Transactions: Concurrency Control

Amol Deshpande
CMSC424

Spring 2020 – Online Instruction Plan

- Week 1: File Organization and Indexes
- Week 2: Query Processing
- Week 3: Query Optimization; Parallel Databases 1
- Week 4: Parallel Databases; Mapreduce; Transactions 1
- Week 5: Transactions 2 (Homework Due May 1)
  - Transactions: Serializability, Recoverability
  - Transactions: Concurrency 1
  - Transactions: Concurrency 2: Other Concurrency Schemes
  - Transactions: Recovery
- Week 6: Distributed Transactions; Miscellaneous Topics (Homework Due May 8)

Transactions: Concurrency 1

- Book Chapters
  - 15.1, 15.2, 15.3
- Key topics:
  - Using locking to guarantee concurrency
  - 2-Phase Locking (2PL)
  - How “deadlocks” can happen and how to avoid them or recover from them
  - Multi-granularity locking and its benefits

Approach, Assumptions etc..

- Approach
  - Guarantee conflict-serializability by allowing certain types of concurrency
    - Lock-based
- Assumptions:
  - Durability is not a problem
    - So no crashes
    - Though transactions may still abort
- Goal:
  - Serializability
  - Minimize the bad effect of aborts (cascade-less schedules only)

Lock-based Protocols

- A transaction *must* get a *lock* before operating on the data
- Two types of locks:
  - *Shared* (S) locks (also called *read locks)*
    - Obtained if we want to only read an item – lock-S() instruction
  - *Exclusive* (X) locks (also called *write locks)*
    - Obtained for updating a data item – lock-X() instruction

T1	T2
read(B)	read(A)
B $\leftarrow$B-50	read(B)
write(B)	display(A+B)
read(A)	
A $\leftarrow$A + 50	
write(A)	

T1	T2
lock-X(B)	lock-S(A)
read(B)	read(A)
B $\leftarrow$B-50	unlock(A)
write(B)	lock-S(B)
unlock(B)	read(B)
lock-X(A)	unlock(B)
read(A)	display(A+B)
A $\leftarrow$A + 50	
write(A)	
unlock(A)	

Lock-based Protocols

- Lock requests are made to the *concurrency control manager*
  - It decides whether to *grant* a lock request
- T1 asks for a lock on data item A, and T2 currently has a lock on it ?
  - Depends

T2 lock type	**T1 lock type**	**Should allow ?**
Shared	Shared	YES
Shared	Exclusive	NO
Exclusive	-	NO

- If *compatible,* grant the lock, otherwise T1 waits in a *queue.*

Lock-based Protocols

- How do we actually use this to guarantee serializability/recoverability ?
  - Not enough just to take locks when you need to read/write something

T1

lock-X(B)
read(B)
B ← B-50
write(B)
unlock(B)

lock-X(A)
read(A)
A ← A + 50
write(A)
unlock(A)

lock-X(A), lock-X(B)
TMP = (A + B) * 0.1
A = A - TMP
B = B + TMP
unlock(A), unlock(B)

NOT SERIALIZABLE

2-Phase Locking Protocol (2PL)

- Phase 1: Growing phase
  - Transaction may obtain locks
  - But may not release them
- Phase 2: Shrinking phase
  - Transaction may only release locks
- Can be shown that this achieves *conflict-serializability*
  - *lock-point*: the time at which a transaction acquired last lock
  - if *lock-point*(T1) < *lock-point*(T2), there can't be an edge from T2 to T1 in the *precedence graph*

T1

lock-X(B)
read(B)
B ← B-50
write(B)
unlock(B)

lock-X(A)
read(A)
A ← A + 50
write(A)
unlock(A)

2 Phase Locking

- Example: T1 in 2PL

	T1
	lock-X(B)
	read(B)
	B ← B - 50
Growing phase	write(B)
	lock-X(A)
	read(A)
	A ← A - 50
	write(A)
Shrinking phase	unlock(B)
	unlock(A)

2 Phase Locking

- Guarantees *conflict-serializability*, but not cascade-less recoverability

T1	T2	T3
lock-X(A), lock-S(B)		
read(A)		
read(B)		
write(A)		
unlock(A), unlock(B)		
	lock-X(A)	
	read(A)	
	write(A)	
	unlock(A)	
	Commit	lock-S(A)
		read(A)
		Commit
<xction fails>		

2 Phase Locking

- Guarantees *conflict-serializability*, but not cascade-less recoverability

- Guaranteeing just recoverability:
  - If T2 reads a dirty data of T1 (ie, T1 has not committed), then T2 can't commit unless T1 either commits or aborts
  - If T1 commits, T2 can proceed with committing
  - If T1 aborts, T2 must abort
    - So cascades still happen

Strict 2PL

- Release *exclusive* locks only at the very end, just before commit or abort

T1	T2	T3
lock-X(A), lock-S(B)		
read(A)		
read(B)		
write(A)		
unlock(A), unlock(B)		
	lock-X(A)	
	read(A)	
	write(A)	
	unlock(A)	
	Commit	lock-S(A)
		read(A)
		Commit
<xction fails>		

Strict 2PL will not allow that

Works. Guarantees cascade-less and recoverable schedules.

Strict 2PL

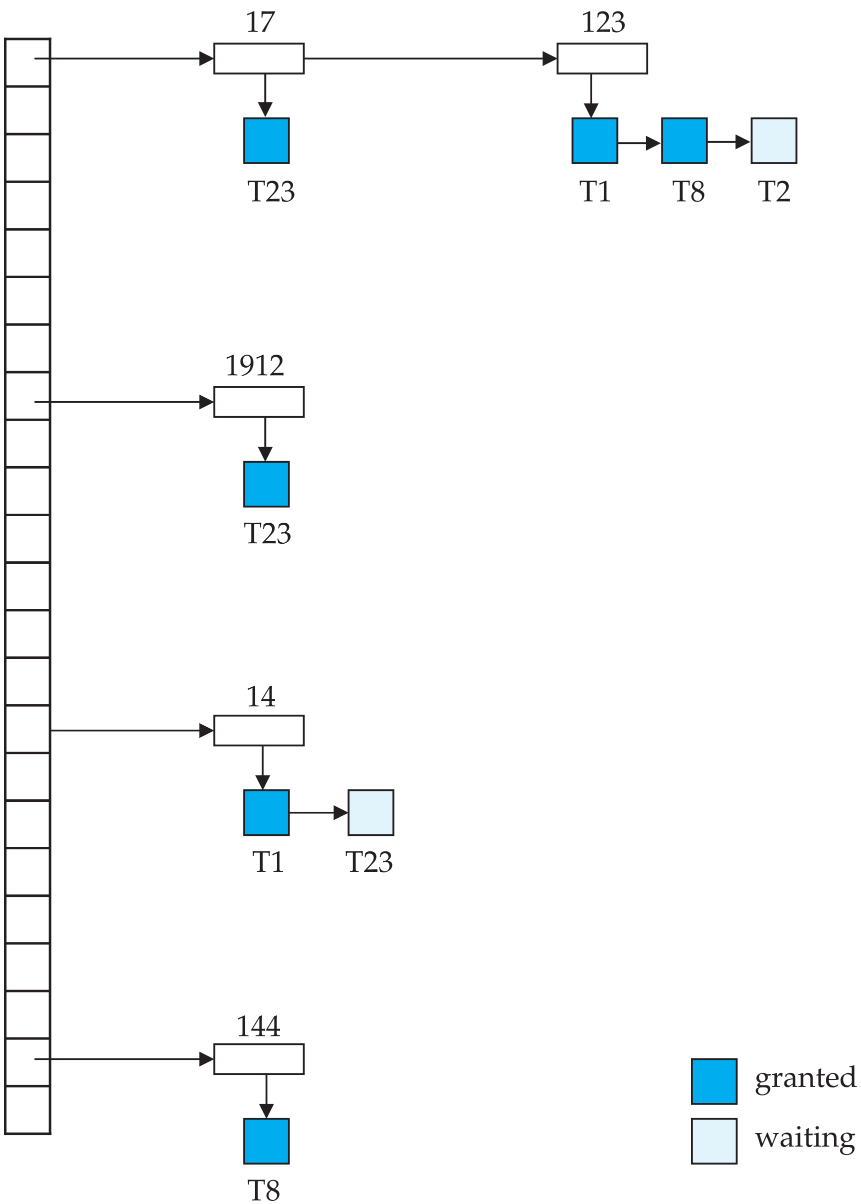
- Release *exclusive* locks only at the very end, just before commit or abort
  - Read locks are not important
- Rigorous 2PL: Release both *exclusive and read* locks only at the very end
  - The serializability order === the commit order
  - More intuitive behavior for the users
    - No difference for the system
- Lock conversion:
  - Transaction might not be sure what it needs a write lock on
  - Start with a S lock
  - *Upgrade* to an X lock later if needed
  - Doesn't change any of the other properties of the protocol

Implementation of Locking

- A separate process, or a separate module

- Uses a *lock table* to keep track of currently assigned locks and the requests for locks

Lock Table



- Black rectangles indicate granted locks, white ones indicate waiting requests
- Lock table also records the type of lock granted or requested
- New request is added to the end of the queue of requests for the data item, and granted if it is compatible with all earlier locks
- Unlock requests result in the request being deleted, and later requests are checked to see if they can now be granted
- If transaction aborts, all waiting or granted requests of the transaction are deleted
  - lock manager may keep a list of locks held by each transaction, to implement this efficiently

Recap so far…

- Concurrency Control Scheme
  - A way to guarantee serializability, recoverability etc
- Lock-based protocols
  - Use *locks* to prevent multiple transactions accessing the same data items
- 2 Phase Locking
  - Locks acquired during *growing phase,* released during *shrinking phase*
- Strict 2PL, Rigorous 2PL

More Locking Issues: Deadlocks

- No xction proceeds:

Deadlock

- T1 waits for T2 to unlock A
- T2 waits for T1 to unlock B

Rollback transactions
Can be costly...

- 2PL does not prevent deadlock
  - Strict doesn't either

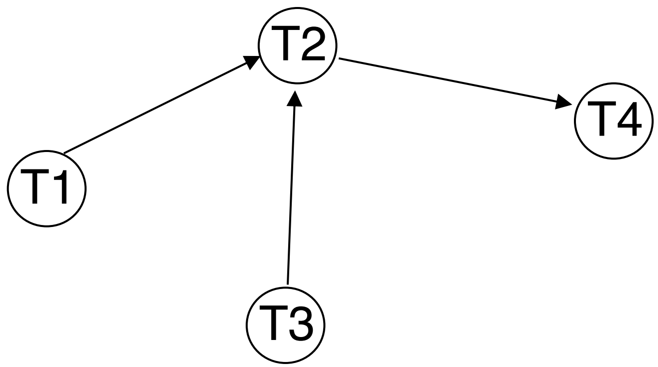
T1	T2
lock-X(B)	
read(B)	
B ← B-50	
write(B)	
	lock-S(A)
	read(A)
	lock-S(B)
lock-X(A)	

Preventing deadlocks

- Solution 1: A transaction must acquire all locks before it begins
  - Not acceptable in most cases
- Solution 2: A transaction must acquire locks in a particular order over the data items
  - Also called *graph-based protocols*
- Solution 3: Use time-stamps; say T1 is older than T2
  - *wait-die scheme:* T1 will wait for T2. T2 will not wait for T1; instead it will abort and restart
  - *wound-wait scheme:* T1 will *wound* T2 (force it to abort) if it needs a lock that T2 currently has; T2 will wait for T1.
- Solution 4: Timeout based
  - Transaction waits a certain time for a lock; aborts if it doesn't get it by then

Deadlock detection and recovery

- Instead of trying to prevent deadlocks, let them happen and deal with them if they happen
- How do you detect a deadlock?
  - Wait-for graph
  - Directed edge from Ti to Tj
    - Ti waiting for Tj



T1	T2	T3	T4
		X(Z)	
	X(V)		
			X(W)
S(V)			
	S(W)		
		S(V)	

Suppose T4 requests lock-S(Z)....

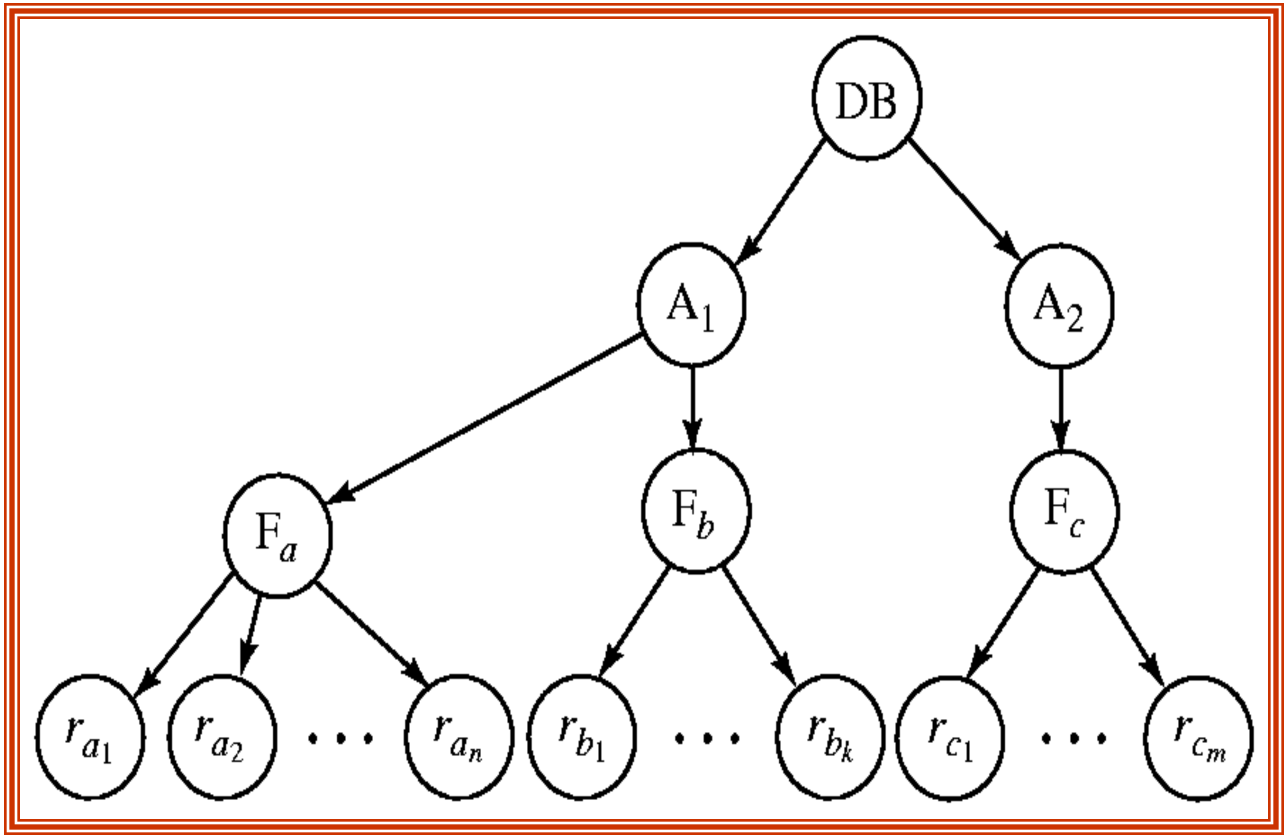
Dealing with Deadlocks

- Deadlock detected, now what ?
  - Will need to abort some transaction
  - Prefer to abort the one with the minimum work done so far
  - Possibility of starvation
    - If a transaction is aborted too many times, it may be given priority in continueing

Locking granularity

- Locking granularity
  - What are we taking locks on ? Tables, tuples, attributes ?
- Coarse granularity
  - e.g. take locks on tables
  - less overhead (the number of tables is not that high)
  - very low concurrency
- Fine granularity
  - e.g. take locks on tuples
  - much higher overhead
  - much higher concurrency
  - What if I want to lock 90% of the tuples of a table ?
    - Prefer to lock the whole table in that case

Granularity Hierarchy



The highest level in the example hierarchy is the entire database.

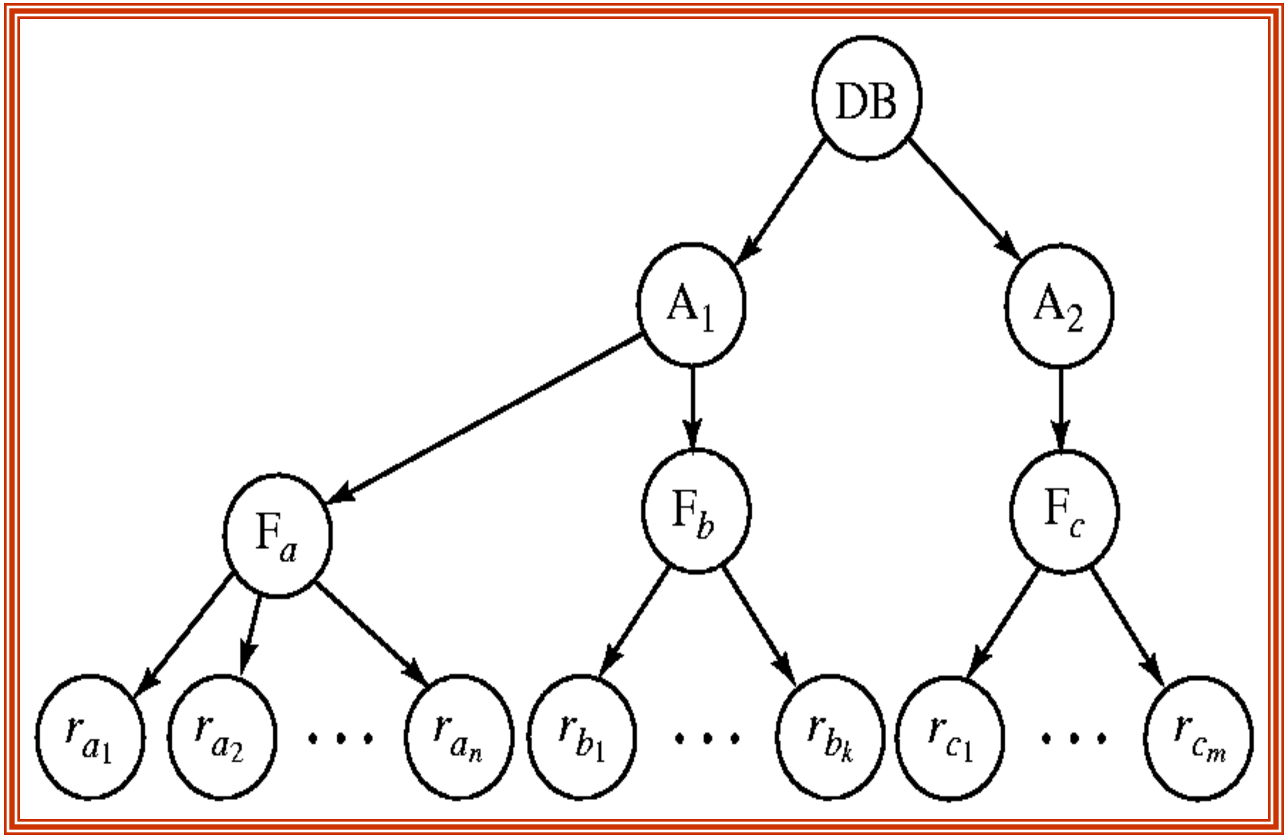
The levels below are of type *area*, *file or relation* and *record* in that order.

Can lock at any level in the hierarchy

Granularity Hierarchy

- New lock mode, called *intentional* locks
  - Declare an intention to lock parts of the subtree below a node
  - IS: *intention shared*
    - The lower levels below may be locked in the shared mode
  - IX: *intention exclusive*
  - *SIX: shared and intention-exclusive*
    - The entire subtree is locked in the shared mode, but I might also want to get exclusive locks on the nodes below
- Protocol:
  - If you want to acquire a lock on a data item, all the ancestors must be locked as well, at least in the intentional mode
  - So you always start at the top *root* node

Granularity Hierarchy

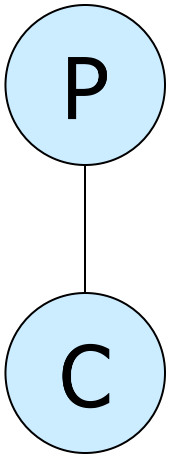


(1) Want to lock *F_a* in shared mode, *DB* and *A1* must be locked in at least IS mode (but IX, SIX, S, X are okay too)

(2) Want to lock *rc1* in exclusive mode, *DB, A2,Fc* must be locked in at least IX mode (SIX, X are okay too)

Granularity Hierarchy

Parent locked in	Child can be locked in
IS	IS, S
IX	IS, S, IX, X, SIX
S	[S, IS] not necessary
SIX	X, IX, [SIX]
X	none



Compatibility Matrix with Intention Lock Modes

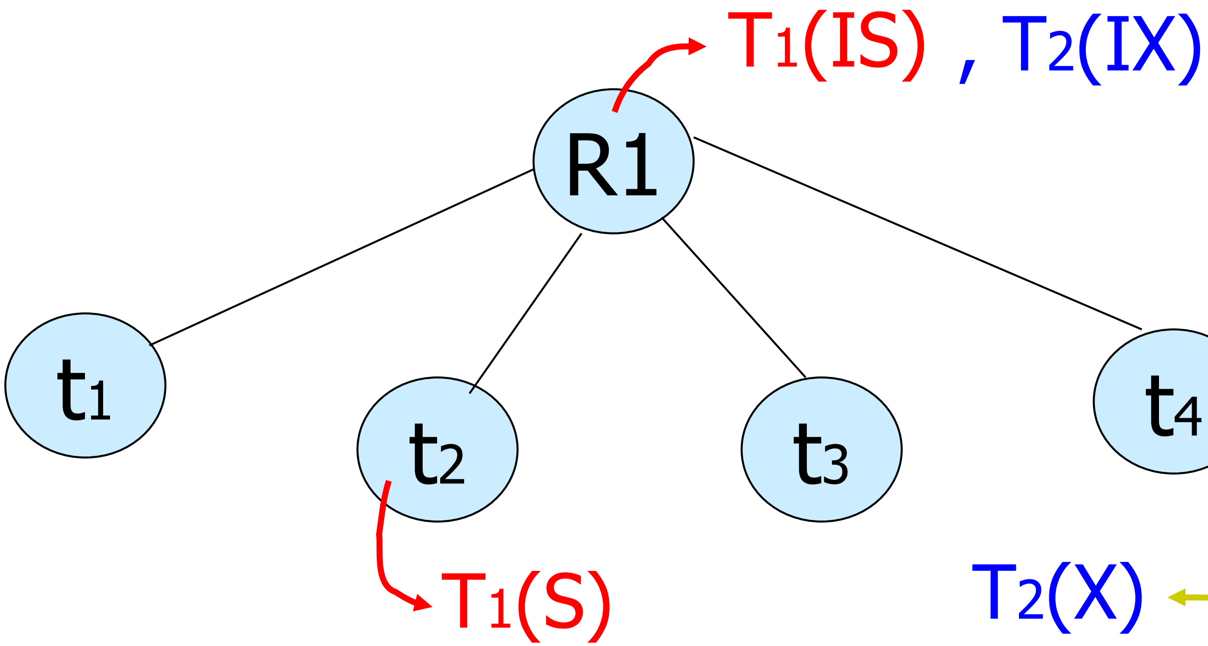
- The compatibility matrix (which locks can be present simultaneously on the same data item) for all lock modes is:

requestor

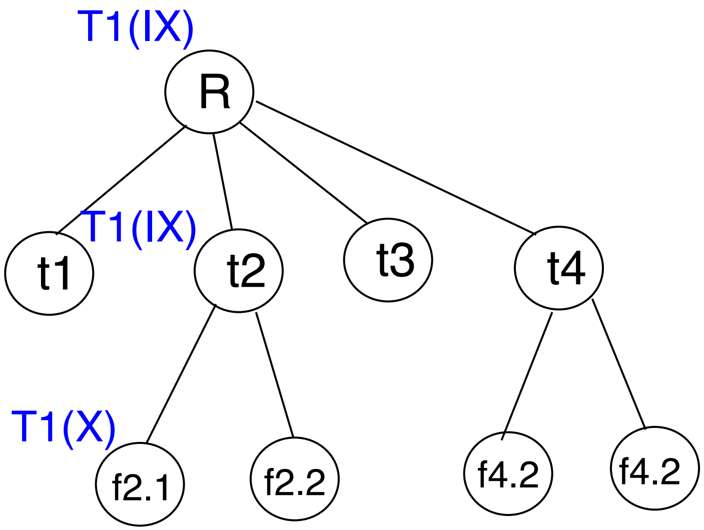
holder

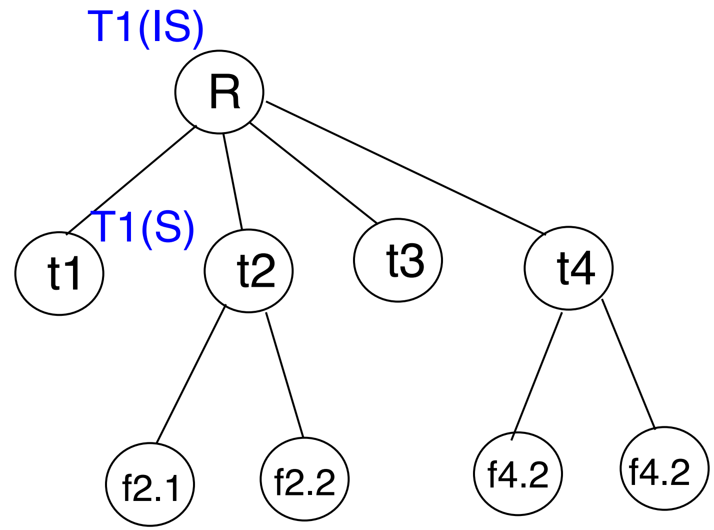
	IS	IX	S	S IX	X
IS	✓	✓	✓	✓	×
IX	✓	✓	×	×	×
S	✓	×	✓	×	×
S IX	✓	×	×	×	×
X	×	×	×	×	×

Example

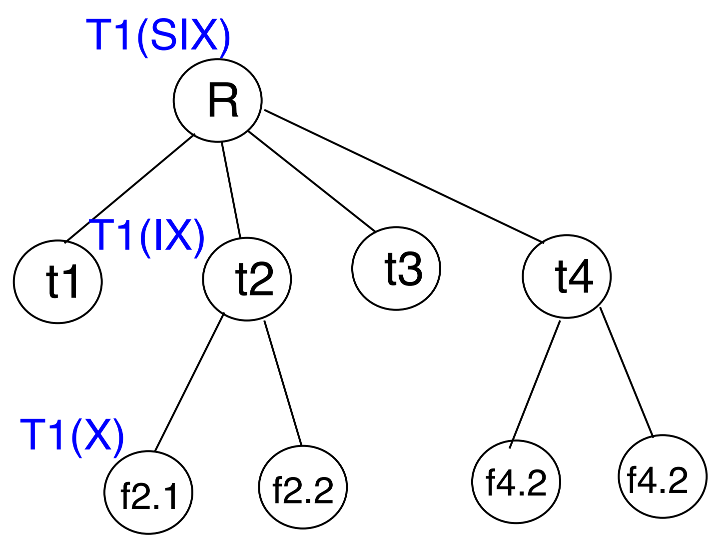


Examples





Can T2 access object f2.2 in X mode?
What locks will T2 get?



Examples

- T1 scans R, and updates a few tuples:
  - T1 gets an SIX lock on R, then repeatedly gets an S lock on tuples of R, and occasionally upgrades to X on the tuples.
- T2 uses an index to read only part of R:
  - T2 gets an IS lock on R, and repeatedly gets an S lock on tuples of R.
- T3 reads all of R:
  - T3 gets an S lock on R.
  - OR, T3 could behave like T2; can

  use lock escalation to decide which.

	--	IS	IX	S	X
--	√	√	√	√	√
IS	√	√	√	√	
IX	√	√	√		
S	√	√		√	
X	√				

Recap, Next….

- Deadlocks
  - Detection, prevention, recovery
- Locking granularity
  - Arranged in a hierarchy
  - Intentional locks
- Next video…
  - Brief discussion of some other concurrency schemes