CARNEGIE MELLON UNIVERSITY
COMPUTER SCIENCE DEPARTMENT
15-445/645 – DATABASE SYSTEMS (FALL 2019)
PROF. ANDY PAVLO

Homework #4 (by Weichen Ke)
Due: **Wednesday Nov 13, 2019 @ 11:59pm**

IMPORTANT:

- **Upload this PDF** with your answers to **Gradescope by 11:59pm on Wednesday Nov 13, 2019**.
- **Plagiarism**: Homework may be discussed with other students, but all homework is to be completed **individually**.
- **You have to use this PDF for all of your answers.**

For your information:

- Graded out of **100** points; **4** questions total
- Rough time estimate: ≈ 1 - 2 hours (0.5 - 1 hours for each question)

Revision : 2019/11/01 18:10

Question	Points	Score
Serializability and 2PL	20	
Deadlock Detection and Prevention	30	
Hierarchical Locking	30	
Optimistic Concurrency Control	20	
Total:	100	

Number of Days this Assignment is Late:

Number of Late Day You Have Left:

Question 1: Serializability and 2PL ....[20 points]

T_1 | T_2
L(A) | L(B)
L

(a) Yes/No questions:

i. **[2 points]** Schedules under rigorous 2PL will not have dirty reads.
☑ Yes ☐ No

ii. **[2 points]** A schedule generated by rigorous 2PL will never cause a deadlock.
☐ Yes ☑ No

iii. **[2 points]** A schedule generated by 2PL is always view serializable.
☑ Yes ☐ No

conflict serializable ∈ view

iv. **[2 points]** A conflict serializable schedule will never contain a cycle in its precedence graph.
☑ Yes ☐ No

v. **[2 points]** Every view serializable schedule is conflict serializable.
☐ Yes ☑ No

(b) Serializability:
Consider the schedule given below in Table 1. R(·) and W(·) stand for 'Read' and 'Write', respectively.

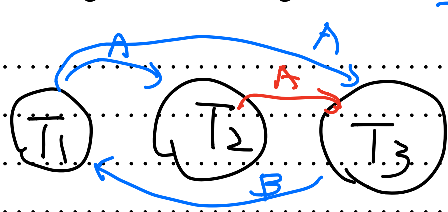
time	t_1	t_2	t_3	t_4	t_5	t_6	t_7	t_8	t_9	t_{10}	t_{11}
T_1	R(A)		W(A)						R(B)		W(B)
T_2				R(C)	R(A)		W(A)			W(C)	
T_3		R(B)				W(B)		R(A)			

Table 1: A schedule with 3 transactions

i. **[1 point]** Is this schedule serial?
☐ Yes ☑ No

a serial schedule should be this: T_1 R(A) W(A) R(B) W(B)
T_2

ii. **[3 points]** Give the dependency graph of this schedule. List each edge in the dependency graph like this: '$T_x \rightarrow T_y$ because of Z'. This notation signifies that T_x precedes T_y because Z was last read/written by T_x before it was read/written by T_y. Order the edges in ascending order with respect to x.



$T_1 \xrightarrow{A} T_2$ $T_2 \xrightarrow{A} T_3$
$T_1 \xrightarrow{A} T_3$
$T_3 \xrightarrow{B} T_1$

iii. **[1 point]** Is this schedule conflict serializable?
☐ Yes ☑ No

iv. **[3 points]** If you answer "yes" to (iii), provide the equivalent serial schedule. If you answer "no", briefly explain why.

This is a cycle inside the dependency graph

v. **[2 points]** Is this schedule possible under 2PL?
☐ Yes ☑ No

2PL gaurantee a conflict serializable schedule

Question 2: Deadlock Detection and Prevention .... [30 points]

(a) **Deadlock Detection:**
Consider the following lock requests in Table 2. And note that

- S(·) and X(·) stand for 'shared lock' and 'exclusive lock', respectively.
- T_1, T_2, and T_3 represent three transactions.
- LM stands for 'lock manager'.
- Transactions will never release a granted lock.

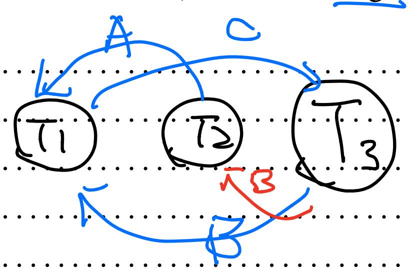
time	t_1	t_2	t_3	t_4	t_5	t_6	t_7
T_1			S(A)	S(B)			S(C)
T_2	S(B)				X(A)		
T_3		X(C)				X(B)	
LM	g	g	g	g	b	b	b

A : S
B : S
C : X

Table 2: Lock requests of three transactions

i. **[3 points]** For the lock requests in Table 2, determine which lock will be granted or blocked by the lock manager. Please write 'g' in the LM row to indicate the lock is granted and 'b' to indicate the lock is blocked or the transaction has already been blocked by a former lock request. For example, in the table, the first lock (S(B)) at time t_1) is marked as granted.

ii. **[4 points]** Give the wait-for graph for the lock requests in Table 2. List each edge in the graph like this: $T_x \to T_y$ because of Z (i.e., T_x is waiting for T_y to release its lock on resource Z). Order the edges in ascending order with respect to x.



$T_1 \xrightarrow{C} T_3$ $T_3 \xrightarrow{B} T_2$

$T_2 \xrightarrow{A} T_1$

$T_3 \xrightarrow{B} T_1$

iii. **[3 points]** Determine whether there exists a deadlock in the lock requests in Table 2. If there is a deadlock, point out one cycle.

Yes, T_1 is waiting for T_3's C lock while T_3 is waiting for T_1's B lock

(b) **Deadlock Prevention:**
Consider the following lock requests in Table 3.
Like before,

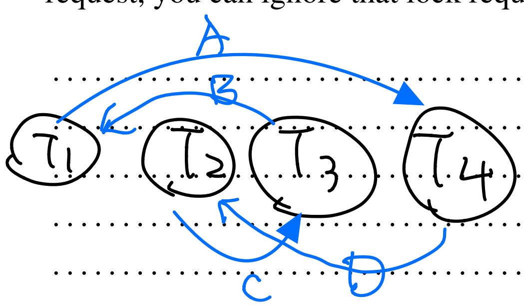
- S(·) and X(·) stand for 'shared lock' and 'exclusive lock', respectively.
- T_1, T_2, T_3, T_4, and ~~T_5~~ represent five transactions.
- LM represents a 'lock manager'.
- Transactions will never release a granted lock.

time	t_1	t_2	t_3	t_4	t_5	t_6	t_7	t_8
T_1	X(B)			S(A)				
T_2					X(D)	X(C)		
T_3			S(C)				X(B)	
T_4		X(A)						S(D)
LM	g	g	g	b	g	b	b	b

Table 3: Lock requests of four transactions

i. **[3 points]** For the lock requests in Table 3, determine which lock request will be granted, blocked or aborted by the lock manager (LM), if it has no deadlock prevention policy. *Please write 'g' for grant, 'b' for block (or the transaction is already blocked), 'a' for abort, and '−' if the transaction has already died.* Again, example is given in the first column.

ii. **[4 points]** Give the wait-for graph for the lock requests in Table 3. List each edge in the graph like this: $T_x \rightarrow T_y$ because of Z (i.e., T_x is waiting for T_y to release its lock on resource Z). Order the edges in ascending order with respect to x. If a lock request is not proposed because the transaction is blocked before making that lock request, you can ignore that lock request, as if it does not exist.



$T_1 \xrightarrow{A} T_4$

$T_2 \xrightarrow{C} T_3$

$T_3 \xrightarrow{B} T_1$

$T_4 \xrightarrow{D} T_2$

iii. **[3 points]** Determine whether there exists a deadlock in the lock requests in Table 3. If there is a deadlock, point out one cycle.

$T_1 \to T_4 \to T_2 \to T_3 \to T_1$

is a cycle

iv. **[5 points]** To prevent deadlock, we use the lock manager (LM) that adopts the Wait-Die policy. We assume that in terms of priority: $T_1 > T_2 > T_3 > T_4$. Here, $T_1 > T_2$ because T_1 is older than T_2 (i.e., older transactions have higher priority). *Determine whether the lock request is granted ('g'), blocked ('b'), aborted ('a'), or already dead('-').* Follow the same format as the previous question.

old waits for young

∵ $T_1 > T_3$

time	t_1	t_2	t_3	t_4	t_5	t_6	t_7	t_8
T_1	X(B)			S(A)				
T_2					X(D)	X(C)		
T_3			S(C)				X(B)	
T_4		X(A)						S(D)
LM	g	g	g	b	g	b	a	a

∵ $T_1 > T_4$

Table 3: Lock requests of four transactions

v. **[5 points]** Now we use the lock manager (LM) that adopts the Wound-Wait policy. We assume that in terms of priority: $T_1 > T_2 > T_3 > T_4$. Here, $T_1 > T_2$ because T_1 is older than T_2 (i.e., older transactions have higher priority). *Determine whether the lock request is granted ('g'), blocked ('b'), granted by aborting another transaction ('a'), or the requester is already dead('-').* Follow the same format as the previous question.

time	t_1	t_2	t_3	t_4	t_5	t_6	t_7	t_8
T_1	X(B)			S(A)				
T_2					X(D)	X(C)		
T_3			S(C)			dead	X(B)	
T_4		X(A)		dead				S(D)
LM	g	g	g	~~g~~ a	g	~~g~~ a	-	-

Table 3: Lock requests of four transactions

Question 3: Hierarchical Locking .... [30 points]

Consider a database (D) consisting of two tables, Tablets (T) and CPUs (C). Specifically,

- `Tablets(tid, brand, CPU_id, OS, year, sales)`, spans 1000 pages, namely T_1 to T_{1000}
- `CPUs(CPU_id, brand, frequency, cache)`, spans 50 pages, namely C_1 to C_{50}

Further, **each page contains 100 records**, and we use the notation $T_3 : 20$ to represent the 20^{th} record on the third page of the Tablets table. Similarly, $C_5 : 10$ represents the 10^{th} record on the fifth page of the CPUs table.

We use Multiple-granularity locking, with **S, X, IS, IX** and **SIX** locks, and **four levels of granularity**: (1) *database-level (D)*, (2) *table-level (T, C)*, (3) *page-level* ($T_1 - T_{1000}$, $C_1 - C_{50}$), (4) *record-level* ($T_1 : 1 - T_{1000} : 100$, $C_1 : 1 - C_{50} : 100$).

For each of the following operations on the database, please determine the sequence of lock requests that should be generated by a transaction that wants to efficiently carry out these operations by maximizing concurrency. **Please use the fewest number of locks in your answer.** If you use much more locks than necessary (more than 10x), you will get **half** points.

Please follow the format of the examples listed below:

- write **"IS(D)"** for a request of **database-level IS lock**
- write **"X(C_2 : 30)"** for a request of **record-level X lock for the 30^{th} record on the second page of the CPUs table**
- write **"S($C_2 : 30 - C_3 : 100$)"** for a request of **record-level S lock from the 30^{th} record on the second page of the CPUs table to the 100^{th} record on the third page of the CPUs table**.

(a) **[6 points]** Fetch the 25^{th} record on page T_{233}.

IS(D), IS(T), IS(T_{233}), S(T_{233} : 25)

(b) **[6 points]** Scan all the records on pages T_1 through T_{10}, and modify the record T_2 : 33.

IX(D), IX(T), S(T_1), S(T_3 — T_{10}), SIX(T_2), X(T_2 : 33)

(c) **[6 points]** Count the number of tablets with 'year' > 2014.

IS(D), S(T) (traverse all pages of T)

(d) **[6 points]** Increase the sales of all tablets by 114514.

IX(D), X(T)
(each record will be touched)

(e) **[6 points]** Capitalize the 'brand' of ALL tablets and ALL CPUs.

X(D) ....

(all pages of T, C will be touched)

Question 4: Optimistic Concurrency Control .... [20 points]

Consider the following set of transactions accessing a database with object *A, B, C, D*. The questions below assume that the transaction manager is using **optimistic concurrency control** (OCC). Assume that a transaction switches from the READ phase immediately into the VALIDATION phase after its last operation executes.

Note: VALIDATION may or may not succeed for each transaction. If validation fails, the transaction will get immediately aborted.

You can assume that the DBMS is using the serial validation protocol discussed in class where only one transaction can be in the validation phase at a time, and each transaction is doing forward validation (i.e. Each transaction, when validating, checks whether it intersects its read/write sets with any active transactions that have not yet committed.)

after ~~validation~~

? after write ?

time	T_1	T_2	T_3
1	READ(A)		
2		READ(A)	
3	READ(B)		
4	WRITE(B)		
5	WRITE(C)		
6	VALIDATE?		
7			READ(D)
8		READ(B)	
9		WRITE(D)	
10		WRITE(B)	
11		~~VALIDATE?~~	
12	WRITE?		
13		~~WRITE?~~	
14			WRITE(D)
15			VALIDATE?
16			WRITE?

writeset(T_1) ∩ readset(T_2)=∅ ∩ writeset(T_2)=∅

writeset(T_1) ∩ readset(T_3)=∅ ∩ writeset(T_3)=∅

Q: committed yet?

writeset(T_2)

abort ∩ readset(T_3)

Figure 1: An execution schedule

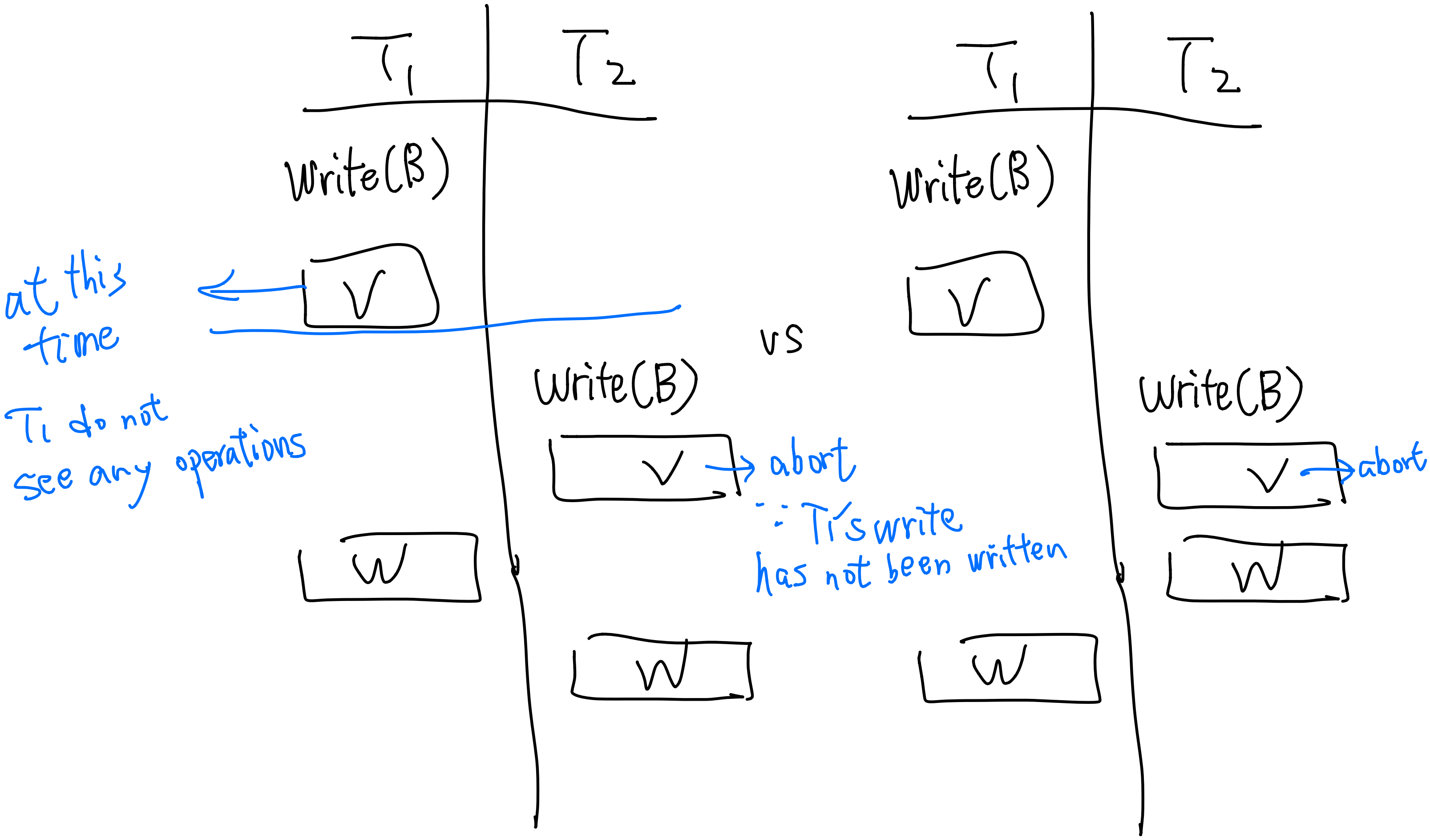
?

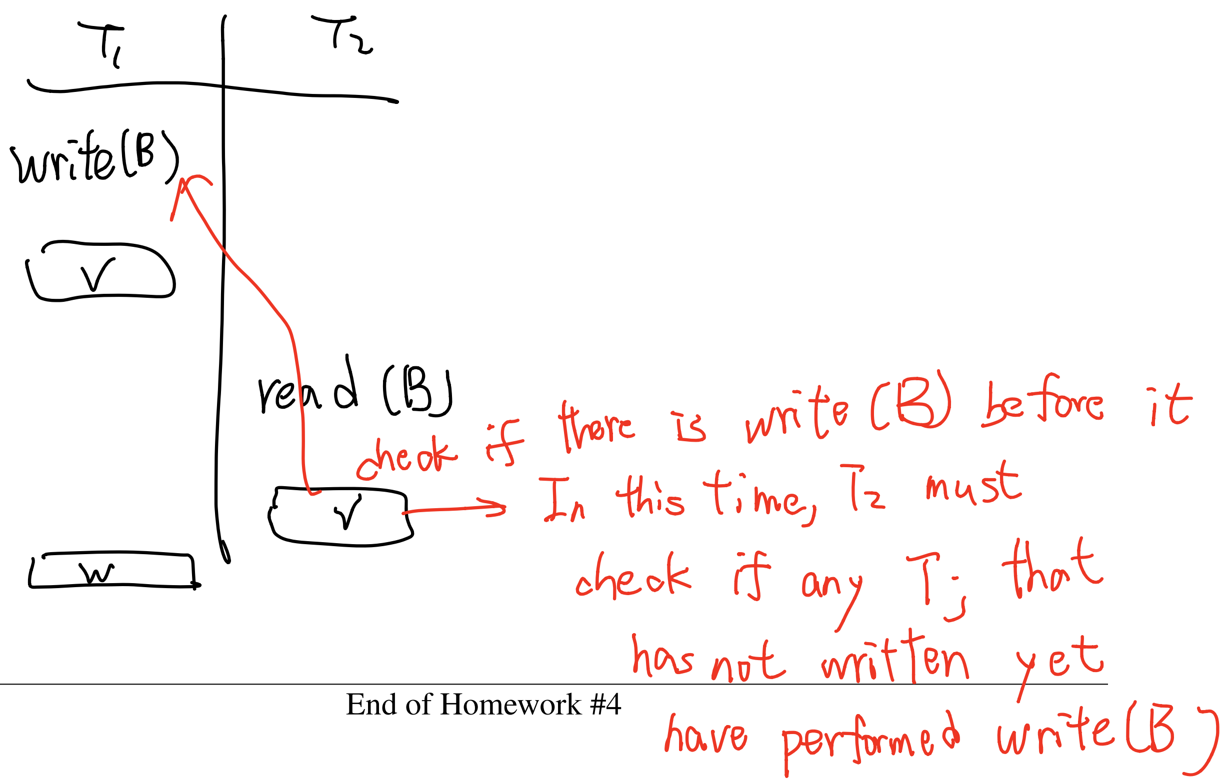
(a) **[6 points]** Will T1 abort?
- ☐ Yes
- ☑ No

(b) **[6 points]** Will T2 abort?
- ☑ Yes
- ☐ No

(c) **[6 points]** Will T3 abort?
- ☐ Yes
- ☑ No

(d) **[2 points]** OCC is good to use when there are few conflicts.
- ☑ True
- ☐ False


T_1
T_2
Write(B)
V
W
at this time
T_1 do not see any operations
Write(B)
V
abort
∵ T_1's write has not been written
W
vs
T_1
T_2
Write(B)
V
W
Write(B)
V
abort
W


T_1
T_2
write(B)
V
W
read (B)
V
check if there is write (B) before it
In this time, T_2 must check if any T_j that has not written yet have performed write(B)

T_1	T_2
write(B)	
$\boxed{V}$	
$\boxed{W}$	
	read(B)
	read(C)
	$\boxed{V}$ → succeed

T_1	T_2
write(B)	
$\boxed{V}$ → TS(T_1)=1	
	read(B)
$\boxed{W}$	
	read(C)
	$\boxed{V}$ TS(T_2)=2

at this time database should like this. And T_2's workspace

Database

Object	Value	W-TS
B		1

T_2's work space

Object	Value	W-TS
B		0

Because $0 < 1$, we know read(B) doesnot read a correct value
$\Rightarrow$ abort