CS 245: Database System Principles

Notes 09: Concurrency Control

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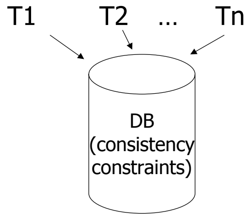
Chapter 9 Concurrency Control



Example:

T1: Read(A)
A ← A+100
Write(A)
Read(B)
B ← B+100
Write(B)

T2: Read(A)
A ← A×2
Write(A)
Read(B)
B ← B×2
Write(B)

Constraint: A=B

Schedule A

T1	T2	A	B
		25	25
Read(A); A ← A+100			
Write(A);		125	
Read(B); B ← B+100;			
Write(B);			125
	Read(A);A ← A×2;		
	Write(A);	250	
	Read(B);B ← B×2;		
	Write(B);		250
		250	250

Schedule B

T1	T2	A	B
		25	25
	Read(A);A ← A×2;		
	Write(A);	50	
	Read(B);B ← B×2;		
	Write(B);		50
Read(A); A ← A+100			
Write(A);		150	
Read(B); B ← B+100;			
Write(B);			150
		150	150

Schedule C

T1	T2	A	B
		25	25
Read(A); A ← A+100			
Write(A);		125	
	Read(A);A ← A×2;		
	Write(A);	250	
Read(B); B ← B+100;			
Write(B);			125
	Read(B);B ← B×2;		
	Write(B);		250
		250	250

Schedule D

T1	T2	A	B
		25	25
Read(A); A ← A+100			
Write(A);		125	
	Read(A);A ← A×2;		
	Write(A);	250	
	Read(B);B ← B×2;		
	Write(B);		50
Read(B); B ← B+100;			
Write(B);			150
		250	150

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

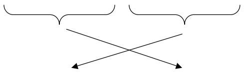
- Want schedules that are "good", regardless of
  - initial state and
  - transaction semantics
- Only look at order of read and writes

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:

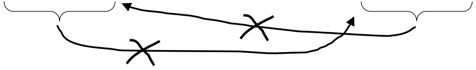
$Sc=r_1(A)w_1(A)\underbrace{r_2(A)w_2(A)}\underbrace{r_1(B)w_1(B)}r_2(B)w_2(B)$



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

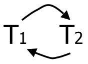
However, for Sd:

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



- 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, $T_1 \rightarrow T_2$



⇨ Sd cannot be rearranged into a serial schedule

⇨ Sd is not "equivalent" to any serial schedule

⇨ Sd is "bad"

Returning to Sc

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

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

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

Concepts

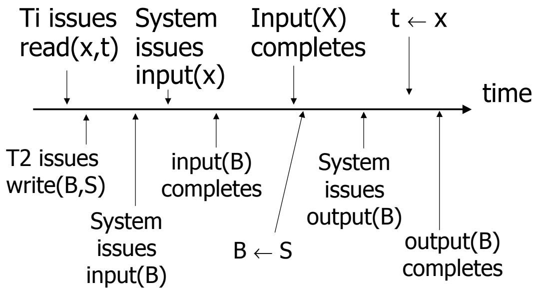
Transaction: sequence of $r_i(x)$, $w_i(x)$ actions

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

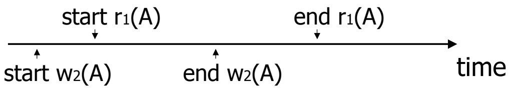
What about concurrent actions?



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 $w_2(A)\ r_1(A)$
- ⇒ 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 → 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

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

$\Rightarrow S_1, S_2$ not conflict equivalent

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

Counter example:

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

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

Theorem

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

($\Leftarrow$) Assume S_1 is conflict serializable

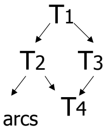
$\Rightarrow \exists\, S_s$: S_s, S_1 conflict equivalent

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

$\Rightarrow P(S_1)$ 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 = ... $q_j(A)$.......$p_1(A)$.....

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

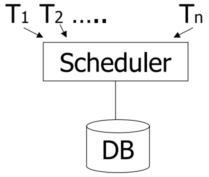
(4) repeat above steps to serialize rest!

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

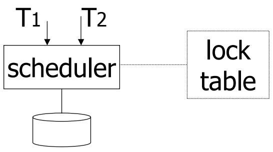
How to enforce serializable schedules?

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 = …….. $l_i(A)$ ……….. $u_i(A)$ ……..

$\longleftrightarrow$ 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 = $l_1(A)l_1(B)r_1(A)w_1(B)\boxed{l_2(B)}u_1(A)u_1(B)$
  $r_2(B)w_2(B)u_2(B)l_3(B)r_3(B)u_3(B)$

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

  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←A+100;Write(A);$u_1(A)$	
	$l_2(A)$;Read(A)
	A←Ax2;Write(A);$u_2(A)$
	$l_2(B)$;Read(B)
	B←Bx2;Write(B);$u_2(B)$
$l_1(B)$;Read(B)	
B←B+100;Write(B);$u_1(B)$	

Schedule F

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

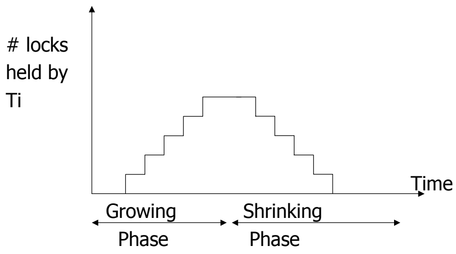
Rule #3 Two phase locking (2PL)

for transactions

T_i = ……. $l_i(A)$ ……….. $u_i(A)$ ……..

$\longleftarrow\!|$ no unlocks

$|\!\longrightarrow$ no locks



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

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)
Read(B);B← B+100	
Write(B); u_1(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)
Read(B);B← B+100	
Write(B); u_1(B)	
	l_2(B); u_2(A);Read(B)
	B ← Bx2;Write(B);u_2(B);

delayed

Schedule H (T$_2$ 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 = $\underbrace{\hspace{4cm}}_{\text{This space intentionally left blank!}}$

Next step:

Show that rules #1,2,3 ⇒ conflict-serializable schedules

Conflict rules for $l_i(A)$, $u_i(A)$:

- $l_i(A)$, $l_j(A)$ 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 ⇒ conflict
(2PL) serializable
schedule

To help in proof:

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

Lemma

Ti → Tj in S ⇒ SH(Ti) $<_S$ SH(Tj)

Proof of lemma:

Ti → Tj means that

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

By rules 1,2:

S = ... $p_i(A)$ ... $u_i(A)$ ... $l_j(A)$ **...** $q_j(A)$ ...

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

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

Theorem Rules #1,2,3 ⇒ conflict
(2PL) serializable
schedule

Proof:

(1) Assume P(S) has cycle

$T_1 \rightarrow T_2 \rightarrow .... T_n \rightarrow T_1$

(2) By lemma: $SH(T_1) < SH(T_2) < ... < SH(T_1)$

(3) Impossible, so P(S) acyclic

(4) ⇒ 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:

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

Do not conflict

Instead:

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

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

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

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

- What about transactions that read and write same object?

Option 1: Request exclusive lock

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

- What about transactions that read and write same object?

Option 2: Upgrade

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

$T_i = ...\ l\text{-}S_1(A)\ ...\ r_1(A)\ ...\ l\text{-}X_1(A)\ ...w_1(A)\ ...u(A)...$

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

Rule #2 Legal scheduler

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

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

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

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 → {S, X}) then no change!

(II) If upgrade releases read (shared) lock (e.g., S → X)
- can be allowed in growing phase

Theorem Rules 1,2,3 ⇒ 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)

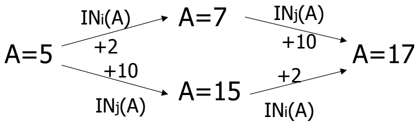
Lock types beyond S/X

Examples:

(1) increment lock
(2) update lock

Example (1): increment lock

- Atomic increment action: $IN_i(A)$
  {Read(A); A ← 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-S_1(A)	
	l-S_2(A)
l-X_1(A)	
	l-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)

New request

Comp

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	TorF	F	F

-> symmetric table?

<u>Note:</u> object A may be locked in different modes at the same time...

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

- 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?

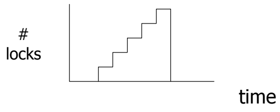
- Every system is different

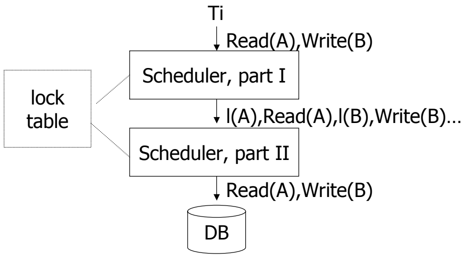
  (E.g., may not even provide CONFLICT-SERIALIZABLE schedules)
- But here is one (simplified) way ...

Sample Locking System:

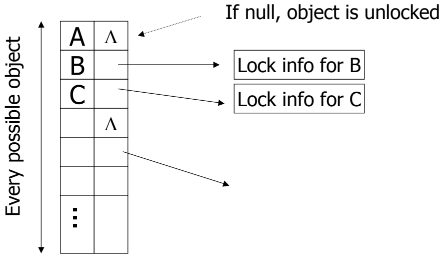
(1) Don’t trust transactions to request/release locks

(2) Hold all locks until transaction commits

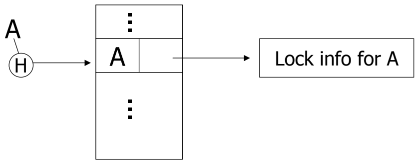




Lock table Conceptually

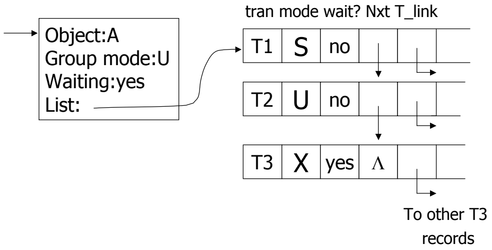


But use hash table:

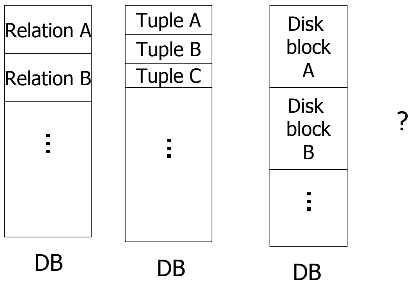


If object not found in hash table, it is unlocked

Lock info for A - example



What are the objects we lock?


Relation A
Relation B
⋮
DB

Tuple A
Tuple B
Tuple C
⋮
DB

Disk block A
Disk block B
⋮
DB

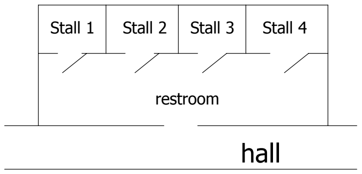
?

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

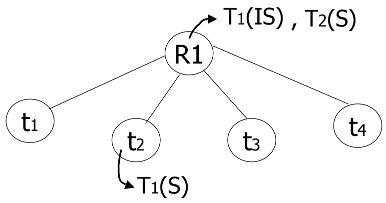
- If we lock large objects (e.g., Relations)
  - Need few locks
  - Low concurrency
- If we lock small objects (e.g., tuples,fields)
  - Need more locks
  - More concurrency

We can have it both ways!!

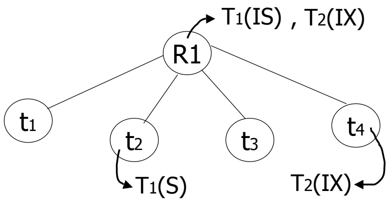
Ask any janitor to give you the solution...



Example



Example



Multiple granularity

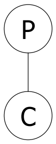
Comp Requestor

		IS	IX	S	SIX	X
	IS					
Holder	IX					
	S					
	SIX					
	X					

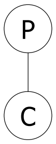
Multiple granularity

Comp		Requestor				
		IS	IX	S	SIX	X
	IS	T	T	T	T	F
Holder	IX	T	T	F	F	F
	S	T	F	T	F	F
	SIX	T	F	F	F	F
	X	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



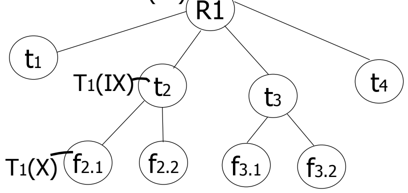
Rules

(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

---

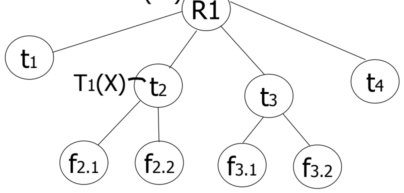
Exercise:

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



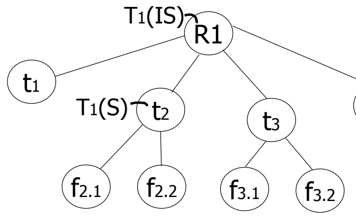
Exercise:

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



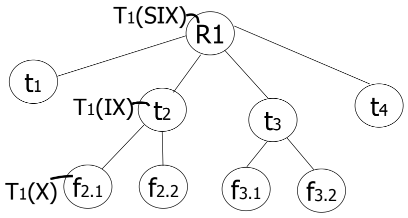
Exercise:

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



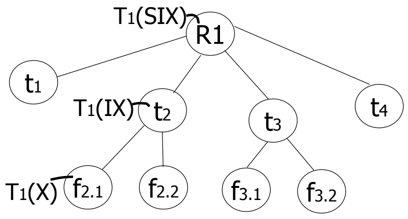
Exercise:

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

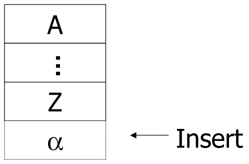


Exercise:

- 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

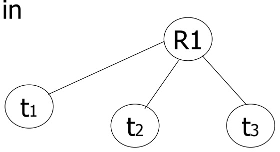
R	E#	Name	….
o1	55	Smith	
o2	75	Jones	

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

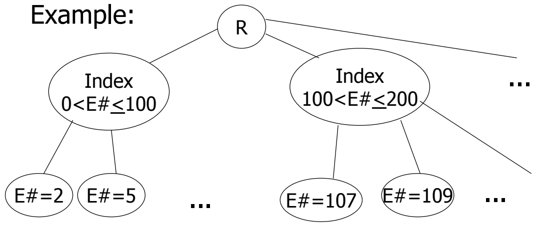


Back to example

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:



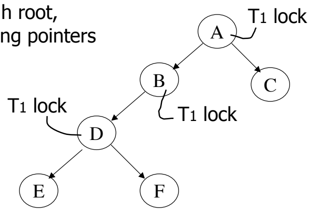
- This approach can be generalized to multiple indexes...

Next:

- Tree-based concurrency control
- Validation concurrency control

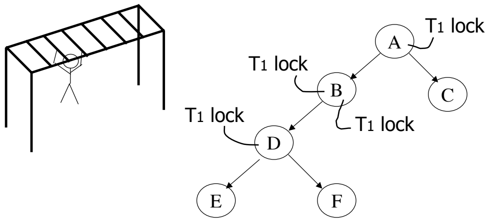
Example

- all objects accessed through root, following pointers



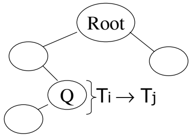
☛ can we release A lock if we no longer need A??

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

Rules: tree protocol (exclusive locks)

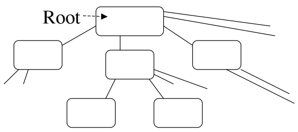
(1) First lock by T_i may be on any item

(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

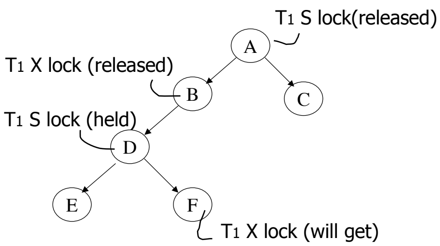
- Tree-like protocols are used typically for B-tree concurrency control



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

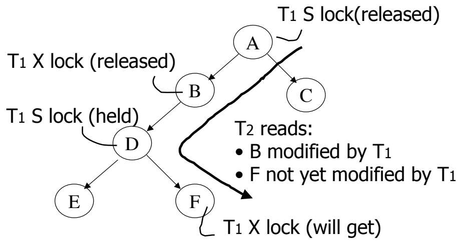
Tree Protocol with Shared Locks

- Rules for shared & exclusive locks?



Tree Protocol with Shared Locks

- Rules for shared & exclusive locks?



T_1 S lock(released)

T_1 X lock (released)

T_1 S lock (held)

T_2 reads:
- B modified by T_1
- F not yet modified by T_1

T_1 X lock (will get)

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

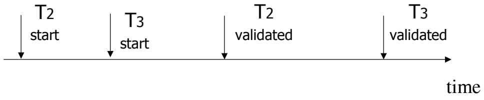
To implement validation, system keeps two sets:

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

Example of what validation must prevent:

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

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



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

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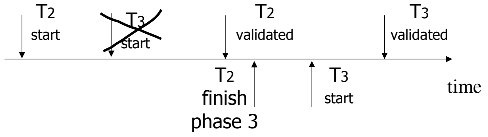
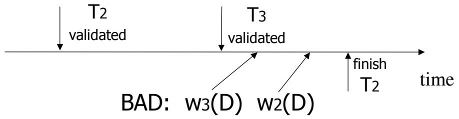


Another thing validation must prevent:

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

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



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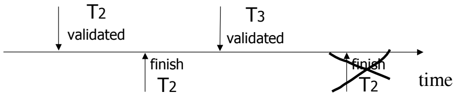


Validation rules for Tj:

```
(1) When $T_j$ starts phase 1:
      ignore($T_j$) ← FIN
(2) at $T_j$ Validation:
          if check ($T_j$) then
              [ VAL ← VAL U {$T_j$};
                do write phase;
                FIN ←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;
```

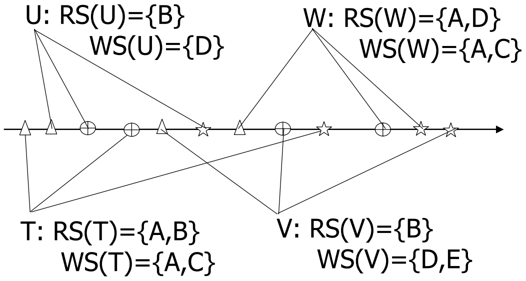
Is this check too restrictive ?

Improving Check(T_i)

```
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