3 -> ST_4 -> $R_1(X)$ -> $R_2(X)$ -> $W_2(X)$ -> $W_1(X)$ -> $W_3(Y)$ -> $W_2(Y)$ -> C_3 -> $W_4(Z)$ -> C_4 -> $R_2(Z)$

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
$R_1(X)$				RT=1		
	$R_2(X)$			RT=2		
	$W_2(X)$			WT=2, C=0		
$W_1(X)$: **abort**						

ST_1 -> ST_2 -> ST_3 -> ST_4 -> $R_1(X)$ -> $R_2(X)$ -> $W_2(X)$ -> $W_1(X)$ -> $W_3(Y)$ -> $W_2(Y)$ -> C_3 -> $W_4(Z)$ -> C_4 -> $R_2(Z)$

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
$R_1(X)$				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

ST_1 -> ST_2 -> ST_3 -> ST_4 -> $R_1(X)$ -> $R_2(X)$ -> $W_2(X)$ -> $W_1(X)$ -> $W_3(Y\ )$ -> $W_2(Y\ )$ -> C_3 -> $W_4(Z)$ -> C_4 -> $R_2(Z)$

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
$R_1(X)$				RT=1		
	$R_2(X)$			RT=2		
	$W_2(X)$			WT=2, C=0		
$W_1(X)$: **abort**						
		$W_3(Y)$				

ST_1 -> ST_2 -> ST_3 -> ST_4 -> $R_1(X)$ -> $R_2(X)$ -> $W_2(X)$ -> $W_1(X)$ -> $W_3(Y\ )$ -> $W_2(Y\ )$ -> C_3 -> $W_4(Z)$ -> C_4 -> $R_2(Z)$

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
$R_1(X)$				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:

$TS(T_3)$ >= $RT(X)$ and $TS(T_3)$ >= $WT(X)$

2. Update WT and C (not committed yet)

ST_1 -> ST_2 -> ST_3 -> ST_4 -> $R_1(X)$ -> $R_2(X)$ -> $W_2(X)$ -> $W_1(X)$ -> $W_3(Y)$ -> $W_2(Y)$ -> C_3 -> $W_4(Z)$ -> C_4 -> $R_2(Z)$

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
$R_1(X)$				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	
	$W_2(Y)$					

ST_1 -> ST_2 -> ST_3 -> ST_4 -> $R_1(X)$ -> $R_2(X)$ -> $W_2(X)$ -> $W_1(X)$ -> $W_3(Y\ )$ -> $W_2(Y\ )$ -> C_3 -> $W_4(Z)$ -> C_4 -> $R_2(Z)$

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
$R_1(X)$				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**					

ST_1 -> ST_2 -> ST_3 -> ST_4 -> $R_1(X)$ -> $R_2(X)$ -> $W_2(X)$ -> $W_1(X)$ -> $W_3(Y)$ -> $W_2(Y)$ -> C_3 -> $W_4(Z)$ -> C_4 -> $R_2(Z)$

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
$R_1(X)$				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:

$TS(T_3) >= RT(X)$ although $TS(T_2) < WT(X)$

2. We could not apply Thomas' write rule **(ignore $W_2(Y)$)** since C=0

ST_1 -> ST_2 -> ST_3 -> ST_4 -> $R_1(X)$ -> $R_2(X)$ -> $W_2(X)$ -> $W_1(X)$ -> $W_3(Y)$ -> $W_2(Y)$ -> C_3 -> $W_4(Z)$ -> C_4 -> $R_2(Z)$

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
$R_1(X)$				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				

ST_1 -> ST_2 -> ST_3 -> ST_4 -> $R_1(X)$ -> $R_2(X)$ -> $W_2(X)$ -> $W_1(X)$ -> $W_3(Y\ )$ -> $W_2(Y\ )$ -> C_3 -> $W_4(Z)$ ->C_4 -> $R_2(Z)$

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
$R_1(X)$				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	

ST_1 -> ST_2 -> ST_3 -> ST_4 -> $R_1(X)$ -> $R_2(X)$ -> $W_2(X)$ -> $W_1(X)$ -> $W_3(Y\ )$ -> $W_2(Y\ )$ -> C_3 -> $W_4(Z)$ -> C_4 -> $R_2(Z)$

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
$R_1(X)$				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!

ST_1 -> ST_2 -> ST_3 -> ST_4 -> $R_1(X)$ -> $R_2(X)$ -> $W_2(X)$ -> $W_1(X)$ -> $W_3(Y)$ -> $W_2(Y)$ -> C_3 -> $W_4(Z)$ ->C_4 ->
$R_2(Z)$

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
$R_1(X)$				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					

ST_1 -> ST_2 -> ST_3 -> ST_4 -> $R_1(X)$ -> $R_2(X)$ -> $W_2(X)$ -> $W_1(X)$ -> $W_3(Y\ )$ -> $W_2(Y\ )$ -> C_3 -> $W_4(Z)$ ->C_4 -> $R_2(Z)$

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**					
			$W_4(Z)$			

ST_1 -> ST_2 -> ST_3 -> ST_4 -> $R_1(X)$ -> $R_2(X)$ -> $W_2(X)$ -> $W_1(X)$ -> $W_3(Y)$ -> $W_2(Y)$ -> C_3 -> $W_4(Z)$ -> C_4 ->

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

2. Update WT and C (not committed yet)

					Y	Z
					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

ST_1 -> ST_2 -> ST_3 -> ST_4 -> $R_1(X)$ -> $R_2(X)$ -> $W_2(X)$ -> $W_1(X)$ -> $W_3(Y)$ -> $W_2(Y)$ -> C_3 -> $W_4(Z)$ ->C_4 ->
$R_2(Z)$

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
			C_4			C=1

ST_1 -> ST_2 -> ST_3 -> ST_4 -> $R_1(X)$ -> $R_2(X)$ -> $W_2(X)$ -> $W_1(X)$ -> $W_3(Y\ )$ -> $W_2(Y\ )$ -> C_3 -> $W_4(Z)$ ->C_4 ->$R_2(Z)$

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
			C_4			C=1
	$R_2(Z)$					

ST_1 -> ST_2 -> ST_3 -> ST_4 -> $R_1(X)$ -> $R_2(X)$ -> $W_2(X)$ -> $W_1(X)$ -> $W_3(Y)$ -> $W_2(Y)$ -> C_3 -> $W_4(Z)$ ->C_4 -> R(Z)

			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**					

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

Abort/rollback

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_{200}
150	200	175	225	RT = 0 WT = 0		
$R_1(A)$				Read		
$W_1(A)$					Create	
	$R_2(A)$				Read	
	$W_2(A)$					Create
		$R_3(A)$			Read	
			$R_4(A)$			Read

Don’t have to abort

Just read a previous value of A

Second Example w/ Multiversion

T_1	T_2	T_3	T_4	T_5	A_0	A_1	A_2	A_3	A_4	A_5
1	2	3	4	5						
			$W_4(A)$							

Second Example w/ Multiversion

T_1	T_2	T_3	T_4	T_5	A_0	A_1	A_2	A_3	A_4	A_5
1	2	3	4	5						
			$W_4(A)$						Create	

Second Example w/ Multiversion

T_1	T_2	T_3	T_4	T_5	A_0	A_1	A_2	A_3	A_4	A_5
1	2	3	4	5						
			$W_4(A)$						Create	
W1(A)										

Second Example w/ Multiversion

T_1	T_2	T_3	T_4	T_5	A_0	A_1	A_2	A_3	A_4	A_5
1	2	3	4	5						
			W_4(A)						Create	
W1(A)						Create				

Second Example w/ Multiversion

T_1	T_2	T_3	T_4	T_5	A_0	A_1	A_2	A_3	A_4	A_5
1	2	3	4	5						
			$W_4(A)$						Create	
W1(A)						Create				
	$R_2(A)$									

Second Example w/ Multiversion

T_1	T_2	T_3	T_4	T_5	A_0	A_1	A_2	A_3	A_4	A_5
1	2	3	4	5						
			$W_4(A)$						Create	
W1(A)						Create				
	$R_2(A)$					RT=2				

Second Example w/ Multiversion

T_1	T_2	T_3	T_4	T_5	A_0	A_1	A_2	A_3	A_4	A_5
1	2	3	4	5						
			$W_4(A)$						Create	
W1(A)						Create				
	$R_2(A)$					RT=2				
		$R_3(A)$								

Second Example w/ Multiversion

T_1	T_2	T_3	T_4	T_5	A_0	A_1	A_2	A_3	A_4	A_5
1	2	3	4	5						
			$W_4(A)$						Create	
W1(A)						Create				
	$R_2(A)$					RT=2				
		$R_3(A)$				RT=3				

Second Example w/ Multiversion

T_1	T_2	T_3	T_4	T_5	A_0	A_1	A_2	A_3	A_4	A_5
1	2	3	4	5						
			$W_4(A)$						Create	
W1(A)						Create				
	$R_2(A)$					RT=2				
		$R_3(A)$				RT=3				
	$W_2(A)$									

Second Example w/ Multiversion

T_1	T_2	T_3	T_4	T_5	A_0	A_1	A_2	A_3	A_4	A_5
1	2	3	4	5						
			$W_4(A)$						Create	
W1(A)						Create				
	$R_2(A)$					RT=2				
		$R_3(A)$				RT=3				
	$W_2(A)$									
	abort									

Second Example w/ Multiversion

T_1	T_2	T_3	T_4	T_5	A_0	A_1	A_2	A_3	A_4	A_5
1	2	3	4	5						
			$W_4(A)$						Create	
W1(A)						Create				
	$R_2(A)$					RT=2				
		$R_3(A)$				RT=3				
	$W_2(A)$									
	abort			$R_5(A)$						

Second Example w/ Multiversion

T_1	T_2	T_3	T_4	T_5	A_0	A_1	A_2	A_3	A_4	A_5
1	2	3	4	5						
			$W_4(A)$						Create	
W1(A)						Create				
	$R_2(A)$					RT=2				
		$R_3(A)$				RT=3				
	$W_2(A)$									
	abort			$R_5(A)$					RT=5	

Second Example w/ Multiversion

T_1	T_2	T_3	T_4	T_5	A_0	A_1	A_2	A_3	A_4	A_5
1	2	3	4	5						
			$W_4(A)$						Create	
W1(A)						Create				
	$R_2(A)$					RT=2				
		$R_3(A)$				RT=3				
	$W_2(A)$									
	abort			$R_5(A)$					RT=5	
				$W_5(A)$						

Second Example w/ Multiversion

T_1	T_2	T_3	T_4	T_5	A_0	A_1	A_2	A_3	A_4	A_5
1	2	3	4	5						
			$W_4(A)$						Create	
W1(A)						Create				
	$R_2(A)$					RT=2				
		$R_3(A)$				RT=3				
	$W_2(A)$									
	abort			$R_5(A)$					RT=5	
				$W_5(A)$						Create

Second Example w/ Multiversion

T_1	T_2	T_3	T_4	T_5	A_0	A_1	A_2	A_3	A_4	A_5
1	2	3	4	5						
			$W_4(A)$						Create	
W1(A)						Create				
	$R_2(A)$					RT=2				
		$R_3(A)$				RT=3				
	$W_2(A)$									
	abort			$R_5(A)$					RT=5	
				$W_5(A)$						Create
			$R_4(A)$							

Second Example w/ Multiversion

T_1	T_2	T_3	T_4	T_5	A_0	A_1	A_2	A_3	A_4	A_5
1	2	3	4	5						
			$W_4(A)$						Create	
W1(A)						Create				
	$R_2(A)$					RT=2				
		$R_3(A)$				RT=3				
	$W_2(A)$									
	abort			$R_5(A)$					RT=5	
				$W_5(A)$						Create
			$R_4(A)$						RT=5	

Second Example w/ Multiversion

T_1	T_2	T_3	T_4	T_5	A_0	A_1	A_2	A_3	A_4	A_5
1	2	3	4	5						
			$W_4(A)$						Create	
W1(A)						Create				
	$R_2(A)$					RT=2				
		$R_3(A)$				RT=3				
	$W_2(A)$									
	abort			$R_5(A)$					RT=5	
				$W_5(A)$						Create
			$R_4(A)$						RT=5	
$R_1(A)$										

Second Example w/ Multiversion

T_1	T_2	T_3	T_4	T_5	A_0	A_1	A_2	A_3	A_4	A_5
1	2	3	4	5						
			$W_4(A)$						Create	
W1(A)						Create				
	$R_2(A)$					RT=2				
		$R_3(A)$				RT=3				
	$W_2(A)$									
	abort			$R_5(A)$					RT=5	
				$W_5(A)$						Create
			$R_4(A)$						RT=5	
$R_1(A)$						RT=3				

Second Example w/ Multiversion

T_1	T_2	T_3	T_4	T_5	A_0	A_1	A_2	A_3	A_4	A_5
1	2	3	4	5						
			$W_4(A)$						Create	
W1(A)						Create				
	$R_2(A)$					RT=2				
		$R_3(A)$				RT=3				
	$W_2(A)$									
	abort			$R_5(A)$					RT=5	
				$W_5(A)$						Create
			$R_4(A)$						RT=5	
$R_1(A)$						RT=3				
C										

Second Example w/ Multiversion

T_1	T_2	T_3	T_4	T_5	A_0	A_1	A_2	A_3	A_4	A_5
1	2	3	4	5						
			$W_4(A)$						Create	
W1(A)						Create				
	$R_2(A)$					RT=2				
		$R_3(A)$				RT=3				
	$W_2(A)$									
	abort			$R_5(A)$					RT=5	
				$W_5(A)$						Create
			$R_4(A)$						RT=5	
$R_1(A)$						RT=3				
C					X					

Second Example w/ Multiversion

T_1	T_2	T_3	T_4	T_5	A_0	A_1	A_2	A_3	A_4	A_5
1	2	3	4	5						
			$W_4(A)$						Create	
W1(A)						Create				
	$R_2(A)$					RT=2				
		$R_3(A)$				RT=3				
	$W_2(A)$									
	abort			$R_5(A)$					RT=5	
				$W_5(A)$						Create
			$R_4(A)$						RT=5	
$R_1(A)$						RT=3				
C					X					

X means that we can delete this version

Second Example w/ Multiversion

T_1	T_2	T_3	T_4	T_5	A_0	A_1	A_2	A_3	A_4	A_5
1	2	3	4	5						
			$W_4(A)$						Create	
W1(A)						Create				
	$R_2(A)$					RT=2				
		$R_3(A)$				RT=3				
	$W_2(A)$									
	abort			$R_5(A)$					RT=5	
				$W_5(A)$						Create
			$R_4(A)$						RT=5	
$R_1(A)$						RT=3				
C					X					
		C								

X means that we can delete this version

Second Example w/ Multiversion

T_1	T_2	T_3	T_4	T_5	A_0	A_1	A_2	A_3	A_4	A_5
1	2	3	4	5						
			$W_4(A)$						Create	
W1(A)						Create				
	$R_2(A)$					RT=2				
		$R_3(A)$				RT=3				
	$W_2(A)$									
	abort			$R_5(A)$					RT=5	
				$W_5(A)$						Create
			$R_4(A)$						RT=5	
$R_1(A)$						RT=3				
C					X					
		C				X				

X means that we can delete this version

Second Example w/ Multiversion

T_1	T_2	T_3	T_4	T_5	A_0	A_1	A_2	A_3	A_4	A_5
1	2	3	4	5						
			$W_4(A)$						Create	
W1(A)						Create				
	$R_2(A)$					RT=2				
		$R_3(A)$				RT=3				
	$W_2(A)$									
	abort			$R_5(A)$					RT=5	
				$W_5(A)$						Create
			$R_4(A)$						RT=5	
$R_1(A)$						RT=3				
C					X					
		C				X				

X means that we can delete this version