CARNEGIE MELLON UNIVERSITY
COMPUTER SCIENCE DEPARTMENT
15-445/645 – DATABASE SYSTEMS (FALL 2022)
PROF. ANDY PAVLO

# Homework #4 (by Joyce Liao)
Due: **Sunday Nov 13, 2022 @ 11:59pm**

**IMPORTANT:**

- Enter all of your answers into **Gradescope by 11:59pm on Sunday Nov 13, 2022**.
- **Plagiarism**: Homework may be discussed with other students, but all homework is to be completed **individually**.

For your information:

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

*Revision* : 2022/10/23 17:34

| Question | Points | Score |
|---|---|---|
| Serializability and 2PL | 27 | |
| Deadlock Detection and Prevention | 35 | |
| Hierarchical Locking | 20 | |
| Optimistic Concurrency Control | 18 | |
| Total: | 100 | |

## Question 1: Serializability and 2PL.....[27 points]

(a) True/False Questions:

i. **[2 points]** Cascading aborts do not happen under rigorous 2PL.
☐ True ☐ False

ii. **[2 points]** A schedule that is view serializable is also conflict serializable.
☐ True ☐ False

iii. **[2 points]** 2PL is a pessimistic concurrency control protocol.
☐ True ☐ False

iv. **[2 points]** Deadlocks cannot happen in non-rigorous 2PL.
☐ True ☐ False

v. **[2 points]** There are not dirty reads in non-rigorous 2PL.
☐ True ☐ False

vi. **[2 points]** A schedule with an acyclic precedence graph is view serializable.
☐ True ☐ False

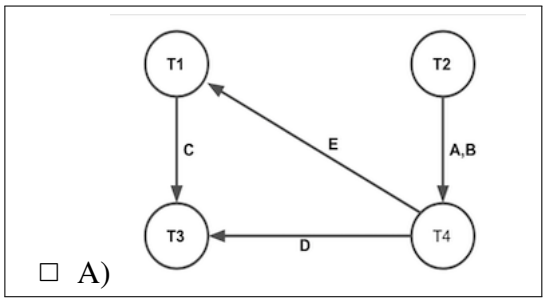
(b) Serializability:
Consider the schedule given below in Table 1. R(·) and W(·) stand for 'Read' and 'Write', respectively.

| time | $t_1$ | $t_2$ | $t_3$ | $t_4$ | $t_5$ | $t_6$ | $t_7$ | $t_8$ | $t_9$ | $t_{10}$ |
|---|---|---|---|---|---|---|---|---|---|---|
| $T_1$ | | | W(E) | | R(D) | | | | W(A) | |
| $T_2$ | | W(B) | | R(A) | | | | | | |
| $T_3$ | | | | | | | | R(E) | | W(C) |
| $T_4$ | W(D) | | | | | R(B) | R(C) | | | |

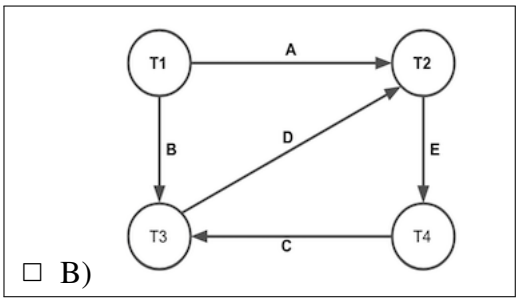
Table 1: A schedule with 4 transactions

i. **[2 points]** Is this schedule serial?
☐ Yes ☐ No

ii. **[3 points]** Choose the correct dependency graph of the schedule given above. Each edge in the dependency graph looks like this: '$T_x \rightarrow T_y$ with $Z$ on the arrow indicating that there is a conflict on $Z$ where $T_x$ read/wrote on $Z$ before $T_y$'.

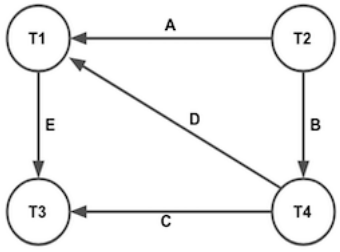


☐ A)

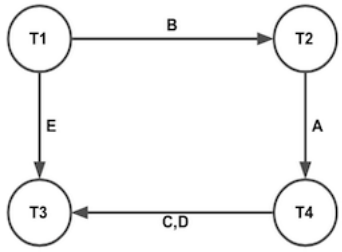


☐ B)

☐ C)




☐ D)




iii. **[2 points]** Is this schedule conflict serializable?
☐ Yes ☐ No

iv. **[4 points]** What is the minimum number of transactions that need to be removed to produce a conflict serializable schedule?
☐ Two (`T1 and T4`)
☐ One (`T1`)
☐ One (`T4`)
☐ Zero (`original schedule is already serializable`)

v. **[4 points]** Which of the following serial schedules is conflict equivalent to the given schedule? Mark all that apply.
☐ `T1,T2,T3,T4`
☐ `T2,T4,T1,T3`
☐ `T2,T3,T1,T4`
☐ None of the above

## Question 2: Deadlock Detection and Prevention . . . . . [35 points]

(a) **Deadlock Detection:**
Consider the following transactions and note that

- S(·) and X(·) stand for 'shared lock' and 'exclusive lock', respectively.
- $T_1$ and $T_2$ represent two transactions.
- Transactions will never release a granted lock until the last operation shown for the transaction is completed.

$T_1$: $(a)$ read(A); $(b)$ write(B); $(c)$ read(C); $(d)$ read(B); $(e)$ read(A); $(f)$ write(C);

i. For each position in $T_1$ above, which lock should be requested?

$\alpha$) **[1 point]** At $(a)$: ☐ S(A) ☐ X(A) ☐ No lock needs to be requested

$\beta$) **[1 point]** At $(b)$: ☐ S(B) ☐ X(B) ☐ No lock needs to be requested

$\gamma$) **[1 point]** At $(c)$: ☐ S(C) ☐ X(C) ☐ No lock needs to be requested

$\delta$) **[1 point]** At $(d)$: ☐ S(B) ☐ X(B) ☐ No lock needs to be requested

$\epsilon$) **[1 point]** At $(e)$: ☐ S(A) ☐ X(A) ☐ No lock needs to be requested

$\zeta$) **[1 point]** At $(f)$: ☐ S(C) ☐ X(C) ☐ No lock needs to be requested

ii. **[4 points]** Which of the following schedule can cause a deadlock?

☐

| | | | | | | |
|---|---|---|---|---|---|---|
| $T_1$ | S(A) | S(B) | | | | S(C) |
| $T_2$ | | | S(A) | X(B) | X(C) | |

☐

| | | | | | | |
|---|---|---|---|---|---|---|
| $T_1$ | S(A) | X(C) | | X(A) | | |
| $T_2$ | | | S(B) | | X(B) | X(A) |

☐

| | | | | | | |
|---|---|---|---|---|---|---|
| $T_1$ | S(A) | | | S(B) | S(C) | |
| $T_2$ | | X(B) | S(C) | | | X(A) |

(b) 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.

i. 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(A) at time $t_1$) is marked as granted.

| time | $t_1$ | $t_2$ | $t_3$ | $t_4$ | $t_5$ | $t_6$ |
|---|---|---|---|---|---|---|
| $T_1$ | S(A) | | | | | S(C) |
| $T_2$ | | | S(B) | | | |
| $T_3$ | | X(B) | | X(C) | X(A) | |
| $LM$ | g | | | | | |

Table 2: Lock requests of three transactions

$\alpha$) **[1 point]** At $t_2$: ☐ g ☐ b

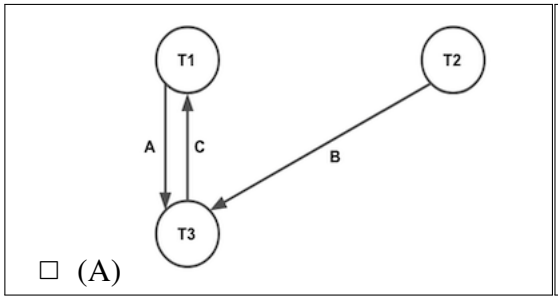
$\beta$) **[1 point]** At $t_3$: ☐ g ☐ b

$\gamma$) **[1 point]** At $t_4$: ☐ g ☐ b

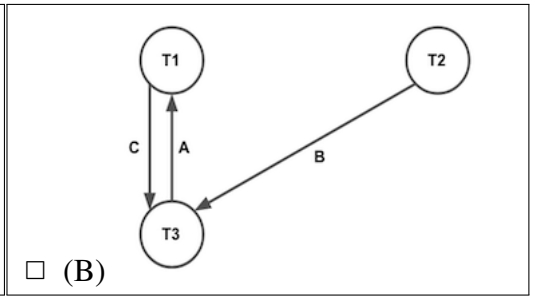
$\delta$) **[1 point]** At $t_5$: ☐ g ☐ b

$\epsilon$) **[1 point]** At $t_6$: ☐ g ☐ b

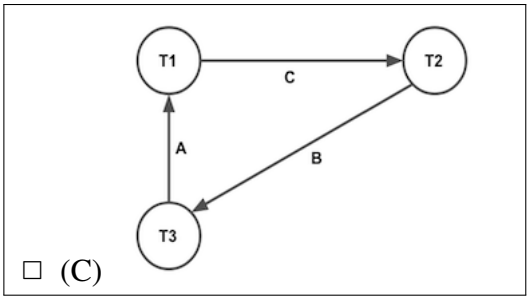
ii. **[4 points]** Mark the correct wait-for graph for the lock requests in Table 2. Each edge in the wait-for graph looks like this: $T_x \rightarrow T_y$ because of $Z$. $Z$ is denoted in the arrow in the figure. (i.e., $T_x$ is waiting for $T_y$ to release its lock on resource $Z$).



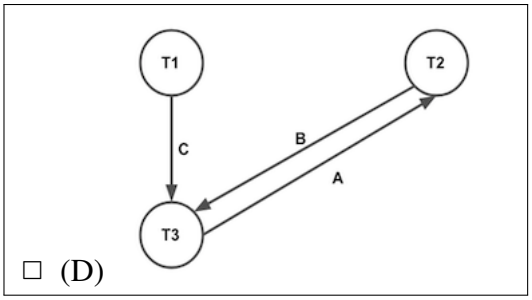

☐ (A)




☐ (B)




☐ (C)




☐ (D)

iii. **[2 points]** Determine whether there exists a deadlock in the lock requests in Table 2.

☐ There is no deadlock
☐ Cycle ($T_1 \rightarrow T_2 \rightarrow T_3$) exists and schedule deadlocks
☐ Cycle ($T_1 \rightarrow T_3 \rightarrow T_1$) exists and schedule deadlocks
☐ Cycle ($T_2 \rightarrow T_3 \rightarrow T_2$) exists and schedule deadlocks

(c) **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(C) | |
| $T_2$ | S(A) | | S(B) | | | S(C) | | |
| $T_3$ | | X(A) | | X(B) | | | | |
| $T_4$ | | | | | X(C) | | | X(B) |
| $LM$ | g | | | | | | | |

Table 3: Lock requests of four transactions

i. To prevent deadlock, we use a 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('–').*

$\alpha$) **[1 point]** At $t_2$: ☐ g ☐ b ☐ a ☐ –
$\beta$) **[1 point]** At $t_3$: ☐ g ☐ b ☐ a ☐ –
$\gamma$) **[1 point]** At $t_4$: ☐ g ☐ b ☐ a ☐ –
$\delta$) **[1 point]** At $t_5$: ☐ g ☐ b ☐ a ☐ –
$\epsilon$) **[1 point]** At $t_6$: ☐ g ☐ b ☐ a ☐ –
$\zeta$) **[1 point]** At $t_7$: ☐ g ☐ b ☐ a ☐ –
$\eta$) **[1 point]** At $t_8$: ☐ g ☐ b ☐ a ☐ –

ii. Now we use a 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.

$\alpha$) **[1 point]** At $t_2$: ☐ g ☐ b ☐ a ☐ –
$\beta$) **[1 point]** At $t_3$: ☐ g ☐ b ☐ a ☐ –
$\gamma$) **[1 point]** At $t_4$: ☐ g ☐ b ☐ a ☐ –
$\delta$) **[1 point]** At $t_5$: ☐ g ☐ b ☐ a ☐ –
$\epsilon$) **[1 point]** At $t_6$: ☐ g ☐ b ☐ a ☐ –
$\zeta$) **[1 point]** At $t_7$: ☐ g ☐ b ☐ a ☐ –
$\eta$) **[1 point]** At $t_8$: ☐ g ☐ b ☐ a ☐ –

## Question 3: Hierarchical Locking . . . . . [20 points]

Consider a database (D) consisting of two tables, Release (R) and Artists (A). Specifically,

- `Release(rid, name, artist_credit, language, status, genre, year, number_sold)`, spans 1000 pages, namely $R_1$ to $R_{1000}$
- `Artists(id, name, type, area, gender, begin_date_year)`, spans 50 pages, namely $A_1$ to $A_{50}$

Further, **each page contains 100 records**, and we use the notation $R_3 : 20$ to represent the $20^{th}$ record on the third page of the Release table. Similarly, $A_5 : 10$ represents the $10^{th}$ record on the fifth page of the Artists 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 (R, A)*, (3) *page-level (*$R_1 - R_{1000}$*,* $A_1 - A_{50}$*)*, (4) *record-level (*$R_1 : 1 - R_{1000} : 100$*,* $A_1 : 1 - A_{50} : 100$*)*.

For each of the following operations on the database, check all the sequence of lock requests based on intention locks that should be generated by a transaction that wants to efficiently carry out these operations by maximizing concurrency. Please take care of efficiency for e.g., share vs. exclusive lock and granularity.

Please follow the format of the examples listed below:

- mark **"IS(D)"** for a request of **database-level IS lock**
- mark **"X(**$A_2 : 30$**)"** for a request of **record-level X lock for the** $30^{th}$ **record on the second page of the Artists table**
- mark **"S(**$A_2 : 30 - A_3 : 100$**)"** for a request of **record-level S lock from the** $30^{th}$ **record on the second page of the Artists table to the** $100^{th}$ **record on the third page of the Artists table**.

(a) **[4 points]** Fetch the record that represents the artist with the earliest `begin_date_year`. Assume there are no ties.

- ☐ `IX(D), X(A)`
- ☐ `IS(D), S(A)`
- ☐ `S(D)`
- ☐ `IS(D), SIX(A), X(`$A_1$`)`

(b) **[4 points]** Modify the $4^{th}$ record on $R_{45}$.

- ☐ `IX(D), IX(R), IX(`$R_{45}$`), X(`$R_{45} : 4$`)`
- ☐ `IX(D), SIX(R), X(`$R_{45}$`)`
- ☐ `IX(D), IX(R), SIX(`$R_{45}$`), X(`$R_{45} : 4$`)`
- ☐ `IS(D), IS(R), IX(`$R_{45}$`), X(`$R_{45} : 4$`)`

(c) **[4 points]** Find the average `number_sold` across all releases.

- ☐ `S(D)`
- ☐ `S(D), S(R)`
- ☐ `IS(D), X(R)`
- ☐ `IS(D), S(R)`

(d) **[4 points]** Scan all records in `R` and modify the $1^{st}$ record on $R_5$
- ☐ `IX(D), SIX(R), IX(`$R_5$`), X(`$R_5 : 1$`)`
- ☐ `IS(D), S(R), IX(`$R_5 : 1$`)`
- ☐ `S(D), IX(R), X(`$R_5 : 1$`)`
- ☐ `IS(D), SIX(R), X(`$R_5$`)`

(e) **[4 points]** Update the `name` of all artists to be in uppercase letters only.
- ☐ `SIX(D), X(A)`
- ☐ `SIX(D), S(A)`
- ☐ `IX(D), X(A)`
- ☐ `IX(D), SIX(A)`

## Question 4: Optimistic Concurrency Control . . . . . [18 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 backward validation (i.e. Each transaction, when validating, checks whether it intersects its read/write sets with any transactions that have already committed. You may assume there are no other transactions in addition to the ones shown below. )

| time | $T_1$ | $T_2$ | $T_3$ |
|---|---|---|---|
| 1 | READ(A) | | |
| 2 | READ(C) | | |
| 3 | | READ(B) | |
| 4 | WRITE(A) | | |
| 5 | | | READ(B) |
| 6 | WRITE(C) | | |
| 7 | VALIDATE? | | |
| 8 | | READ(D) | |
| 9 | WRITE? | | |
| 10 | | WRITE(D) | |
| 11 | | WRITE(B) | |
| 12 | | VALIDATE? | |
| 13 | | | READ(A) |
| 14 | | WRITE? | |
| 15 | | | WRITE(A) |
| 16 | | | WRITE(B) |
| 17 | | | VALIDATE? |
| 18 | | | WRITE? |

Figure 1: An execution schedule

(a) **[4 points]** Will T1 abort?
- ☐ Yes
- ☐ No

(b) **[4 points]** Will T2 abort?
- ☐ Yes
- ☐ No

(c) **[4 points]** Will T3 abort?
- ☐ Yes
- ☐ No

Question 4 continues. . .

(d) **[2 points]** OCC works best when concurrent transactions access the same subset of data in a database.
☐ True ☐ False

(e) **[2 points]** Transactions can suffer from *phantom reads* in OCC.
☐ True ☐ False

(f) **[2 points]** Aborts due to OCC are wasteful because they happen after a transaction has already finished executing.
☐ True ☐ False