Transactions & Concurrency Control 2

R&G 16/17

There are three side effects of acid. Enhanced long term memory, decreased short term memory, and I forget the third.

- Timothy Leary

Berkeley
cs186

TWO PHASE LOCKING

Two Phase Locking (2PL)

- **The most common scheme for enforcing conflict serializability**
- **A bit “pessimistic”**
  - Sets locks for fear of conflict… Some cost here.
  - Alternative schemes use multiple versions of data and “optimistically” let transactions move forward
    - Abort when conflicts are detected.
    - Some names to know/look up:
      - Optimistic Concurrency Control
      - Timestamp-Ordered Multiversion Concurrency Control
    - We will not study these schemes in this lecture

Two Phase Locking (2PL), Part 2

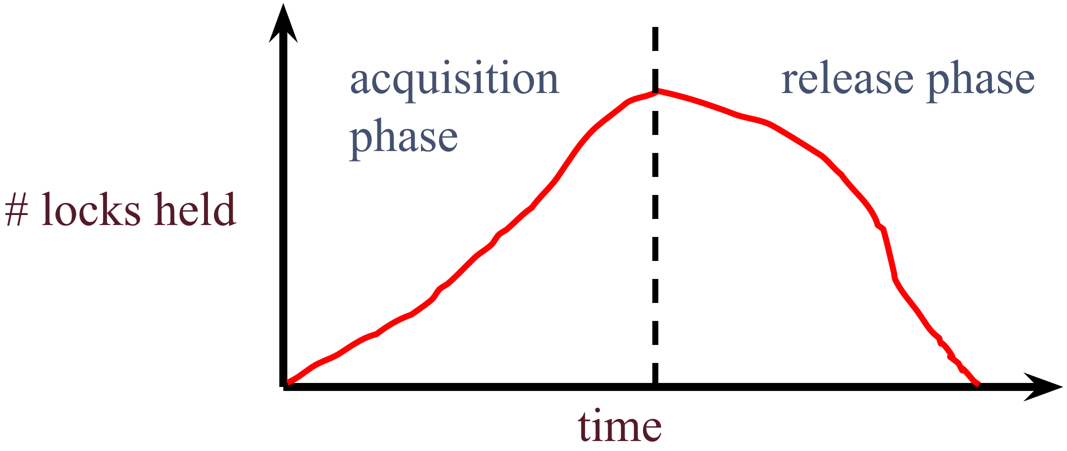
- Rules:
  - Xact must obtain a S (shared) lock before reading, and an X (exclusive) lock before writing.
  - **Xact cannot get new locks after releasing any locks**

Lock Compatibility Matrix

	S	X
S	√	–
X	–	–

Two Phase Locking (2PL), Part 3

- **2PL guarantees conflict serializability (why?)**
- But, does not prevent **cascading aborts**



Why 2PL guarantees conflict serializability

- When a committing transaction has reached the end of its acquisition phase…
  - Call this the "lock point"
  - At this point, it has *everything it needs* locked…
  - … and any conflicting transactions either:
    - started release phase before this point
    - are blocked waiting for this transaction
- Visibility of actions of two conflicting transactions are ordered by their lock points
- The order of lock points gives us an equivalent serial schedule!

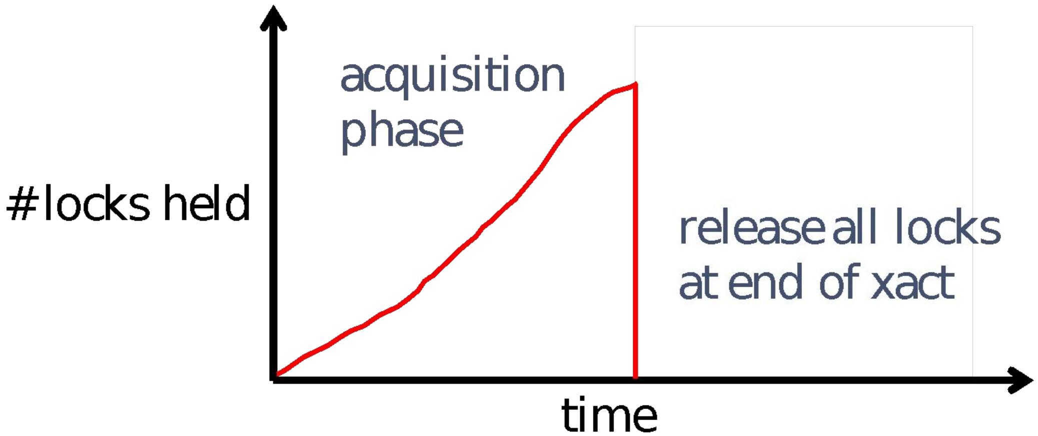
Strict Two Phase Locking (2PL)

- **Problem: Cascading Aborts**
- Example: rollback of T1 requires rollback of T2!

T1:	**R(A), W(A)**		**Abort**
T2:		**R(A), W(A)**	

Strict Two Phase Locking

- Same as 2PL, except all locks released together when transaction completes
  - (i.e.) either
    - Transaction has committed (all writes durable), OR
    - Transaction has aborted (all writes have been undone)



Next ...

- A few examples

Non-2PL, A = 1000, B = 2000, Output = ?

T1	T2
Lock_X(A)	
Read(A)	
	Lock_S(A)
A: = A-50	
Write(A)	
Unlock(A)	
	Read(A)
	Unlock(A)
	Lock_S(B)
Lock_X(B)	
	Read(B)
	Unlock(B)
	PRINT(A), PRINT(B), PRINT(A+B)
Read(B)	
B := B +50	
Write(B)	
Unlock(B)	

Output: 950, 2000, 2950

Non-2PL, A = 1000, B = 2000, Output = ? cont

T1	T2
Lock_X(A)	
Read(A): (A=1000)	
	Lock_S(A)
A: = A-50 (A=950)	
Write(A) A=950	
Unlock(A)	
	Read(A) (A = 950)
	Unlock(A)
	Lock_S(B)
Lock_X(B)	
	Read(B) (B=2000)
	Unlock(B)
	PRINT(A), PRINT(B), PRINT(A+B)
Read(B) (B=2000)	
B := B +50 (B=2050)	
Write(B) B=2050	
Unlock(B)	

Output: 950, 2000, 2950

2PL, A = 1000, B = 2000, Output = ?

T1	T2
Lock_X(A)	
Read(A)	
A: = A-50	
Write(A)	
Lock_X(B)	
Unlock(A)	
	Lock_S(A)
	Read(A)
Read(B)	
B := B +50	
Write(B)	
Unlock(B)	
	Lock_S(B)
	Unlock(A)
	Read(B)
	Unlock(B)
	PRINT(A), PRINT(B), PRINT(A+B)

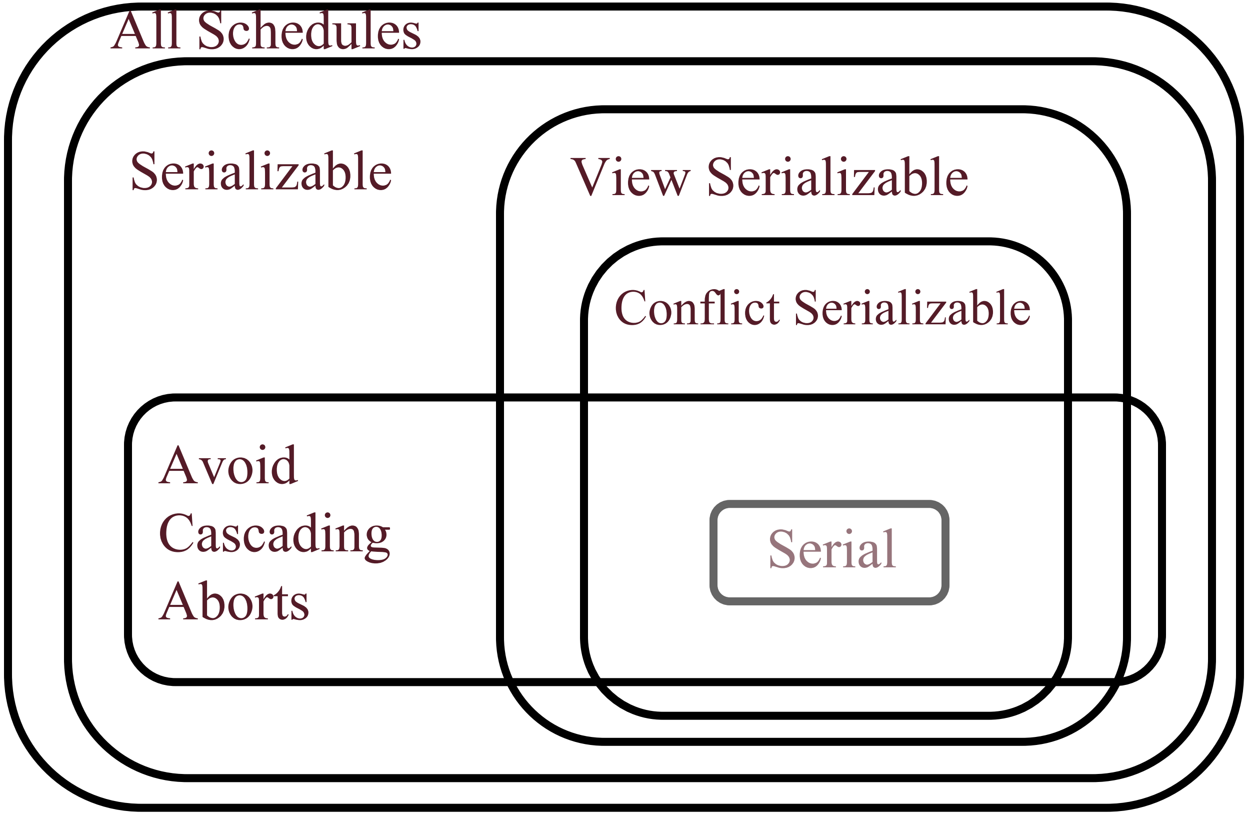
Output: 950, 2050, 3000

Strict 2PL, A = 1000, B = 2000, Output = ?

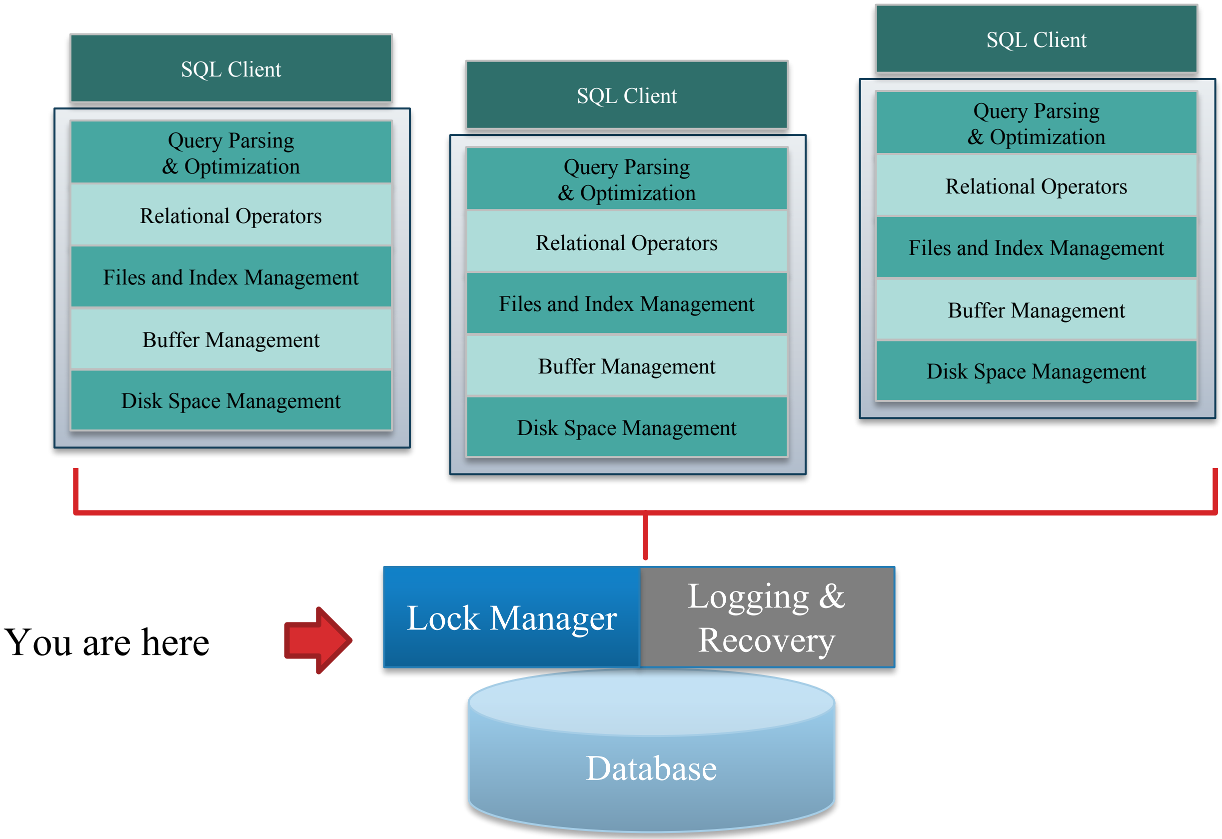
T1	T2
Lock_X(A)	
Read(A)	
	Lock_S(A)
A: = A-50	
Write(A)	
Lock_X(B)	
Read(B)	
B := B +50	
Write(B)	
Unlock(A)	
Unlock(B)	
	Read(A)
	Lock_S(B)
	Read(B)
	PRINT(A), PRINT(B), PRINT(A+B)
	Unlock(A)
	Unlock(B)

Output: 950, 2050, 3000

Which schedules does Strict 2PL allow?



Architecture



How Do We Lock Data?

- Not by any crypto or hardware enforcement
  - There are no adversaries here … this is all within the DBMS

- We lock by simple convention:
  - Within DBMS internals, we observe a lock *protocol*
  - If your transaction *holds* a lock, and my transaction *requests* a conflicting lock, then I am queued up waiting for that lock.

Lock Management

- Lock and unlock requests handled by Lock Manager

- LM maintains a hashtable, keyed on names of objects being locked.

- LM keeps an entry for each currently held lock
- Entry contains
  - Granted set: Set of xacts currently granted access to the lock
  - Lock mode: Type of lock held (shared or exclusive)
  - Wait Queue: Queue of lock requests

	Granted Set	Mode	Wait Queue
A	{T1, T2}	S	T3(X) ⍰ T4(X)
B	{T6}	X	T5(X) ⍰ T7(S)

Lock Management (continued)

- **When lock request arrives:**
  - Does any xact in Granted Set or Wait Queue want a conflicting lock?
    - If no, put the requester into "granted set" and let them proceed
    - If yes, put requester into wait queue (typically FIFO)

- **Lock upgrade:**
  - Xact with shared lock can request to upgrade to exclusive

	Granted Set	Mode	Wait Queue
A	{T1, T2}	S	**T2(X)** → T3(X) → T4(X)
B	{T6}	X	T5(X) → T7(S)

Example

Lock_X(A)	
	Lock_S(B)
	Read(B)
	Lock_S(A)
Read(A)	
A: = A-50	
Write(A)	
Lock_X(B)	

Final lock table state:

A:

X lock held by T1
wait queue = [T2 wants S]

B:

S lock held by T2
wait queue = [T1 wants X]

Uh-oh, T1 and T2 are waiting for each other!

DEADLOCK

Deadlocks, cont

- **Deadlock: Cycle of Xacts waiting for locks to be released by each other.**
- **Three ways of dealing with deadlocks:**
  - Prevention
  - Avoidance
  - Detection and Resolution
- **Many systems just punt and use timeouts**
  - What are the dangers with this approach?

Deadlock Scenarios

- They can just happen (unavoidable)

	Granted Set	Mode	Wait Queue
A	{T1}	S	T2(X)
B	{T2}	X	T1(S)

- Bad implementation of Lock Upgrade (avoidable! prioritize upgrades)

	Granted Set	Mode	Wait Queue
A	{T1, T2}	S	T3(X) ⍰ T4(X) ⍰ T2(X)

- Multiple Lock Upgrades (unavoidable)

	Granted Set	Mode	Wait Queue
A	{T1, T2}	S	**T2(X)** ⍰ **T1(X)** ⍰ T3(X) ⍰ T4(X)

Deadlock Scenarios

- They can just happen (unavoidable)

	Granted Set	Mode	Wait Queue
A	{T1}	S	T2(X)
B	{T2}	X	T1(S)

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	Granted Set	Mode	Wait Queue
A	{T1, T2}	S	T2(X) □ T3(X) □ T4(X)

- Multiple Lock Upgrades (unavoidable)

	Granted Set	Mode	Wait Queue
A	{T1, T2}	S	**T2(X)** □ **T1(X)** □ T3(X) □ T4(X)

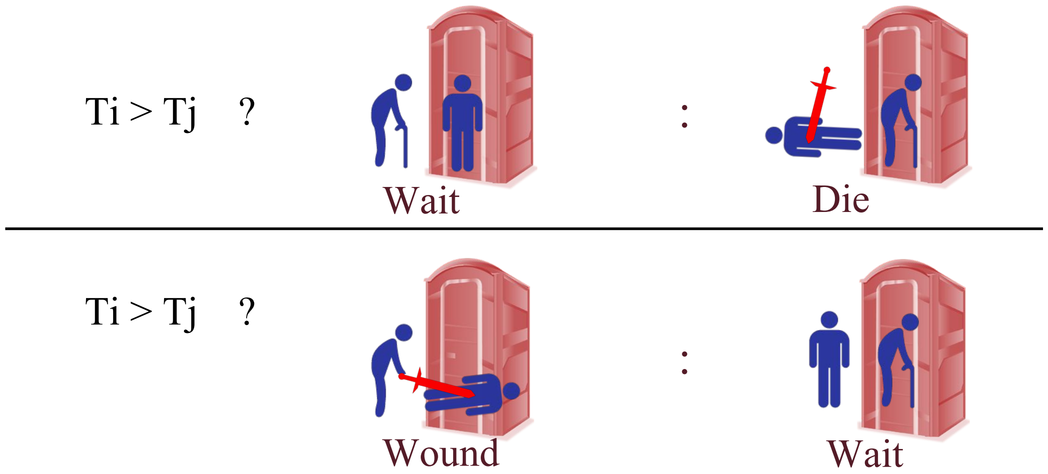
Deadlock Prevention

- **Common technique in operating systems**
- **Standard approach: resource ordering**
  - Screen < Network Card < Printer
- **Why is this problematic for Xacts in a DBMS?**
  - What order would you impose?

Deadlock Avoidance

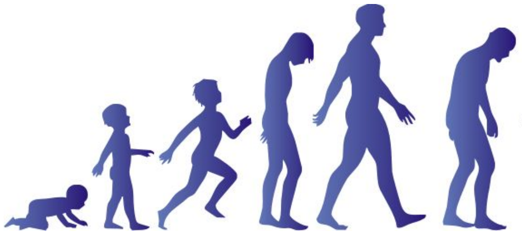
- **Assign priorities based on age: (now – start_time).**
- Say Ti wants a lock that Tj holds. Two possible policies:
  - **Wait-Die:** If Ti has higher priority, Ti waits for Tj; else Ti aborts
  - **Wound-Wait:** If Ti has higher priority, Tj aborts; else Ti waits

  - Read each of these like a ternary operator (C/C++/java/javascript)



Deadlock Avoidance: Analysis

- Q: Why do these schemes guarantee no deadlocks?
    - Q: What do the previous images have in common?
- Important Detail: If a transaction re-starts, make sure it gets its original timestamp. Why?
- Note: other priority schemes make sense
    - E.g. measures of resource consumption, like #locks acquired



Deadlock Detection

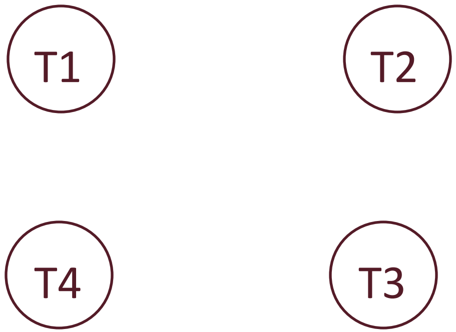
- Create and maintain a **“waits-for” graph**
- Periodically check for cycles in a graph

Deadlock Detection, Part 2

Example:

T1:
T2:
T3:

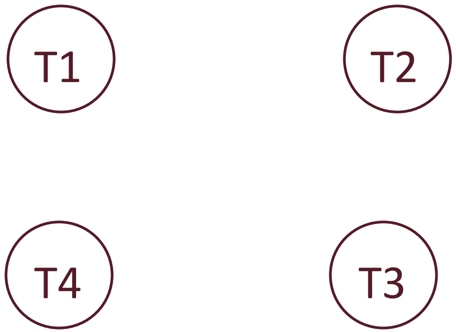
T4:



Deadlock Detection, Part 3

Example:

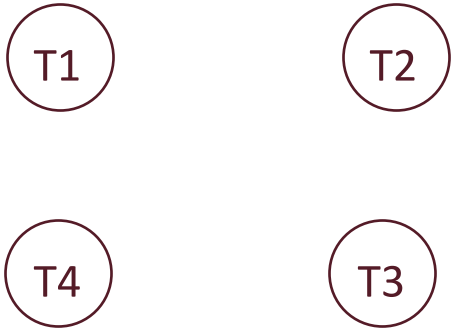
T1: S(A)
T2:
T3:
T4:



Deadlock Detection, Part 4

Example:

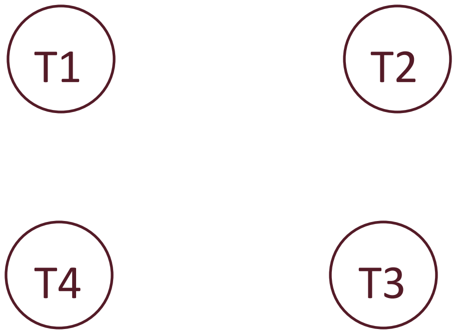
T1: S(A) S(D)
T2:
T3:
T4:



Deadlock Detection, Part 5

Example:

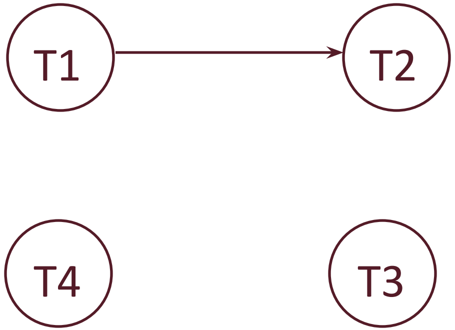
T1: S(A) S(D)
T2: X(B)
T3:
T4:



Deadlock Detection, Part 6

Example:

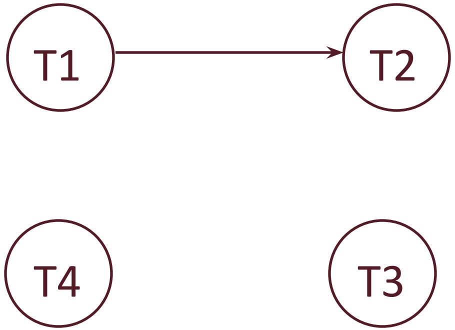
T1: S(A) S(D) S(B)
T2: X(B)
T3:
T4:



Deadlock Detection, Part 7

Example:

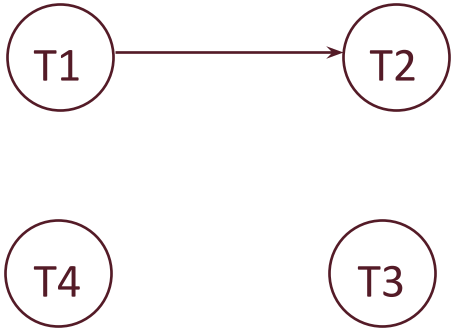
T1:	**S(A)**		**S(D)**		**S(B)**
T2:		**X(B)**			
T3:				**S(D)**	
T4:					



Deadlock Detection, Part 8

Example:

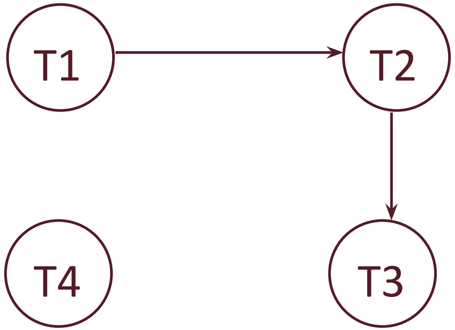
T1: S(A) S(D) S(B)
T2: X(B)
T3: S(D), S(C)
T4:



Deadlock Detection, Part 9

Example:

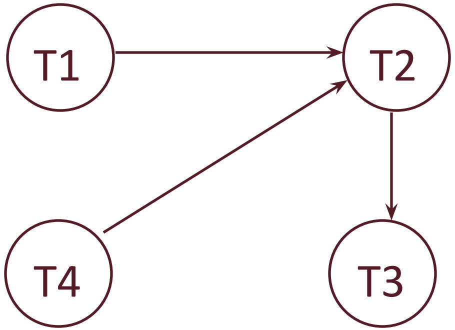
T1:	**S(A)**	**S(D)**			**S(B)**		
T2:		**X(B)**				**X(C)**	
T3:				**S(D)**	**S(C)**		
T4:							



Deadlock Detection, Part 10

Example:

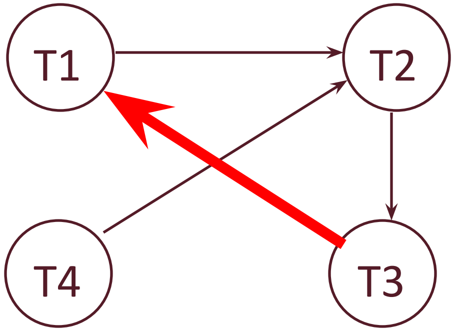
T1: S(A) S(D) S(B)
T2: X(B) X(C)
T3: S(D) S(C)
T4: X(B)



Deadlock Detection, Part 11

Example:

T1: S(A) S(D) S(B)
T2: X(B) X(C)
T3: S(D) S(C) X(A)
T4: X(B)



Deadlock!

- **T1, T2, T3 are deadlocked**
  - Doing no good, and holding locks
- **T4 still cruising**
- **In the background, run a deadlock detection algorithm**
  - Periodically extract the waits-for graph
  - Find cycles
  - “Shoot” a transaction on the cycle
- **Empirical fact**
  - Most deadlock cycles are small (2-3 transactions)

LOCK GRANULARITY

Lock Granularity, cont

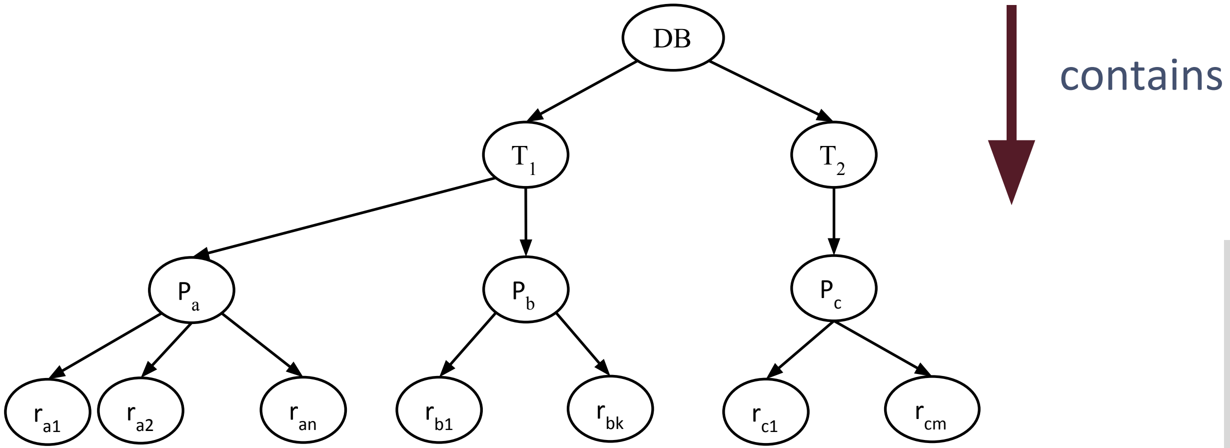
- Hard to decide what granularity to lock
  - Tuples vs Pages vs Tables?
- What is the tradeoff?
  - Fine-grained availability of resources would be nice (e.g. lock per tuple)
  - Small # of locks to manage would also be nice (e.g. lock per table)
  - Can’t have both!
    - Or can we???

Multiple Locking Granularity

- **Shouldn’t have to make same decision for all transactions!**
- Allow data items to be of various sizes
- Define a hierarchy of data granularities, small nested within large
  - Can be represented graphically as a tree.

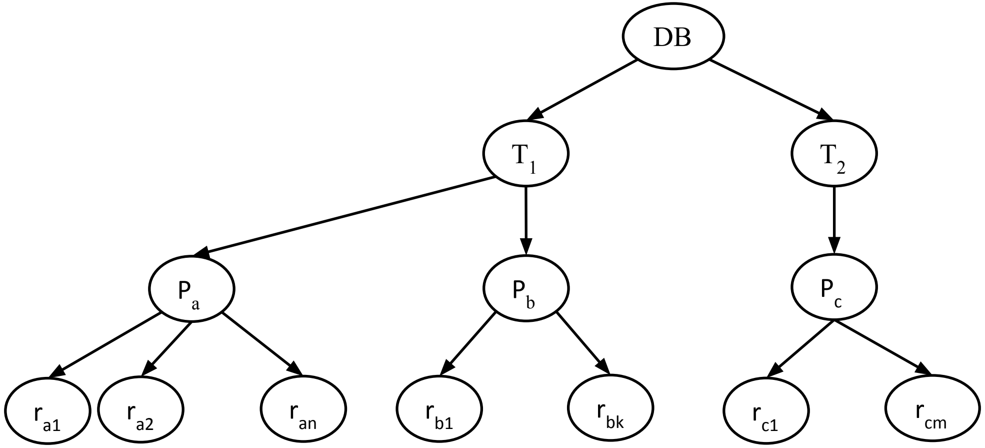
Example of Granularity Hierarchy (RDBMS)

- Data "containers" can be viewed as nested.
- The levels, starting from the coarsest (top) level are
  - Database, Tables, Pages, Records
- When a transaction locks a node in the tree ***explicitly***, it ***implicitly*** locks all the node's descendants in the same mode.



Multiple Locking Granularity

- Granularity of locking (level in tree where locking is done):
  - **Fine granularity** (lower in tree): High concurrency, lots of locks (overhead)
  - **Coarse granularity** (higher in tree): Few locks (low overhead), lost concurrency
    - Lost potential concurrency if you don't need everything inside the coarse grain



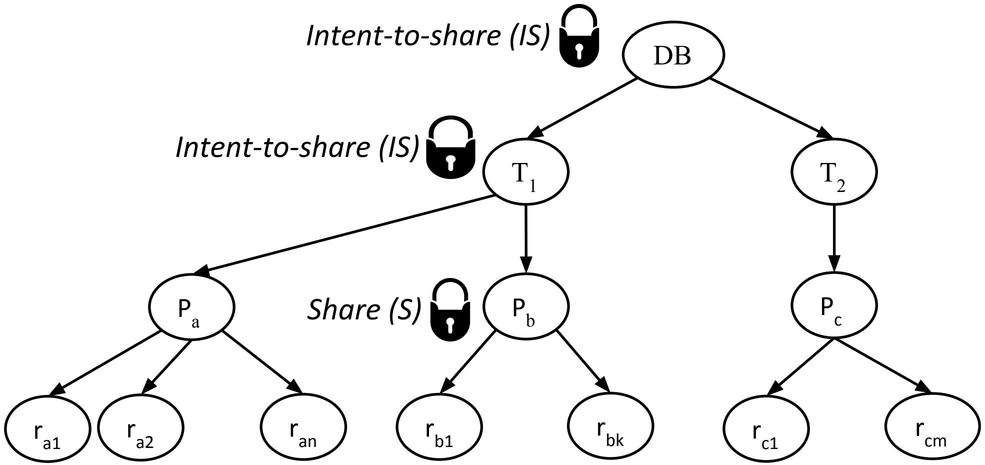
Real-World Locking Granularities

Resource	Description
RID	A row identifier used to lock a single row within a heap.
KEY	A row lock within an index used to protect key ranges in serializable transactions.
PAGE	An 8-kilobyte (KB) page in a database, such as data or index pages.
EXTENT	A contiguous group of eight pages, such as data or index pages.
HoBT	A heap or B-tree. A lock protecting a B-tree (index) or the heap data pages in a table that does not have a clustered index.
TABLE	The entire table, including all data and indexes.
FILE	A database file.
APPLICATION	An application-specified resource.
METADATA	Metadata locks.
ALLOCATION_UNIT	An allocation unit.

From MS SQL Server
https://technet.microsoft.com/en-us/library/jj856598(v=sql.110).aspx

Solution: New Lock Modes, Protocol

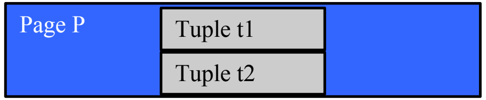
- Allow xacts to lock at each level, but with a special protocol using new "intent" locks:
- Before getting S or X lock, Xact must have proper intent locks on all its ancestors in the granularity hierarchy.



New Lock Modes – Intention Lock Modes

- 3 additional lock modes:
  - ***IS:*** *Intent to get S lock(s) at finer granularity.*
  - ***IX:*** *Intent to get X lock(s) at finer granularity.*
  - ***SIX:*** *Like S & IX at the same time. Why useful?*

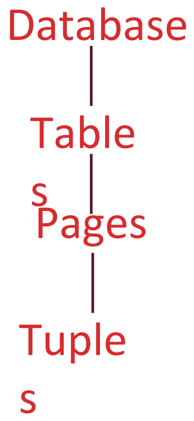
- Intention locks allow a higher level node to be locked in S or X mode without having to check all descendent nodes



Multiple Granularity Locking Protocol

- Each Xact starts from the root of the hierarchy.
- To get S or IS lock on a node, must hold IS or IX on parent node.
    - What if Xact holds S on parent? SIX on parent?
- To get X or IX or SIX on a node, must hold IX or SIX on parent node.
- Must release locks in bottom-up order.

- 2-phase and lock compatibility matrix rules enforced as well
- Protocol is correct in that it is *equivalent to directly setting locks at leaf levels of the hierarchy*.



Lock Compatibility Matrix

- IS – Intent to get S lock(s) at finer granularity.
- IX – Intent to get X lock(s) at finer granularity.
- SIX mode: Like S & IX at the same time.

	IS	IX	S	SIX	X
IS					
IX					
S			true		false
SIX					
X			false		false

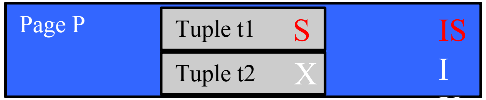
Database

Table
s

Pages

Tuple
s

Handy simple case to remember:
Could 2 intent locks be compatible?



Lock Compatibility Matrix, Cont

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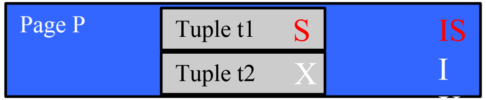


	IS	IX	S	SIX	X
IS	true	true	true	true	false
IX	true	true	false	false	false
S	true	false	true	false	false
SIX	true	false	false	false	false
X	false	false	false	false	false

Database

Tables

Pages

Tuples

Real-World Lock Compatibility Matrix

	NL	SCH-S	SCH-M	S	U	X	IS	IU	IX	SIU	SIX	UIX	BU	RS-S	RS-U	RI-N	RI-S	RI-U	RI-X	RX-S	RX-U	RX-X
NL	N	N	N	N	N	N	N	N	N	N	N	N	N	N	N	N	N	N	N	N	N	N
SCH-S	N	N	C	N	N	N	N	N	N	N	N	N	N	I	I	I	I	I	I	I	I	I
SCH-M	N	C	C	C	C	C	C	C	C	C	C	C	C	I	I	I	I	I	I	I	I	I
S	N	N	C	N	N	C	N	N	C	N	C	C	C	N	N	N	N	N	C	N	N	C
U	N	N	C	N	C	C	N	C	C	C	C	C	C	N	C	N	N	C	C	N	C	C
X	N	N	C	C	C	C	C	C	C	C	C	C	C	C	C	N	C	C	C	C	C	C
IS	N	N	C	N	N	C	N	N	N	N	N	N	C	I	I	I	I	I	I	I	I	I
IU	N	N	C	N	C	C	N	N	N	N	N	C	C	I	I	I	I	I	I	I	I	I
IX	N	N	C	C	C	C	N	N	N	C	C	C	C	I	I	I	I	I	I	I	I	I
SIU	N	N	C	N	C	C	N	N	C	N	C	C	C	I	I	I	I	I	I	I	I	I
SIX	N	N	C	C	C	C	N	N	C	C	C	C	C	I	I	I	I	I	I	I	I	I
UIX	N	N	C	C	C	C	N	C	C	C	C	C	C	I	I	I	I	I	I	I	I	I
BU	N	N	C	C	C	C	C	C	C	C	C	C	N	I	I	I	I	I	I	I	I	I
RS-S	N	I	I	N	N	C	I	I	I	I	I	I	I	N	N	C	C	C	C	C	C	C
RS-U	N	I	I	N	C	C	I	I	I	I	I	I	I	N	C	C	C	C	C	C	C	C
RI-N	N	I	I	N	N	N	I	I	I	I	I	I	I	C	C	N	N	N	N	C	C	C
RI-S	N	I	I	N	N	C	I	I	I	I	I	I	I	C	C	N	N	N	C	C	C	C
RI-U	N	I	I	N	C	C	I	I	I	I	I	I	I	C	C	N	N	C	C	C	C	C
RI-X	N	I	I	C	C	C	I	I	I	I	I	I	I	C	C	N	C	C	C	C	C	C
RX-S	N	I	I	N	N	C	I	I	I	I	I	I	I	C	C	C	C	C	C	C	C	C
RX-U	N	I	I	N	C	C	I	I	I	I	I	I	I	C	C	C	C	C	C	C	C	C
RX-X	N	I	I	C	C	C	I	I	I	I	I	I	I	C	C	C	C	C	C	C	C	C

Key

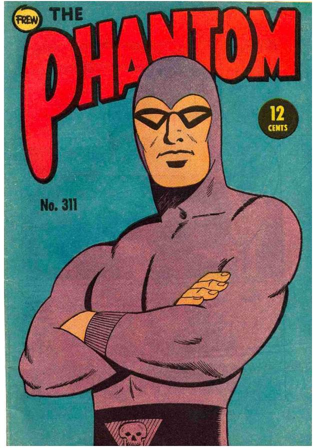
N	No Conflict	SIU	Share with Intent Update
I	Illegal	SIX	Shared with Intent Exclusive
C	Conflict	UIX	Update with Intent Exclusive
		BU	Bulk Update
NL	No Lock	RS-S	Shared Range-Shared
SCH-S	Schema Stability Locks	RS-U	Shared Range-Update
SCH-M	Schema Modification Locks	RI-N	Insert Range-Null
S	Shared	RI-S	Insert Range-Shared
U	Update	RI-U	Insert Range-Update
X	Exclusive	RI-X	Insert Range-Exclusive
IS	Intent Shared	RX-S	Exclusive Range-Shared
IU	Intent Update	RX-U	Exclusive Range-Update
IX	Intent Exclusive	RX-X	Exclusive Range-Exclusive

From MS SQL Server
https://technet.microsoft.com/en-us/library/jj856598(v=sql.110).aspx

For Your Information: Indexes

- **2PL on B+ tree pages is a rotten idea.**
  - Think about the first thing you would lock, and how that affects other xacts!
- **Instead, do short locks (latches) in a clever way**
  - Idea: Upper levels of B+ tree just need to direct traffic correctly. Don't need serializability or 2PL!
  - Different tricks to exploit this
    - The *B-link* tree is elegant
    - The *Bw-tree* is a recent variant for main memory DBs
- **Note: this is pretty complicated!**

For Your Information: Phantoms



- **Suppose you query for sailors with rating between 10 and 20, using an Alternative 2 B+ tree**
  - You set tuple-level locks in the Heap File
- **I insert "Dread Pirate Roberts", with rating 12**
- **You do your query again via the index**
  - Yikes! A phantom
- **Problem: Serializability assumed a static DB**
- **What we want: lock the logical range 10-20**
  - Hard to imagine that lock table! Doesn't work well.
- **What is done: set locks in indexes cleverly**
  - So-called "next key locking"

Summary, cont.

- **Correctness criterion for isolation is "serializability".**
  - In practice, we use "conflict serializability" which is conservative but easy to enforce
- **Two Phase Locking and Strict 2PL: Locks implement the notions of conflict directly**
  - The lock manager keeps track of the locks issued.
  - **Deadlocks** may arise; can either be prevented or detected.
- **Multi-Granularity Locking:**
  - Allows flexible tradeoff between lock "scope" in DB, and # of lock entries in lock table
- **More to the story**
  - Optimistic/Multi-version/Timestamp CC
  - Index "latching", phantoms
  - Actually, there's much much more :-)