# Concurrency Control

Hector Garcia-Molina and
Mahmoud SAKR

# Invited Lectures

## Extensible Databases - 6/10/2021

### Dimitri Fontaine

CITUS BLOG AUTHOR PROFILE

PostgreSQL major contributor & author of "The Art of PostgreSQL". Contributed extension facility & event triggers feature in Postgres. Maintains pg_auto_failover. Speaker at so many conferences.

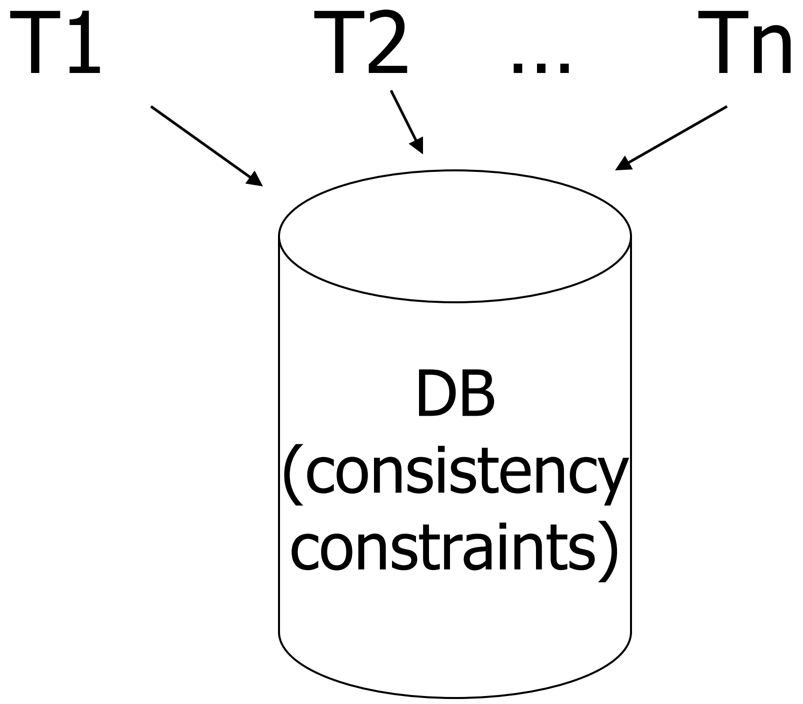
## Distributed Databases - 8/12/2021

### Marco Slot

CITUS BLOG AUTHOR PROFILE

Lead engineer on the Citus engine team at Microsoft. Speaker at Postgres Conf EU, PostgresOpen, pgDay Paris, Hello World, SIGMOD, & lots of meetups. PhD in distributed systems. Loves mountain hiking.

# Chapter 18 [18] Concurrency Control




1 transaction - multiple statements
1 schedule - multiple transactions

Two transactions are said to be concurrent if multiple transactions are executing concurrently (at the same time) without causing data inconsistencies.

Isolation - one transaction does not interfere another transaction

# Example:

T1: Read(A)
$A \leftarrow A+100$
Write(A)
Read(B)
$B \leftarrow B+100$
Write(B)

T2: Read(A)
$A \leftarrow A\times2$
Write(A)
Read(B)
$B \leftarrow B\times2$
Write(B)

Constraint: $A=B$

# Schedule A

| T1 | T2 |
|---|---|
| Read(A); A $\leftarrow$ A+100 | |
| Write(A); | |
| Read(B); B $\leftarrow$ B+100; | |
| Write(B); | |
| | Read(A);A $\leftarrow$ A$\times$2; |
| | Write(A); |
| | Read(B);B $\leftarrow$ B$\times$2; |
| | Write(B); |

# Schedule A

| T1 | T2 | A | B |
|---|---|---|---|
| | | 25 | 25 |
| Read(A); A $\leftarrow$ A+100 | | | |
| Write(A); | | 125 | |
| Read(B); B $\leftarrow$ B+100; | | | |
| Write(B); | | | 125 |
| | Read(A);A $\leftarrow$ A$\times$2; | | |
| | Write(A); | 250 | |
| | Read(B);B $\leftarrow$ B$\times$2; | | |
| | Write(B); | | 250 |
| | | 250 | 250 |

# Schedule B

| T1 | T2 |
|---|---|
| | Read(A); $A \leftarrow A\times2$; |
| | Write(A); |
| | Read(B); $B \leftarrow B\times2$; |
| | Write(B); |
| Read(A); $A \leftarrow A+100$ | |
| Write(A); | |
| Read(B); $B \leftarrow B+100$; | |
| Write(B); | |

# Schedule B

| T1 | T2 | A | B |
|---|---|---|---|
| | | 25 | 25 |
| | Read(A);A $\leftarrow$ A$\times$2; | | |
| | Write(A); | 50 | |
| | Read(B);B $\leftarrow$ B$\times$2; | | |
| | Write(B); | | 50 |
| Read(A); A $\leftarrow$ A+100 | | | |
| Write(A); | | 150 | |
| Read(B); B $\leftarrow$ B+100; | | | |
| Write(B); | | | 150 |
| | | 150 | 150 |

# Schedule C

| T1 | T2 |
|---|---|
| Read(A); A $\leftarrow$ A+100 | |
| Write(A); | |
| | Read(A);A $\leftarrow$ A$\times$2; |
| | Write(A); |
| Read(B); B $\leftarrow$ B+100; | |
| Write(B); | |
| | Read(B);B $\leftarrow$ B$\times$2; |
| | Write(B); |

# Schedule C

| T1 | T2 | A | B |
|---|---|---|---|
| | | 25 | 25 |
| Read(A); A $\leftarrow$ A+100 | | | |
| Write(A); | | 125 | |
| | Read(A);A $\leftarrow$ A$\times$2; | | |
| | Write(A); | 250 | |
| Read(B); B $\leftarrow$ B+100; | | | |
| Write(B); | | | 125 |
| | Read(B);B $\leftarrow$ B$\times$2; | | |
| | Write(B); | | 250 |
| | | 250 | 250 |

# Schedule D

| T1 | T2 |
|---|---|
| Read(A); $A \leftarrow A+100$ | |
| Write(A); | |
| | Read(A);$A \leftarrow A \times 2$; |
| | Write(A); |
| | Read(B);$B \leftarrow B \times 2$; |
| | Write(B); |
| Read(B); $B \leftarrow B+100$; | |
| Write(B); | |

# Schedule D

| T1 | T2 | A | B |
|---|---|---|---|
| | | 25 | 25 |
| Read(A); A $\leftarrow$ A+100 | | | |
| Write(A); | | 125 | |
| | Read(A);A $\leftarrow$ A$\times$2; | | |
| | Write(A); | 250 | |
| | Read(B);B $\leftarrow$ B$\times$2; | | |
| | Write(B); | | 50 |
| Read(B); B $\leftarrow$ B+100; | | | |
| Write(B); | | | 150 |
| | | 250 | 150 |

# Schedule E

Same as Schedule D but with new T2′

| T1 | T2′ |
|---|---|
| Read(A); $A \leftarrow A+100$ | |
| Write(A); | |
| | Read(A); $A \leftarrow A \times 1$; |
| | Write(A); |
| | Read(B); $B \leftarrow B \times 1$; |
| | Write(B); |
| Read(B); $B \leftarrow B+100$; | |
| Write(B); | |

# Schedule E

Same as Schedule D but with new T2′

| T1 | T2′ | A | B |
|---|---|---|---|
| | | 25 | 25 |
| Read(A); A ← A+100 | | | |
| Write(A); | | 125 | |
| | Read(A);A ← A×1; | | |
| | Write(A); | 125 | |
| | Read(B);B ← B×1; | | |
| | Write(B); | | 25 |
| Read(B); B ← B+100; | | | |
| Write(B); | | | 125 |
| | | 125 | 125 |

- Want schedules that are “good”, regardless of
  - initial state and
  - transaction semantics
- Only look at order of read and writes

Example:

$Sc=r_1(A)w_1(A)r_2(A)w_2(A)r_1(B)w_1(B)r_2(B)w_2(B)$

# Example:

$$Sc = r_1(A)w_1(A)r_2(A)w_2(A)r_1(B)w_1(B)r_2(B)w_2(B)$$

$$Sc' = \underbrace{r_1(A)w_1(A)\ r_1(B)w_1(B)}_{T_1}\underbrace{r_2(A)w_2(A)r_2(B)w_2(B)}_{T_2}$$

# The Transaction Game

| | | | | | | | | |
|---|---|---|---|---|---|---|---|---|
| **A** | | | | | | | | |
| **B** | | | | | | | | |
| **T1** | | | | | | | | |
| **T2** | | | | | | | | |

# The Transaction Game

| | | | | | | | | |
|---|---|---|---|---|---|---|---|---|
| **A** | **r** | **w** | **r** | **w** | | | | |
| **B** | | | | | **r** | **w** | **r** | **w** |
| **T1** | **r** | **w** | | | **r** | **w** | | |
| **T2** | | | **r** | **w** | | | **r** | **w** |

# The Transaction Game

we can move column until shifting column hits something
A schedule can be said to be good if by shifting columns, we will get another schedule which is serializable i.e. if schedule cannot be converted serial schedule by rearranging

| | | | | | | | | |
|---|---|---|---|---|---|---|---|---|
| **A** | **r** | **w** | **r** | **w** | | | | |
| **B** | | | | | **r** | **w** | **r** | **w** |
| **T1** | **r** | **w** | | | **r** | **w** | | |
| **T2** | | | **r** | **w** | | | **r** | **w** |

until column hits something

can move column

| | | | | | | | | |
|---|---|---|---|---|---|---|---|---|
| **A** | r | w | r | w | | | | |
| **B** | | | | | r | w | r | w |
| **T1** | r | w | | | r | w | | |
| **T2** | | | r | w | | | r | w |

move

move

| | | | | | | | | |
|---|---|---|---|---|---|---|---|---|
| **A** | r | w | | | r | w | | |
| **B** | | | r | w | | | r | w |
| **T1** | r | w | r | w | | | | |
| **T2** | | | | | r | w | r | w |

# Schedule D

| | | | | | | | | |
|---|---|---|---|---|---|---|---|---|
| **A** | **r** | **w** | **r** | **w** | | | | |
| **B** | | | | | **r** | **w** | **r** | **w** |
| **T1** | **r** | **w** | | | | | **r** | **w** |
| **T2** | | | **r** | **w** | **r** | **w** | | |

not Serializable schedule

However, for Sd:

$Sd = r_1(A)w_1(A)r_2(A)w_2(A)\ r_2(B)w_2(B)r_1(B)w_1(B)$

- as a matter of fact,

  $T_2$ must precede $T_1$

  in any equivalent schedule,

  i.e., $T_2 \rightarrow T_1$

- $T_2 \rightarrow T_1$
- Also, $T_1 \rightarrow T_2$

$$\begin{tikzcd} T_1 \arrow[r, bend left] & T_2 \arrow[l, bend left] \end{tikzcd}$$

$\Rightarrow$ Sd cannot be rearranged into a serial schedule

$\Rightarrow$ Sd is not "equivalent" to any serial schedule

$\Rightarrow$ Sd is "bad"

# Returning to Sc

$$Sc=r_1(A)w_1(A)r_2(A)w_2(A)r_1(B)w_1(B)r_2(B)w_2(B)$$

$$T_1 \rightarrow T_2 \qquad\qquad T_1 \rightarrow T_2$$

# Returning to Sc

$$Sc = r_1(A)w_1(A)r_2(A)w_2(A)r_1(B)w_1(B)r_2(B)w_2(B)$$

$T_1 \rightarrow T_2$ $\qquad\qquad$ $T_1 \rightarrow T_2$

☛ no cycles $\Rightarrow$ Sc is "equivalent" to a serial schedule (in this case $T_1$,$T_2$)

# Concepts

*Transaction:* sequence of $r_i(x)$, $w_i(x)$ actions

*Conflicting actions:*

$r_1(A)$ / $w_2(A)$ $\quad$ $w_2(A)$ / $r_1(A)$ $\quad$ $w_1(A)$ / $w_2(A)$

*Schedule:* represents chronological order in which actions are executed

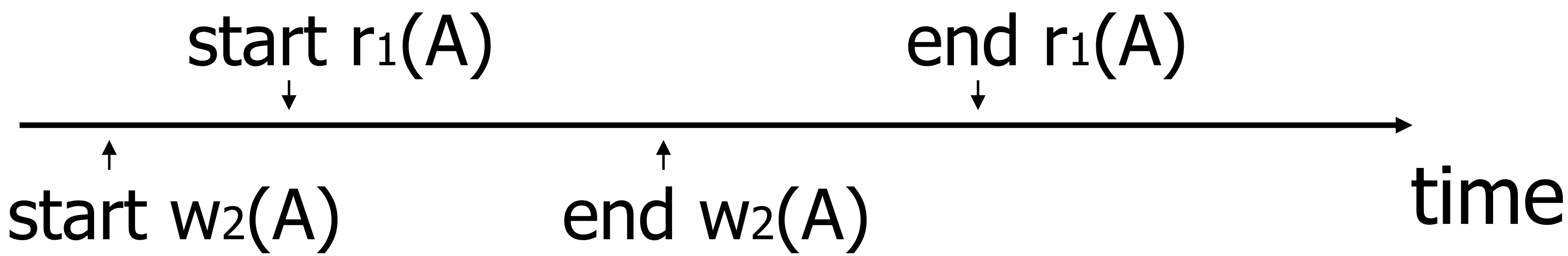
*Serial schedule:* no interleaving of actions or transactions

A serial schedule in the context of database transactions refers to a scenario where transactions are executed one after the other, without any interleaving or overlap in their execution.

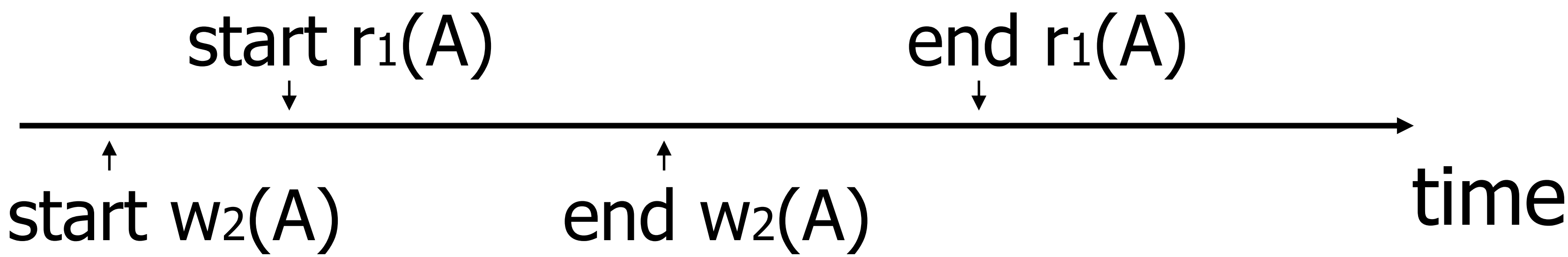
Is it OK to model reads & writes as occurring at a single point in time in a schedule?

- S=… $r_1(x)$ … $w_2(b)$ …

# What about conflicting, concurrent actions on same object?



# What about conflicting, concurrent actions on same object?




- Assume equivalent to either $r_1(A)$ $w_2(A)$

  or $w_2(A)$ $r_1(A)$
- $\Rightarrow$ low level synchronization mechanism
- Assumption called "atomic actions"

# Definition

$S_1$, $S_2$ are conflict equivalent schedules if $S_1$ can be transformed into $S_2$ by a series of swaps on non-conflicting actions.

# Definition

A schedule is conflict serializable if it is conflict equivalent to some serial schedule.

# Precedence graph $P(S)$ ($S$ is schedule)

Nodes: transactions in $S$

Arcs: $Ti \rightarrow Tj$ whenever

- $p_i(A)$, $q_j(A)$ are actions in $S$
- $p_i(A) <_S q_j(A)$
- at least one of $p_i$, $q_j$ is a write

# Exercise:

- What is P(S) for
  $S = w_3(A)\ w_2(C)\ r_1(A)\ w_1(B)\ r_1(C)\ w_2(A)\ r_4(A)\ w_4(D)$

- Is S serializable?

# Another Exercise:

- What is P(S) for
  $S = w_1(A)\ r_2(A)\ \ r_3(A)\ w_4(A)$ ?

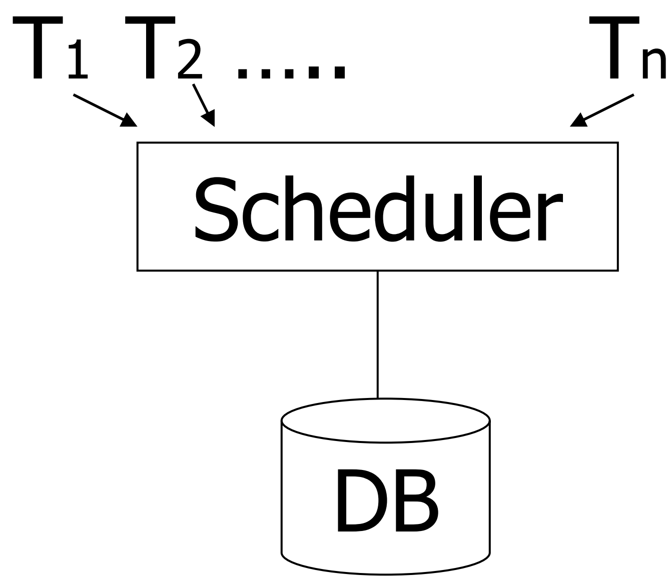
# How to enforce serializable schedules?

*Option 1:* run system, recording P(S);
at end of day, check for P(S)
cycles and declare if execution
was good

Serializable schedules are good

# How to enforce serializable schedules?

*Option 2:* prevent P(S) cycles from occurring

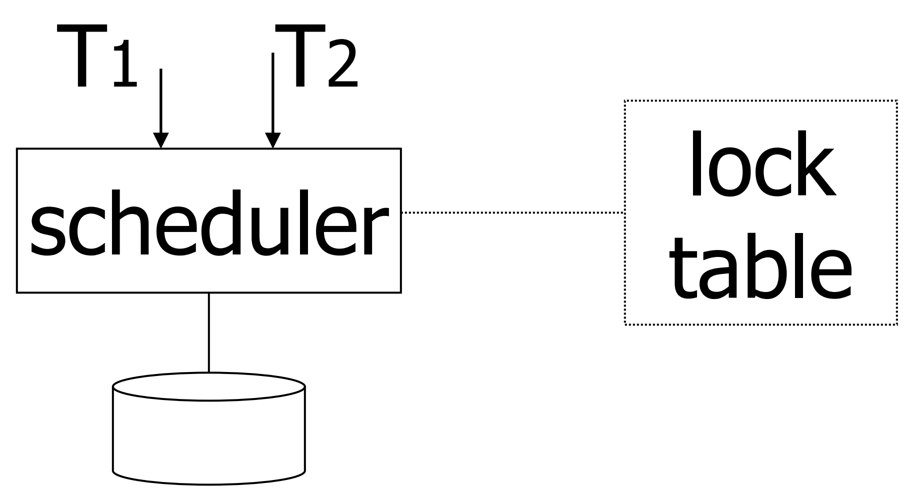


# A locking protocol

Two new actions:

lock (exclusive): $l_i$ (A)

unlock: $u_i$ (A)



# Rule #1: Well-formed transactions

$T_i$: … $l_i(A)$ … $p_i(A)$ … $u_i(A)$ …

# Rule #2 Legal scheduler

$$S = \ldots\ldots\ldots\; l_i(A)\; \underbrace{\ldots\ldots\ldots\ldots\ldots}_{\text{no } l_j(A)}\; u_i(A)\; \ldots\ldots\ldots$$

# Exercise:

- What schedules are legal?
  What transactions are well-formed?

$S1 = l_1(A)l_1(B)r_1(A)w_1(B)l_2(B)u_1(A)u_1(B)$
$r_2(B)w_2(B)u_2(B)l_3(B)r_3(B)u_3(B)$

well formed
not legal

$S2 = l_1(A)r_1(A)w_1(B)u_1(A)u_1(B)$
$l_2(B)r_2(B)w_2(B)l_3(B)r_3(B)u_3(B)$

not well formed

$S3 = l_1(A)r_1(A)u_1(A)l_1(B)w_1(B)u_1(B)$
$l_2(B)r_2(B)w_2(B)u_2(B)l_3(B)r_3(B)u_3(B)$

well formed
legal

# Exercise:

- What schedules are legal?
  What transactions are well-formed?

$S1 = l_1(A)l_1(B)r_1(A)w_1(B)l_2(B)u_1(A)u_1(B)$
$r_2(B)w_2(B)u_2(B)l_3(B)r_3(B)u_3(B)$

$S2 = l_1(A)r_1(A)w_1(B)u_1(A)u_1(B)$
$l_2(B)r_2(B)w_2(B)l_3(B)r_3(B)u_3(B)$ $u_2(B)$?

$S3 = l_1(A)r_1(A)u_1(A)l_1(B)w_1(B)u_1(B)$
$l_2(B)r_2(B)w_2(B)u_2(B)l_3(B)r_3(B)u_3(B)$

# Schedule F

| T1 | T2 |
|---|---|
| $l_1(A)$;Read(A) | |
| $A \leftarrow A+100$;Write(A);$u_1(A)$ | |
| | $l_2(A)$;Read(A) |
| | $A \leftarrow Ax2$;Write(A);$u_2(A)$ |
| | $l_2(B)$;Read(B) |
| | $B \leftarrow Bx2$;Write(B);$u_2(B)$ |
| $l_1(B)$;Read(B) | |
| $B \leftarrow B+100$;Write(B);$u_1(B)$ | |

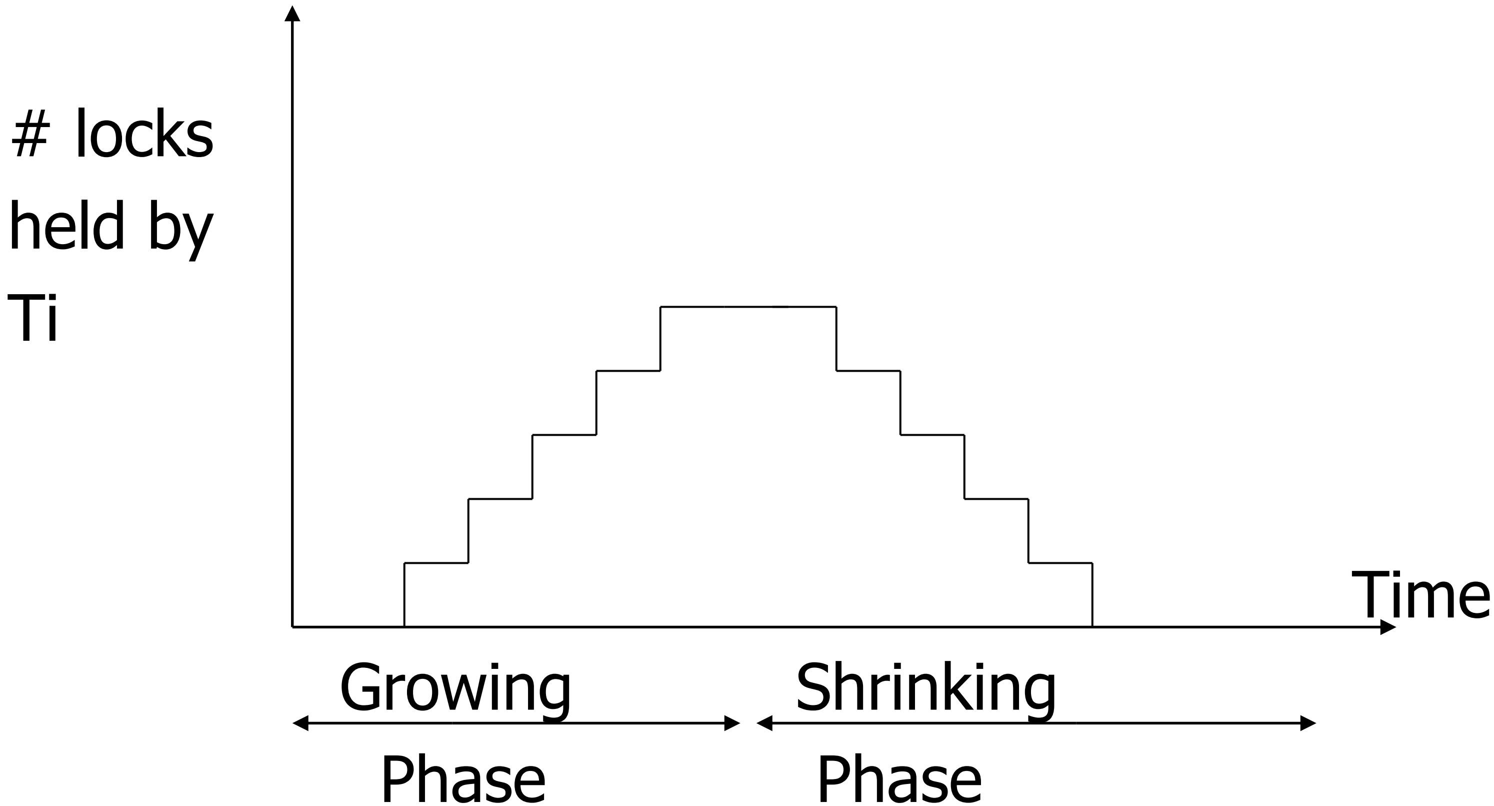
# Schedule F

| T1 | T2 | A | B |
|---|---|---|---|
| | | 25 | 25 |
| $l_1(A)$;Read(A) | | | |
| $A \leftarrow A+100$;Write(A);$u_1(A)$ | | 125 | |
| | $l_2(A)$;Read(A) | | |
| | $A \leftarrow Ax2$;Write(A);$u_2(A)$ | 250 | |
| | $l_2(B)$;Read(B) | | |
| | $B \leftarrow Bx2$;Write(B);$u_2(B)$ | | 50 |
| $l_1(B)$;Read(B) | | | |
| $B \leftarrow B+100$;Write(B);$u_1(B)$ | | | 150 |
| | | 250 | 150 |

# Rule #3 Two phase locking (2PL) for transactions

$T_i = \ldots\ldots\; l_i(A) \;\ldots\ldots\ldots\ldots\; u_i(A) \;\ldots\ldots\ldots$

no unlocks    no locks



# locks held by Ti
Time
Growing Phase
Shrinking Phase

# Schedule G

| T1 | T2 |
|---|---|
| $l_1(A)$;Read(A) | |
| $A \leftarrow A+100$;Write(A) | |
| $l_1(B)$; $u_1(A)$ | |
| | $l_2(A)$;Read(A) |
| | $A \leftarrow Ax2$;Write(A); $l_2(B)$ |

delayed

# Schedule G

| T1 | T2 |
|---|---|
| $l_1$(A);Read(A) | |
| A ← A+100;Write(A) | |
| $l_1$(B); $u_1$(A) | |
| | $l_2$(A);Read(A) |
| | A ← Ax2;Write(A); $l_2$(B) — delayed |
| Read(B);B ← B+100 | |
| Write(B); $u_1$(B) | |

# Schedule G

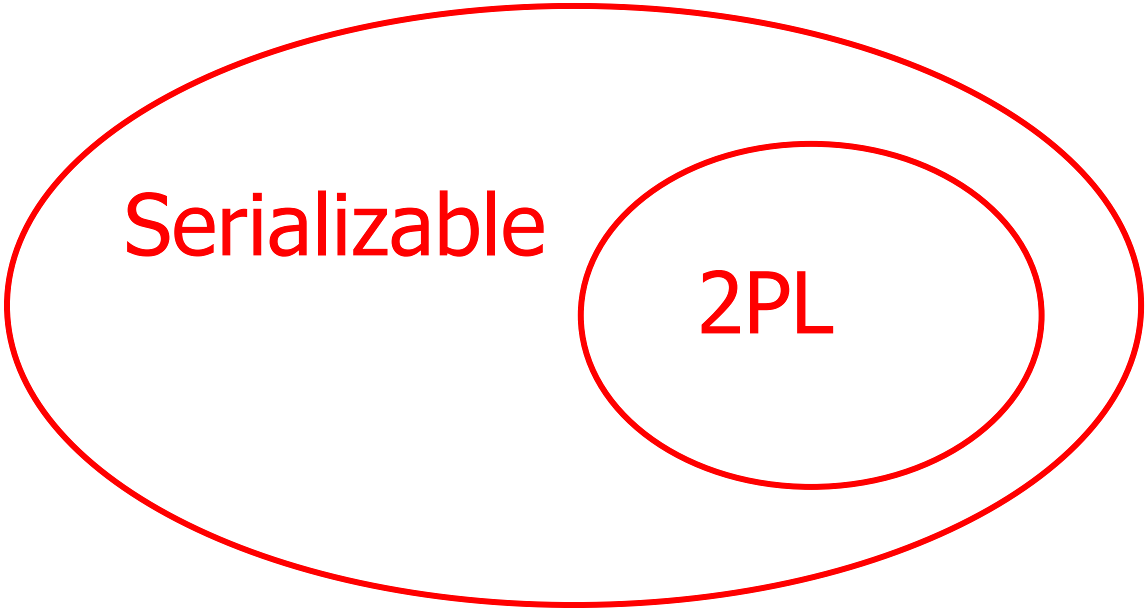
| T1 | T2 | |
|---|---|---|
| $l_1(A)$;Read(A) | | |
| $A \leftarrow A+100$;Write(A) | | |
| $l_1(B)$; $u_1(A)$ | | |
| | $l_2(A)$;Read(A) | delayed |
| | $A \leftarrow Ax2$;Write(A);$l_2(B)$ | |
| Read(B);$B \leftarrow B+100$ | | |
| Write(B); $u_1(B)$ | | |
| | $l_2(B)$; $u_2(A)$;Read(B) | |
| | $B \leftarrow Bx2$;Write(B);$u_2(B)$; | |

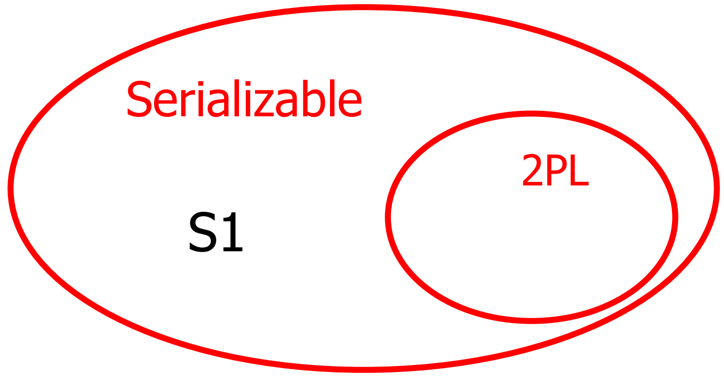
# Schedule H (T$_2$ reversed)

| T1 | T2 |
|---|---|
| $l_1$(A); Read(A) | $l_2$(B);Read(B) |
| A $\leftarrow$ A+100;Write(A) | B $\leftarrow$ Bx2;Write(B) |
| $l_1$(B) delayed | $l_2$(A) delayed |

# 2PL subset of Serializable

2PL is more strict
2PL leads to dead lock issue
relax 2 phase locking in order to cover bigger space of serailizable






S1: w1(x) w3(x) w2(y) w1(y)

# S1: w1(x) w3(x) w2(y) w1(y)

- S1 cannot be achieved via 2PL:
  The lock by T1 for y must occur after w2(y), so the unlock by T1 for x must occur after this point (and before w1(x)). Thus, w3(x) cannot occur under 2PL where shown in S1 because T1 holds the x lock at that point.
- However, S1 is serializable (equivalent to T2, T1, T3).

two phase will lead to deadlock
but it is serializable

If you need a bit more practice:

Are our schedules $S_C$ and $S_D$ 2PL schedules?

$S_C$: w1(A) w2(A) w1(B) w2(B)

no

$S_D$: w1(A) w2(A) w2(B) w1(B)

no

- Beyond this simple 2PL protocol, it is all a matter of improving performance and allowing more concurrency….
  – Shared locks
  – Multiple granularity have multiple granular locks
  – Inserts, deletes and phantoms
  – Other types of C.C. mechanisms

# Shared locks

So far:

tran 1 wants to read A and will lock and unlock

tran 2 wants to read A and will lock and unlock

$S = ...l_1(A)\ r_1(A)\ u_1(A)\ ...\ l_2(A)\ r_2(A)\ u_2(A)\ ...$

Do not conflict

this tran is not concurrent
here, we also look into semantics, reads and writes

# Shared locks

So far:

$S = \ldots l_1(A)\ r_1(A)\ u_1(A)\ \ldots\ l_2(A)\ r_2(A)\ u_2(A)\ \ldots$

Do not conflict

## Instead:

instead of lock unlock, use shared lock

$S = \ldots\ ls_1(A)\ r_1(A)\ ls_2(A)\ r_2(A)\ \ldots.\ us_1(A)\ us_2(A)$

## Lock actions (Shared, Exclusive)

$l\text{-}t_i(A)$: lock A in t mode (t is S or X)

$u\text{-}t_i(A)$: unlock t mode (t is S or X)

## Shorthand:

$u_i(A)$: unlock whatever modes
$T_i$ has locked A

# Rule #1 Well formed transactions

$T_i = \ldots\ l\text{-}S_1(A) \ldots r_1(A) \ldots u_1(A) \ldots$

$T_i = \ldots\ l\text{-}X_1(A) \ldots w_1(A) \ldots u_1(A) \ldots$

before any read, have shared and/or exclusive lock and realease afterwards
before any write, have exclusive locka dn release afterwards

- What about transactions that read and write same object?

<u>Option 1:</u> Request exclusive lock

$T_i$ = ...$l\text{-}X_1(A)$ ... $r_1(A)$ ... $w_1(A)$ ... $u(A)$ ...

if same tranasaction performs read and write, okay to have exclusive lock

- What about transactions that read and write same object?

## Option 2: Upgrade

(E.g., need to read, but don't know if will write…)

$T_i$=… l-$S_1$(A) … $r_1$(A) … l-$X_1$(A) …$w_1$(A) …u(A)…

Think of
- Get 2nd lock on A, or
- Drop S, get X lock

update lock
when read finish and wants to write, it will upgrade lock by holding exclusive lock

# Rule #2 Legal scheduler

$S = \ldots\ldots l\text{-}S_i(A) \ldots \quad \ldots u_i(A) \ldots$

if we have shared lock, another transaction cannot have exclusive lock on same object until first transaction unlock

no $l\text{-}X_j(A)$

$S = \ldots\ l\text{-}X_i(A) \ldots \quad \ldots u_i(A) \ldots$

if we have exclusive lock for a transaction, then we cannot have another shared of exclusive lock

no $l\text{-}X_j(A)$
no $l\text{-}S_j(A)$

# A way to summarize Rule #2

Compatibility matrix

new transaction requesting for lock

Comp

transaction already has a lock

| | S | X |
|---|---|---|
| S | true | false |
| X | false | false |

lock all unlock all
cannot do lock and then unlock

# Rule # 3 2PL transactions

upgrade can be seen in two ways
only allow unlock in this case
with shared lock we allow unlocking

No change except for upgrades:

(I) If upgrade gets more locks

(e.g., S $\rightarrow$ {S, X}) then no change!

(II) If upgrade releases read (shared) lock (e.g., S $\rightarrow$ X)

- can be allowed in growing phase

# Lock types beyond S/X

Examples:

(1) increment lock

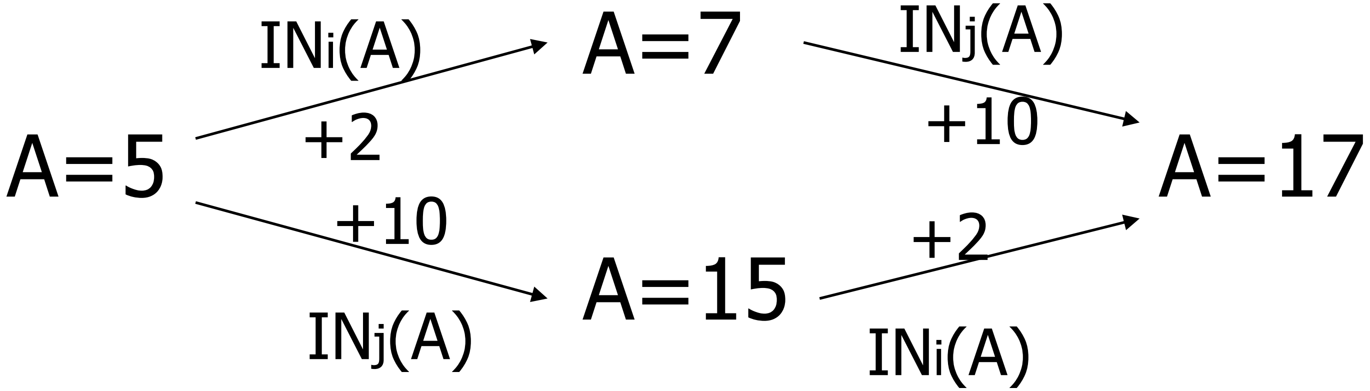
(2) update lock

# Example (1): increment lock

- Atomic increment action: $IN_i(A)$

  $\{Read(A);\ A \leftarrow A+k;\ Write(A)\}$

- $IN_i(A)$, $IN_j(A)$ do not conflict!



Comp

| | S | X | I |
|---|---|---|---|
| S | | | |
| X | | | |
| I | | | |

requested lock

# Comp

have lock

| | S | X | I |
|---|---|---|---|
| S | T | F | F |
| X | F | F | F |
| I | F | F | T |

# Update locks

A common deadlock problem with upgrades:

| T1 | T2 |
|---|---|
| $l\text{-}S_1(A)$ | |
| | $l\text{-}S_2(A)$ |
| $l\text{-}X_1(A)$ | |
| tran 1 wants to update the lock but it cannot because transaction 2 is holding shared lock in it | |
| | $l\text{-}X_2(A)$ |
| | tran 2 wants to update the lock but it cannot because tran 1 is holding shared lock in it |

--- Deadlock ---

# Solution

If $T_i$ wants to read A and knows it may later want to write A, it requests <u>update</u> lock (not shared)

Comp

New request

Lock already held in

| | S | X | U |
|---|---|---|---|
| S | | | |
| X | | | |
| U | | | |

New request

Comp

Lock already held in

| | S | X | U |
|---|---|---|---|
| S | T | F | T |
| X | F | F | F |
| U | F | F | F |

here we are reducing concurrency

# Note: object A may be locked in different modes at the same time...

not allowed

$$S_1 = \ldots l\text{-}S_1(A) \ldots l\text{-}S_2(A) \ldots l\text{-}U_3(A) \ldots \begin{cases} l\text{-}S_4(A) \ldots ? \\ l\text{-}U_4(A) \ldots ? \end{cases}$$

not allowed

Note:
update lock cha bhane write garna mildaina
but exclusive lock request garera ani write garna milcha

# Note: object A may be locked in different modes at the same time...

check against most strict lock

$$S_1 = \ldots l\text{-}S_1(A) \ldots l\text{-}S_2(A) \ldots l\text{-}U_3(A) \ldots \begin{cases} l\text{-}S_4(A) \ldots ? \\ l\text{-}U_4(A) \ldots ? \end{cases}$$

- To grant a lock in mode t, mode t must be compatible with all currently held locks on object

# How does locking work in practice?

- Every system is different

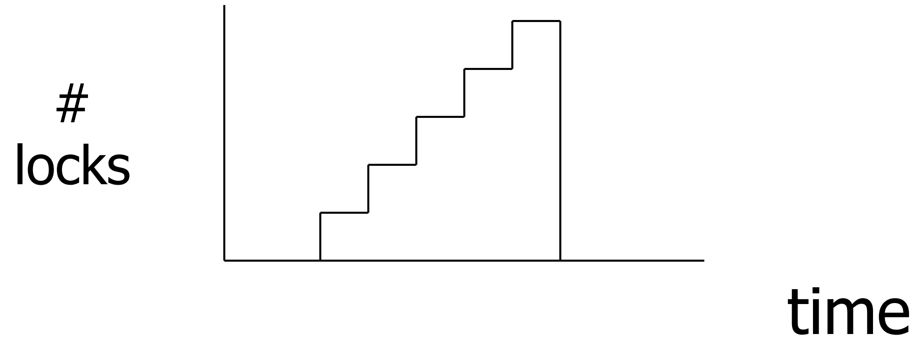
  (E.g., may not even provide
  CONFLICT-SERIALIZABLE schedules)

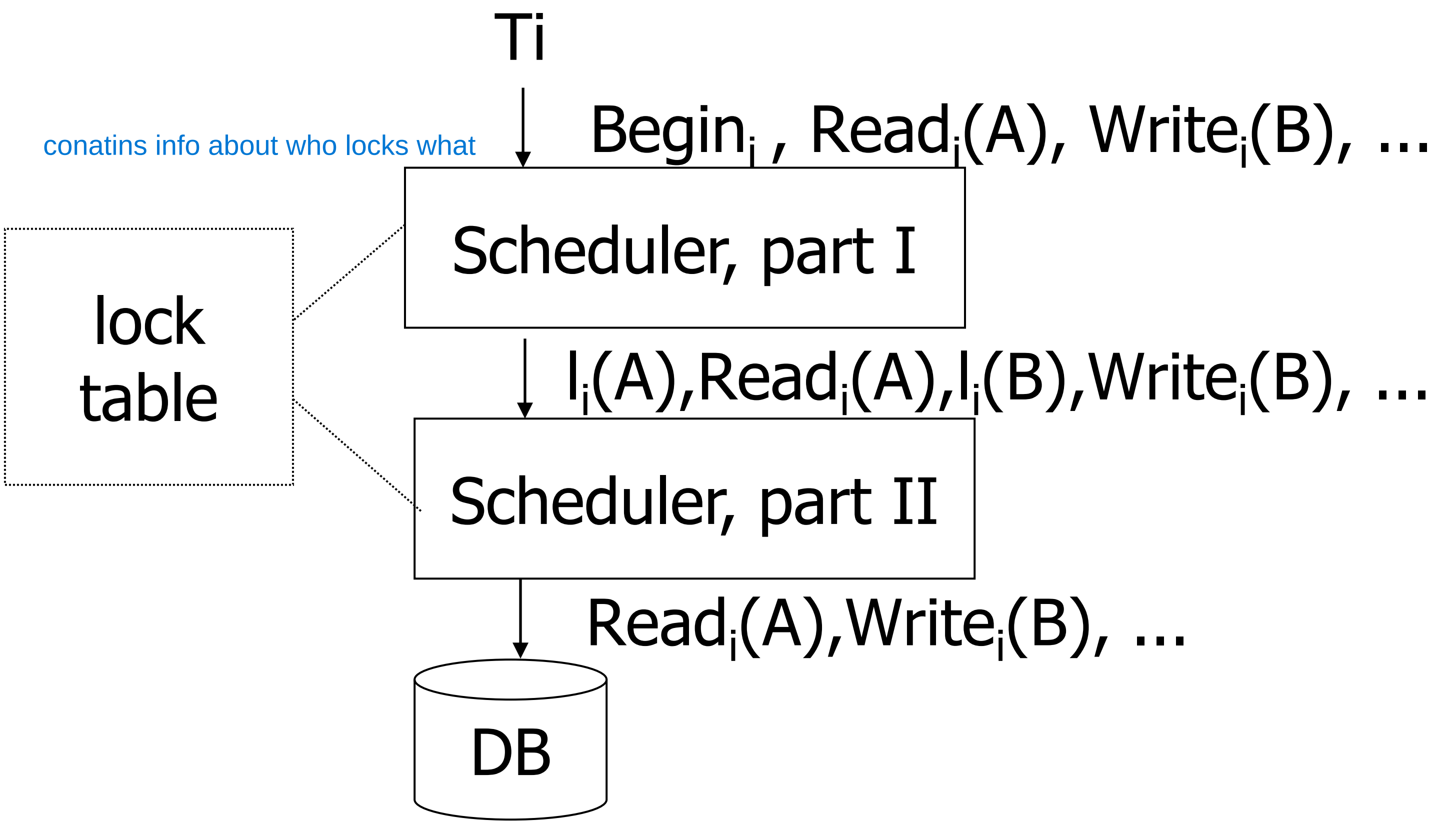
- But here is one (simplified) way ...

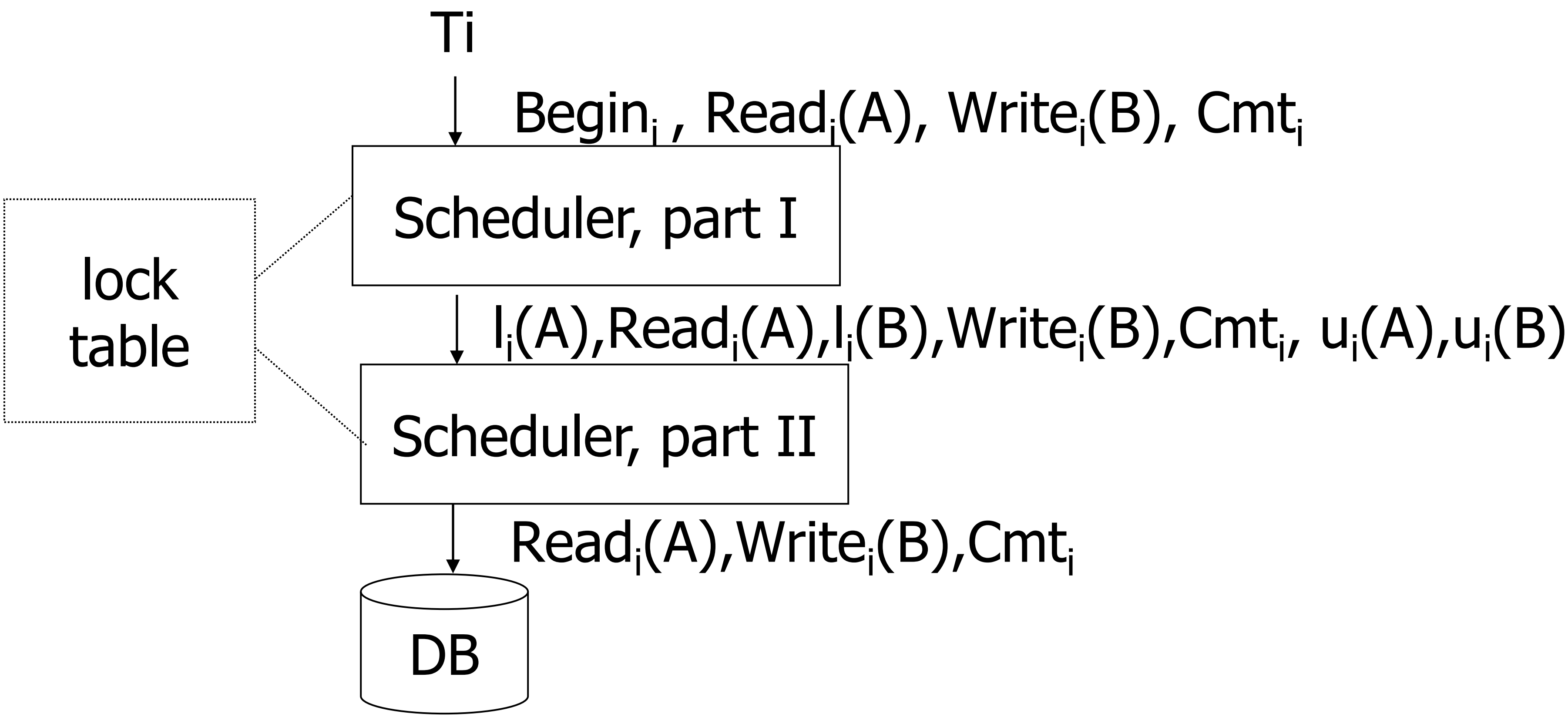
# Sample Locking System:

(1) Don't trust transactions to
request/release locks

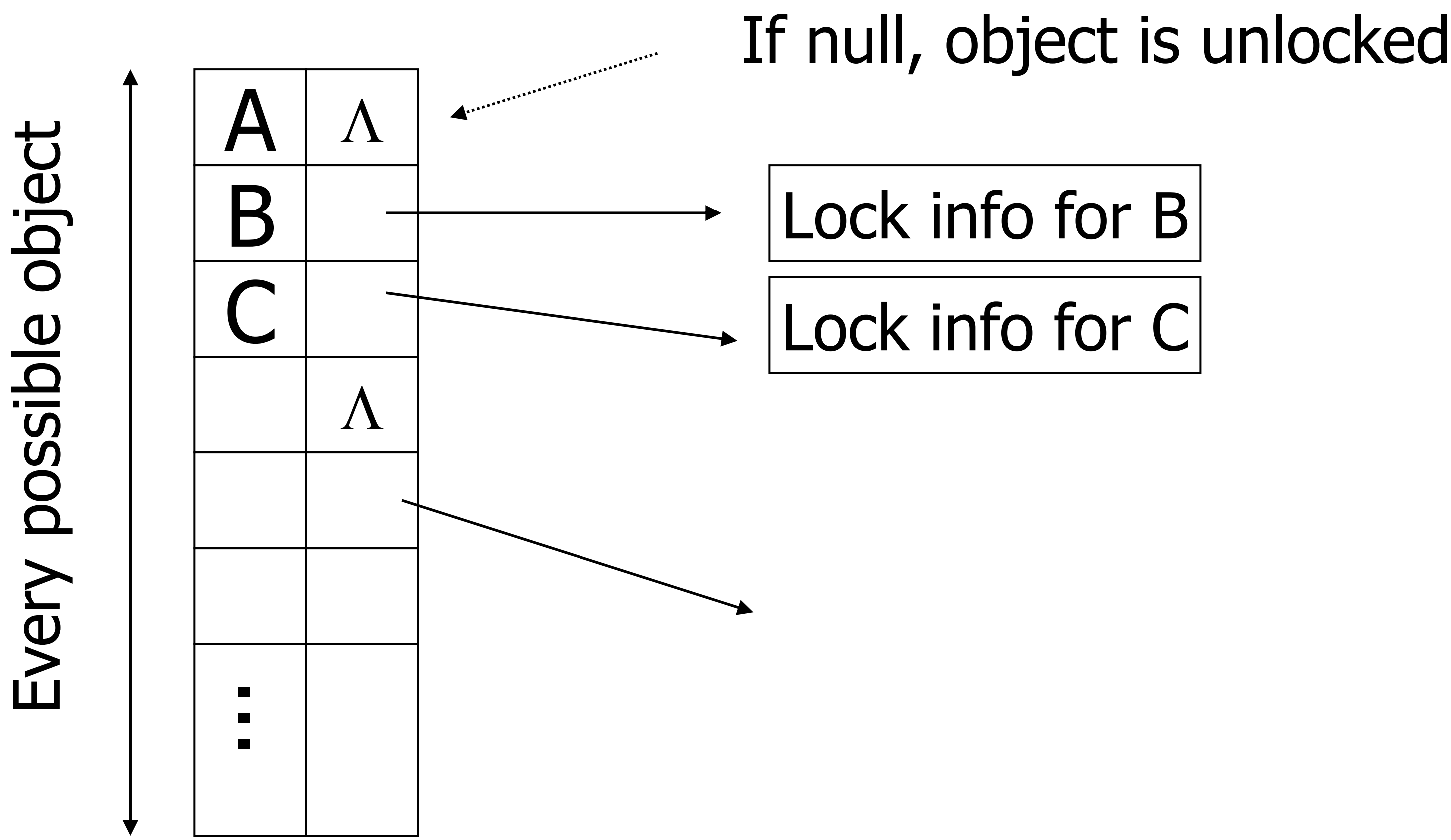
(2) Hold all locks until transaction
commits




Ti
Begin$_i$ , Read$_i$(A), Write$_i$(B), ...
conatins info about who locks what
Scheduler, part I
lock table
l$_i$(A),Read$_i$(A),l$_i$(B),Write$_i$(B), ...
Scheduler, part II
Read$_i$(A),Write$_i$(B), ...
DB

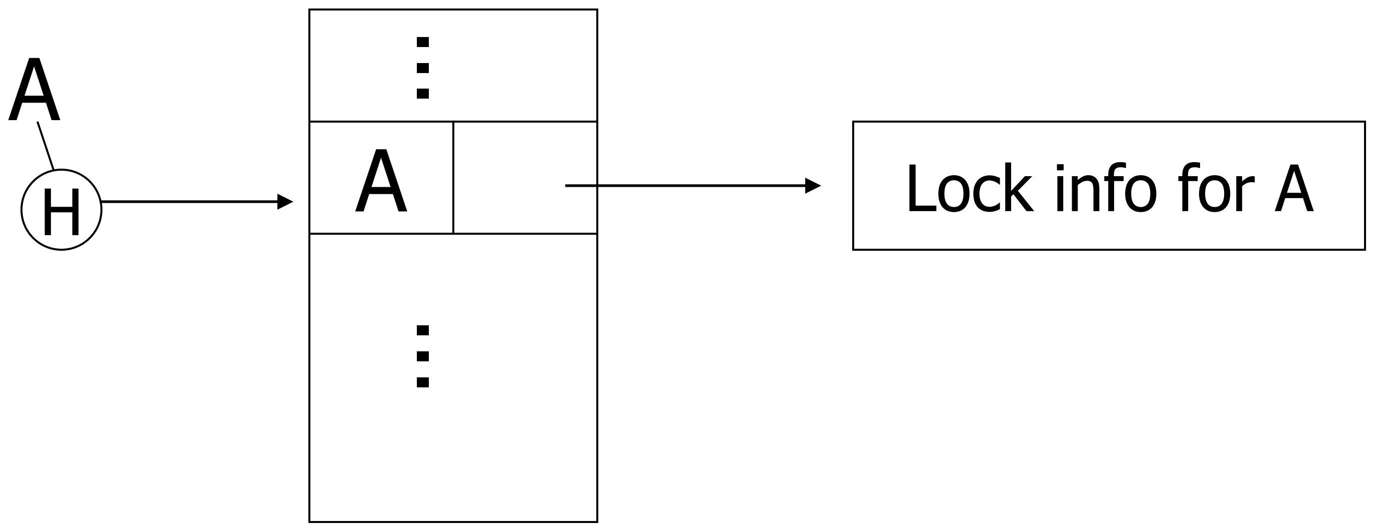

Ti
$Begin_i$ , $Read_i(A)$, $Write_i(B)$, $Cmt_i$
Scheduler, part I
lock
table
$l_i(A)$,$Read_i(A)$,$l_i(B)$,$Write_i(B)$,$Cmt_i$, $u_i(A)$,$u_i(B)$
Scheduler, part II
$Read_i(A)$,$Write_i(B)$,$Cmt_i$
DB

# Lock table    Conceptually




one side all database object
other side lock and unlock info

# But use hash table:

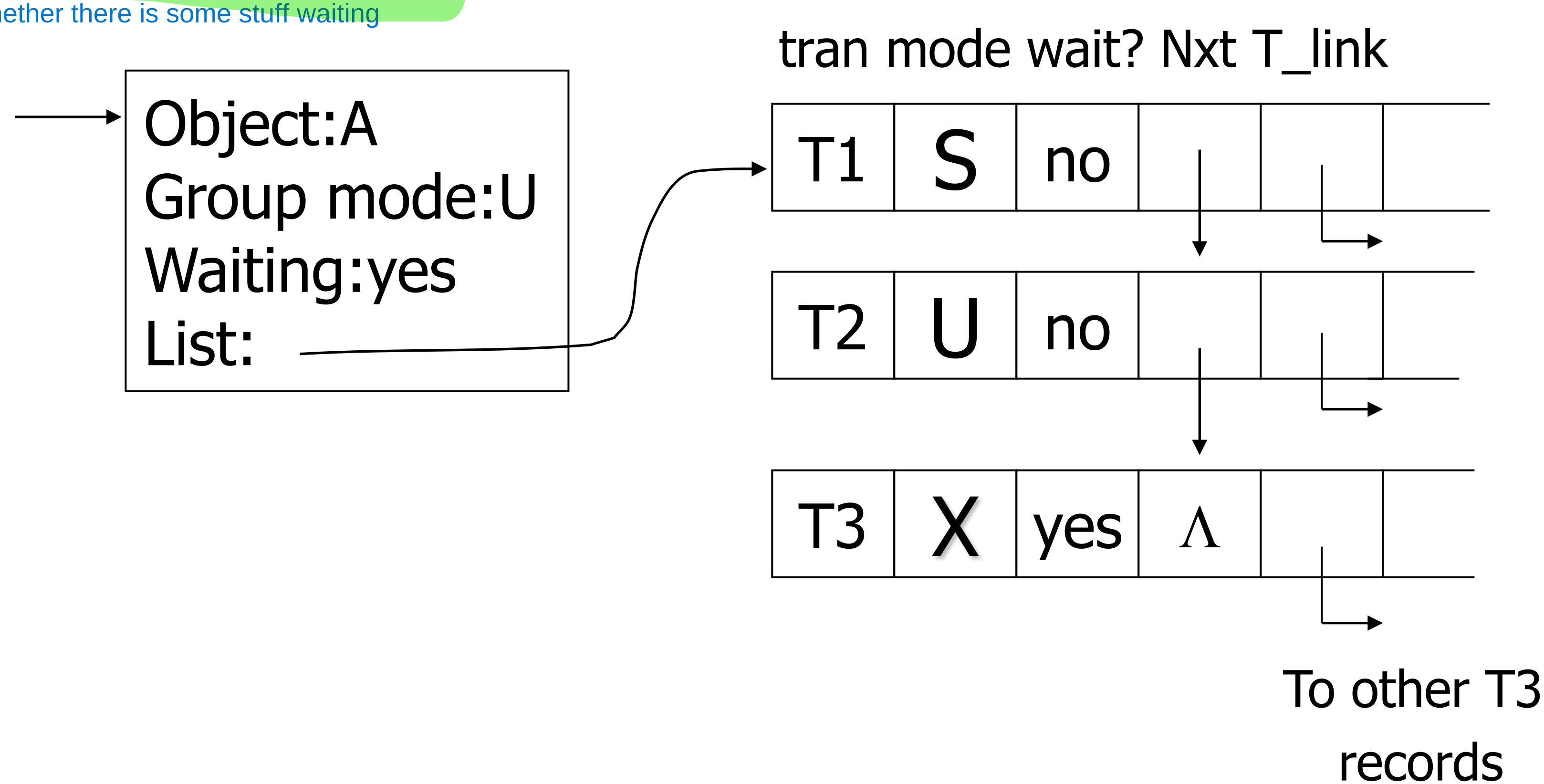



If object not found in hash table, it is unlocked

# Lock info for A - example

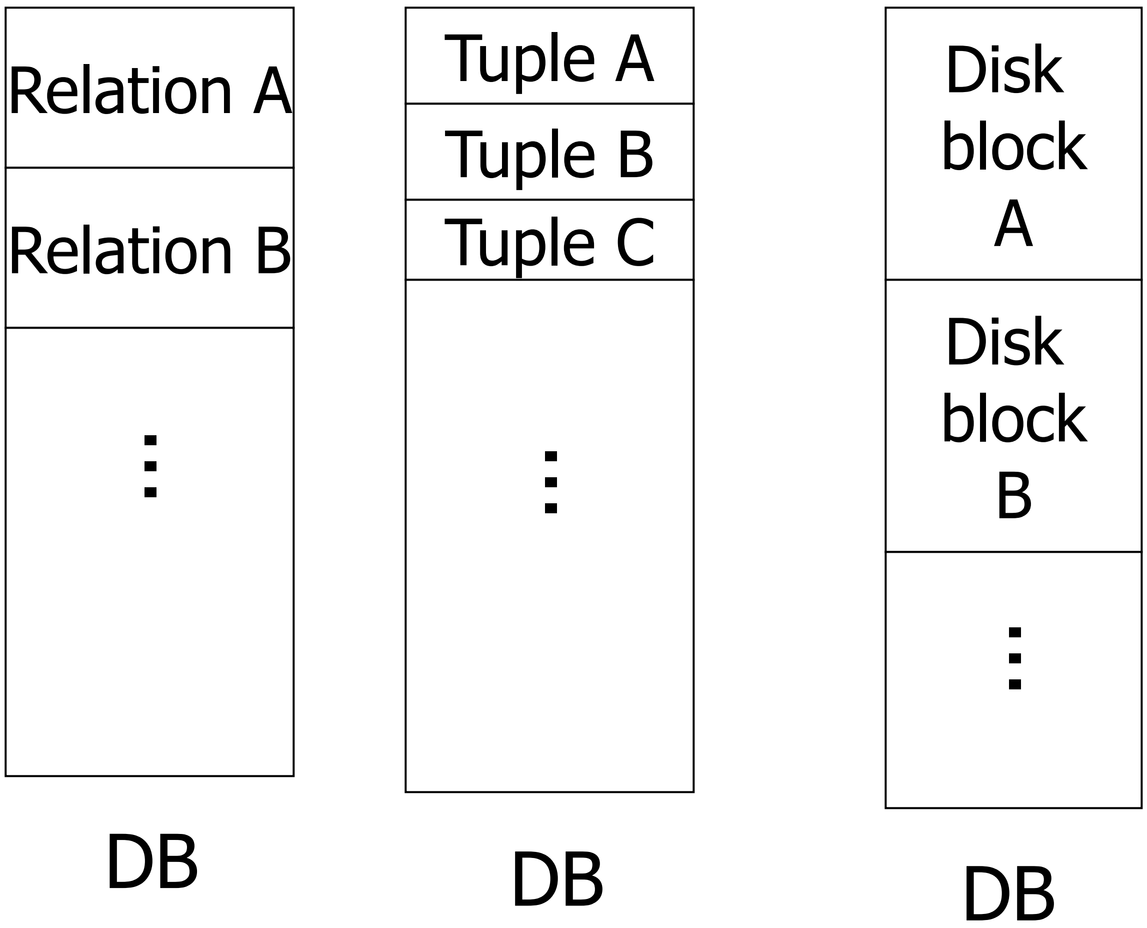
all transactions
type of lock
whether they are waiting or not
T3 asked exclusive lock dn is waiting

summary
obj A
look all locks which are active not waiting and keep most strict one
whether there is some stuff waiting



# What are the objects we lock?

table
row
attribute
page
database




?

- Locking works in any case, but should we choose <u>small</u> or <u>large objects?</u>

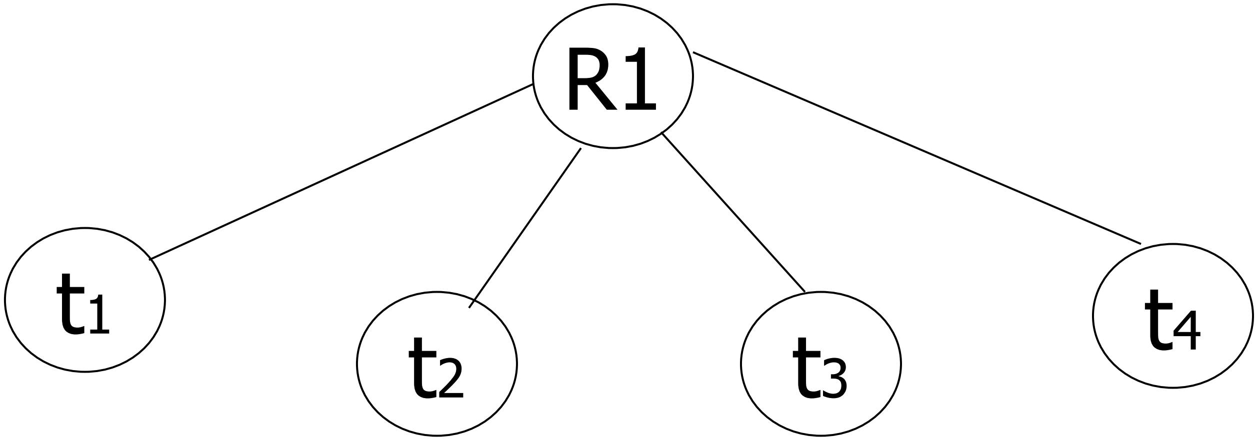
if we lock large object, our lock table will be smaller
but we have low concurrency

if same object is locked
more concurrency
large lock table

- Locking works in any case, but should we choose small or large objects?

- If we lock large objects (e.g., Relations)
  - Need few locks
  - Low concurrency
- If we lock small objects (e.g., tuples,fields)
  - Need more locks
  - More concurrency

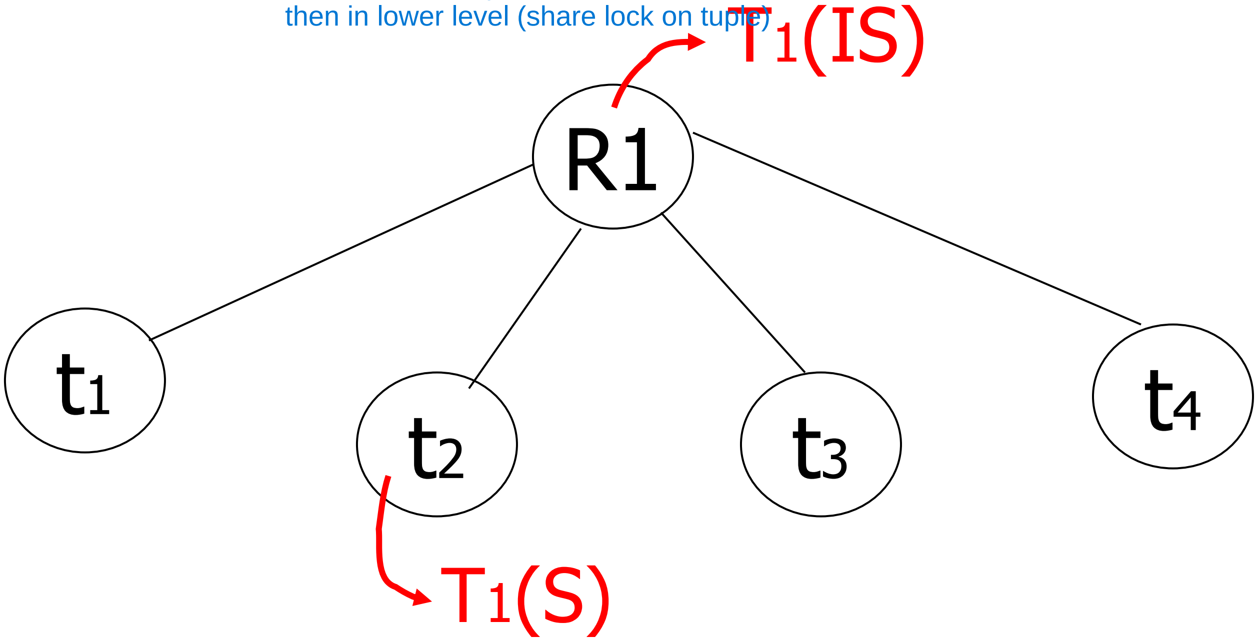
# Example



# Example

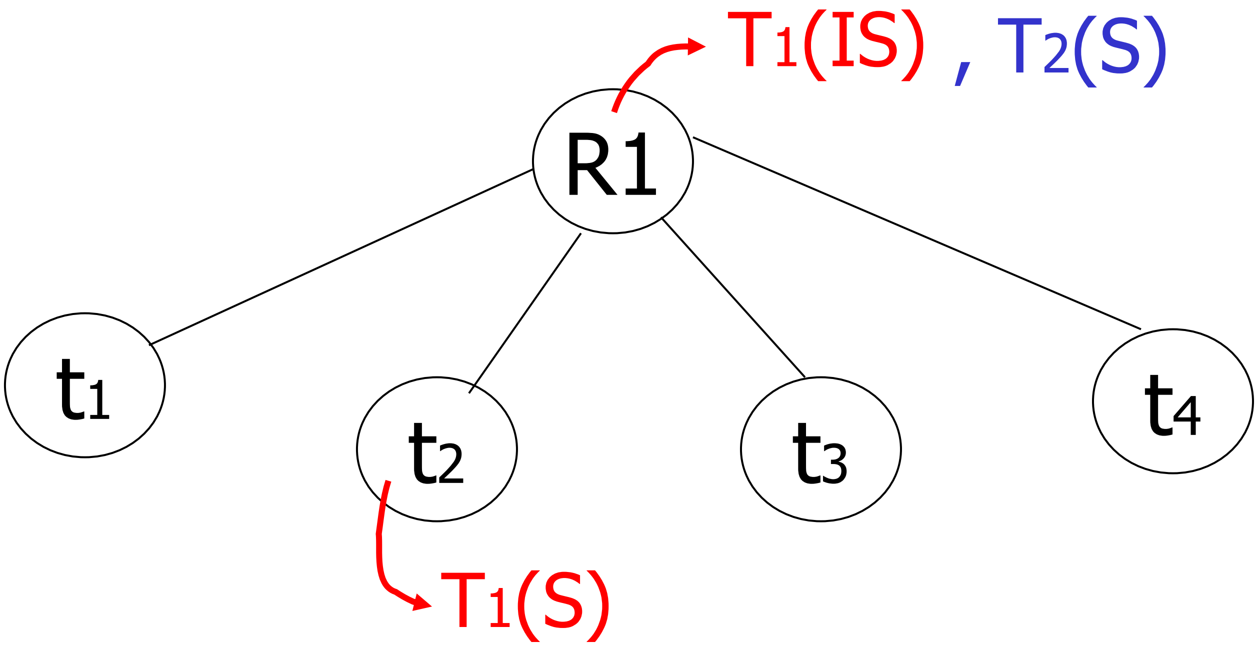
multi granular lock
lock at multiple levels

intensional locks
T1 wats to read tuple 2
it will hold 2 lock
lock on relation (
then in lower level (share lock on tuple)



came tran 2 who wants to hold shared lock on whole relation

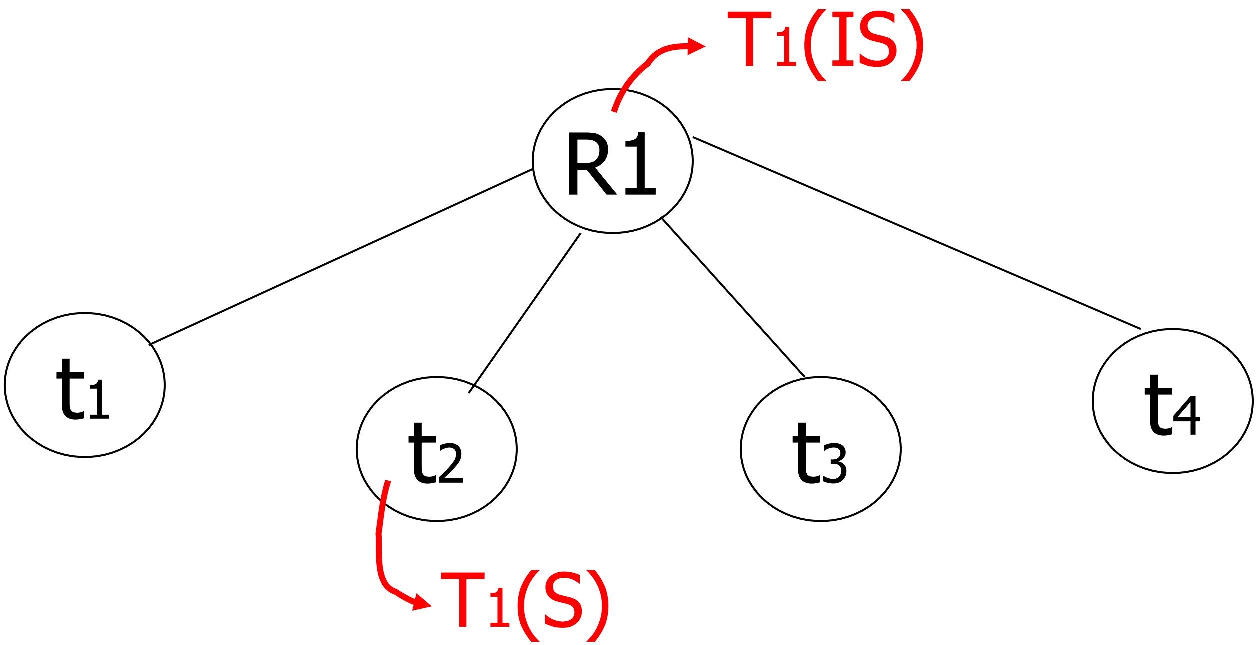
# Example




allowed

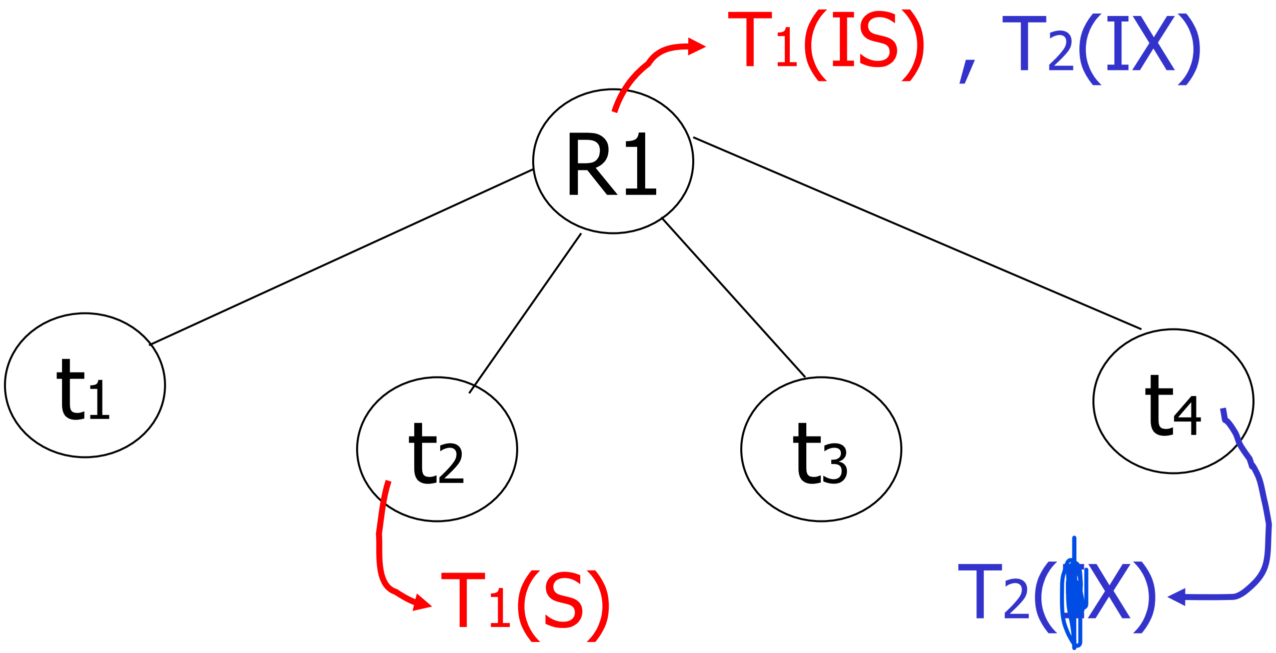
is means it wants lower level
S means it wants that level

# Example (b)



will it allow t2?
depends in which part it wants to write
allow only if t2 is not written

# Example



# Multiple granularity

| Comp | | Requestor | | | | |
|---|---|---|---|---|---|---|
| | | IS | IX | S | SIX | X |
| Holder | IS | | | | | |
| | IX | | | | | |
| | S | | | | | |
| | SIX | | | | | |
| | X | | | | | |

# Multiple granularity

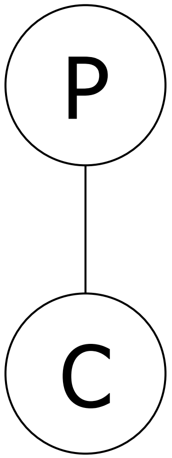
Comp — Requestor

| Holder | IS | IX | S | SIX | X |
|---|---|---|---|---|---|
| IS | T | T | T | T | F |
| IX | T | T | F | F | F |
| S | T | F | T | F | F |
| SIX | T | F | F | F | F |
| X | F | F | F | F | F |

shared lock on whole object
intension write on children

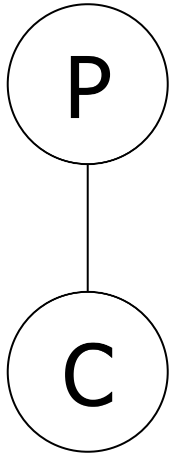
in single transation

| Parent locked in | Child can be locked in |
|---|---|
| IS | |
| IX | |
| S | |
| SIX | |
| X | |



| Parent locked in | Child can be locked by same transaction in |
| --- | --- |
| IS | IS, S |
| IX | IS, S, IX, X, SIX |
| S | none |
| SIX | X, IX, [SIX] |
| X | none |

not necessary




SIX -
Shared + Intensional write
complete S on parent and
intention write on children

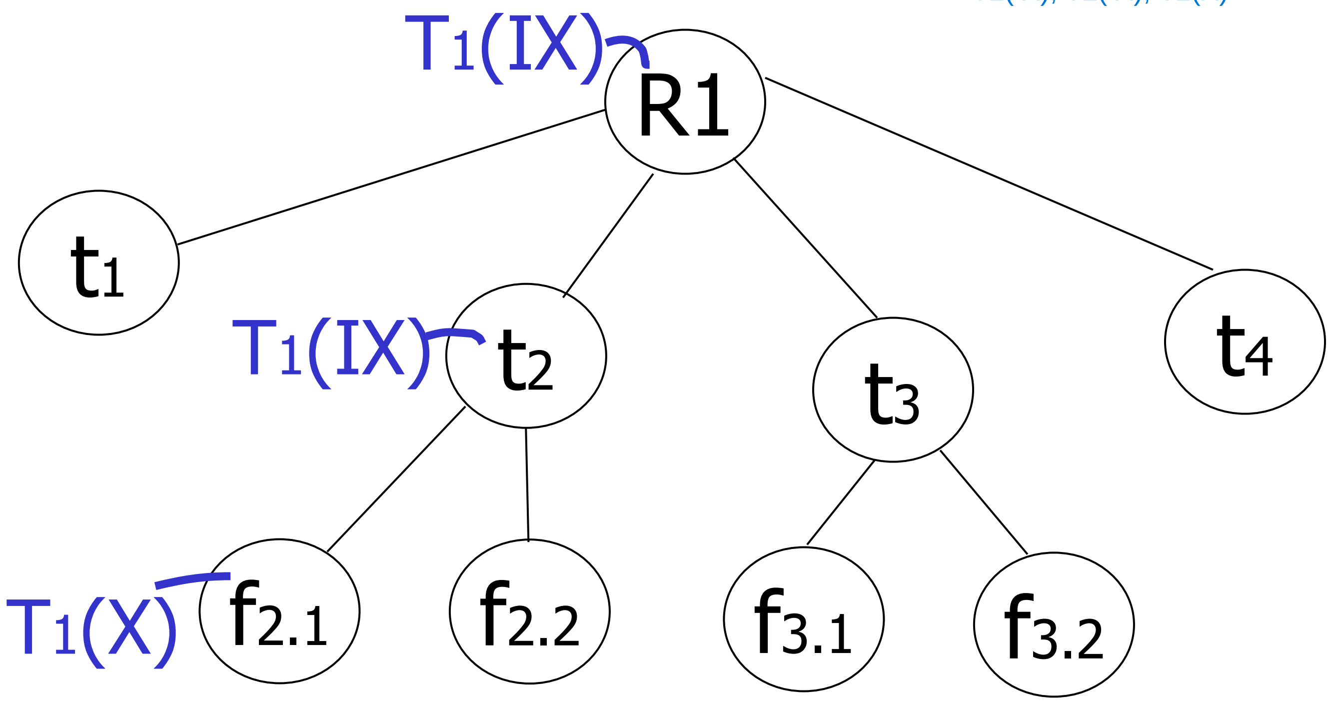
# Rules

(1) Follow multiple granularity comp function
(2) Lock root of tree first, any mode
(3) Node Q can be locked by Ti in S or IS only if parent(Q) locked by Ti in IX or IS
(4) Node Q can be locked by Ti in X,SIX,IX only if parent(Q) locked by Ti in IX,SIX
(5) Ti is two-phase
(6) Ti can unlock node Q only if none of Q's children are locked by Ti

# Exercise:

- Can $T_2$ access object $f_{2.2}$ in X mode? What locks will $T_2$ get?

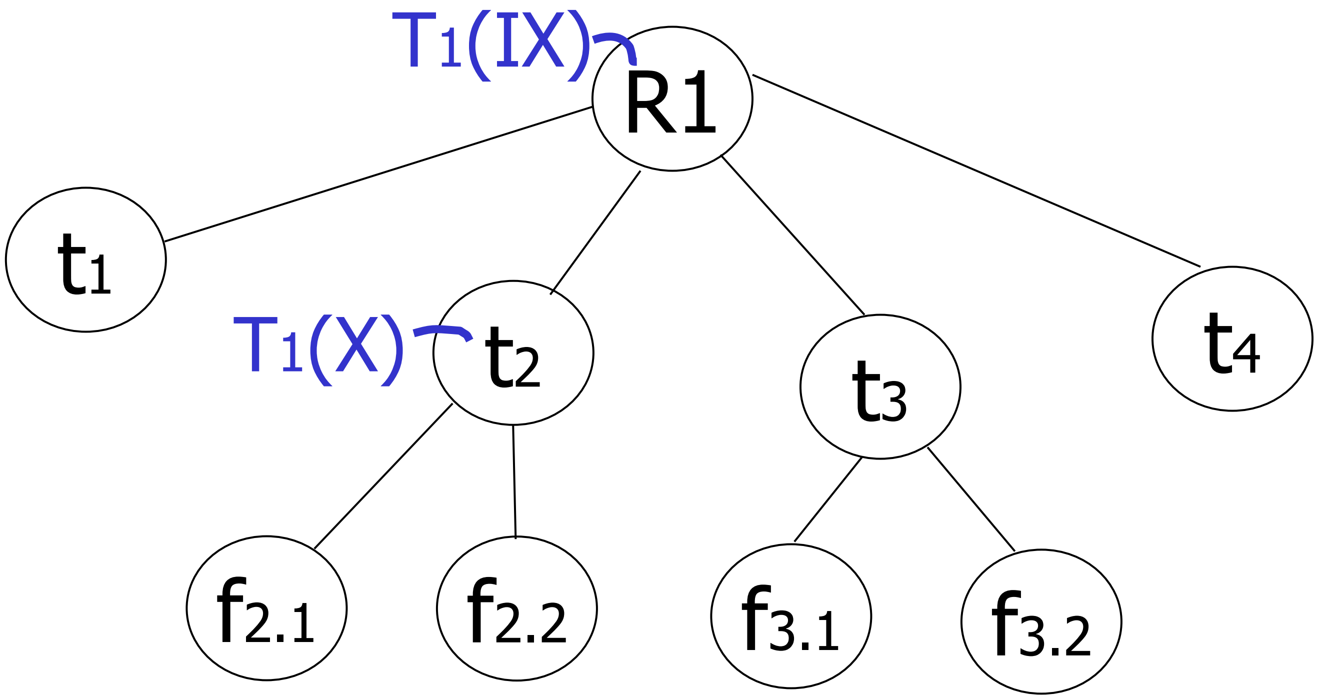
IX allows another IX
granted
finally, T2 holds 3 locks
T2(IX), T2(IX), T2(X)



# Exercise:

- Can $T_2$ access object $f_{2.2}$ in X mode? What locks will $T_2$ get?

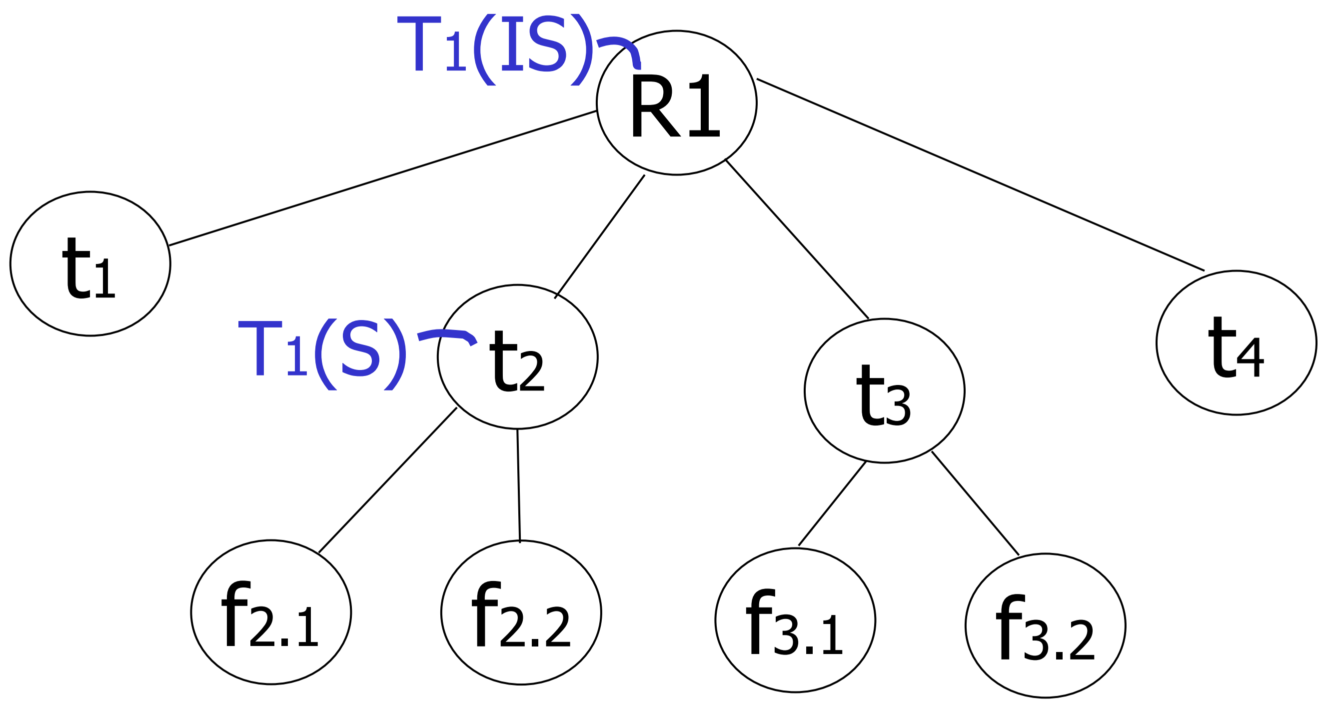
No



# Exercise:

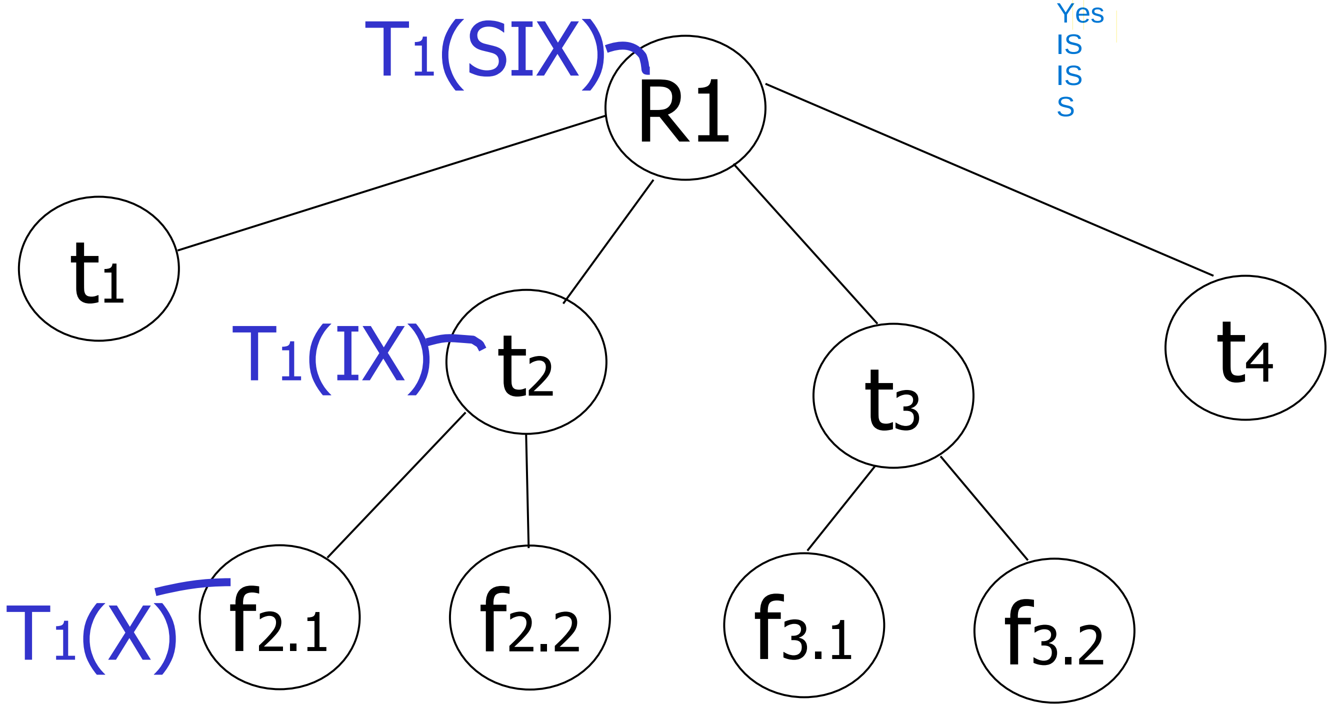
- Can $T_2$ access object $f_{3.1}$ in X mode? What locks will $T_2$ get?

Yes



# Exercise:

- Can $T_2$ access object $f_{2.2}$ in S mode? What locks will $T_2$ get?

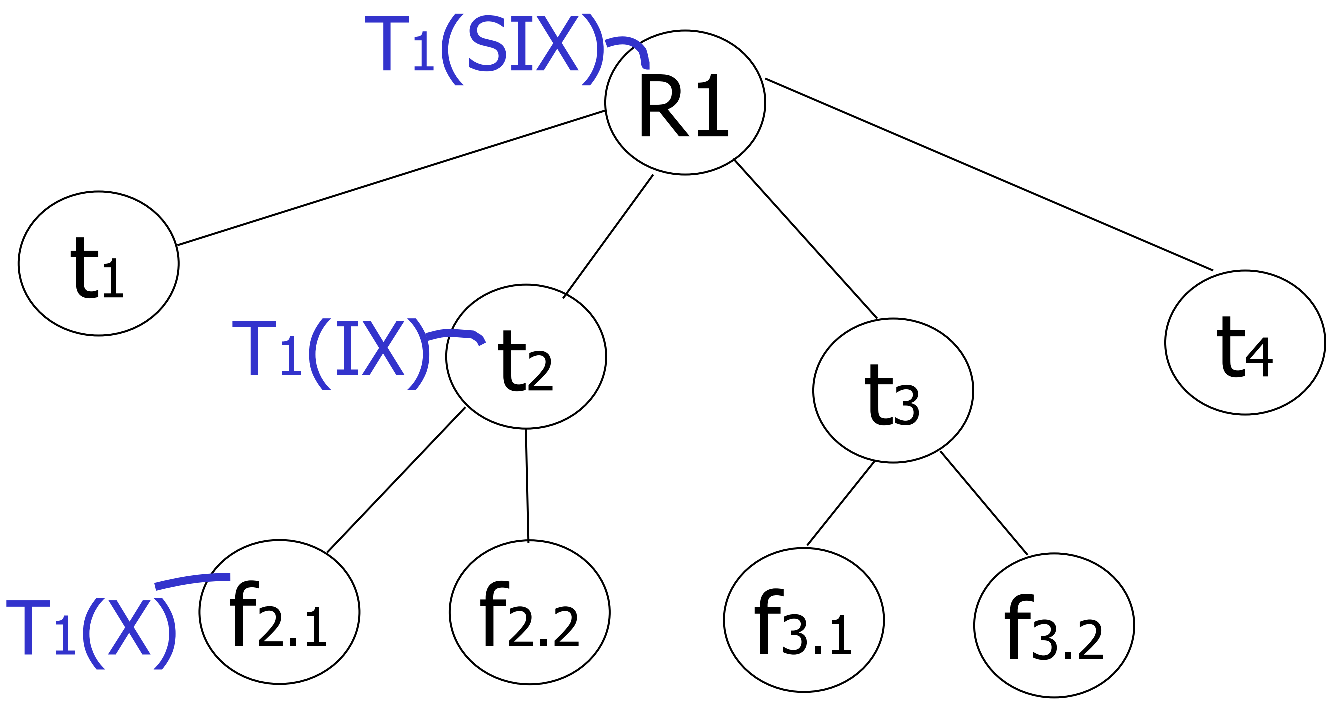



Yes
IS
IS
S

# Exercise:

- Can $T_2$ access object $f_{2.2}$ in X mode? What locks will $T_2$ get?

No



# Reading

Ch18 Concurrency Control

Héctor García-Molina, Jeffrey Ullman, and Jennifer Widom. Database Systems: The Complete Book.