

Data Bases II  
*Exercises*

Christian Rossi

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## **Abstract**

The course aims to prepare software designers on the effective development of database applications.

First, the course presents the fundamental features of current database architectures, with a specific emphasis on the concept of transaction and its realization in centralized and distributed systems.

Then, the course illustrates the main directions in the evolution of database systems, presenting approaches that go beyond the relational model, like active databases, object systems and XML data management solutions.

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# Chapter 1

## Exercise session I

### 1.1 Anomalies classification

Can the following schedules produce anomalies?  $c_i$  and  $a_i$  indicate the transactional decision commit and abort.

1.  $r_1(x)w_1(x)r_2(x)w_2(y) a_1 c_2$
2.  $r_1(x)w_1(x)r_2(y)w_2(y) a_1 c_2$
3.  $r_1(x)r_2(x)r_2(y)w_2(y)r_1(z) a_1 c_2$
4.  $r_1(x)r_2(x)w_2(x)w_1(x) c_1 c_2$
5.  $r_1(x)r_2(x)w_2(x)r_1(y) c_1 c_2$
6.  $r_1(x)w_1(x)r_2(x)w_2(x) c_1 c_2$

### Solution

1. We have a serial execution, but with the abort of the first transaction. Since the second transaction reads the modified value of  $x$  before the abort, we have a dirty read.
2. We have a serial execution and the two transactions require different resources, so there are no anomalies.
3. There are no anomalies because the last operation of the first transaction works on a different resource.

4. Both transactions first reads in sequence the resource  $x$  and then updates it without considering the updated value, so we have a lost update.
5. There are no anomalies because the last operation of the first transaction works on a different resource.
6. We have a serial execution, so the schedule is correct.

## 1.2 Anomalies classification

The following schedule may produce 2 anomalies: a lost update and a phantom update. Identify them.

$$r_1(x)r_2(x)r_3(x)w_1(x)r_4(y)w_2(x)r_4(x)w_4(y)r_3(y)w_4(x)r_5(y)w_6(y)w_5(y)w_7(y)$$

### Solution

We can write the schedule in the following way:

$$\begin{array}{ccccccccc}
 r_1(x) & & w_1(x) & & & & & & \\
 & r_2(x) & & & w_2(x) & & & & \\
 & & r_3(x) & & & & & & \\
 & & & r_4(y) & & r_4(x) & & w_4(y) & r_3(y) \\
 & & & & & & w_4(x) & & \\
 & & & & & & & r_5(y) & \\
 & & & & & & & & w_6(y) & w_5(y) \\
 & & & & & & & & & \\
 & & & & & & & & & & w_7(y)
 \end{array}$$

And we can see that there is a lost update with transactions  $T_1$  and  $T_2$  and a phantom update with  $T_3$  and  $T_4$ .

### 1.3 Schedule classification

Classify the following schedule with respect to CSR and VSR classes:

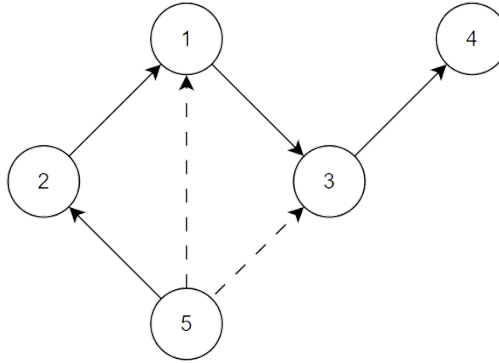
$$r_1(x)r_2(y)w_3(y)r_5(x)w_5(u)w_3(s)w_2(u)w_3(x)w_1(u)r_4(y)w_5(z)r_5(z)$$

#### Solution

Since CSR contains VSR we check with the conflict graph. To do so we first divide the schedule based on the resources:

- $x : r_1 r_5 w_3$
- $y : r_2 w_3 r_4$
- $z : w_5 r_5$
- $s : w_3$
- $u : w_5 w_2 w_1$

The nodes are  $\{1, 2, 3, 4, 5\}$  and the arcs are found with the write-write or write-read relations found in the previous groups. So we have the following graph:



Some arcs can be omitted if the nodes are connected in another way (in this case we can remove arcs  $\{\{5, 1\}, \{5, 3\}\}$ ).

There are no cycles: the schedule is CSR (and also VSR).

## 1.4 Schedule classification

Classify the following schedule with respect to CSR and VSR classes:

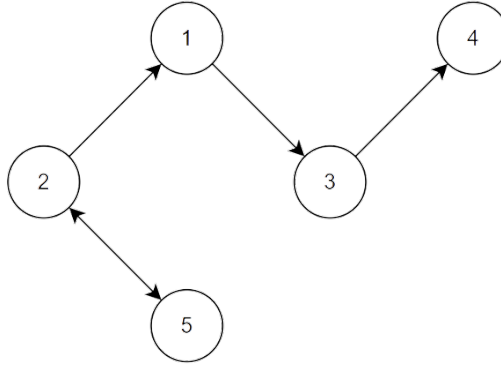
$r_2(u)w_2(s)r_1(x)r_2(y)w_3(y)r_5(x)w_5(u)w_3(s)w_2(u)w_3(x)w_1(u)r_4(y)w_5(z)r_5(z)$

### Solution

Since CSR contains VSR we check with the conflict graph. To do so we first divide the schedule based on the resources:

- $x : r_1 \ r_5 \ w_3$
- $y : r_2 \ w_3 \ r_4$
- $z : w_5 \ r_5$
- $s : w_2 \ w_3$
- $u : r_2 \ w_5 \ w_2 \ w_1$

The nodes are  $\{1, 2, 3, 4, 5\}$  and the arcs are found with the write-write or write-read relations found in the previous groups. So we have the following graph:



It is possible to see that there is a cycle between two and five. The definition of VSR states that we need to have the same reads-from relations and final writes. So, we try to find a view-equivalent schedule that is also CSR. One possible solution is simply to swap the two writes on the resource  $u$  and that is sufficient to eliminate the cycle. So, the schedule:

$r_2(u)w_2(s)r_1(x)r_2(y)w_3(y)r_5(x)w_2(u)w_5(u)w_3(s)w_3(x)w_1(u)r_4(y)w_5(z)r_5(z)$

is CSR and also VSR.



## 1.5 Schedule classification

Classify the following schedule with respect to CSR and VSR classes:

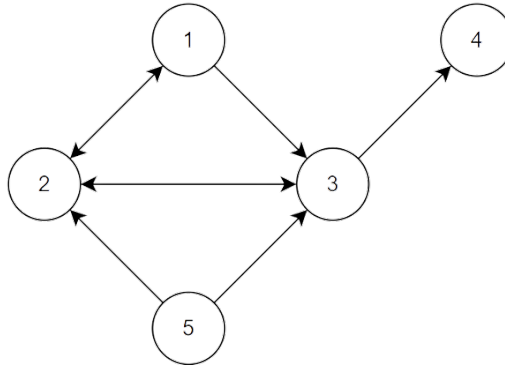
$r_1(x)r_2(y)w_3(y)r_5(x)w_5(u)w_3(s)w_2(u)w_3(x)w_1(u)r_4(y)w_5(z)r_5(z)r_2(u)w_2(s)$

### Solution

Since CSR contains VSR we check with the conflict graph. To do so we first divide the schedule based on the resources:

- $x : r_1 r_5 w_3$
- $y : r_2 w_3 r_4$
- $z : w_5 r_5$
- $s : w_3 w_2$
- $u : w_5 w_2 w_1 r_2$

The nodes are  $\{1, 2, 3, 4, 5\}$  and the arcs are found with the write-write or write-read relations found in the previous groups. So we have the following graph:



In this case it is not possible to find a VSR schedule because it is impossible to do so without changing the final write on  $s$ .

## 1.6 Schedule classification

Classify the following schedule with respect to CSR and VSR classes:

$$r_5(x)r_3(y)w_3(y)r_6(t)r_5(t)w_5(z)w_4(x)r_3(z)w_1(y) \dots$$

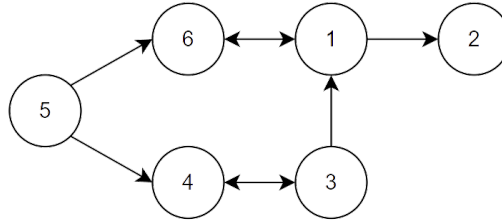
$$\dots r_6(y)w_6(t)w_4(z)w_1(t)w_3(x)w_1(x)r_1(z)w_2(t)w_2(z)$$

### Solution

Since CSR contains VSR we check with the conflict graph. To do so we first divide the schedule based on the resources:

- $t : r_6 r_5 w_6 w_1 w_2$
- $x : r_5 w_4 w_3 w_1$
- $y : r_3 w_3 w_1 r_6$
- $z : w_5 r_3 w_4 r_1 w_2$

The nodes are  $\{1, 2, 3, 4, 5, 6\}$  and the arcs are found with the write-write or write-read relations found in the previous groups. So we have the following graph:



We have two cycles. It is impossible to find a VSR schedule because only the conflict between four and three can be eliminated (the other one changes a read-write relation).

# Chapter 2

## Exercise session II

### 2.1 Schedule classification

Classify the following schedule with respect to 2PL and strict 2PL classes:

$$r_1(x)r_2(y)w_3(y)r_5(x)w_5(u)w_3(s)w_2(u)w_3(x)w_1(u)r_4(y)w_5(z)r_5(z)$$

#### Solution

For strict 2PL we assume that all transactions commit and release all locks immediately after their last operation, and check if releases can be executed at commit time.

	1	2	3	4	5	6	7	8	9	10	11	12
$S$						$w_3$						
$U$					$w_5$		$\searrow_5 w_2 \downarrow_2$		$w_1 \downarrow_1$			
$X$	$r_1$			$r_5$				$\searrow_1 w_3$				
$Y$		$r_2 \searrow_2$	$w_3$							$r_4$		
$Z$											$w_5$	$r_5 \downarrow_5$

$S$  clearly cannot be in strict 2PL. The contradictions are:

- $T_1$  must release  $X$  before 8.
- $T_2$  must release  $Y$  before 7.
- $T_5$  must release  $U$  before 12.

For 2PL we have:

	1	2	3	4	5	6	7	8	9	10	11	12
$S$												
$U$						$\nearrow_3 w_3$		$\searrow_3$				
$X$	$\nearrow_1 r_1$			$\nearrow_5 r_5$	$\nearrow_5 w_5 \searrow_5$	$\searrow_5$	$\nearrow_2 w_2 \searrow_2 \nearrow_1$	$\searrow_1 \nearrow_3 w_3 \searrow_3$	$w_1 \searrow_1$			
$Y$		$\nearrow_2 r_2 \searrow_2$	$\nearrow_3 w_3$						$\searrow_3$	$\nearrow_4 r_4 \searrow_4$		
$Z$				$\nearrow_5$							$w_5 \quad r_5 \searrow_5$	

It is also not in 2PL: an assignment is not possible for  $T_2$  (which must release  $Y$  before locking  $U$ ).

## 2.2 Schedule classification

Classify the following schedule with respect to 2PL and strict 2PL classes:

$r_4(x)r_2(x)w_4(x)w_2(y)w_4(y)r_3(y)w_3(x)w_4(z)r_3(z)r_6(z)r_8(z)w_6(z)w_9(z)r_5(z)r_10(z)$

### Solution

For strict 2PL we assume that all transactions commit and release all locks immediately after their last operation, and check if releases can be executed at commit time.

	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15
X	$r_4$	$r_2$	$\searrow_2$	$w_4$			$w_3$								
Y				$w_2$	$\downarrow_2$	$w_4$	$r_3$								
Z								$w_4$	$r_3$	$r_6$	$r_8$	$w_6$	$w_9$	$r_5$	$r_{10}$

It is therefore clear that the schedule cannot be in 2PL-strict, due to  $T_2$  and  $T_4$ :  $T_2$  ends after 4, but  $T_4$  wants to write X at 3, and  $T_2$  would thus be required to release X earlier, which is impossible if  $T_2$  has to keep all locks until after 4.

For 2PL we have:

	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15
X	$\nearrow_4 r_4$	$\nearrow_2 r_2$	$\searrow_4 w_4$		$\searrow_4$		$\nearrow_3 w_3$			$\searrow_3$					
Y		$\nearrow_2$		$w_2$	$\searrow_2$	$\nearrow_4 w_4$	$\searrow_4$	$\nearrow_3 r_3$		$\searrow_3$					
Z			$\nearrow_4$						$w_4$	$\searrow_4$	$\nearrow_3 r_3$	$r_6$	$r_8$	$\searrow_3$	$w_6$ $w_9$ $r_5$ $r_{10}$

We need to look at those acquisitions that must be anticipated and to those releases that must be delayed to not violate the 2PL rules.  $T_4$  can only get the XL on X only after 2 and on Y after 4 and has to release Y before 6 and X before 7. Thus, the lock on Z must be acquired before 6.  $T_2$  can get all the locks at the beginning and release them immediately after each use.  $T_3$  can acquire X, Y and Z just before using them and release them all before 12. All other transactions ( $T_6, T_9, T_5, T_{10}$ ) clearly pose no problems.

## 2.3 Schedule classification

Classify the following schedule with respect to 2PL and strict 2PL classes:

$$r_1(A)r_2(A)w_2(A)r_1(B)w_1(C)w_2(C)r_3(C)w_3(A)w_2(B)w_3(B)$$

### Solution

For strict 2PL we assume that all transactions commit and release all locks immediately after their last operation, and check if releases can be executed at commit time.

	1	2	3	4	5	6	7	8	9	10
A	$r_1$	$r_2 \searrow_1$	$w_2$					$w_3$		
B					$w_1 \downarrow_1$	$w_2$	$r_3$			
C				$r_1$					$w_2$	$w_3$

The schedule is not strict 2PL.

For 2PL we have:

	1	2	3	4	5	6	7	8	9	10
A	$\nearrow_1 r_1$	$\nearrow_2 r_2 \searrow_1$	$\nearrow_2 w_2$			$\searrow_2$		$\nearrow_3 w_3$		$\searrow_3$
B		$\nearrow_1$			$w_1 \searrow_1$	$\nearrow_2 w_2 \searrow_2$	$\nearrow_3 r_3$			$\searrow_3$
C		$\nearrow_1$		$r_1 \searrow_1$					$w_2 \searrow_2$	$\nearrow_3 w_3 \searrow_3$

The schedule is 2PL.

## 2.4 Schedule classification

Classify the following schedule with respect to 2PL and strict 2PL classes:

$$r_1(x)w_2(x)r_1(z)w_1(y)r_3(x)r_4(x)w_3(z)w_2(y)r_3(y)w_4(x)w_4(y)$$

### Solution

For strict 2PL we assume that all transactions commit and release all locks immediately after their last operation, and check if releases can be executed at commit time.

	1	2	3	4	5	6	7	8	9	10	11
X	$r_1 \searrow_1$	$w_2$			$r_3$	$r_4$				$w_4$	
Y				$w_1 \downarrow_1$				$w_2$	$r_3$		$w_4$
Z			$r_1$				$w_3$				

The schedule is not strict 2PL.

For 2PL we have:

	1	2	3	4	5	6	7	8	9	10	11
X	$\nearrow_1 r_1 \searrow_1$	$\nearrow_2 w_2$			$\searrow_2 \nearrow_3 r_3$	$\nearrow_4 r_4$			$\searrow_3$	$\nearrow_4 w_4$	$\searrow_4$
Y	$\nearrow_1$			$w_1 \searrow_1 \nearrow_2$				$w_2 \searrow_2$	$\nearrow_3 r_3 \searrow_3$		$\nearrow_4 w_4 \searrow_4$
Z	$\nearrow_1$		$r_1 \searrow_1$				$\nearrow_3 w_3$		$\searrow_3$		

The schedule is 2PL.

## 2.5 Update locks

Given the schedule:

$$r1(x)r2(x)r3(y)w3(y)w1(x)w2(y)$$

show the sequence of lock and unlock requests produced by the transactions in a 2PL execution, in a system with update lock (available locks:  $SL, UL, XL$ ).

### Solution

The locking phases with update locks are the following:

$X$	$Y$
$UL_1(x)$ $r_1(x)$ $SL_2(x)$ $r_2(x)$	$UL_3(y)$ $r_3(y)$ $XL_3(y)[\text{upgrade}]$ $w_3(y)$ $\text{rel}(XL_3(y))$ $XL_2(y)$
$\text{rel}(SL_2(x))$ $XL_1(x)[\text{upgrade}]$ $w_1(x)$ $\text{rel}(XL_1(x))$	$w_2(y)$ $\text{rel}(XL_2(y))$



## 2.6 Update locks

Update lock was introduced to contrast deadlocks. Can we state that deadlocks are impossible in the presence of update locks?

1. If so, concisely explain why.
2. If not, provide a counter-example.

### Solution

1. Clearly deadlocks are possible in the presence of UL. Indeed, UL only makes deadlock less likely, by preventing one type of deadlock, due to update patterns, when two transactions compete for the same resource ( $r_1(x)r_2(x)w_1(x)w_2(x)$ ).
2. Consider two distinct resources  $X$  and  $Y$ , and two transactions that want to access them in this order:  $r_1(X)r_2(Y)w_1(Y)w_2(X)$ . It is likely that they end up in deadlock, especially if the system on which they run applies 2PL. UL is totally irrelevant here, because there is no update pattern.

# Chapter 3

## Exercise session III

### 3.1 Obermarck's algorithm

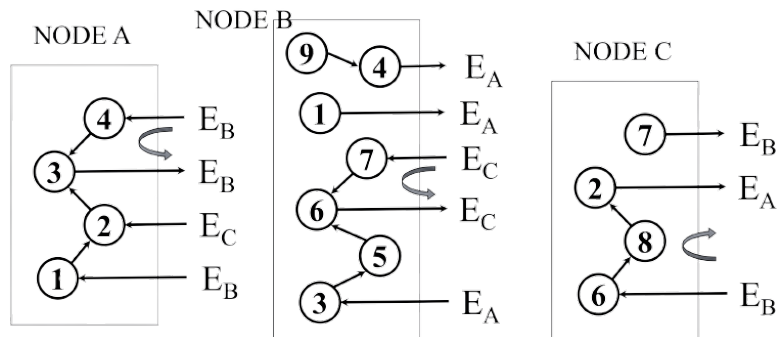
Consider the following waiting conditions:

- Node A:  $E_B \rightarrow t_1, t_1 \rightarrow t_2, E_C \rightarrow t_2, t_2 \rightarrow t_3, t_3 \rightarrow E_B, E_B \rightarrow t_4, t_4 \rightarrow t_3$
- Node B:  $E_A \rightarrow t_3, t_3 \rightarrow t_5, t_5 \rightarrow t_6, t_6 \rightarrow E_C, E_C \rightarrow t_7, t_7 \rightarrow t_6, t_9 \rightarrow t_4, t_4 \rightarrow E_A, t_1 \rightarrow E_A$
- Node C:  $E_B \rightarrow t_6, t_6 \rightarrow t_8, t_8 \rightarrow t_2, t_2 \rightarrow E_A, t_7 \rightarrow E_B$

Simulate the Obermarck algorithm and indicate whether there is a distributed deadlock.

### Solution

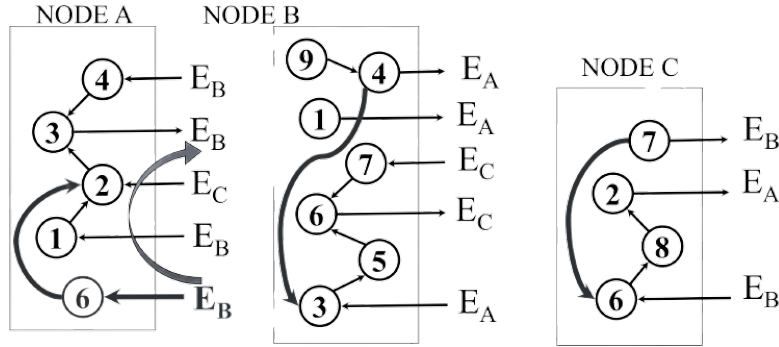
We need to construct the graph with the given constraints, that is:



We have to check all the nodes where the sender has a lower value than the receiver. In this case we have that the update is sent to the other distributed node. The interesting cases are highlighted in the image. So, we now have to add the nodes:

- $4 \rightarrow 3$  in  $E_B$ .
- $7 \rightarrow 6$  in  $E_C$ .
- $6 \rightarrow 2$  in  $E_A$ .

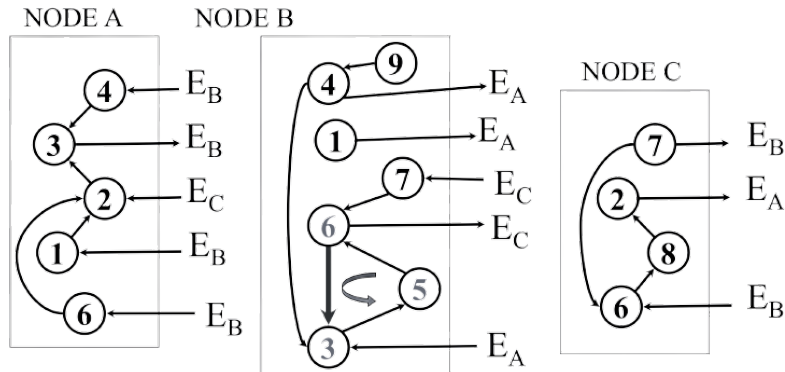
If the numbered node is not present we can add it to the graph of the distributed node. We obtain the following graphs:



We have to check if other messages are sent. We have:

- $6 \rightarrow 3$  in  $E_B$ .

So the updated graph is:



We have found find a cycle, so there is a deadlock.

## 3.2 Obermarck's algorithm

The nodes  $A$ ,  $B$ , and  $C$  of a distributed transactional system are aware of the following remote and local waiting conditions:

- Node  $A$  :  $E_B \rightarrow t_3, E_C \rightarrow t_2, t_1 \rightarrow E_C, t_3 \rightarrow t_5, t_5 \rightarrow t_1$
- Node  $B$  :  $E_C \rightarrow t_2, t_3 \rightarrow E_A, t_2 \rightarrow t_3$
- Node  $C$  :  $t_2 \rightarrow E_A, t_2 \rightarrow E_B, t_1 \rightarrow t_4, t_4 \rightarrow t_2$

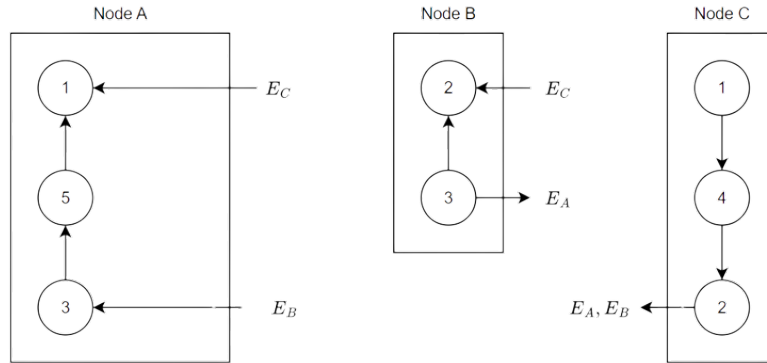
Execute the Obermarck's algorithm twice, with different conventions:

1. Sending messages of the form  $E_X \rightarrow t_i \rightarrow t_j \rightarrow E_Y$  forward (toward node  $Y$ ) and only if and only if  $i > j$ .
2. With the opposite conventions, so if and only if  $i < j$

Discuss the outcome, and explain it, taking into account the properties of the algorithm and the initial conditions.

### Solution

The graph is the following:



1. We have to add the nodes (connections are distributed):
  - $3 \rightarrow 1$  in  $E_C$ .
  - $3 \rightarrow 2$  in  $E_A$ .
  - $3 \rightarrow 2$  in  $E_B$ .

By adding those nodes we found that the third one creates a deadlock.

2. We have to add the node (connections are distributed):

- $2 \rightarrow 3$  in  $E_A$ .

No cycles are found, so no deadlocks found.

The algorithm is independent of the conventions but the initial conventions, but the initial conditions must be consistent and complete. On a faulty dataset even the best algorithm returns untrustworthy results. In this case we have a link missing between node  $A$  and  $C$ .

### 3.3 Schedule classification

Classify the following schedule with respect to timestamps:

$r_4(x)r_2(x)w_4(x)w_2(y)w_4(y)r_3(y)w_3(x)w_4(z)r_3(z)r_6(z)r_8(z)w_6(z)w_9(z)r_5(z)r_{10}(z)$

#### Solution

We can identify pairs of operations that cause killings:

- $X : r_4r_2w_4w_3$
- $Y : w_2w_4r_3$
- $Z : w_4r_3r_6r_8w_6w_9r_5r_{10}$

On  $X$  we have that  $w_3$  is too late with respect to  $r_4$  and  $w_4$ . On  $Y$  we have that  $r_3$  is late with respect to  $w_4$ . On  $Z$  we have that  $r_3$  is late with respect to  $w_4$ ,  $w_6$  with respect to  $r_8$ ,  $r_5$  with respect to both  $w_6$  and  $w_9$ . So, the schedule is not in TS-mono.

The schedule is also outside TS-multi, because  $w_3(X)$  comes too late ( $r_4(X)$  was already given the initial version instead) and also because  $w_6(Z)$  is late with respect to  $r_8(Z)$ . The other five reasons were due to reads (that are always accepted in TS-multi).

### 3.4 Schedule classification

Classify the following schedule with respect to timestamps:

$$r_1(x)r_2(y)w_3(y)r_5(x)w_5(u)w_3(s)w_2(u)w_3(x)w_1(u)r_4(y)w_5(z)r_5(z)$$

#### Solution

We can identify pairs of operations that cause killings:

- $S : w_3$
- $U : w_5w_2w_1$
- $X : r_1r_5w_3$
- $Y : r_2w_3r_4$
- $Z : w_5r_5$

$S$ ,  $Y$  and  $Z$  are ok,  $U$  is ok only if the Thomas rule is applied, and  $X$  is not ok for both TS-mono and TS-multi.

### 3.5 Schedule classification

Classify the following schedule:

$$r_1(X)w_1(Y)w_2(Y)w_3(Z)r_1(Z)w_4(X)r_4(Y)w_3(X)r_5(Y)w_5(X)$$

#### Solution

Firstly, we check if it is CSR:

- $X : r_1w_4w_3w_5$
- $Y : w_1w_2r_4r_5$
- $Z : w_3r_1$

We found a cycle between the nodes three and one, so it is not CSR. It is also not VSR. We now check for TS using the same list: we find that  $w_4w_3$  are not in the correct order, so it is not in TS-mono, neither in TS-multi (it is a write that causes the problem).



### 3.6 Schedule classification

Classify the following schedule:

$$r_1(x)r_2(y)w_3(x)r_5(z)w_6(z)w_2(x)w_3(y)r_7(z)w_4(x)$$

#### Solution

Firstly, we check if it is CSR:

- $X : r_1w_3w_2w_4$
- $Y : r_2w_3$
- $Z : r_5w_6r_7$

There is a cycle between two and three, so it is not CSR, but by swapping  $w_3w_2$  we can obtain a VSR schedule without changing the schedule.

The schedule is not TS-mono because we have  $w_3w_2$  and so also non TS-multi.

### 3.7 Schedule classification

Given the resources above and the following transactions:

$$T_1 : r_1(C)w_1(B)w_1(C)$$

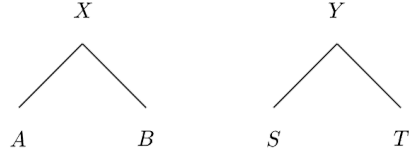
$$T_2 : w_2(A)r_2(C)$$

Consider that  $T_1$  and  $T_2$  can only be scheduled in 10 different ways (two serial, eight interleaved). What can be stated about the 2PL-strict compatibility of these schedules?

#### Solution

We note that the only potential conflict is between  $w_1(C)$  and  $r_2(C)$ . But these are also the last operations of their respective transactions: to check for compatibility, we can always assume that the commit occurs right after the last operation, and that all locks are released in favor of the other one. But this argument is independent of the order of the operations, and is therefore valid for all the 8 interleaved schedules. So, all the schedules are strict 2PL.

### 3.8 Hierarchical lock



Given the resource hierarchy above, is the following schedule compatible with a 2PL-strict scheduler that applies hierarchical locking?

$$r_1(A)w_1(S)w_2(T)r_2(A)w_1(A)$$

#### Solution

The lock manager works as follows:

	<i>X</i>	<i>A</i>	<i>B</i>	<i>Y</i>	<i>S</i>	<i>T</i>	
$r_1(A)$	ISL <sub>1</sub>	-	-	-	-	-	
	ISL <sub>1</sub>	SL <sub>1</sub>	-	-	-	-	
$w_1(S)$	ISL <sub>1</sub>	SL <sub>1</sub>	-	IXL <sub>1</sub>	-	-	
	ISL <sub>1</sub>	SL <sub>1</sub>	-	IXL <sub>1</sub>	XL <sub>1</sub>	-	
$w_2(T)$	ISL <sub>1</sub>	SL <sub>1</sub>	-	IXL <sub>1,2</sub>	XL <sub>1</sub>	-	
	ISL <sub>1</sub>	SL <sub>1</sub>	-	IXL <sub>1,2</sub>	XL <sub>1</sub>	XL <sub>2</sub>	
$r_2(A)$	ISL <sub>1,2</sub>	SL <sub>1</sub>	-	IXL <sub>1,2</sub>	XL <sub>1</sub>	XL <sub>2</sub>	
	ISL <sub>1,2</sub>	SL <sub>1,2</sub>	-	IXL <sub>1,2</sub>	XL <sub>1</sub>	XL <sub>2</sub>	
commit $T_2$							End of $T_2$
$w_1(A)$	<b>ISL</b> <sub>1</sub>	SL <sub>1</sub>	-	IXL <sub>1</sub>	XL <sub>1</sub>	-	
	<b>IXL</b> <sub>1</sub>	<b>SL</b> <sub>1</sub>	-	IXL <sub>1</sub>	XL <sub>1</sub>	-	
commit $T_1$	IXL <sub>1</sub>	<b>XL</b> <sub>1</sub>	-	IXL <sub>1</sub>	XL <sub>1</sub>	-	
							End of $T_1$

So, it is compatible with a strict 2PL scheduler.

### 3.9 Hierarchical lock

Consider the following short schedule occurring on a system with hierarchical lock over a hierarchy where *PagA* contains tuples  $t_1$  and  $t_2$ :

$$r_1(PagA), w_2(t1), w_1(t2)$$

Show a possible sequence of locks, unlocks, lock upgrades, and lock downgrades performed by transactions  $T_1$  and  $T_2$  such that the schedule is in 2PL.

#### Solution

We have that:

	PagA	t2	t1
SIXL <sub>1</sub> ( <i>PagA</i> )	SIXL <sub>1</sub>	-	-
XL <sub>1</sub> ( $t_2$ )	SIXL <sub>1</sub>	XL <sub>1</sub>	-
$r_1(PagA)$			
U-SL <sub>1</sub> ( <i>PagA</i> )	IXL <sub>1</sub> , IXL <sub>2</sub>	XL <sub>1</sub>	-
IXL <sub>2</sub> ( <i>PagA</i> )	IXL <sub>1</sub> , IXL <sub>2</sub>	XL <sub>1</sub>	-
XL <sub>2</sub> ( $t_1$ )	IXL <sub>1</sub> , IXL <sub>2</sub>	XL <sub>1</sub>	XL <sub>2</sub>
$w_2(t1)$			
U-XL <sub>2</sub> ( $t_1$ )	IXL <sub>1</sub> , IXL <sub>2</sub>	XL <sub>1</sub>	-
U-IXL <sub>2</sub> ( <i>PagA</i> )	IXL <sub>1</sub>	XL <sub>1</sub>	-
Commit $T_2$			
$w_1(t2)$			
U-XL <sub>1</sub> ( $t_2$ )	IXL <sub>1</sub>	-	-
U-IXL <sub>1</sub> ( <i>PagA</i> )	-	-	-
Commit $T_1$			

So the schedule is 2PL.