Chapter 13: Concurrency Control

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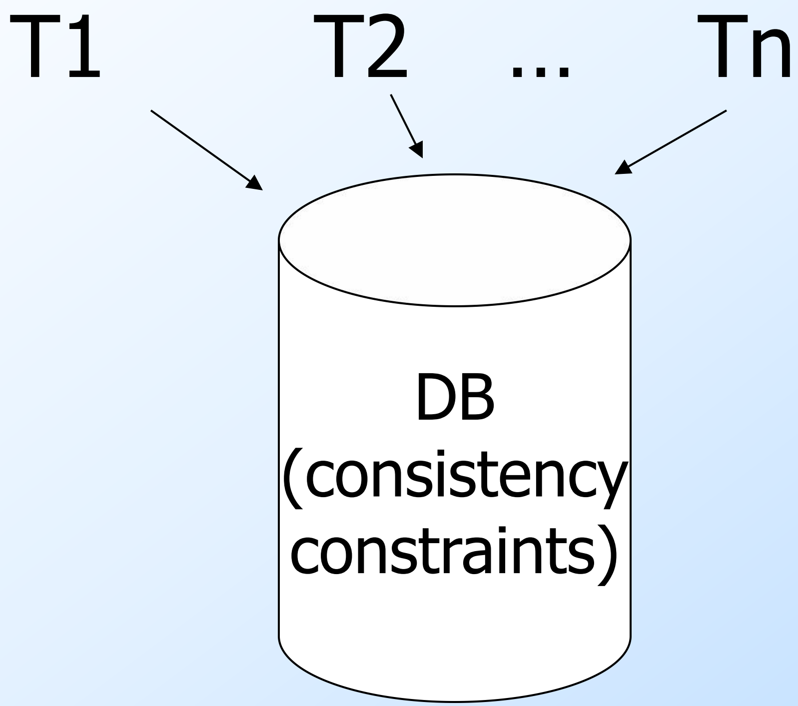
Concurrency Control



Example:

T1:	Read(A)	T2:	Read(A)
	$A \leftarrow A+100$		$A \leftarrow A \times 2$
	Write(A)		Write(A)
	Read(B)		Read(B)
	$B \leftarrow B+100$		$B \leftarrow B \times 2$
	Write(B)		Write(B)

Constraint: $A=B$

Schedule A

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

Schedule B

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

Schedule C

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

Schedule D

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

Same as Schedule D
but with new T2′

Schedule E

T1	T2′	A	B
		25	25
Read(A); A $\leftarrow$ A+100			
Write(A);		125	
	Read(A);A $\leftarrow$ A$\times$1;		
	Write(A);	125	
	Read(B);B $\leftarrow$ B$\times$1;		
	Write(B);		25
Read(B); B $\leftarrow$ 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:

$Sc = r_1(A)w_1(A)\underbrace{r_2(A)w_2(A)}\underbrace{r_1(B)w_1(B)}r_2(B)w_2(B)$

$Sc' = r_1(A)w_1(A)$
$\quad r_1(B)w_1(B)r_2(A)w_2(A)r_2(B)w_2(B)$

$\underbrace{\qquad\qquad\qquad\qquad}_{T_1}\underbrace{\qquad\qquad\qquad\qquad}_{T_2}$

However, for Sd:

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

- 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, $T_1 \rightarrow T_2$

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

⇨ Sd cannot be rearranged into a serial schedule

⇨ Sd is not "equivalent" to any serial schedule

⇨ Sd is "bad"

Returning to Sc

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

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

☛ 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

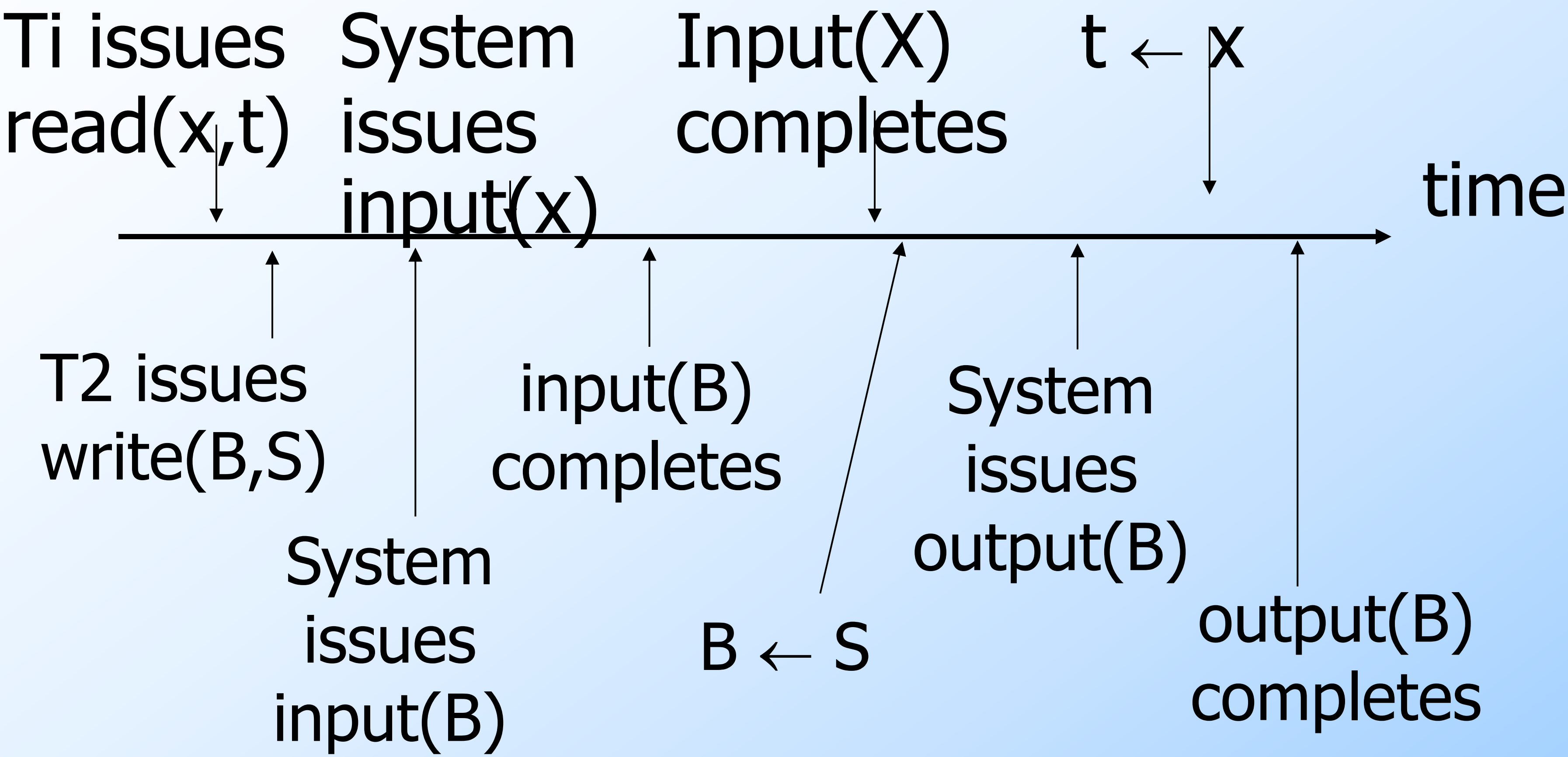
Conflicting actions:

$r_1(A)$	$w_2(A)$	$w_1(A)$
$w_2(A)$	$r_1(A)$	$w_2(A)$

Schedule: represents chronological order in which actions are executed

Serial schedule: no interleaving of actions or transactions

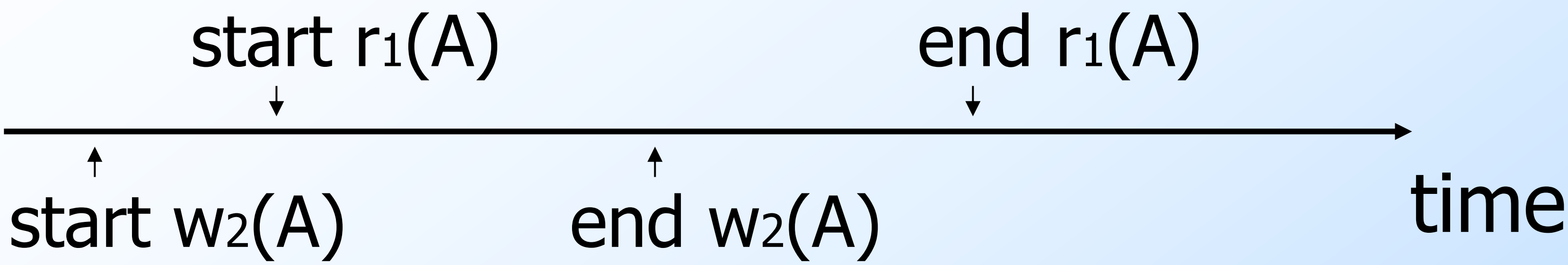
What about concurrent actions?



So net effect is either

- $S = \ldots r_1(x) \ldots w_2(b) \ldots$ or
- $S = \ldots w_2(B) \ldots r_1(x) \ldots$

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.

<u>Precedence graph</u> 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
  $S = w_1(A)\ r_2(A)\ \ r_3(A)\ w_4(A)$?

Lemma

S_1, S_2 conflict equivalent $\Rightarrow P(S_1)=P(S_2)$

Proof:

Assume $P(S_1) \neq P(S_2)$

$\Rightarrow \exists\ T_i: T_i \rightarrow T_j$ in S_1 and not in S_2

$$\left.\begin{array}{l} \Rightarrow S_1 = \ldots p_i(A) \ldots\ q_j(A) \ldots \\ \quad\ S_2 = \ldots q_j(A) \ldots p_i(A) \ldots \end{array}\right\} \begin{array}{l} p_i,\ q_j \\ \text{conflict} \end{array}$$

$\Rightarrow S_1, S_2$ not conflict equivalent

Note: $P(S_1)=P(S_2) \not\Rightarrow S_1, S_2$ conflict equivalent

<u>Counter example:</u>

$S_1=w_1(A)\ r_2(A) \quad w_2(B)\ r_1(B)$

$S_2=r_2(A)\ w_1(A) \quad r_1(B)\ w_2(B)$

Theorem

$P(S_1)$ acyclic $\Longleftrightarrow$ S_1 conflict serializable

($\Leftarrow$) Assume S_1 is conflict serializable

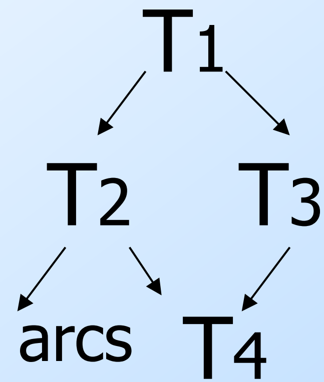
$\Rightarrow \exists\ S_s$: S_s, S_1 conflict equivalent

$\Rightarrow P(S_s) = P(S_1)$

$\Rightarrow P(S_1)$ acyclic since $P(S_s)$ is acyclic

Theorem

$P(S_1)$ acyclic $\Longleftrightarrow$ S_1 conflict serializable



($\Rightarrow$) Assume $P(S_1)$ is acyclic

Transform S_1 as follows:

(1) Take T_1 to be transaction with no incident arcs

(2) Move all T_1 actions to the front

$$S_1 = \ldots\ldots\; q_j(A) \ldots\ldots p_1(A) \ldots\ldots$$

(3) we now have S_1 = < T_1 actions ><... rest ...>

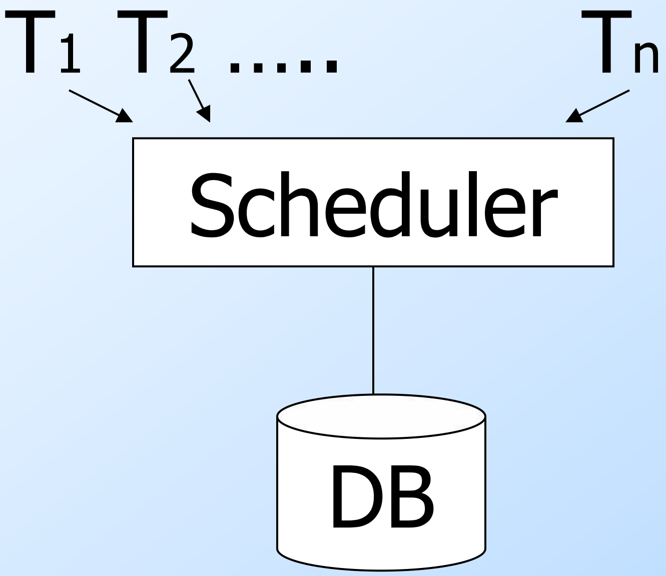
(4) repeat above steps to serialize rest!

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

How to enforce serializable schedules?

Option 2: prevent P(S) cycles from occurring

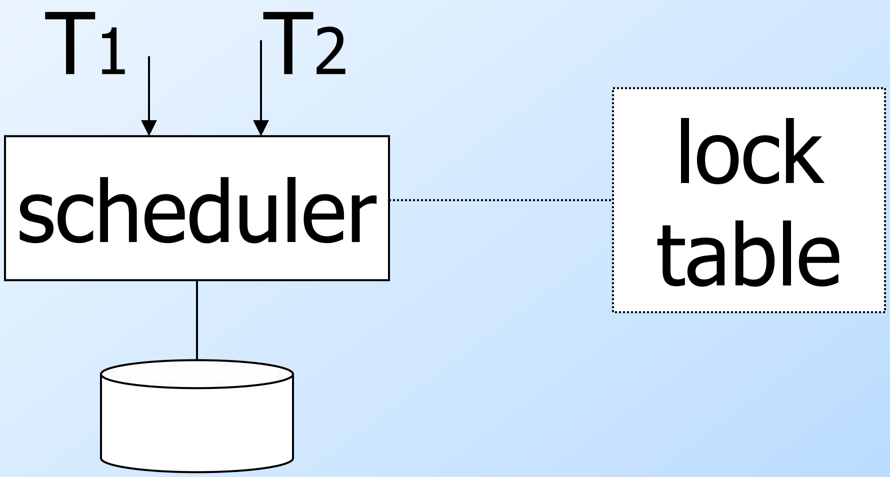


A locking protocol

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

$S = \ldots\ldots.. \; l_i(A) \; \ldots\ldots\ldots\ldots \; u_i(A) \; \ldots\ldots\ldots$

no $l_j(A)$

Exercise:

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

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

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

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

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

  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
$l_1(A)$;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);$u_1(B)$	

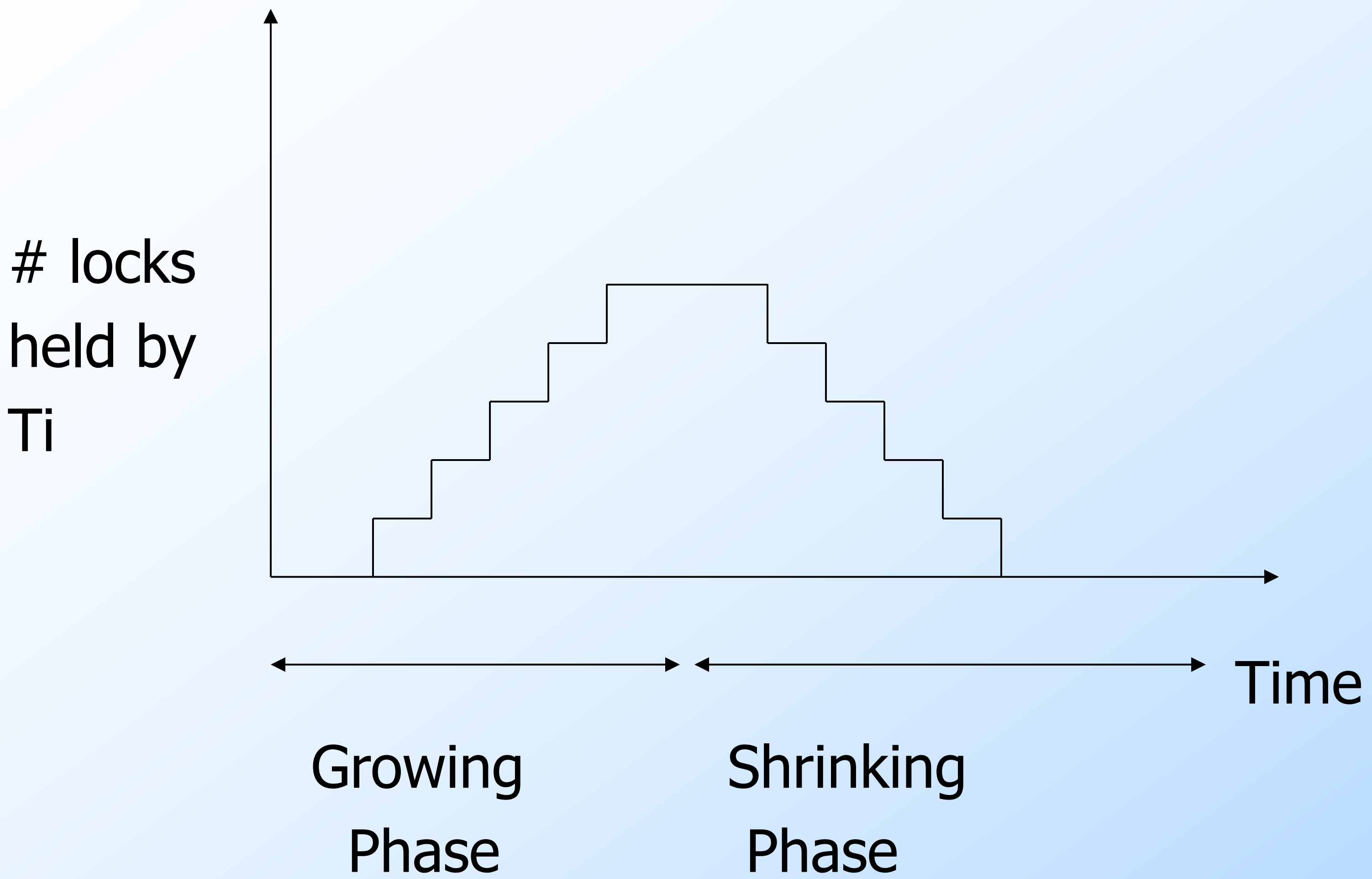
A	B

Rule #3 Two phase locking (2PL)

for transactions

T_i = ……. $l_i(A)$ ………… $u_i(A)$ ………

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)	
$A \leftarrow A+100$;Write(A)	
$l_1(B)$; $u_1(A)$	
	$l_2(A)$;Read(A)
	$A \leftarrow Ax2$;Write(A);$l_2(B)$ delayed
Read(B);$B \leftarrow B+100$	
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)
	$A \leftarrow Ax2$;Write(A);$l_2(B)$ delayed
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 (T2 reversed)

T1	T2
$l_1(A)$; Read(A)	$l_2(B)$;Read(B)
A ← A+100;Write(A)	B ← Bx2;Write(B)
$l_1(B)$	$l_2(A)$
delayed	delayed

- Assume deadlocked transactions are rolled back
  - They have no effect
  - They do not appear in schedule

E.g., Schedule H = $\underbrace{\qquad\qquad\qquad\qquad}_{\text{This space intentionally left blank!}}$

Next step:

Show that rules #1,2,3 $\Rightarrow$ conflict-serializable schedules

<u>Conflict rules for</u> $l_i(A)$, $u_i(A)$:

- $l_i(A)$, $l_j(A)$ conflict
- $l_i(A)$, $u_j(A)$ conflict

Note: no conflict $< u_i(A), u_j(A)>$, $< l_i(A), r_j(A)>$,...

Theorem Rules #1,2,3 $\Rightarrow$ conflict
(2PL) serializable
schedule

To help in proof:

Definition Shrink(Ti) = SH(Ti) =
first unlock action of Ti

Lemma

$Ti \rightarrow Tj$ in $S \Rightarrow SH(Ti) <_S SH(Tj)$

Proof of lemma:

$Ti \rightarrow Tj$ means that

$S = \ldots p_i(A) \ldots q_j(A) \ldots;$ p,q conflict

By rules 1,2:

$S = \ldots p_i(A) \ldots u_i(A) \ldots l_j(A) \ldots q_j(A) \ldots$

By rule 3: SH(Ti) SH(Tj)

So, $SH(Ti) <_S SH(Tj)$

Theorem Rules #1,2,3 $\Rightarrow$ conflict
(2PL) serializable
schedule

Proof:

(1) Assume P(S) has cycle

$$T_1 \rightarrow T_2 \rightarrow \ldots T_n \rightarrow T_1$$

(2) By lemma: $SH(T_1) < SH(T_2) < \ldots < SH(T_1)$

(3) Impossible, so P(S) acyclic

(4) $\Rightarrow$ S is conflict serializable

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

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:

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

Lock actions

$l\text{-}t_i(A)$: 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 =... l-S_1(A) … r_1(A) … u_1 (A) …

T_i =... l-X_1(A) … w_1(A) … u_1 (A) …

- What about transactions that read and write same object?

Option 1: Request exclusive lock

T_i = ...l-X_1(A) ... r_1(A) ... w_1(A) ... u(A) ...

Option 2: Upgrade

- What about transactions that read and write same object?

(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

Rule #2 Legal scheduler

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

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

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

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

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

A way to summarize Rule #2

Compatibility matrix

Comp

	S	X
S	true	false
X	false	false

Rule # 3 2PL transactions

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

Theorem Rules 1,2,3 $\Rightarrow$ Conf.serializable
for S/X locks schedules

Proof: similar to X locks case

Detail:

l-t_i(A), l-r_j(A) do not conflict if comp(t,r)

l-t_i(A), u-r_j(A) do not conflict if comp(t,r)

Lock types beyond S/X

Examples:

(1) increment lock

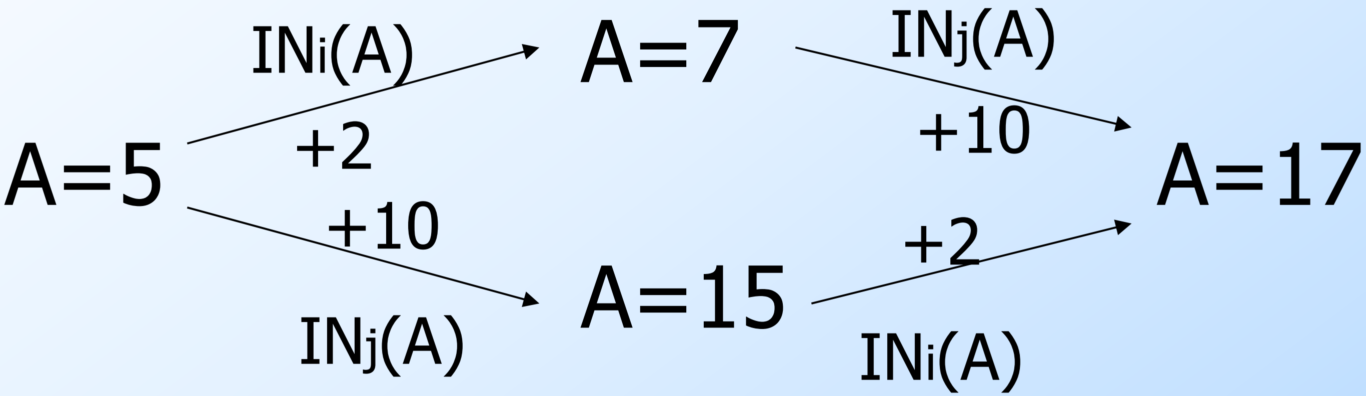
(2) update lock

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			

Comp

	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
$l\text{-}S_1(A)$	
	$l\text{-}S_2(A)$
$l\text{-}X_1(A)$	
	$l\text{-}X_2(A)$

--- 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			

Comp

New request

Lock already held in

	S	X	U
S	T	F	T
X	F	F	F
U	TorF	F	F

-> symmetric table?

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

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

- 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

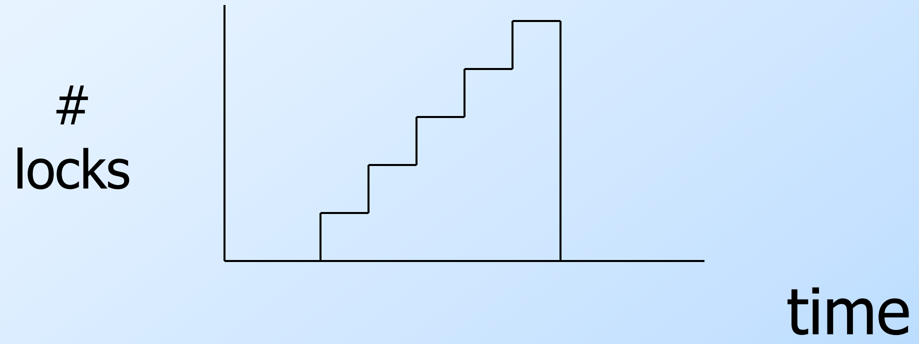
  (E.g., may not even provide
  CONFLICT-SERIALIZABLE schedules)

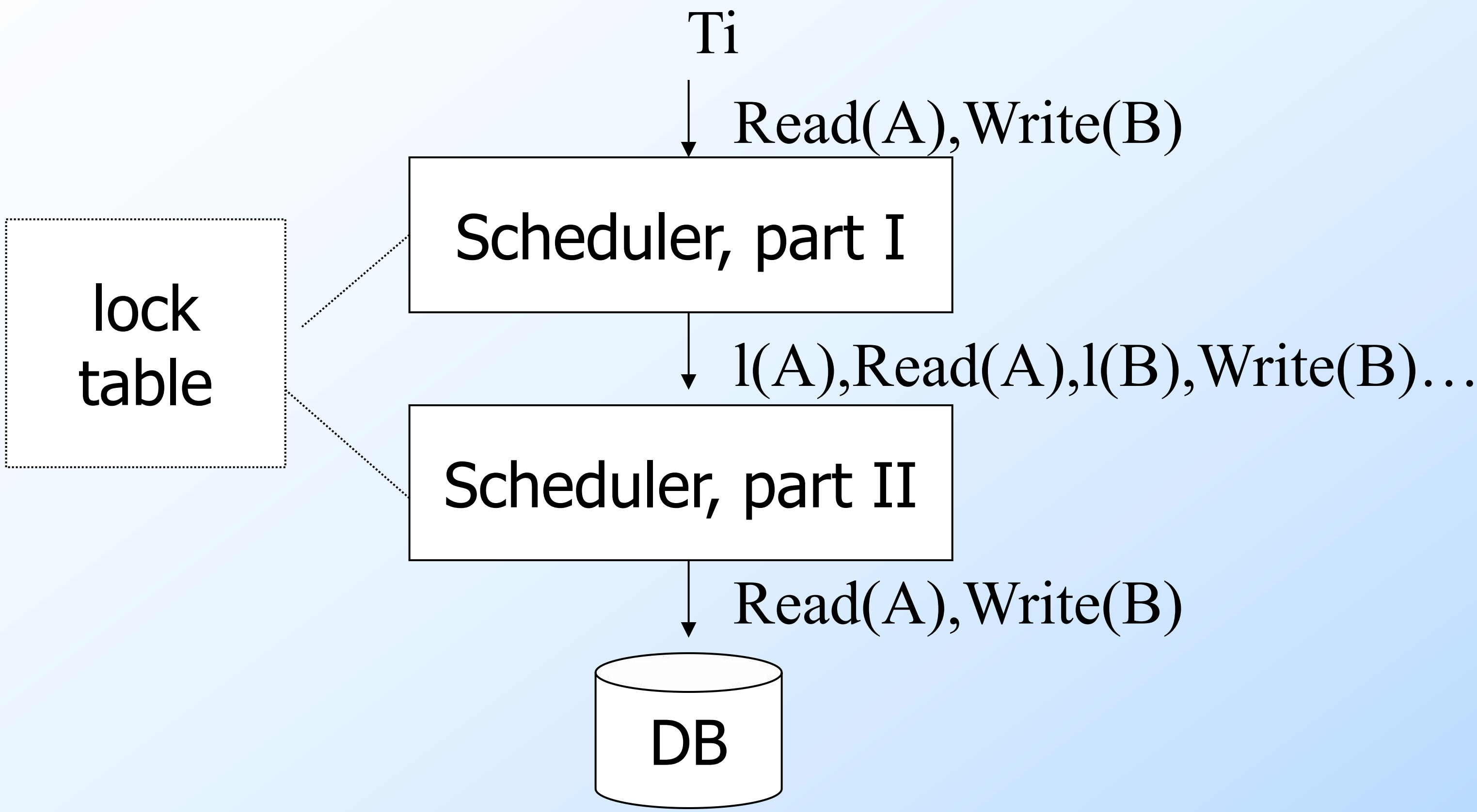
- But here is one (simplified) way ...

Sample Locking System:

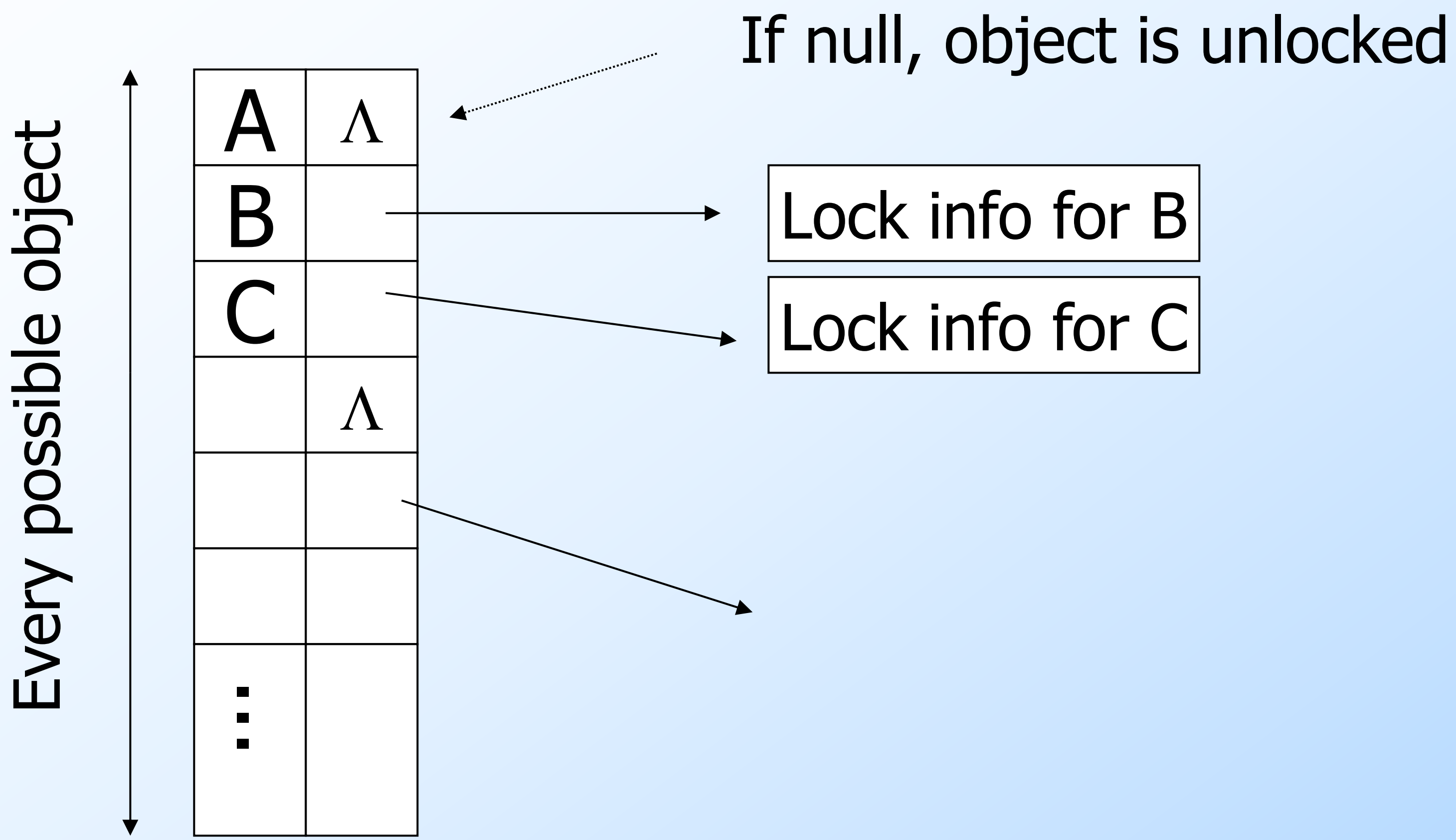
(1) Don't trust transactions to request/release locks

(2) Hold all locks until transaction commits

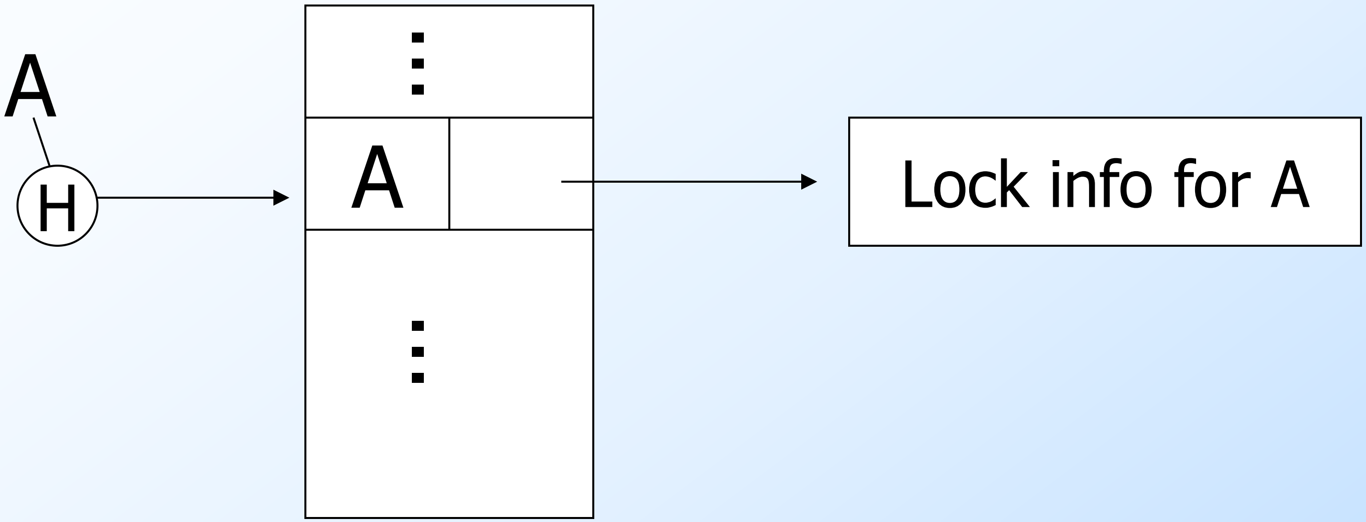



Ti
Read(A),Write(B)
Scheduler, part I
lock
table
l(A),Read(A),l(B),Write(B)…
Scheduler, part II
Read(A),Write(B)
DB

Lock table Conceptually

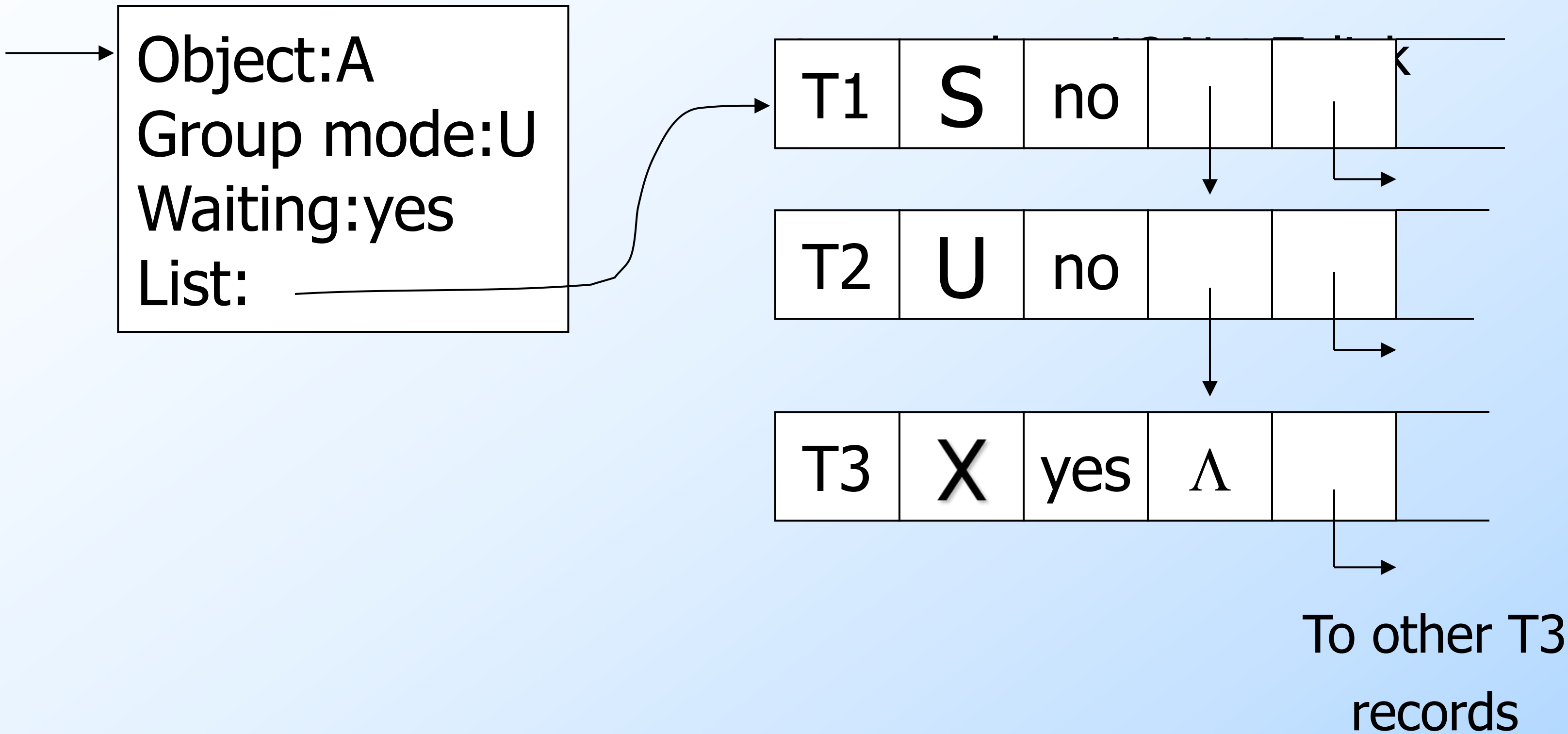


But use hash table:

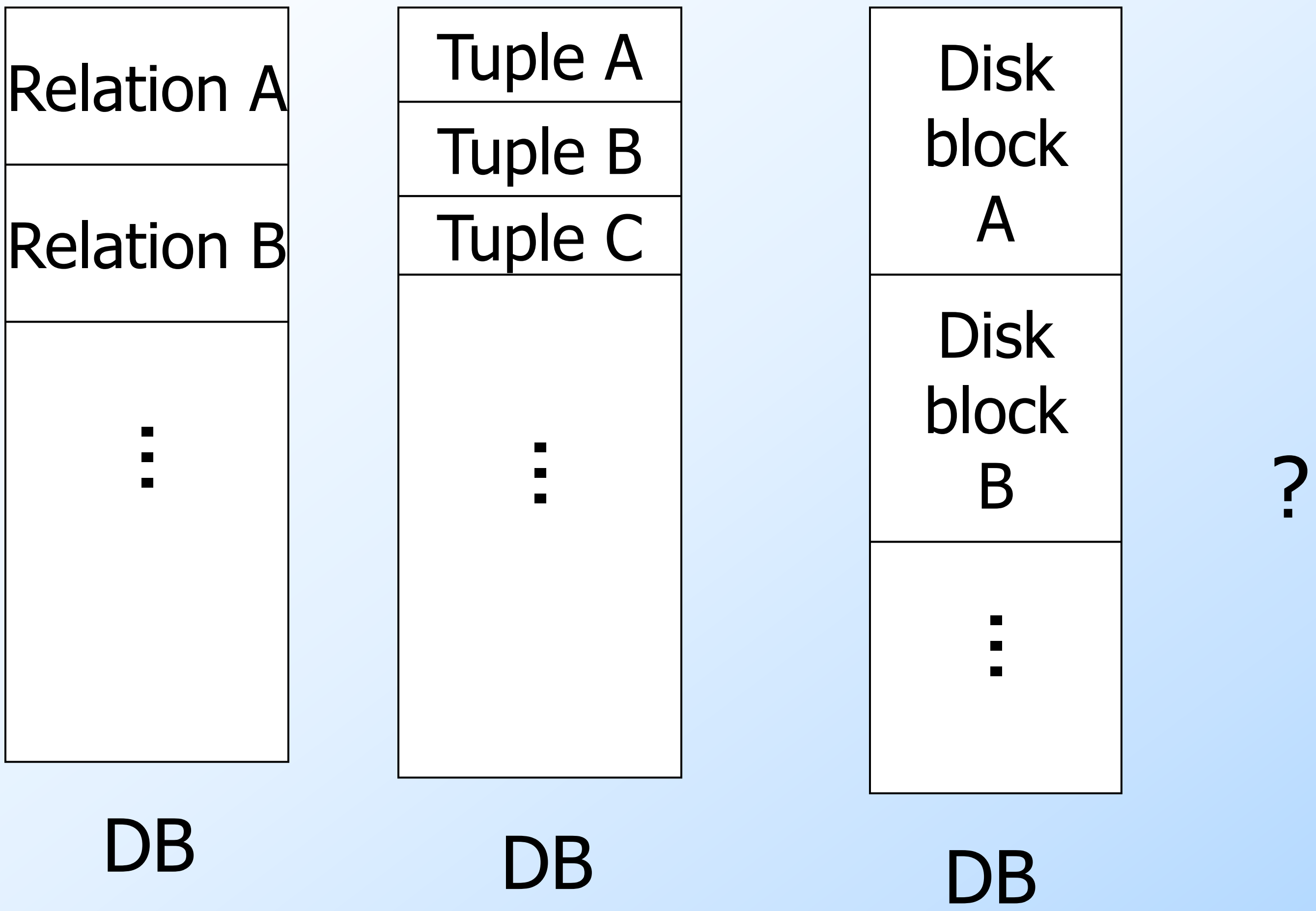


If object not found in hash table, it is unlocked

Lock info for A - example



What are the objects we lock?

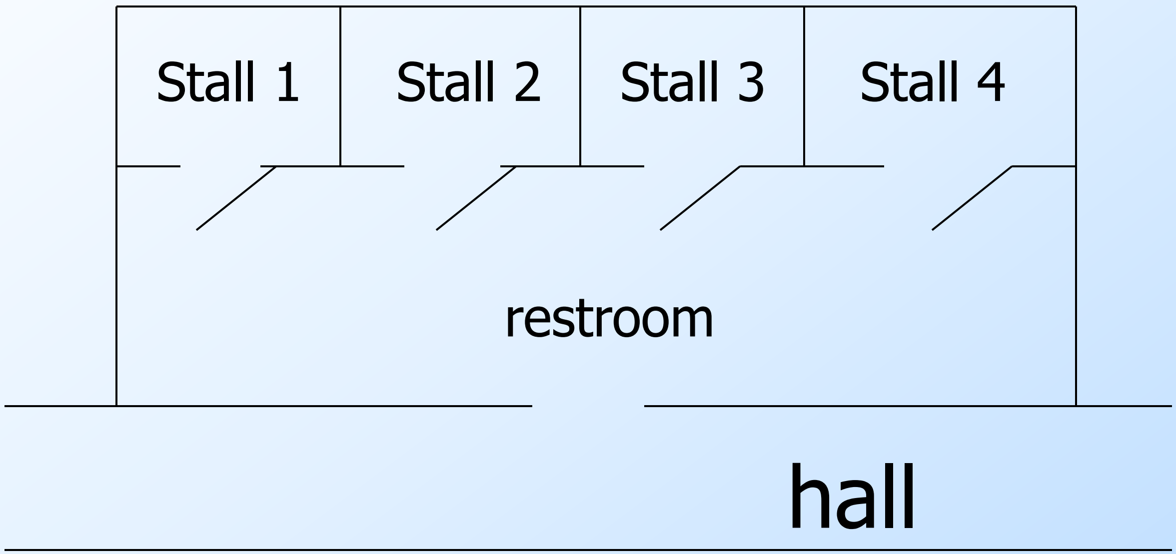


- Locking works in any case, but should we choose <u>small</u> or <u>large objects?</u>

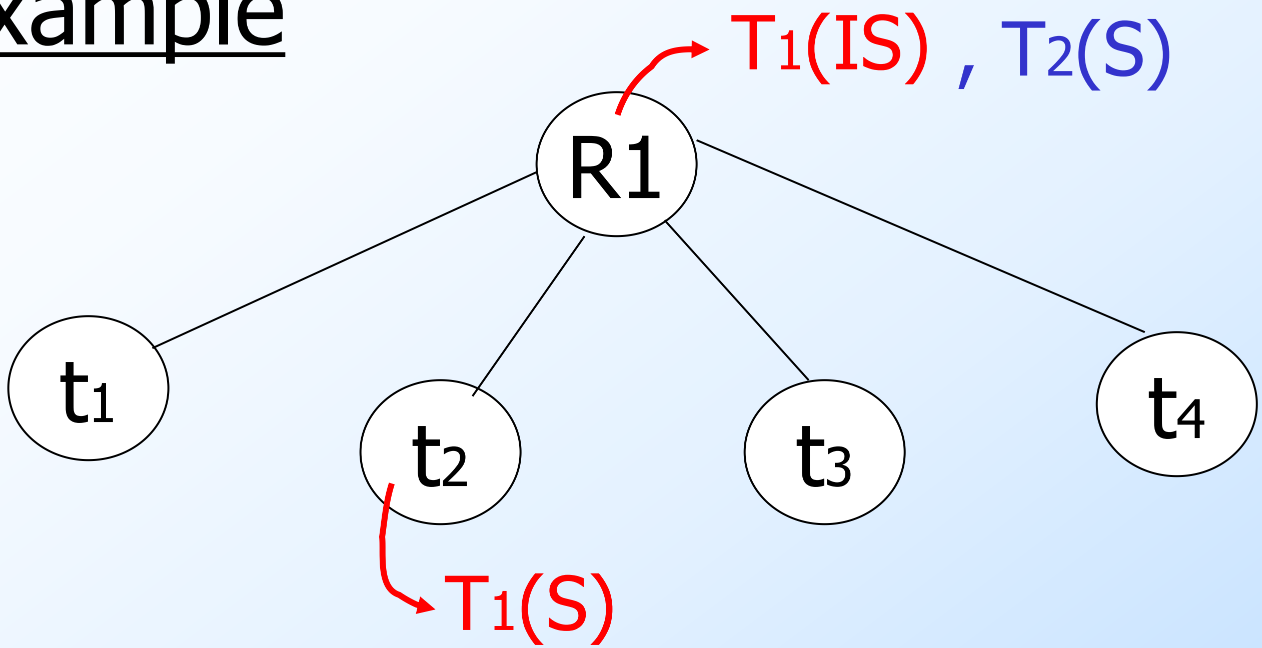
- If we lock <u>large</u> objects (e.g., Relations)
  - Need few locks
  - Low concurrency
- If we lock small objects (e.g., tuples,fields)
  - Need more locks
  - More concurrency

We <u>can</u> have it both ways!!

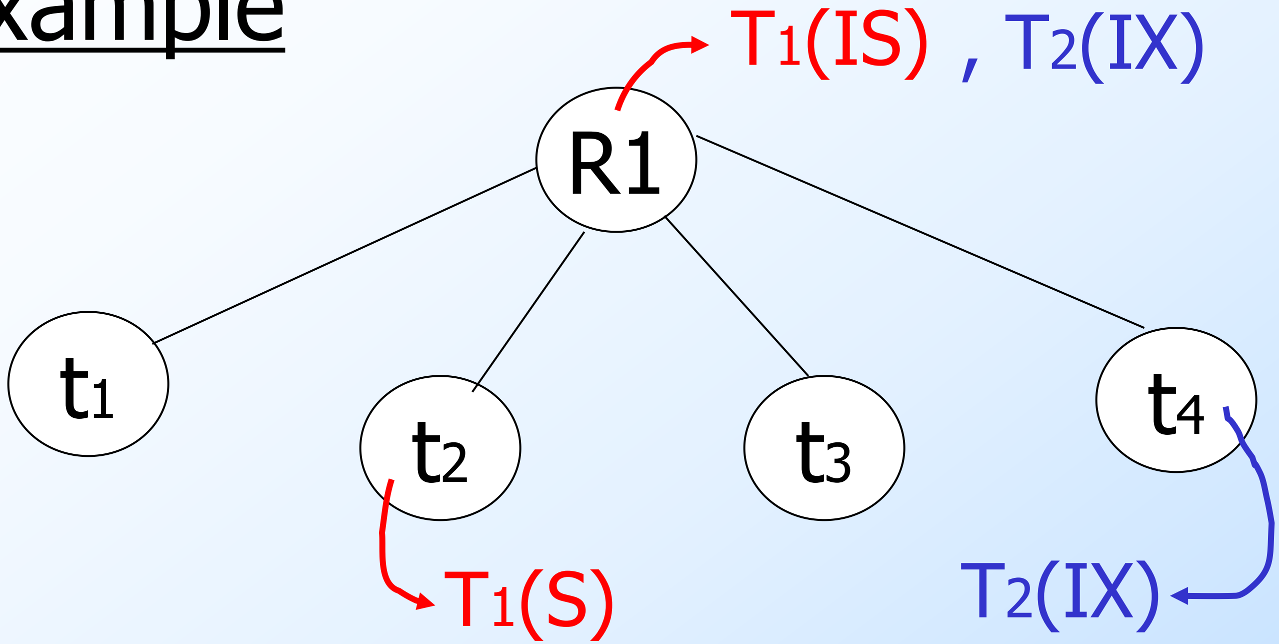
Ask any janitor to give you the solution...



Example



Example



Multiple granularity

Comp | Requestor

Holder

IS					
IX					
S					
SIX					
X					

Multiple granularity

Comp

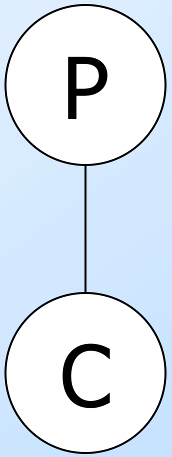
Requestor

Holder

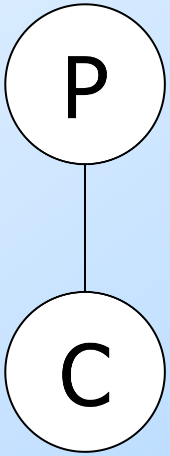
IS
IX
S
SIX
X

T	T	T	T	F
T	T	F	F	F
T	F	T	F	F
T	F	F	F	F
F	F	F	F	F

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	[S, IS] not necessary
SIX	X, IX, [SIX]
X	none

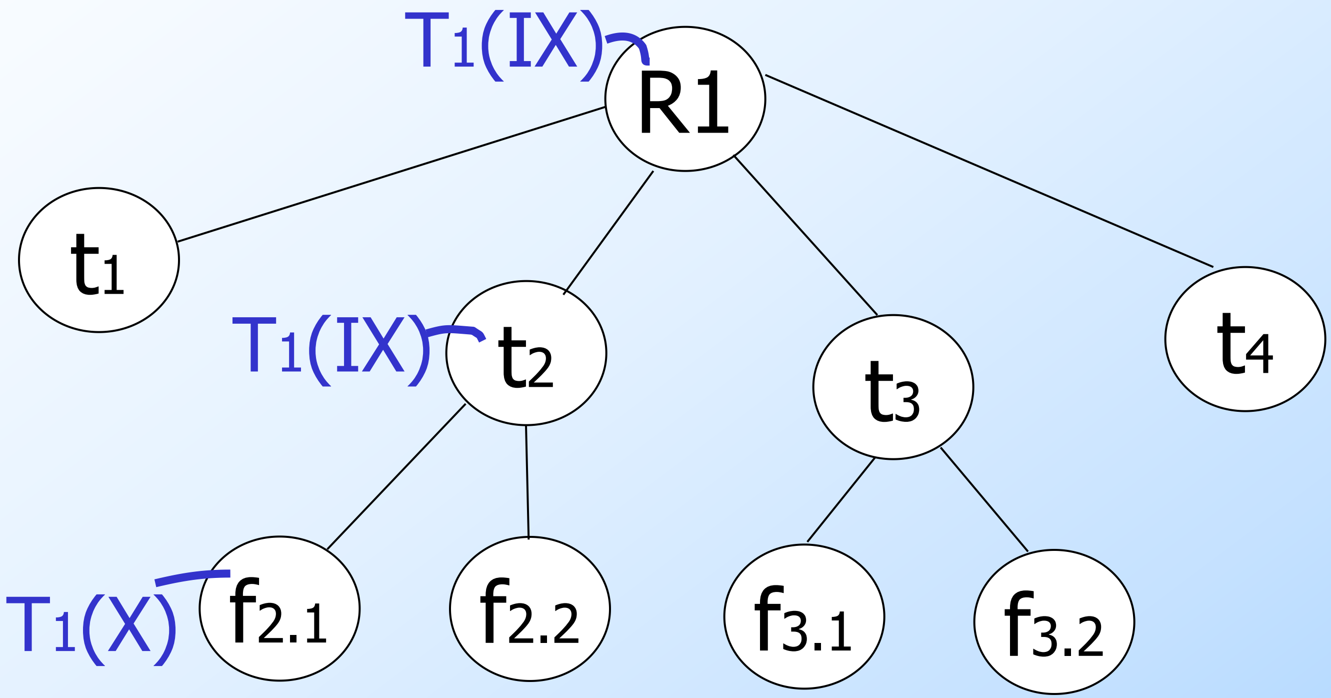


Rules

(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

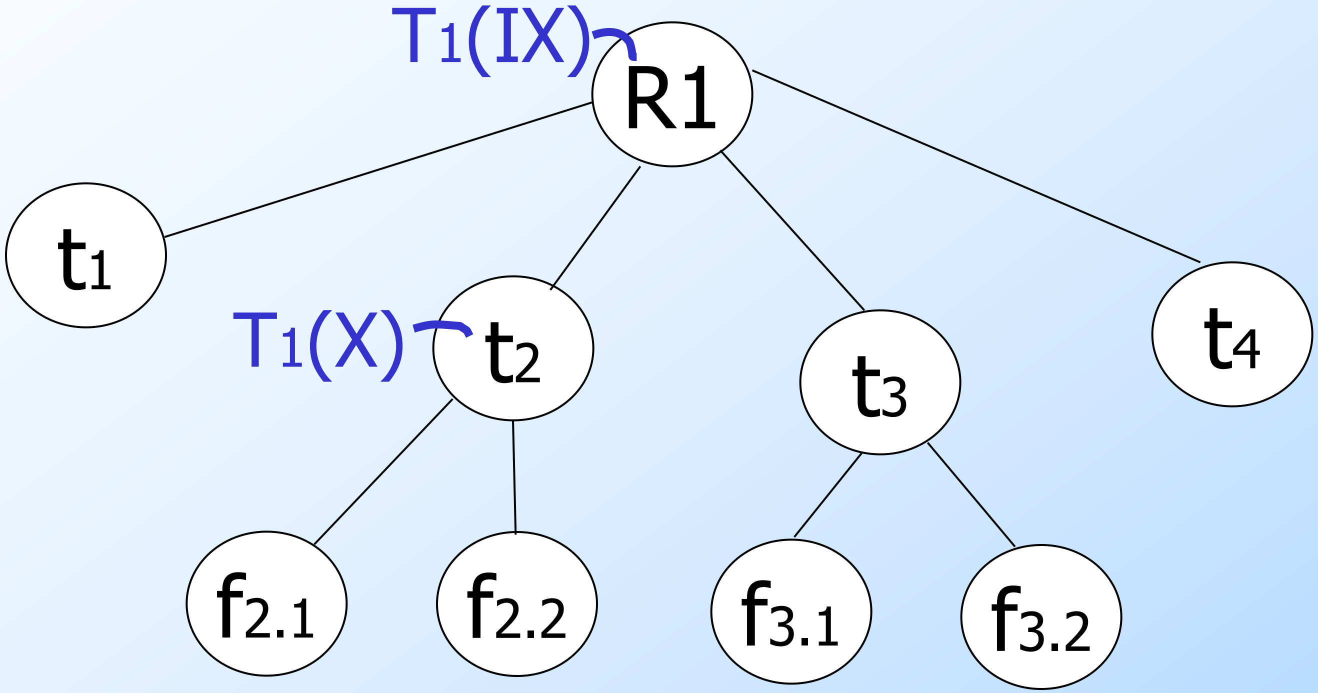
Exercise:

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



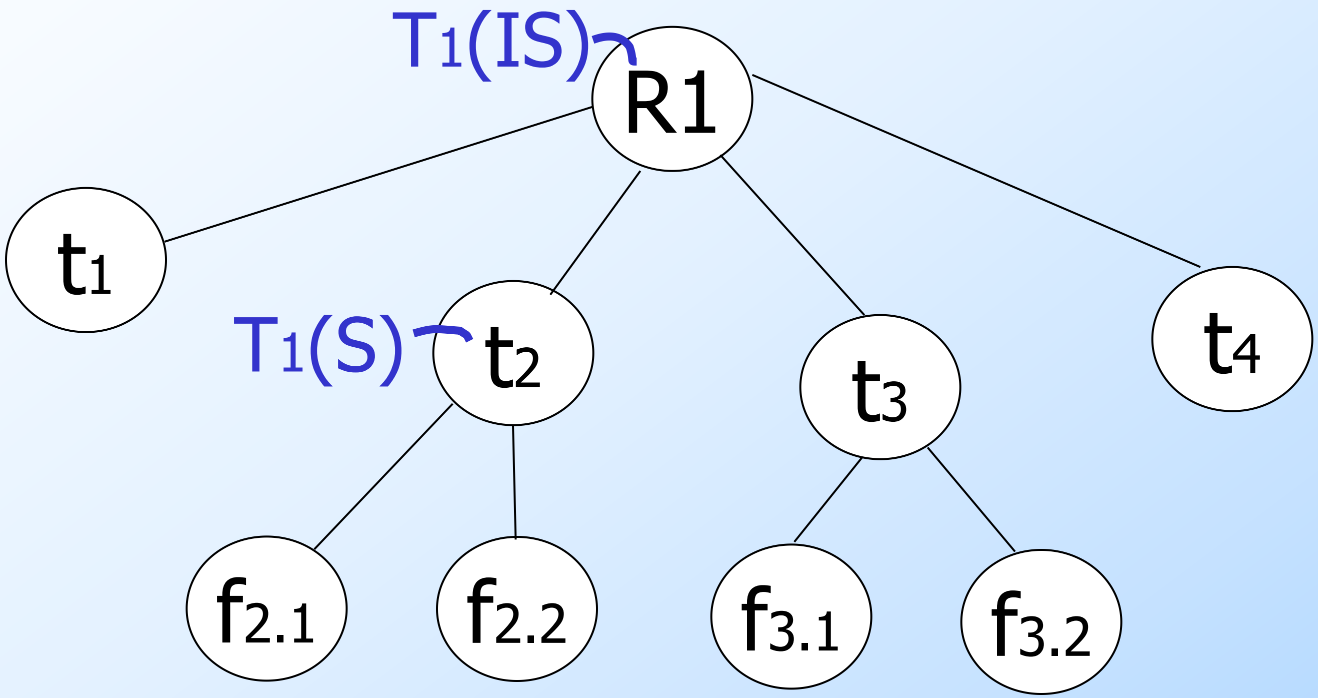
Exercise:

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



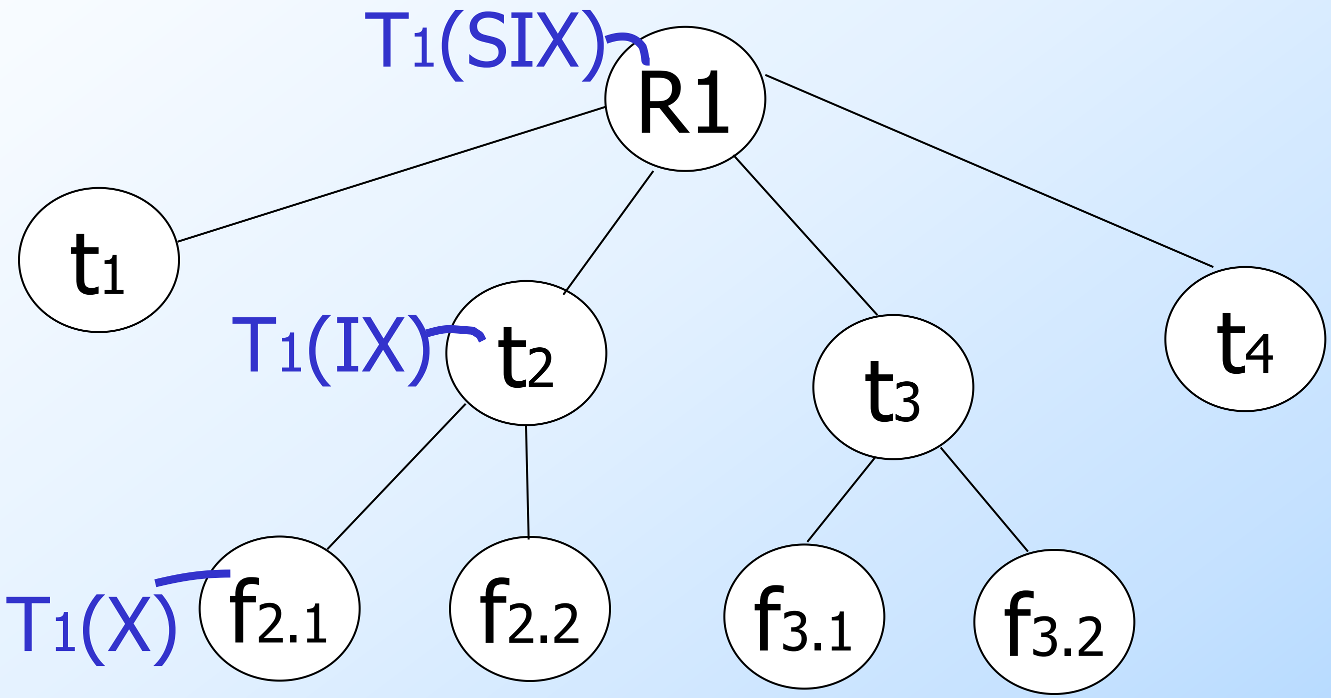
Exercise:

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



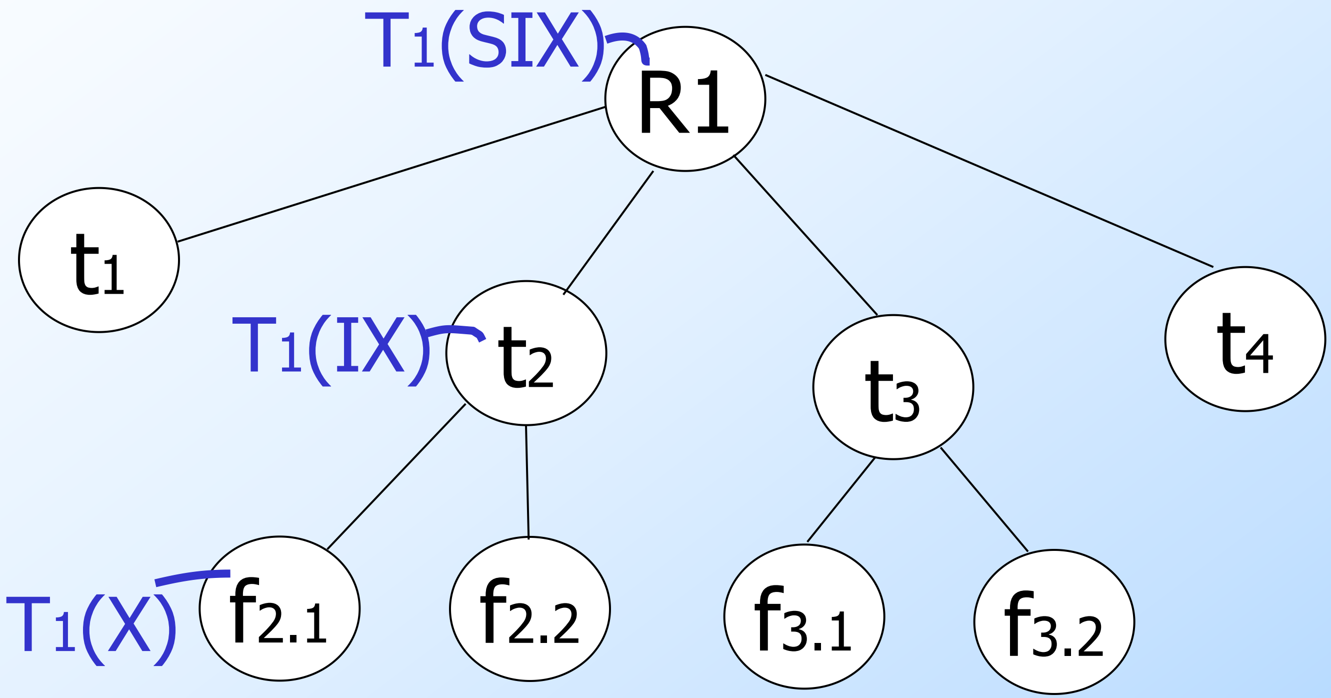
Exercise:

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

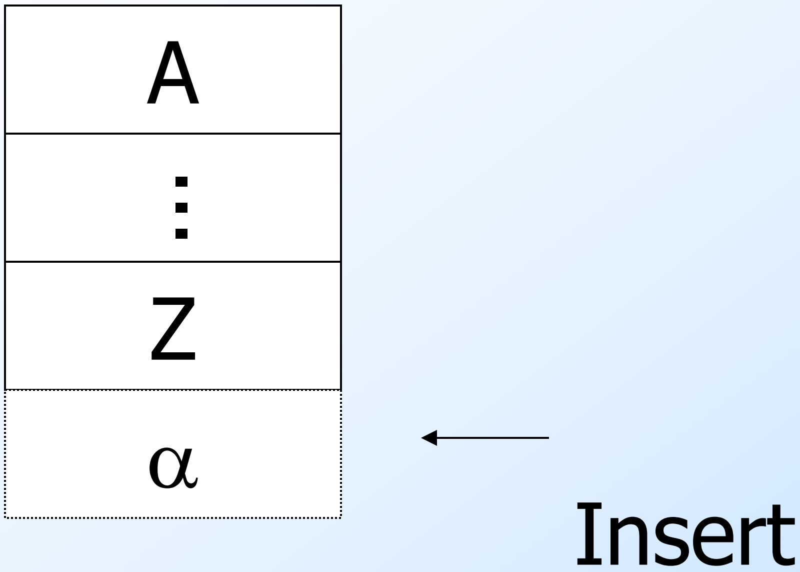


Exercise:

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



Insert + delete operations



Modifications to locking rules:

(1) Get exclusive lock on A before deleting A

(2) At insert A operation by Ti, Ti is given exclusive lock on A

Still have a problem: **Phantoms**

Example: relation R (E#,name,…)

constraint: E# is key

use tuple locking

R

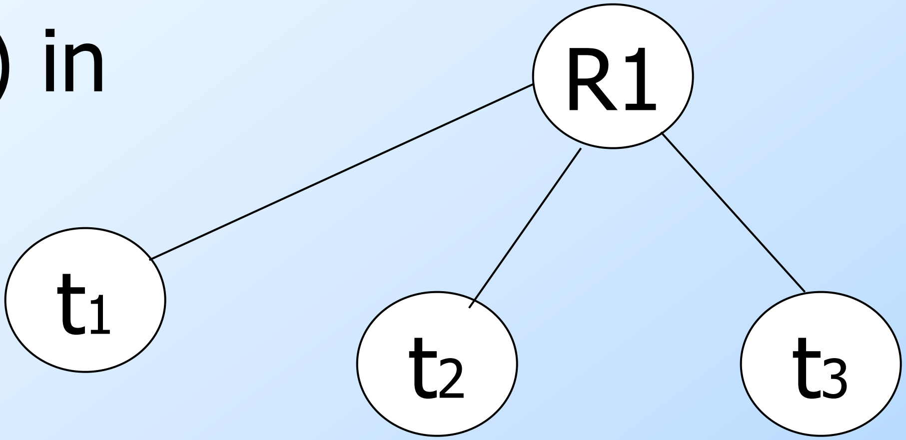
	E#	Name	….
o1	55	Smith	
o2	75	Jones	

T_1: Insert <04,Kerry,…> into R
T_2: Insert <04,Bush,…> into R

T_1	T_2
$S_1(o_1)$	$S_2(o_1)$
$S_1(o_2)$	$S_2(o_2)$
Check Constraint	Check Constraint
⋮	⋮
Insert o_3[04,Kerry,..]	
	Insert o_4[04,Bush,..]

Solution

- Use multiple granularity tree
- Before insert of node Q, lock parent(Q) in X mode

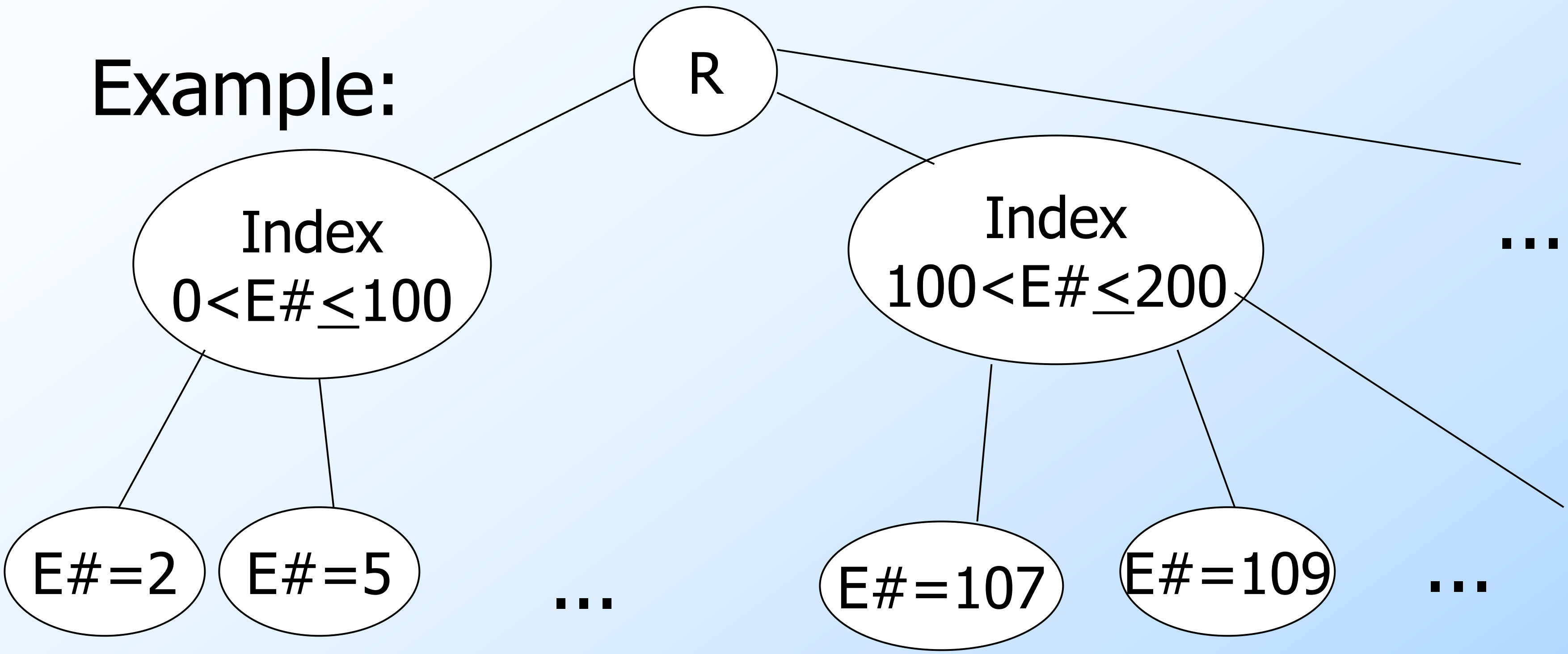


Back to example

T_1: Insert<04,Kerry>	T_2: Insert<04,Bush>
T_1	T_2
$X_1(R)$	
	$X_2(R)$ *delayed*
Check constraint	
Insert<04,Kerry>	
$U(R)$	
	$X_2(R)$
	Check constraint
	Oops! e# = 04 already in R!

Instead of using R, can use index on R:

Example:



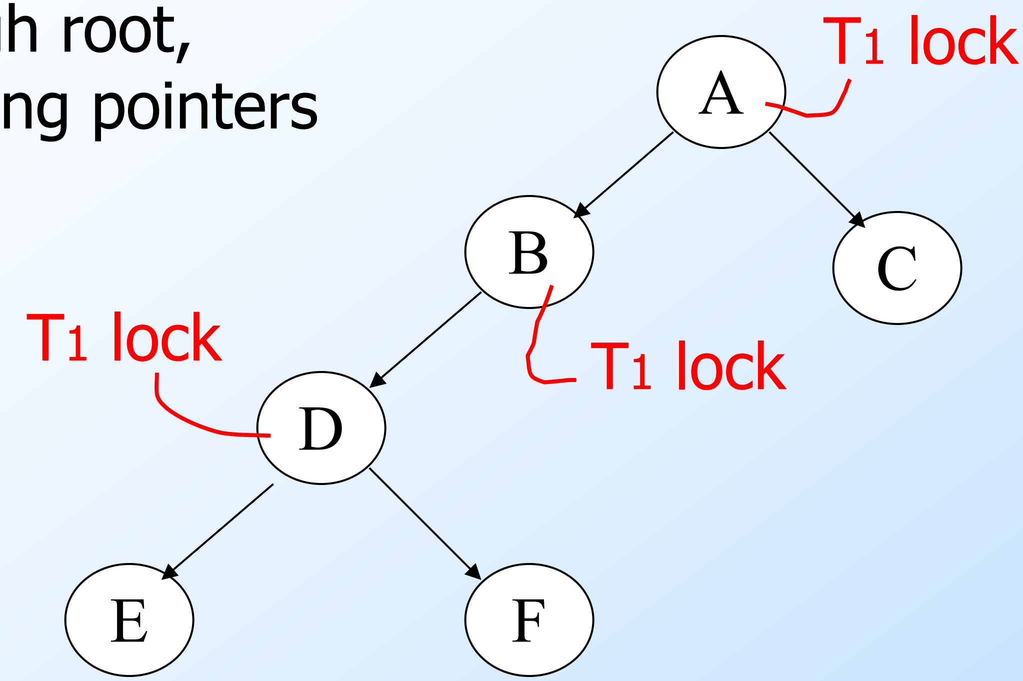
- This approach can be generalized to multiple indexes...

Next:

- Tree-based concurrency control
- Validation concurrency control

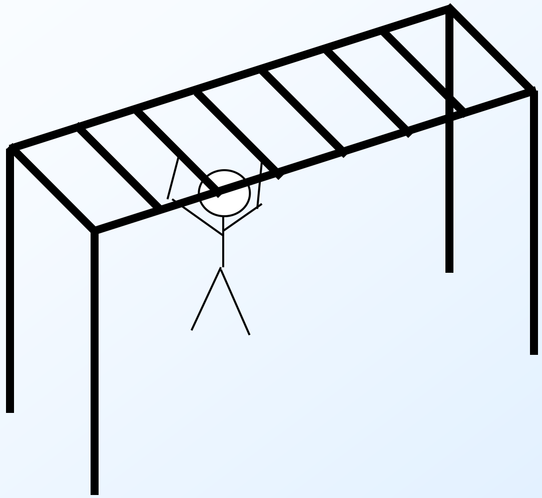
Example

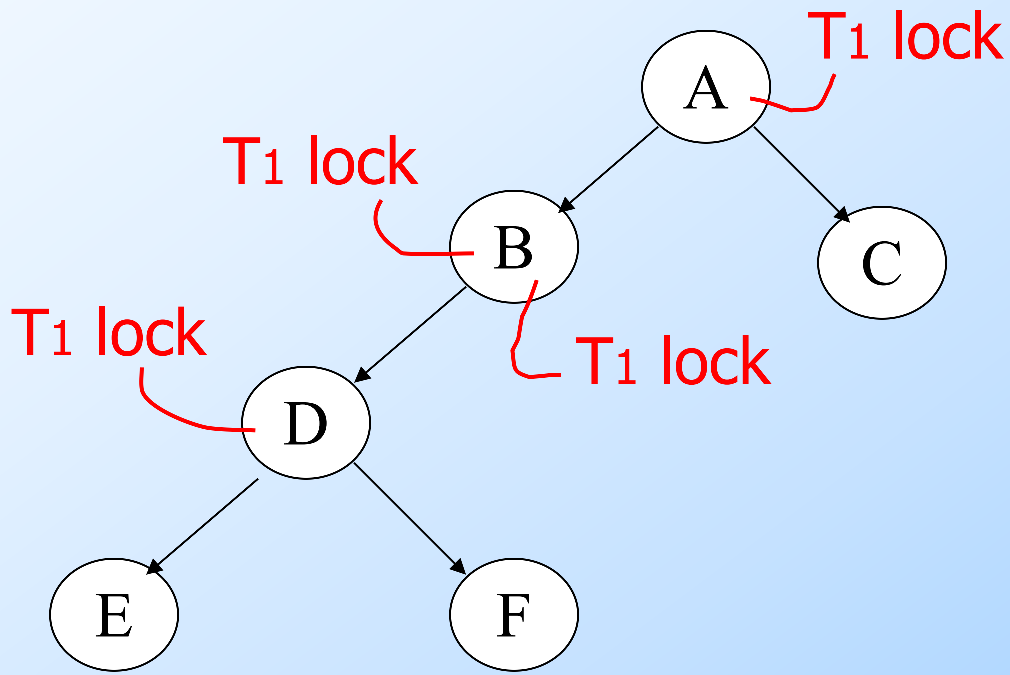
- all objects accessed through root, following pointers



☛ can we release A lock if we no longer need A??

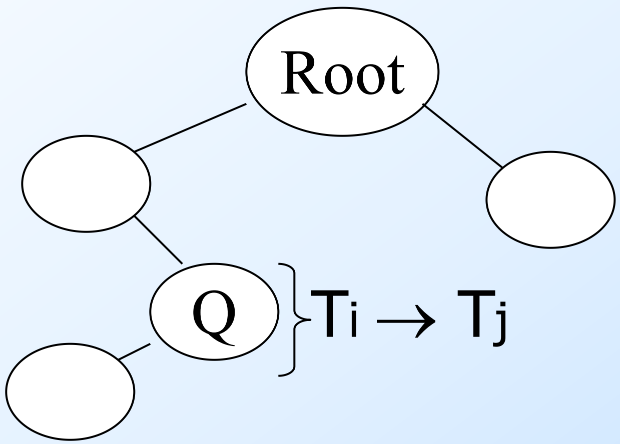
Idea: traverse like "Monkey Bars"





Why does this work?

- Assume all T_i start at root; exclusive lock
- $T_i \rightarrow T_j \Rightarrow T_i$ locks root before T_j



- Actually works if we don't always start at root

<u>Rules: tree protocol</u> (exclusive locks)

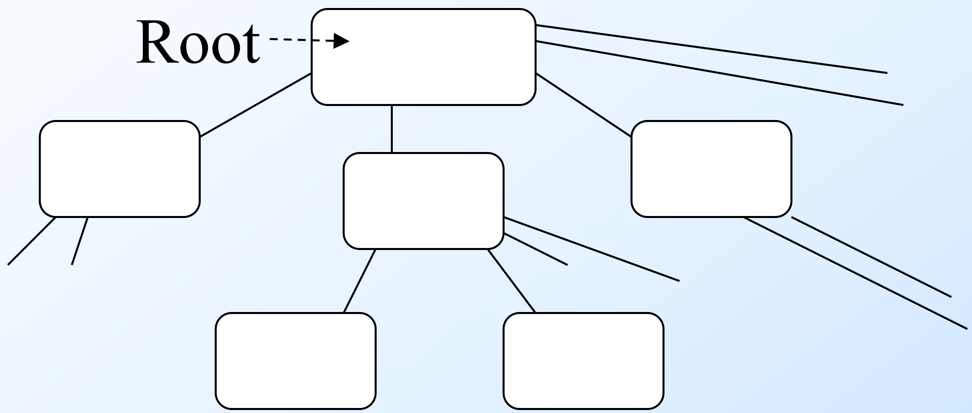
(1) First lock by T_i may be on any item

(2) After that, item Q can be locked by T_i only if parent(Q) locked by T_i

(3) Items may be unlocked at any time

(4) After T_i unlocks Q, it cannot relock Q

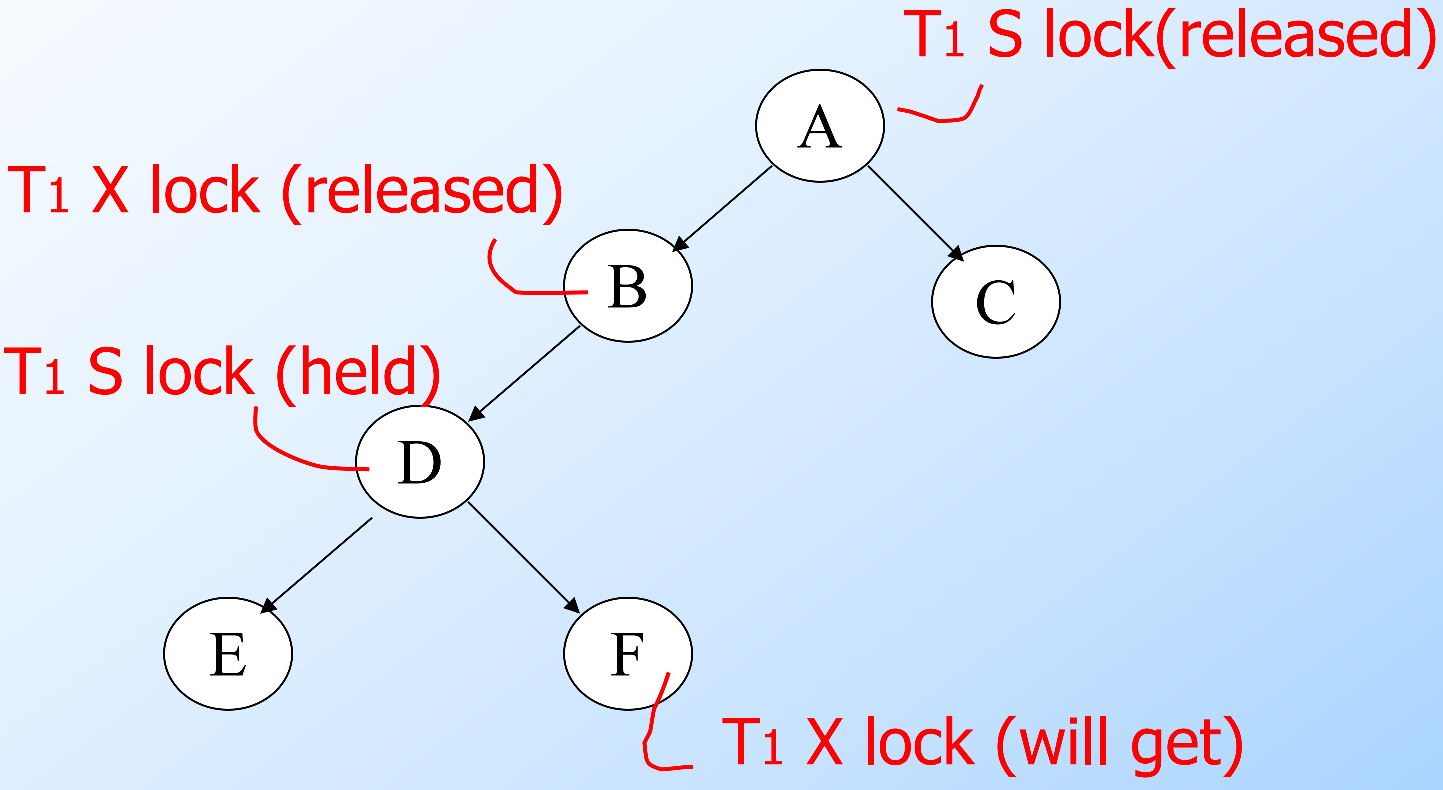
- Tree-like protocols are used typically for B-tree concurrency control



E.g., during insert, do not release parent lock, until you are certain child does not have to split

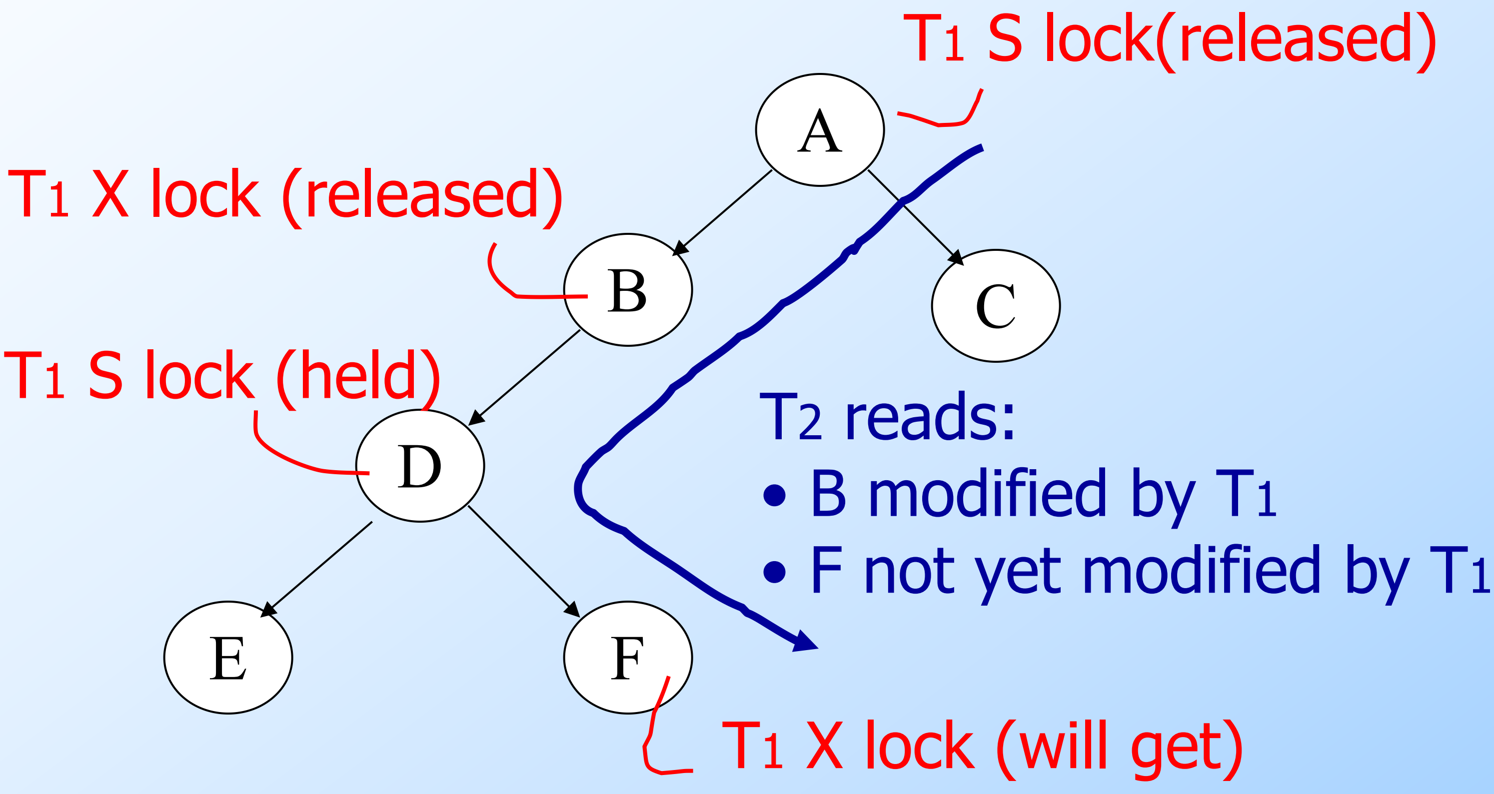
Tree Protocol with Shared Locks

- Rules for shared & exclusive locks?



Tree Protocol with Shared Locks

- Rules for shared & exclusive locks?



Tree Protocol with Shared Locks

- Need more restrictive protocol
- Will this work??
  - Once T_1 locks one object in X mode, all further locks down the tree must be in X mode

Validation

Transactions have 3 phases:

(1) Read

- all DB values read
- writes to temporary storage
- no locking

(2) Validate

- check if schedule so far is serializable

(3) Write

- if validate ok, write to DB

Key idea

- Make validation atomic
- If T_1, T_2, T_3, … is validation order, then resulting schedule will be conflict equivalent to $S_s = T_1 \, T_2 \, T_3 \ldots$

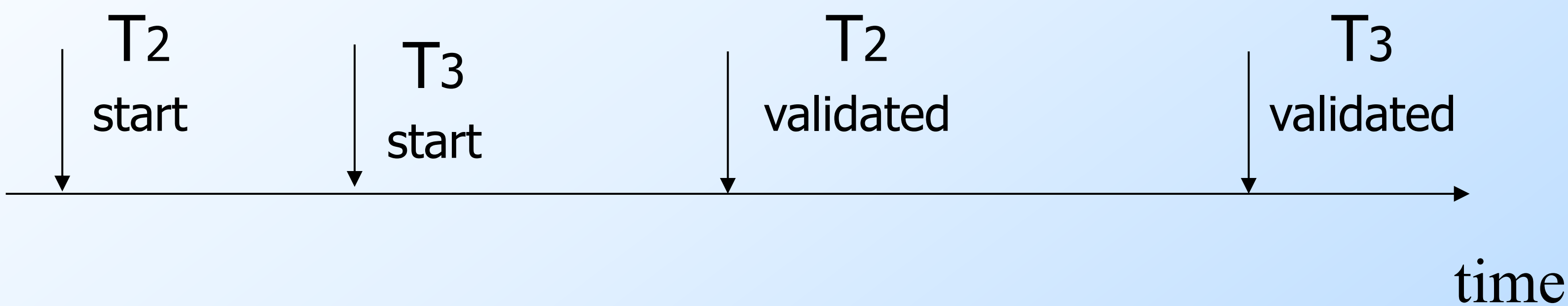
To implement validation, system keeps <u>two sets:</u>

- <u>FIN</u> = transactions that have finished phase 3 (and are all done)
- <u>VAL</u> = transactions that have successfully finished phase 2 (validation)

Example of what validation must prevent:

$RS(T_2)=\{B\}$ $\quad \cap \quad$ $RS(T_3)=\{A,B\} \neq \phi$

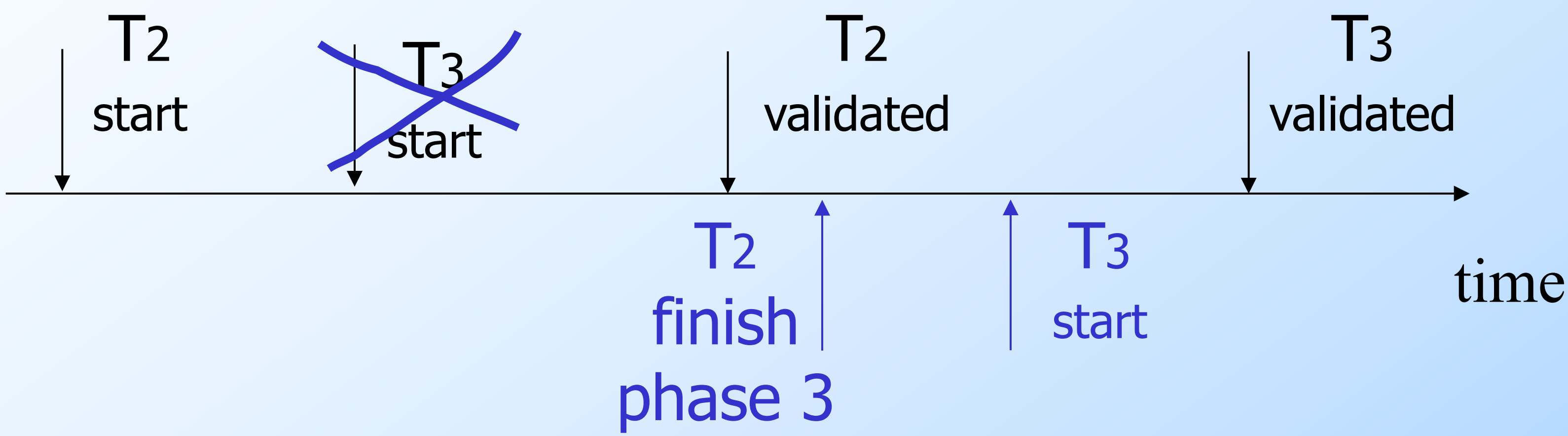
$WS(T_2)=\{B,D\}$ $\quad\quad$ $WS(T_3)=\{C\}$



Example of what validation must ~~prevent~~ allow:

$RS(T_2)=\{B\}$ $\qquad\cap\qquad$ $RS(T_3)=\{A,B\} \neq \phi$

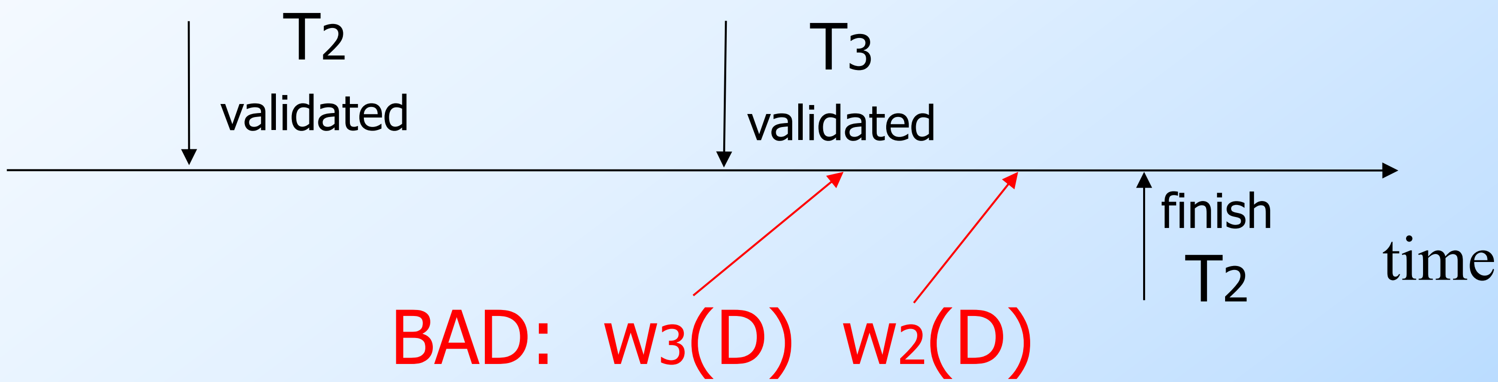
$WS(T_2)=\{B,D\}$ $\qquad\qquad$ $WS(T_3)=\{C\}$



Another thing validation must prevent:

$RS(T_2)=\{A\}$ $\quad$ $RS(T_3)=\{A,B\}$

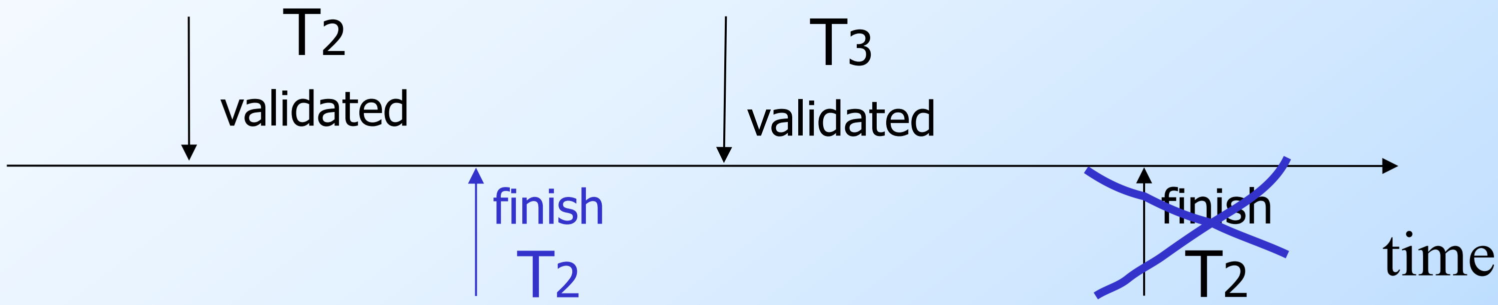
$WS(T_2)=\{D,E\}$ $\quad$ $WS(T_3)=\{C,D\}$



Another thing validation must ~~prevent:~~ allow

$RS(T_2)=\{A\}$ $RS(T_3)=\{A,B\}$

$WS(T_2)=\{D,E\}$ $WS(T_3)=\{C,D\}$



Validation rules for T_j:

(1) When T_j starts phase 1:

    ignore(T_j) $\leftarrow$ FIN

(2) at T_j Validation:

    if check (T_j) then

        [VAL $\leftarrow$ VAL U {T_j};

        do write phase;

        FIN $\leftarrow$ FIN U {T_j}]

Check (T_j):

For $T_i \in$ VAL - IGNORE (T_j) DO

IF [WS(T_i) $\cap$ RS(T_j) $\neq \emptyset$ OR

$T_i \notin$ FIN] THEN RETURN false;

RETURN true;

Is this check too restrictive ?

Improving Check(T_j)

For $T_i \in$ VAL - IGNORE (T_j) DO

IF [WS(T_i) $\cap$ RS(T_j) $\neq \emptyset$ OR

($T_i \notin$ FIN AND WS(T_i) $\cap$ WS(T_j) $\neq \emptyset$)]

THEN RETURN false;

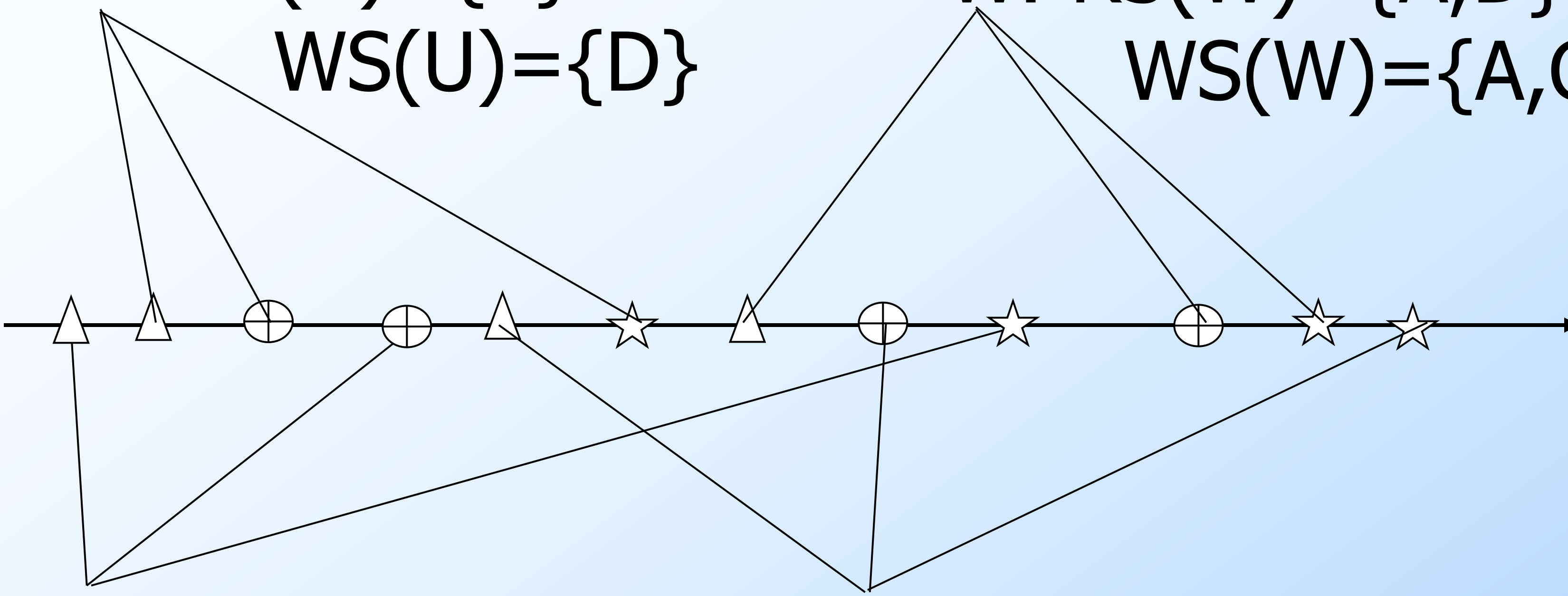
RETURN true;

Exercise:

start
validate
finish

U: RS(U)={B}
WS(U)={D}

W: RS(W)={A,D}
WS(W)={A,C}



T: RS(T)={A,B}
WS(T)={A,C}

V: RS(V)={B}
WS(V)={D,E}

Validation (also called optimistic concurrency control) is useful in some cases:

- Conflicts rare
- System resources plentiful
- Have real time constraints

Summary

Have studied C.C. mechanisms used in practice

- 2 PL
- Multiple granularity
- Tree (index) protocols
- Validation