Data Bases II

Schedules and Concurrency Control

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Exercise S.1

Classify the following schedule (CSR/VSR)

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

If possible, add/remove/move one action in order to change the class of the schedule.

How to check if a schedule is CSR:

1. Split operations by resource
2. Identify conflicts
   - $w_x ... w_y \Rightarrow x$ conflicts with y
   - $r_x ... w_y \Rightarrow x$ conflicts with y
   - $w_x ... r_y \Rightarrow x$ conflicts with y
3. Build the conflict graph
4. The schedule is CSR if and only if there are no cycles

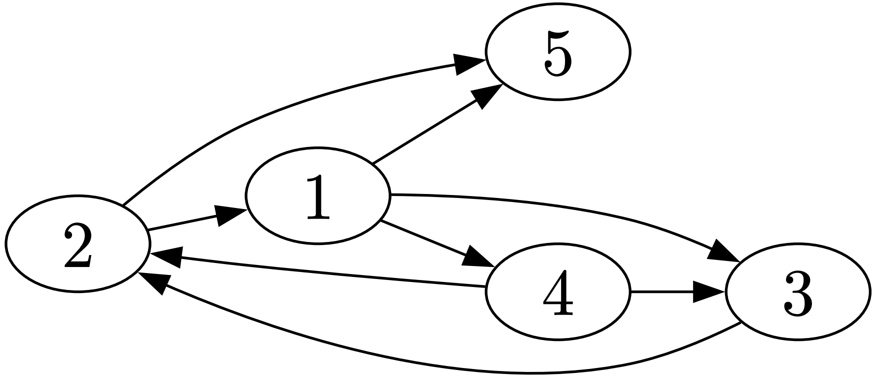
$$r_1(X)r_4(X)w_4(X)r_1(Y)r_4(Z)w_4(Z)w_3(Y)w_3(Z)w_2(T)w_2(Z)w_1(T)w_5(T)$$

T: $w_2 w_1 w_5$

X: $r_1 r_4 w_4$

Y: $r_1 w_3$

Z: $r_4 w_4 w_3 w_2$



We can see there is a cycle (more than one).

Hence, the schedule is **not** CSR. It could be VSR.

How to check if a schedule is VSR:

1. Split operations by resource
2. Try and find a *serial* schedule that has
   - the same *read-from* relations ($w_x ... r_y \Rightarrow y$ reads from x)
   - the same *last writes*
3. If found, the schedule is VSR

Alternatively, build a graph showing all the necessary relations

1. *read-from* relations
2. *last writes* relations
3. moreover, $r_x ... w_y$ means y must come after x, otherwise a new *read-from* relation would be born out of nowhere

Method 1

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

T: $w_2 w_1 w_5$
X: $r_1 r_4 w_4$
Y: $r_1 w_3$
Z: $r_4 w_4 w_3 w_2$

It is VSR: t_1, t_4, t_3, t_2, t_5 is view-equivalent.

There are no read-froms. Last-writes are immediate (e.g., t_5 must follow t_1 and t_2 for T, and so on).

Note: we can swap w_2 and w_1 in T without modifying anything. This is because w_5 always overwrites T, and there are no read-froms on T.

Method 2

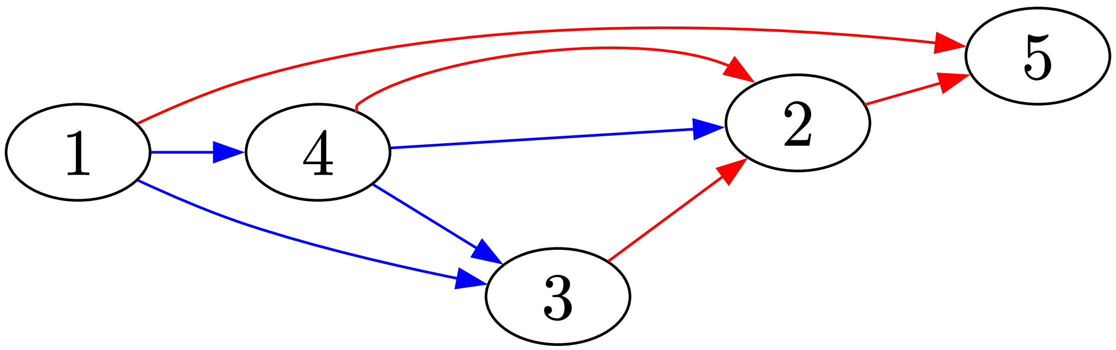
$$r_1(X)r_4(X)w_4(X)r_1(Y)r_4(Z)w_4(Z)w_3(Y)w_3(Z)w_2(T)w_2(Z)w_1(T)w_5(T)$$

T: $w_2 w_1 w_5$

X: $r_1 r_4 w_4$

Y: $r_1 w_3$

Z: $r_4 w_4 w_3 w_2$



In *red*, last writes constraints. In *blue*, to prevent new read-froms (no existing read-froms). There is no cycle, so it is VSR.

If possible, add/remove/move one action in order to change the class of the schedule.

If we add $w_1(Y)$ at the end, the schedule is no longer VSR.

Swapping $w_1(T)$ and $w_2(T)$ (a couple of *blind writes*) we build a schedule that is in CSR. Note that this swapping does not modify the reads-from and final write relationships. This confirms that the initial schedule was VSR.

Exercise S.2

Classify the following schedule

$$r_4(X)r_2(X)w_4(X)w_2(Y)w_4(Y)r_3(Y)w_3(X)$$
$$w_4(Z)r_3(Z)r_6(Z)r_8(Z)w_6(Z)w_9(Z)r_5(Z)r_{10}(Z)$$

$r_4(X)r_2(X)w_4(X)w_2(Y)w_4(Y)r_3(Y)w_3(X)w_4(Z)r_3(Z)r_6(Z)r_8(Z)w_6(Z)w_9(Z)r_5(Z)r_{10}(Z)$

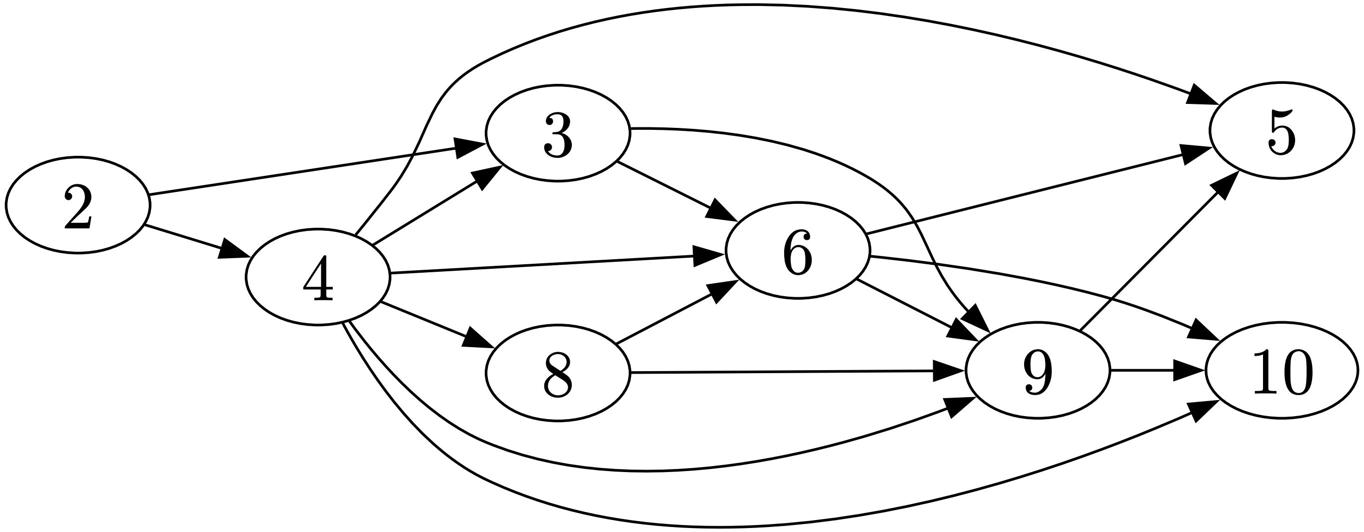
Is it CSR?

X: $r_4r_2w_4w_3$

Y: $w_2w_4r_3$

Z: $w_4r_3r_6r_8w_6w_9r_5r_{10}$

Is there any cycle? **No**. Therefore, *it is CSR* (and *VSR* too).

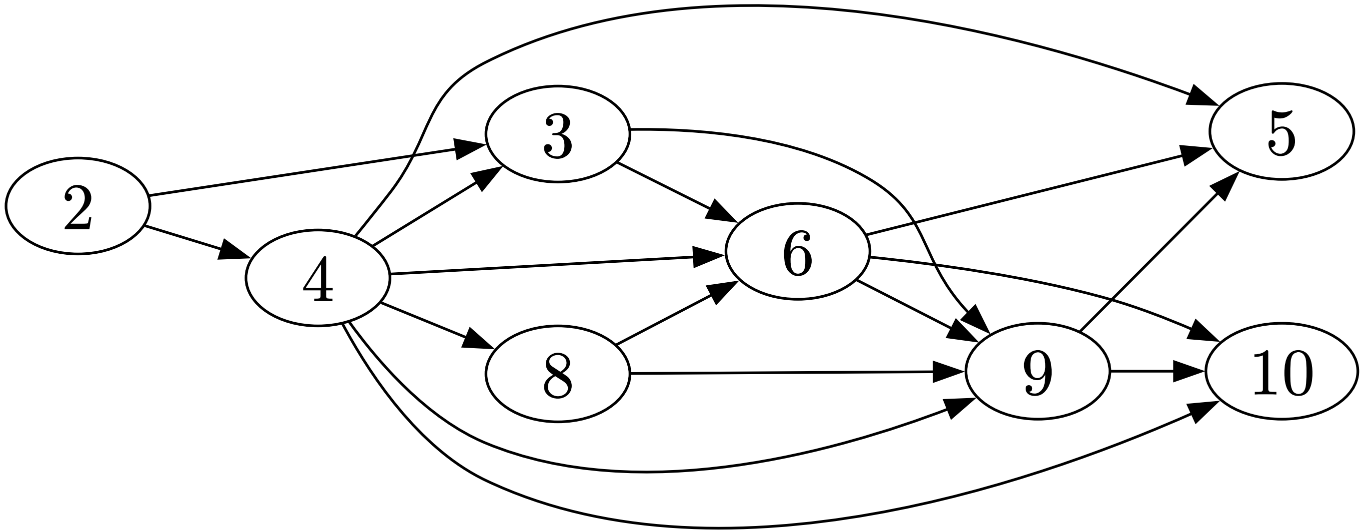


Quick interlude: how do we check for acyclicity?

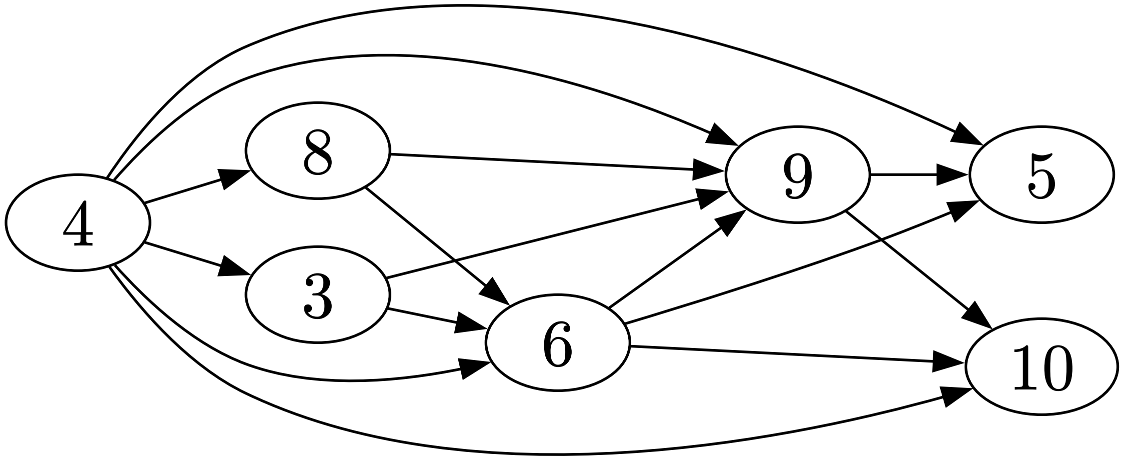
A node can be part of a cycle *if and only if* it has **both** incoming and outgoing edges.

Nodes with only incoming or outgoing arcs **cannot** be part of a cycle, and can be ignored.

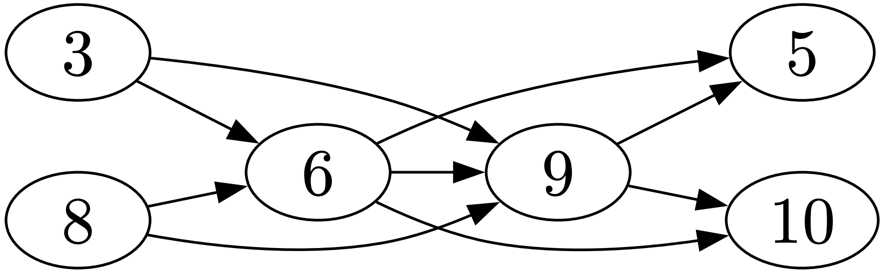
Let’s see an example with the previous graph.



Node 2 has no incoming edges: it can be deleted.



Now node 4 can be removed.



The process can be repeated.

If no node remains, there is no cycle.

Exercise S.2 – 2PL

$$r_4(X)r_2(X)w_4(X)w_2(Y)w_4(Y)r_3(Y)w_3(X)w_4(Z)r_3(Z)r_6(Z)r_8(Z)w_6(Z)w_9(Z)r_5(Z)r_{10}(Z)$$

Back on track: is the schedule **2PL-strict**?

We have to

1. Split operations per resource, and organize by *time*
2. For each transaction
   1. Find where it ends: it can release locks only after this point
   2. If it cannot acquire all locks before this point, or release them after, it's not 2PL-strict

$$r_4(X)r_2(X)w_4(X)w_2(Y)w_4(Y)r_3(Y)w_3(X)w_4(Z)r_3(Z)r_6(Z)r_8(Z)w_6(Z)w_9(Z)r_5(Z)r_{10}(Z)$$

Let's check t_2.

X	r_4	r_2	w_4				w_3								
Y				w_2	w_4	r_3									
Z								w_4	r_3	r_6	r_8	w_6	w_9	r_5	r_{10}

t_4 at time 3 must acquire an exclusive lock (XL) on X, i.e., t_2 must release X. But, t_2 finishes later at time 4. Hence, the schedule **is not** 2PL-strict.

$$r_4(X)r_2(X)w_4(X)w_2(Y)w_4(Y)r_3(Y)w_3(X)w_4(Z)r_3(Z)r_6(Z)r_8(Z)w_6(Z)w_9(Z)r_5(Z)r_{10}(Z)$$

Is it **2PL**? Let's check t_4.

X	r_4	r_2	w_4					w_3								
Y				w_2	w_4		r_3									
Z									w_4	r_3	r_6	r_8	w_6	w_9	r_5	r_{10}
						4										

$$r_4(X)r_2(X)w_4(X)w_2(Y)w_4(Y)r_3(Y)w_3(X)w_4(Z)r_3(Z)r_6(Z)r_8(Z)w_6(Z)w_9(Z)r_5(Z)r_{10}(Z)$$

Is it **2PL**? Let's check t_2.

X	r_4	r_2	w_4				w_3								
Y				w_2	w_4	r_3									
Z								w_4	r_3	r_6	r_8	w_6	w_9	r_5	r_{10}
		2													

$$r_4(X)r_2(X)w_4(X)w_2(Y)w_4(Y)r_3(Y)w_3(X)w_4(Z)r_3(Z)r_6(Z)r_8(Z)w_6(Z)w_9(Z)r_5(Z)r_{10}(Z)$$

Is it **2PL**? Let's check t_3.

X	r_4	r_2	w_4				w_3								
Y				w_2	w_4	r_3									
Z								w_4	r_3	r_6	r_8	w_6	w_9	r_5	r_{10}

3

$$r_4(X)r_2(X)w_4(X)w_2(Y)w_4(Y)r_3(Y)w_3(X)w_4(Z)r_3(Z)r_6(Z)r_8(Z)w_6(Z)w_9(Z)r_5(Z)r_{10}(Z)$$

Is it **2PL**? **Yes**.

Other transactions pose no problem.

Exercise S.2 – TS

$$r_4(X)r_2(X)w_4(X)w_2(Y)w_4(Y)r_3(Y)w_3(X)w_4(Z)r_3(Z)r_6(Z)r_8(Z)w_6(Z)w_9(Z)r_5(Z)r_{10}(Z)$$

Is it **TS-mono**? How to check:

1. Build a table with RTM and WTM for each resource
2. For each action
   - $r_{i(X)}$: `if` $i < \mathrm{WTM}(X)$ reject, `else` update RTM with max
   - $w_{i(X)}$: `if` $i < \mathrm{RTM}(X) \vee i < \mathrm{WTM}(X)$ reject, `else` update WTM
3. If there is a reject, it's not TS-mono

	X		Y		Z		Killed?
	RTM	WTM	RTM	WTM	RTM	WTM	
(begin)	0	0	0	0	0	0	
$r_4(X)$	4	0	0	0	0	0	
$r_2(X)$	4	0	0	0	0	0	
$w_4(X)$	4	4	0	0	0	0	
$w_2(Y)$	4	4	0	2	0	0	
$w_4(Y)$	4	4	0	4	0	0	
$r_3(Y)$	4	4	0	4	0	0	yes, $3 < \mathrm{WTM}(Y)$

There has been a kill, so it's **not TS-mono**.

$$r_4(X)r_2(X)w_4(X)w_2(Y)w_4(Y)r_3(Y)w_3(X)w_4(Z)r_3(Z)r_6(Z)r_8(Z)w_6(Z)w_9(Z)r_5(Z)r_{10}(Z)$$

Is it **TS-multi**? How to check:

1. Build a table with RTM and WTM for each resource and keep *multiple written versions*
2. For each action
   - $r_{i(X)}$: ok, read the correct version, update RTM as before
   - $w_{i(X)}$: reject if $i < \mathrm{RTM}(X)$, otherwise update WTM adding the version
3. If there is a reject, it's not TS-multi

	X		Y		Z		Killed?
	RTM	WTM	RTM	WTM	RTM	WTM	
(begin)	0	0	0	0	0	0	
$r_4(X)$	4_0	0	0	0	0	0	
$r_2(X)$	4_0	0	0	0	0	0	
$w_4(X)$	4_0	$0, 4$	0	0	0	0	
$w_2(Y)$	4_0	$0, 4$	0	$0, 2$	0	0	
$w_4(Y)$	4_0	$0, 4$	0	$0, 2, 4$	0	0	
$r_3(Y)$	4_0	$0, 4$	3_2	$0, 2, 4$	0	0	
$w_3(X)$	4_0	$0, 4$	3_2	$0, 2, 4$	0	0	yes, $3 < \mathrm{RTM}$

As before, there has been a kill: it's **not TS-multi**.

Exercise S.3

Is the following schedule CSR or VSR?

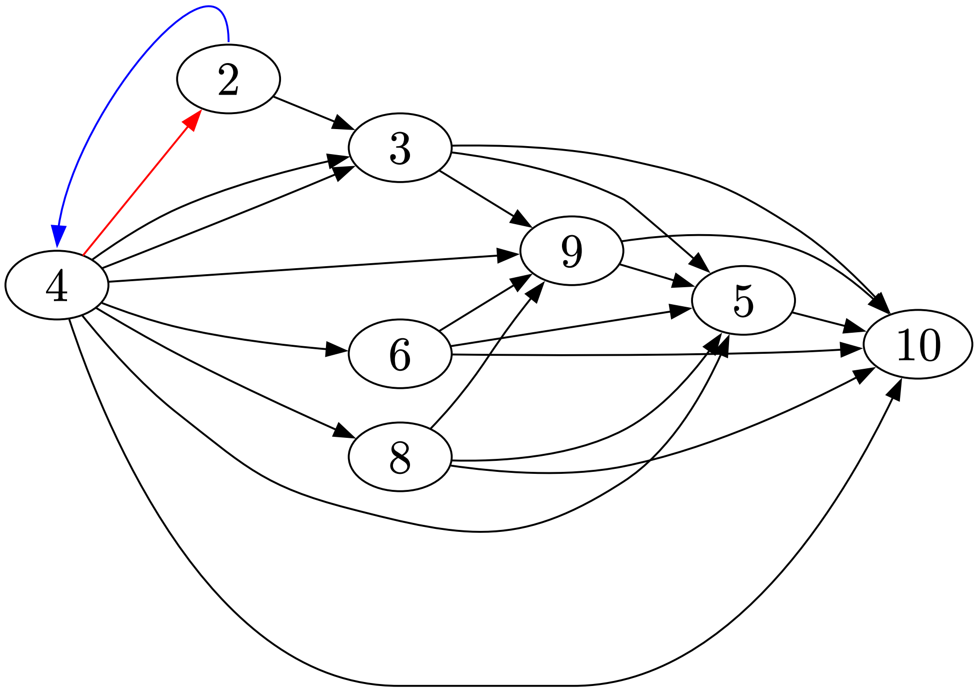
$$w_4(X)r_2(X)w_2(Y)w_4(Y)w_3(X)w_4(Z)$$
$$r_3(Z)r_6(Z)r_8(Z)w_9(Z)w_5(Z)r_{10(Z)}$$

Let’s build the conflicts graph

X: $w_4 r_2 w_3$

Y: $w_2 w_4$

Z: $w_4 r_3 r_6 r_8 w_9 w_5 r_{10}$



There is a cycle: **not CSR**.

Is it VSR? **No**.

We must have $t_4 \to t_2$, because otherwise we would introduce a new read-from on X.

But we must also have $t_2 \to t_4$, otherwise the last-write on Y would change.

Hence, the schedule cannot be VSR.

Exercise S.4 – A lesson about blind writes

Classify the following schedule in CSR and/or VSR

$$r_5(X)r_3(Y)w_3(Y)r_6(T)r_5(T)w_5(Z)w_4(X)r_3(Z)w_1(Y)$$
$$r_6(Y)w_6(T)w_4(Z)w_1(T)w_3(X)w_1(X)r_1(Z)w_2(T)w_2(Z)$$

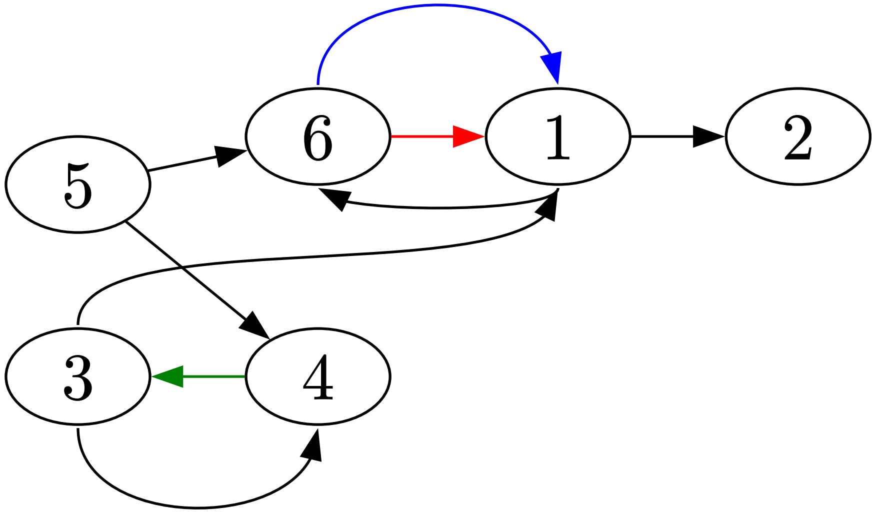
T: $r_6 r_5 w_6 w_1 w_2$

X: $r_5 w_4 w_3 w_1$

Y: $r_3 w_3 w_1 r_6$

Z: $w_5 r_3 w_4 r_1 w_2$

Let's draw a partial graph.



It is **not in CSR**. Cycle 3-4 can be broken (blind writes). However, $w_6(T) w_1(T)$ are blind writes, but the cycle cannot be resolved (there is $r_6(T) \ldots w_1(T)$).

Hence, the schedule **cannot be in VSR**.

The lesson: *be careful when drawing conflict arcs*.

As an extra, what about TS? $w_1(T)$ is sufficient to exclude that the schedule is both TS-mono and TS-multi. The reason is left as an exercise for the reader.

Exercise S.5

The following schedule is in **VSR**. Classify it with respect to CSR, TS-mono, TS-multi, 2PL-strict

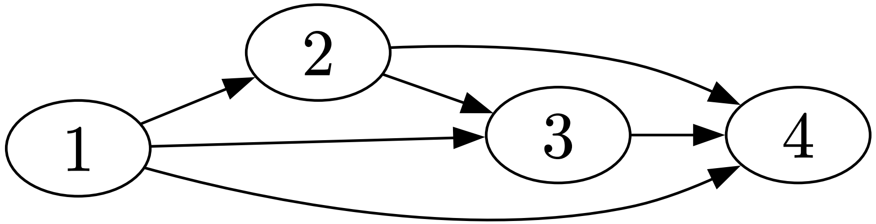
$$r_1(X)w_2(X)r_1(Z)w_1(Y)r_3(X)r_4(X)w_3(Z)w_2(Y)r_3(Y)w_4(X)w_4(Y)$$

Is it **CSR**? Yes.

X: $r_1 w_2 r_3 r_4 w_4$

Y: $w_1 w_2 r_3 w_4$

Z: $r_1 w_3$



No cycles: **it is CSR**.

Is it **2PL-strict**? No.

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

Focus on t_1. It has to release a lock on X before 2, but it doesn't end until 4. Hence, it cannot be 2PL-strict.

Is it **TS-mono** or **TS-multi**?

We *could* do the table, but note that, for each resource, all operations are in increasing index order.

Hence it is surely both **TS-mono** and **TS-multi**.

To conclude

- It is clear that t_1 must release the SL on X before 2 (for t_2 to acquire XL on it), but this is not compatible with 2PL-strict, as the last operation of t_1 occurs at 4.
- The conflict graph is acyclic, hence the schedule is in CSR.
- Eventually, it is easy to observe that the schedule is both in TS-mono and TS-multi, even without simulating the evolution of RTM and WTM counters, because transaction indeces occur in strictly increasing order in the operations for to each resource.

Exercise S.6

Verify whether the following schedule is compatible with a 2PL system (non strict):

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

Let's use another technique to check: **temporal constraints**.

It is necessary to impose temporal constraints upon the lock and unlock requests, when such requests are in wait status.

	1	2	3	4	5	6	7	8	9	10	11
A	r_1			r_2						w_1	w_3
B		r_2			r_1			w_2	r_3		
C			w_1			w_2	r_3				

The locking rules imply, for t_1 and t_2

$$4 < U_2^r(A) < L_1^w(A)$$

$$U_1^r(B) < L_2^w(B) < 8$$

	1	2	3	4	5	6	7	8	9	10	11
A	r_1			r_2						w_1	w_3
B		r_2			r_1			w_2	r_3		
C			w_1			w_2	r_3				

The 2PL rule imposes not to acquire a new lock after an unlock

$$L_1^w(A) < U_1^r(B)$$

$$L_2^w(B) < U_2^r(A)$$

	1	2	3	4	5	6	7	8	9	10	11
A	r_1			r_2						w_1	w_3
B		r_2			r_1			w_2	r_3		
C			w_1			w_2	r_3				

Combining the two we get an impossible condition

$$U_2^r(A) < L_1^w(A) < U_1^r(B) < L_2^w(B) < U_2^r(A)$$

and the schedule is not 2PL.

Exercise S.7

Verify whether the following sequence of operations is consistent with 2PL

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

(Note it's not the same as the previous exercise).

	1	2	3	4	5	6	7	8	9	10	11
A	r_1			r_2						w_2	w_3
B		r_2			r_1			w_2	r_3		
C			w_1			w_2	r_3				

- t_1 can acquire all locks at 1 and release after each use
- t_3 can acquire all locks just before use and release at the end
- t_2 must release C between 6 and 7, and cannot acquire B before 6, but all this is possible

Exercise C.1

The isolation class *read-committed* requires that transactions comply with 2PL-strict for the write lock, and can release read lock for reading, even before the end of the transaction.

Show an example of a schedule that is *read-committed* but *not VSR*.

Show an example of a schedule that is *read-committed* but *not VSR*.

In order to find such a schedule, we must violate the rules of 2PL with some read operations (as writes follow the 2PL-strict rules), otherwise our schedule would still be 2PL, and therefore also VSR.

We need to build a schedule where releasing a read lock before some other lock is acquired by the same transaction is necessary for the schedule to complete.

We can simply interleave non-view-serializable operations on one resource, such as:

$$S_1 = r_1(X)w_2(X)w_1(X)$$

Exercise C.2

Continued from the previous exercise.

Now, extend the known classification graph of classes VSR, CSR, and 2PL with the representation of the read-committed isolation class.

Read-committed is, by definition, a relaxation of class 2PL-strict, and therefore contains this class.

As for 2PL, CSR, and VSR, we can easily find a schedule that is in 2PL but not in read-committed, such as

$$S_2 = w_1(X)w_2(X)r_1(Y)$$

hence it does not contain the entire 2PL.

Graphically, this is the new diagram