Transactions Introduction and Concurrency Control

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Review

Database

Tables

Pages

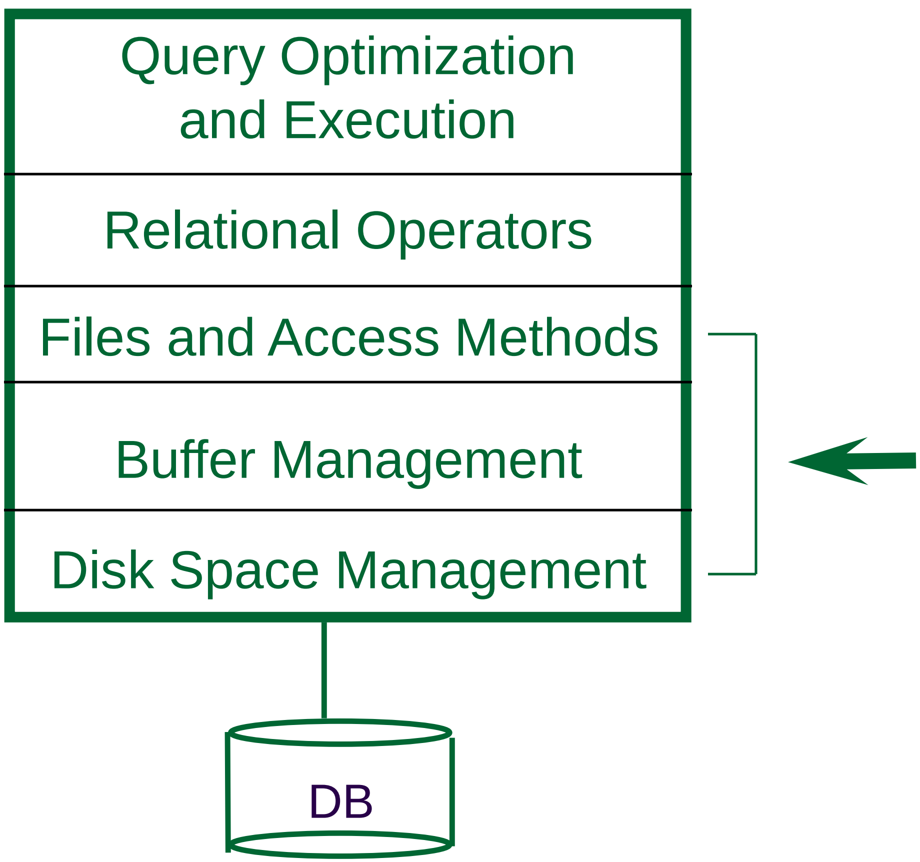
Tuples

- 数据库中的数据对象具有嵌套层次结构
- 数据库操作
  - 读：select
  - 写：insert,delete,update
- 完整性约束：域约束、主键约束、外键约束…

Concurrency Control and Recovery

- Concurrency Control(并发控制)
  - Provide correct and highly available(高可用) data access in the presence of concurrent access by many users.
- Recovery(崩溃恢复)
  - Ensures database is fault tolerant(容错), and not corrupted by software, system or media failure
  - 24x7 access to mission critical data
- A boon to application authors!
  - Existence of CC&R allows applications to be written without explicit concern for concurrency and fault tolerance.

Structure of a DBMS



These layers must consider concurrency control and recovery (Transaction, Lock, Recovery Managers)

Transactions and Concurrent Execution
事务和并发执行

- Transaction ("xact"):
  DBMS's abstract view of a user program (or activity)
  - A sequence of reads and writes of database objects.
  - Batch of work that must commit or abort as an atomic unit

- Transaction Manager controls execution of xacts.
  - User's program logic is invisible to DBMS!
    - Arbitrary computation possible on data fetched from the DB
    - The DBMS only sees data read/written from/to the DB.
  - Challenge: provide atomic xacts to concurrent users!
    - Given only the read/write interface.

A Sample Transaction

```
1:   Begin_Transaction
2:   get (K1, K2, CHF) from terminal
3:   Select BALANCE Into S1 From ACCOUNT Where ACCOUNTNR = K1;
4:   S1 := S1 - CHF;
5:   Update ACCOUNT Set BALANCE = S1 Where ACCOUNTNR = K1;
6:   Select BALANCE Into S2 From ACCOUNT Where ACCOUNTNR = K2;
7:   S2 := S2 + CHF;
8:   Update ACCOUNT Set BALANCE = S2 Where ACCOUNTNR = K2;
9:   Insert Into BOOKING(ACCOUNTNR,DATE,AMOUNT,TEXT)
                 Values (K1, today, -CHF, 'Transfer');
10:  Insert Into BOOKING(ACCOUNTNR,DATE,AMOUNT,TEXT)
                 Values (K2, today, CHF, 'Transfer');
12:  If S1<0 Then Abort_Transaction
11:  End_Transaction
```

Concurrency: Why bother? 动机

- The *latency(延迟)* argument
  - Response time: the average time taken to complete an xact.
    - A short xact could get stuck behind a long xact, leading to unpredictable delays in response time.
- The *throughput(吞吐量)* argument
  - Throughput: the average number of xacts completed in a given time.
    - Overlapping I/O and CPU activity reduces the amount of time disks and CPU are idle.

ACID properties of Transaction Executions

- A tomicity –原子性:
  - All actions in the Xact happen, or none happen.
- C onsistency-一致性:
  - If the DB (Database) starts consistent, it ends up consistent at end of Xact.
- I solation-隔离性:
  - Execution of one Xact is isolated from that of other Xacts.
- D urability-持久性:
  - If an Xact commits, its effects persist.

Implications of Atomicity and Durability

- A transaction **ends** in one of two ways:
  - *commit* (提交)after completing all its actions
    - "commit" is a contract with the caller of the DB
  - *abort* (中止,or be aborted by the DBMS) after executing some actions.
    - Or *system crash* while the xact is in progress; treat as abort.

- *Atomicity* means the effect of aborted xacts must be removed
- *Durability* means the effects of a committed xact must survive failures.

- DBMS ensures the above by *logging* all actions:
  - *Undo（撤销）* the actions of aborted/failed xacts.
  - *Redo（重做）* actions of committed xacts not yet propagated to disk when system crashes.

Transaction Consistency

- Xacts preserve DB *consistency*
  - Given a consistent DB state, produce another consistent DB state
- DB consistency expressed as a set of declarative Integrity Constraints
  - CREATE TABLE/ASSERTION statements
- Xacts that violate ICs are aborted
  - That's all the DBMS can automatically check!

Isolation (Concurrency)

- 并发执行的现象：DBMS interleaves actions of many xacts（交叉执行多个事务的操作）
  - Actions = reads/writes of DB objects
- 隔离性：Users should be able to understand an xact without considering the effect of other concurrently executing xacts.
  - Each xact executes as if it were running by itself.
  - Concurrent accesses have no effect on an xact’s behavior
- 如何确保Isolation？Net effect *must be* identical to executing all xacts for *some* serial order.

Schedule of Executing Transactions

- A schedule(调度，交叉执行的一个操作序列) is
  - a list of actions (READ, WRITE, ABORT, or COMMIT) from a set of xacts,
  - and the order in which two actions of an xact *T* appears in a schedule must be the same as the order in which they appear in *T*.

- A complete schedule(完全调度) is
  - A schedule that contains either an abort or a commit for each xact（每个事务都是结束的）.

A Schedule Involving Two Transactions:

An Incomplete Schedule（不完全调度）

$T1$	$T2$
$R(A)$	
$W(A)$	
	$R(B)$
	$W(B)$
$R(C)$	
$W(C)$	

Serial Schedule

正确的调度

- Serial schedule(串行调度)
  - Each xact runs from start to finish, without any intervening actions from other xacts.
- an example : *T1*; *T2*.

Serializable Schedule-可串行化调度

也是正确的调度

- Two schedules are equivalent if:
  - They involve the same actions of the same xacts,
  - and they leave the DB in the same final state.

- A serializable schedule over a set *S* of xacts is
  - a schedule whose effect on any consistent database instance is guaranteed to be identical to that of **some** complete serial schedule over the set of **committed** xacts in *S*.

A Serializable Schedule of Two Transactions

T1	T2
R(*A*)	
W(*A*)	
	R(*A*)
	W(*A*)
R(*B*)	
W(*B*)	
	R(*B*)
	W(*B*)
	Commit
Commit	

The result of this schedule is equivalent to the result of the serial schedule:
T1; *T2*.

Important Points of Serializability
对于可串行调度，注意以下两点：

T1; *T2*.

① Executing xacts serially in different orders may produce different results,

T2; *T1*.

- but all are presumed to be acceptable; 串行调度是正确的调度
- the DBMS makes no guarantees about which of them will be the outcome of an interleaved execution.

② Uncommitted xacts can appear in a serializable schedule *S*, but their effects are cancelled out by UNDO（撤销）.

Conflicting Actions-冲突操作

- Need an easier check for equivalence of schedules
  - Use notion of “conflicting” actions
    - Anomalies（异常） with interleaved execution are simply caused by conflicting actions.
- Two actions are said conflict if:
  - They are by different xacts,
  - they are on the same object,
  - and at least one of them is a write.
  - Three kinds of conflicts:
    - Write-Read (WR) conflict,
    - Read-Write (RW) and
    - Write-Write (WW) conflicts.

Conflicts: Anomalies（异常） with Interleaved Execution

- Reading Uncommitted Data (WR Conflicts, “dirty reads-脏读”): 读未提交的数据

T1: R(A), W(A), R(B), W(B), Abort
T2: R(A), W(A), Commit

- Unrepeatable Reads (RW Conflicts),不可重复的读:

T1: R(A), R(A), W(A), Commit
T2: R(A), W(A), Commit

Conflicts (Continued)

- Overwriting Uncommitted Data (WW Conflicts): 丢失更新，脏写

T1:	W(A),			W(B), Commit
T2:		W(A),	W(B), Commit	

Schedules Involving Aborted Xacts

- Serializability relies on UNDOing aborted xacts completely, which may be impossible in some situations.

不可恢复调度

An Unrecoverable Schedule:

- T2 has already committed, and so can not be undone.

$T1$	$T2$
$R(A)$	
$W(A)$	
	$R(A)$
	$W(A)$
	$R(B)$
	$W(B)$
	Commit
Abort	

Reading Uncommitted Data (WR Conflicts, “dirty reads-脏读”):

T1:	R(A), W(A),		R(B), W(B), Abort
T2:		R(A), W(A), Commit	

Recoverable Schedule-可恢复调度

- In a recoverable schedule, xacts commit only after (and if) all xacts whose changes they read commit.（有脏读的事务必须在被脏读的事务提交之后再提交）

$T1$	$T2$
$R(A)$	
$W(A)$	
	$R(A)$
	$W(A)$
	$R(B)$
	$W(B)$
	Commit
Abort	

  - If xacts read only the changes of committed xacts（只读取已提交的更改，即没有脏读）, not only is the schedule recoverable,
  - but also can avoid cascading aborts(级联中止).

有脏读的事务

Reading Uncommitted Data (WR Conflicts, “dirty reads-脏读”):

T1:	R(A), W(A),		R(B), W(B), Abort
T2:		R(A), W(A), Commit	

Conflict Serializable Schedules
冲突可串行化调度

- Two schedules are conflict equivalent(冲突等价) if:
  - They involve the same set of actions of the same xacts,
  - and they order every pair of conflicting actions of two committed xacts in the same way.
- Schedule S is conflict serializable if:
  - S is conflict equivalent to some serial schedule.
- Note, some serializable schedules are NOT conflict serializable.
  - A price we pay to achieve efficient enforcement.

Conflict Serializability – Intuition

- A schedule S is conflict serializable if:
  - You can transform S into a serial schedule by swapping **consecutive non-conflicting** operations of different xacts. 交换相邻的两个不冲突的操作
- *Example:*

R(A)	W(A)			R(B)	W(B)		
		R(A)	W(A)			R(B)	W(B)

≡

R(A)	W(A)	R(B)	W(B)				
				R(A)	W(A)	R(B)	W(B)

Serializable Schedule That is Not Conflict Serializable

$T1$	$T2$	$T3$
$R(A)$		
	$W(A)$	
	Commit	
$W(A)$		
Commit		
		$W(A)$
		Commit

- This schedule is equivalent to the serial schedule : *T*1; *T*2; *T*3.

- However it is not conflict quivalent to the serial schedule because the writes of *T*1 and *T*2 are ordered differently.

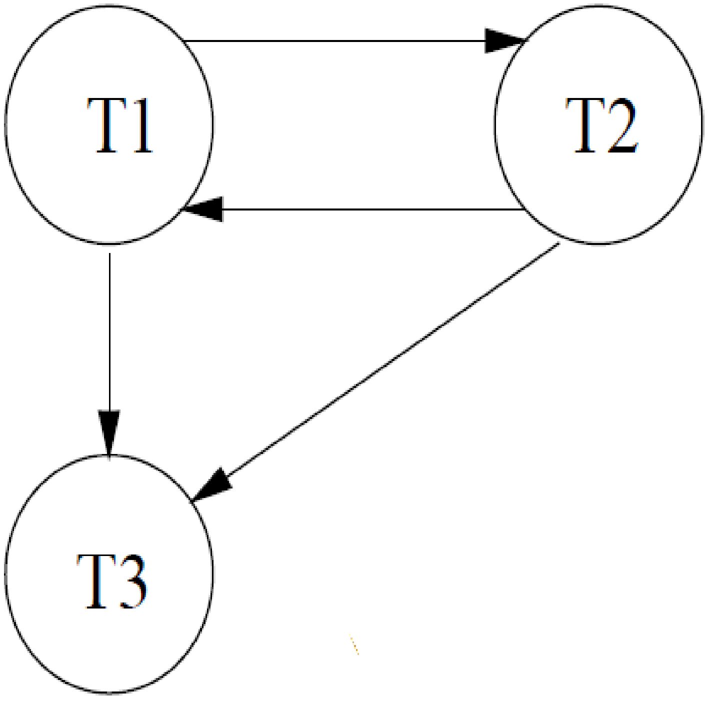
Dependency Graph
依赖图,优先图

- We use a dependency graph, also called a precedence graph, to capture all potential conflicts between the xacts in a schedule.
- The dependency graph for a schedule *S* contains:
  - A node for each committed xact
  - An edge from T_i to T_j if an action of T_i precedes and conflicts with one of T_j's actions.

- Theorem: Schedule is conflict serializable *if and only if* its dependency graph is acyclic.(无环路)

Example of Dependency Graph

$T1$	$T2$	$T3$
$R(A)$		
	$W(A)$	
	Commit	
$W(A)$		
Commit		
		$W(A)$
		Commit



Two-Phase Locking (2PL) 两阶段封锁

- The most common scheme for enforcing conflict serializability.
- "Pessimistic"-悲观的
  - Sets locks for fear of conflict
  - The alternative scheme is called Optimistic (乐观) Concurrency Control.

Two-Phase Locking (2PL)

Lock Compatibility Matrix

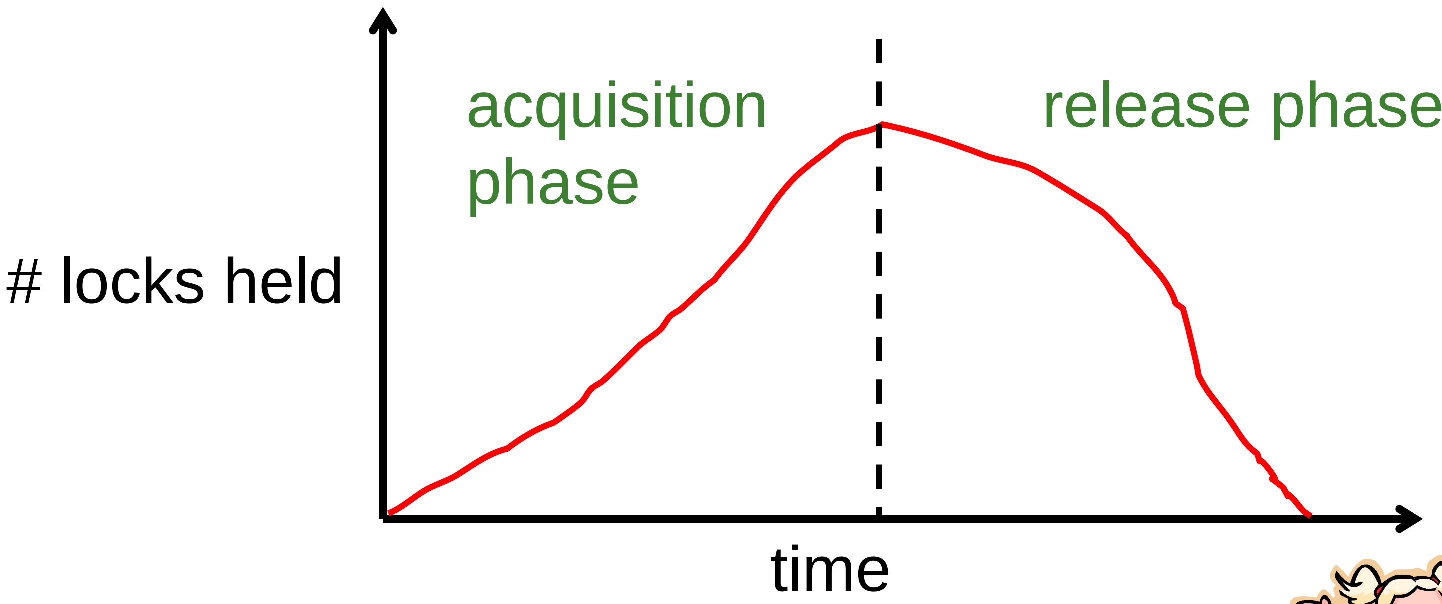
	S	X
S	√	–
X	–	–

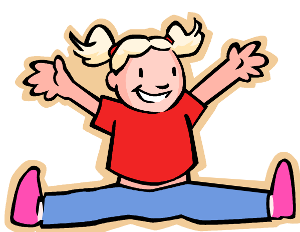
rules:

- An xact must obtain
  - a **S** (*shared*) lock before reading, 共享锁、读锁
  - and an **X** (*exclusive*) lock before writing. 排他锁、写锁

- An xact cannot request additional locks once it releases any lock.

Two-Phase Locking (2PL), cont.



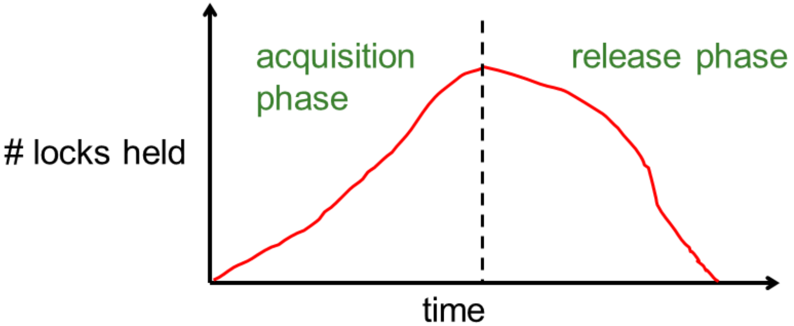


2PL guarantees conflict serializability

反证：使用依赖图，若一个事务处于环中，则不能到达最高点

But, does *not* prevent **Cascading Aborts**.

Strict 2PL
严格的2PL

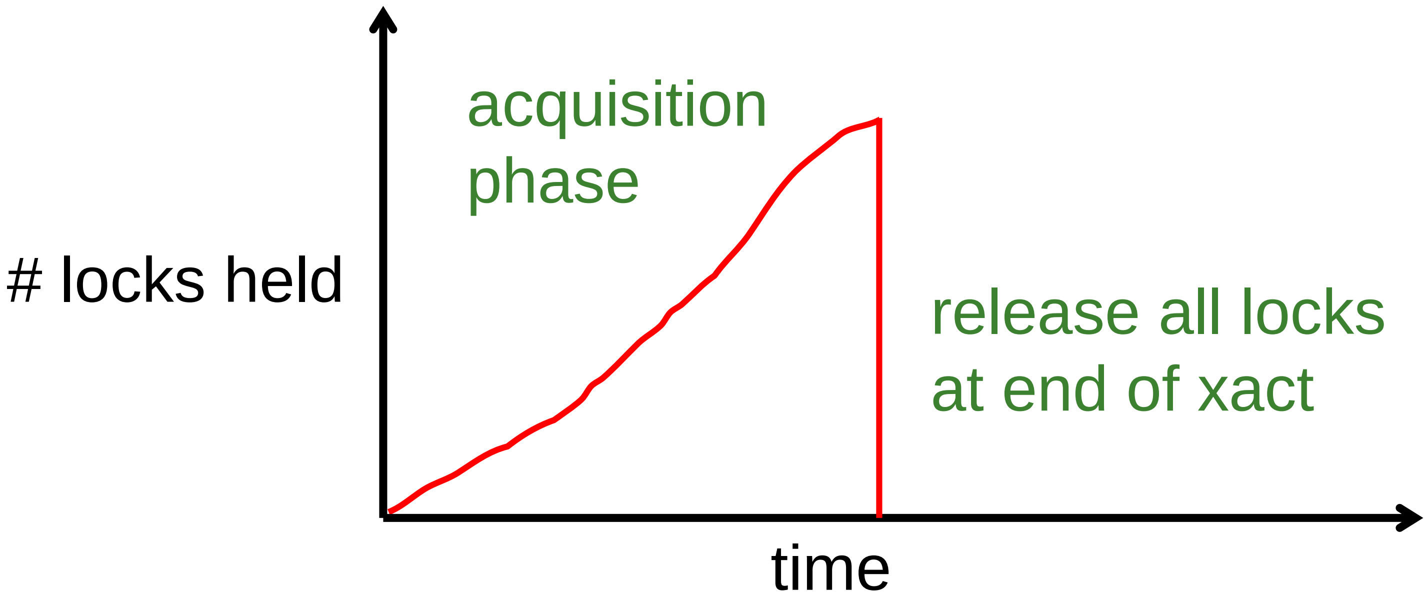


- *Problem:* Cascading Aborts（存在脏读）
- *Example:* rollback of T1 requires rollback of T2!

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

- Strict Two-phase Locking (Strict 2PL) protocol:
  Same as 2PL, except:
  Locks released only when an xact completes
  i.e., either:
  (a) the xact has committed (commit record on disk),
  or
  (b) the xact has aborted and rollback is complete.

Strict 2PL (continued)



T1:	R(A), W(A), R(B), W(B),	Commit/Abort	
T2:			R(A), W(A)

xacts read only the changes of committed xacts（避免脏读）

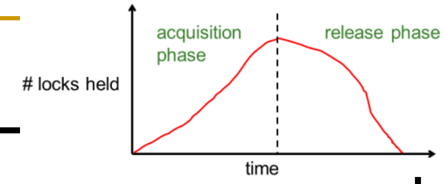
Next ...

- A few examples

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

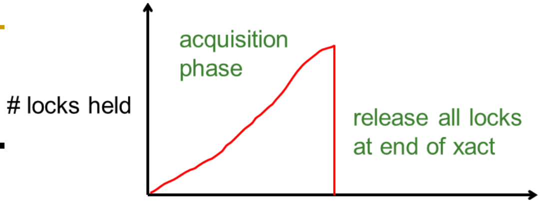
Lock_X(A)	
Read(A)	Lock_S(A)
A: = A-50	
Write(A)	
Unlock(A)	
	Read(A)
	Unlock(A)
	Lock_S(B)
Lock_X(B)	
	Read(B)
	Unlock(B)
	PRINT(A+B)
Read(B)	
B := B +50	
Write(B)	
Unlock(B)	

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



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

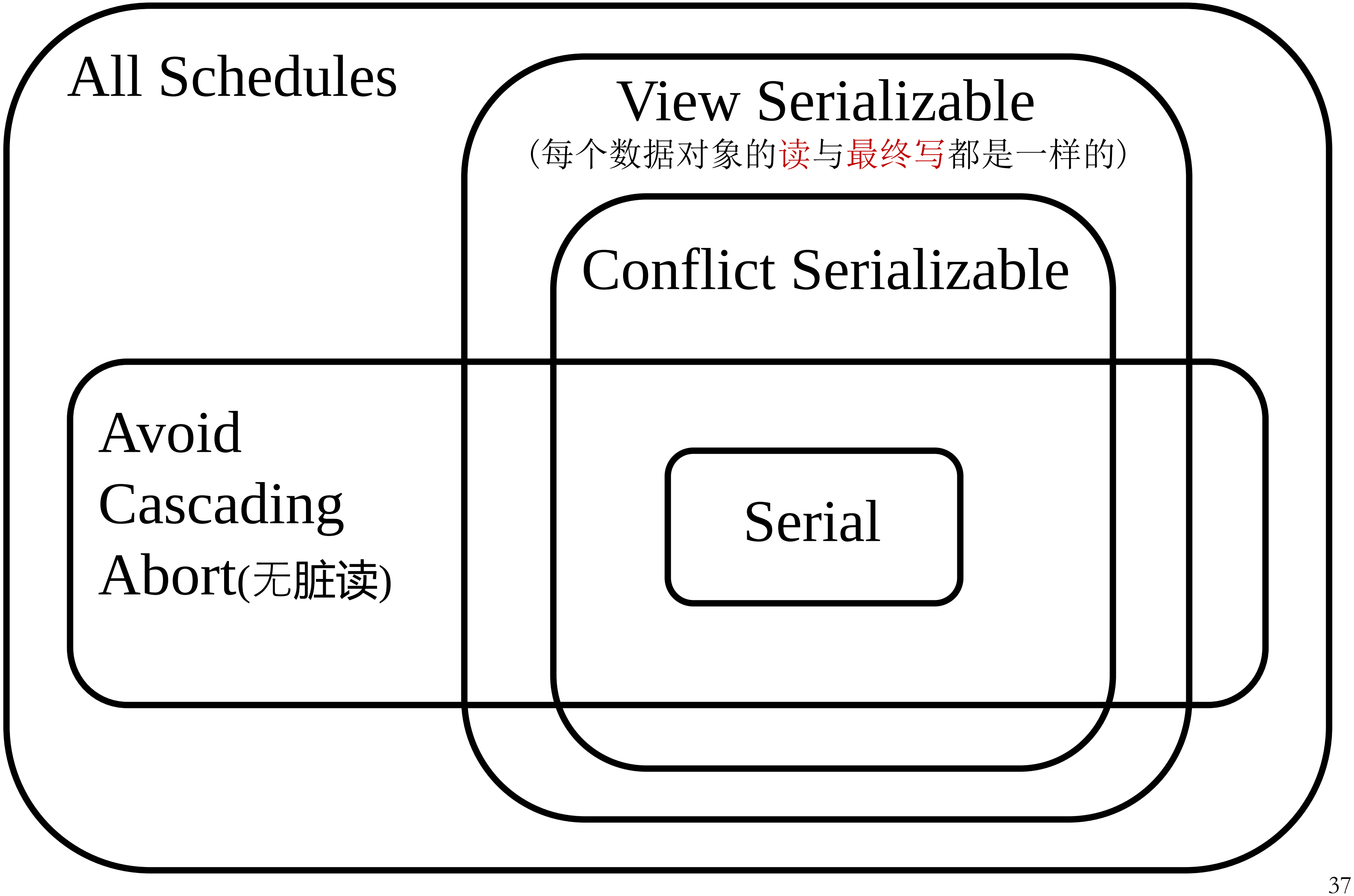
Strict 2PL, A= 1000, B=2000, Output =?



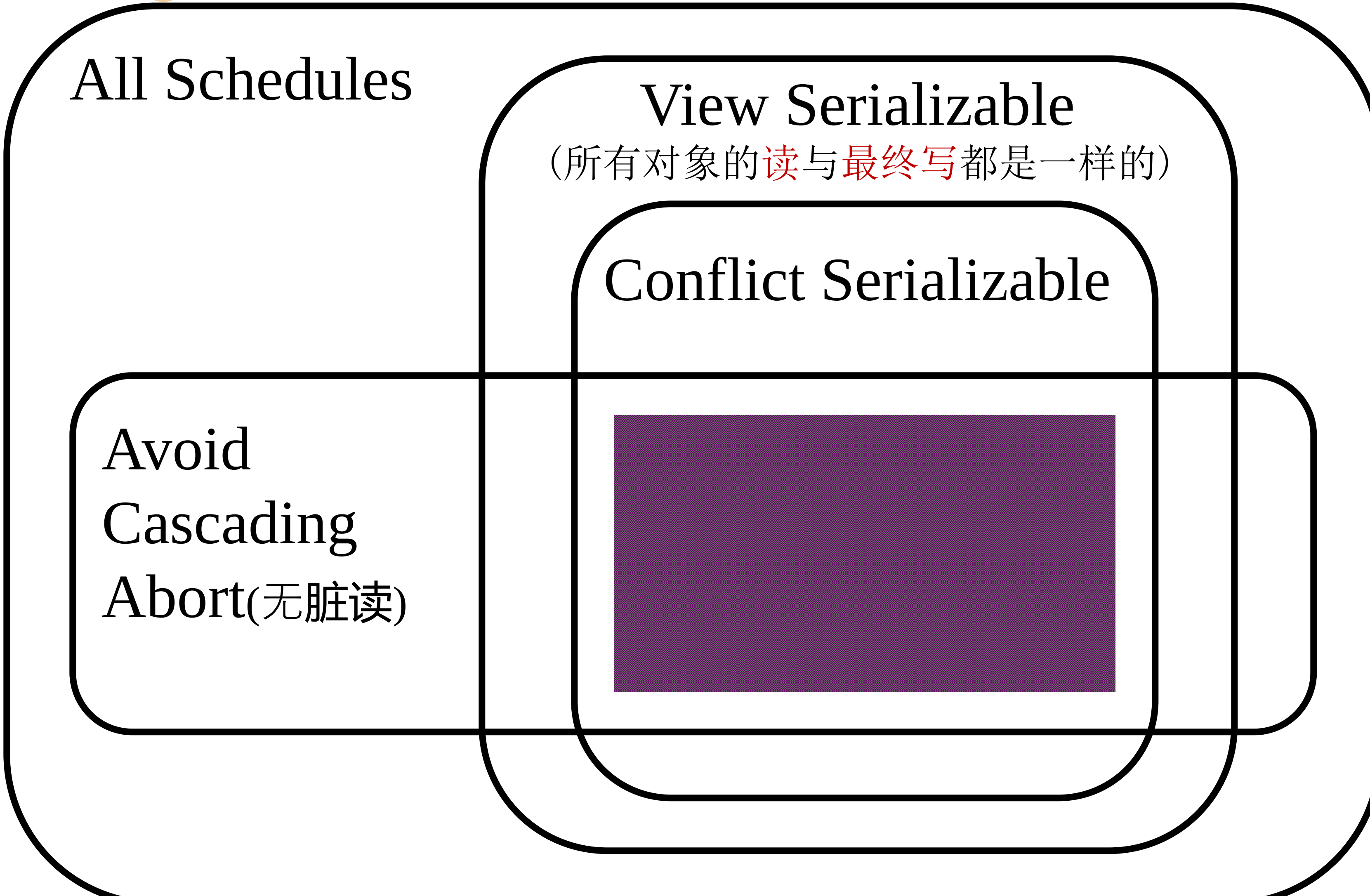
- 编程好处:只需定义事务即可
- 提高并发度的情况: 无冲突

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+B)
	Unlock(A)
	Unlock(B)

Venn Diagram for Schedules



Which schedules does Strict 2PL allow?



Lock Management 封锁管理

- Lock and unlock requests handled by Lock Manager.
- LM keeps an entry for each currently held lock.
- Entry contains:
  - 某个数据对象标识
  - Type of lock held (shared or exclusive)
  - List of xacts currently holding lock
  - Queue of lock requests

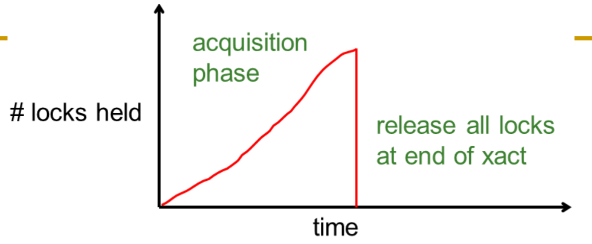
Lock Management (Contd.)

- Entry contains:
  - 某个数据对象标识
  - List of xacts currently holding lock
  - Type of lock held (shared or exclusive)
  - Queue of lock requests

- When lock request arrives:
  - Does any other transaction hold a conflicting lock?
    - If no, grant the lock.
    - If yes, put requestor into wait queue.

- Lock upgrade(锁升级):
  - A transaction with shared lock can request to upgrade to exclusive.

Deadlocks-死锁



- Deadlock: Cycle of transactions waiting for locks to be released by each other.

- Ways of dealing with deadlocks:
  - prevention 预防
  - Detection 检测
  - avoidance 避免

- Many systems just punt and use Timeouts（超时策略）
  - What are the dangers with this approach?

Deadlock Prevention 死锁预防

- Common technique in operating systems
- Standard approach: resource ordering 资源排序
  - Screen < Network Card < Printer
- Why is this problematic for Xacts in a DBMS? 数据对象太多，难以排序

Deadlock Detection 死锁检测

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

Deadlock Detection (Continued)

"waits-for" graph 等待图

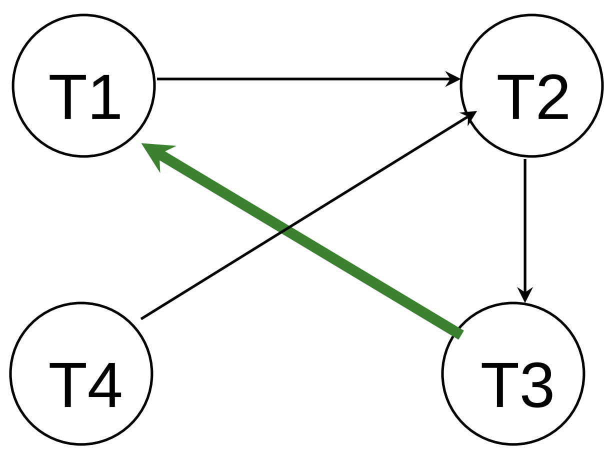
Example:

T1: S(A), S(D), S(B)

T2: X(B), X(C)

T3: S(D), S(C), X(A)

T4: X(B)



Deadlock Avoidance 死锁避免

- 为每个事务 Assign priorities based on timestamps(时间戳). 事务的启动时间越早，其优先级越高
- Say Ti wants a lock that Tj holds

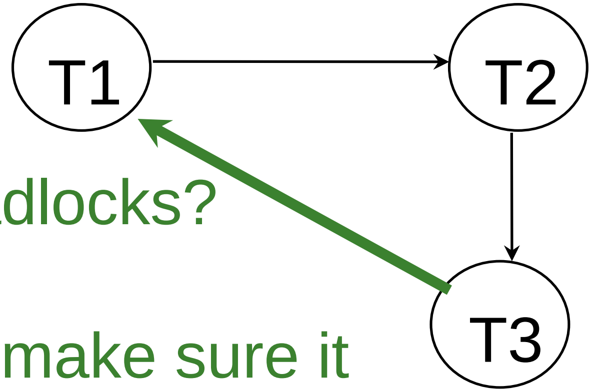
  Two policies are possible:

  1. **Wait-Die(等待-死亡)**: If Ti has higher priority, Ti waits for Tj; otherwise Ti aborts.即：高优先级等待低优先级事务

     高→低

  2. **Wound-wait(伤害-等待)**: If Ti has higher priority, Tj aborts; otherwise Ti waits.即：低优先级等待高优先级事务

     低→高



- Why do these schemes guarantee no deadlocks? 不会出现闭环
- Important detail: If a transaction re-starts, make sure it gets its original timestamp. -- Why?

Locking Granularity(封锁粒度) 封锁对象的大小

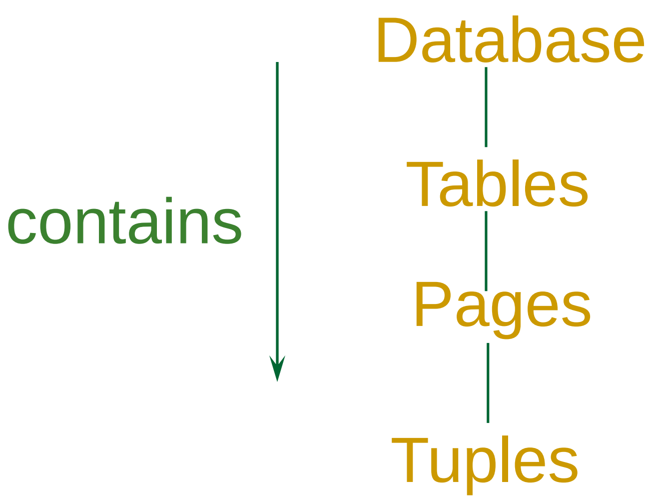
(tuples vs. pages vs. tables)

- Entry contains:
  - 某个数据对象标识
  - List of xacts currently holding lock
  - Type of lock held (shared or exclusive)
  - Queue of lock requests

- Hard to decide what granularity to lock.
- *why?　锁开销和并发度*
  - 封锁粒度越细，封锁的开销越大，但并发度越高
  - 封锁粒度越粗，封锁的开销越小，但并发度越低

Multiple-Granularity Locks
多粒度封锁

- Shouldn’t have to make same decision for all transactions!
- Data “containers” are nested（数据对象的嵌套层次结构）:



Solution: New Lock Modes, Protocol

- Allow Xacts to lock at each level, but with a special protocol using new "intent" locks:

意向锁

部分读
  - IS – Intent to get S lock(s) at finer granularity.

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

Database
Tables
Pages
Tuples

全读 全写

- Still need S and X locks, but before locking an item, Xact must have proper intent locks on all its ancestors in the granularity hierarchy.

Lock Compatibility Matrix

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

S 全读
X 全写
IS 部分读
IX 部分写

Database
Tables
Pages
Tuples

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.

Multiple Granularity Lock Protocol

Database

Tables

Pages

Tuples

- 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.

Protocol is correct in that it is equivalent to directly setting locks at the leaf levels of the hierarchy.

Examples – 2 level hierarchy

Tables

Tuples

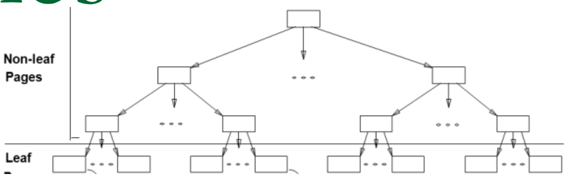
- T1 scans R, and updates a few tuples:
  - T1 gets an SIX lock on R, then get X lock on tuples that are updated.
- T2 uses an index to read only part of R:
  - T2 gets an IS lock on R, and repeatedly gets an S lock on tuples of R.
- T3 reads all of R:
  - T3 gets an S lock on R.
  - OR, T3 could behave like T2; can use lock escalation(锁升级) to decide which.
    - Lock escalation dynamically asks for coarser-grained locks when too many low level locks acquired

	IS	IX	SIX	S	X
IS	√	√	√	√	
IX	√	√			
SIX	√				
S	√			√	
X					

Just so you're aware: Optimistic CC

- Basic idea: let all transactions run to completion
  - Make tentative updates on private copies of data
  - At commit time, check schedules for serializability
  - If you can't guarantee it, restart transaction
    else "install" updates in DBMS
- Pros & Cons
  - No waiting or lock overhead in serializable cases
  - Restarted transactions waste work, slow down others
- OCC a loser to 2PL in traditional DBMSs
  - Plays a secondary role in some DBMSs

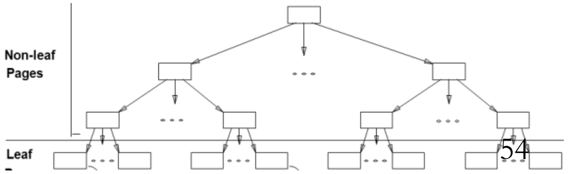
Just So You're Aware: Indexes



- 2PL on B+-tree pages is a rotten idea.
  - Why? 封锁根节点相当于封锁整棵树
- Instead, do short locks (latches,闩锁,短期锁) in a clever way
  - Idea: Upper levels of B+-tree just need to direct traffic correctly. Don't need to be serializably handled!
  - Different tricks to exploit this
- Note: this is pretty complicated!

Just So You're Aware: Phantoms-幻影

- 事务1：Suppose you query for sailors with rating between 10 and 20, using a B+-tree
  - Tuple-level locks in the Heap File
- 事务2： I insert a Sailor with rating 12
- 事务1： You do your query again
  - Yikes! A phantom!
  - Problem: Serializability assumed a static DB!
- What we want: (谓词锁)lock the *logical* range 10-20
  - Imagine that lock table!
  - What is done: set locks in indexes cleverly



Summary

- Correctness criterion for isolation is “serializability”.
  - In practice, we use “conflict serializability,” which is somewhat more restrictive 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 locking overhead in RAM and CPU
- More to the story
  - Optimistic/Multi-version/Timestamp CC
  - Index “latching”, phantoms

Summary

- 要求:
  - 理解串行调度、可串行化调度、冲突可串行化调度、可恢复调度、避免级联中止、严格调度的概念
    - 有脏读X-R（但后提交） 无脏读X-R 无脏读/写 X-R/X
  - 能够根据给定的一个调度，绘制其优先图，从而判断是否冲突可串行化调度？
  - 理解2PL、严格2PL协议，能够绘制等待图并判断是否存在死锁？