Last Class

- Leader election
- Distributed mutual exclusion

Transactions

- Transactions provide higher level mechanism for *atomicity* of processing in distributed systems
  - Have their origins in databases
- Banking example: Three accounts A:\$100, B:\$200, C:\$300
  - Client 1: transfer \$4 from A to B
  - Client 2: transfer \$3 from C to B
- Result can be inconsistent unless certain properties are imposed on the accesses

Client 1	Client 2
Read A: \$100	
Write A: \$96	
	Read C: \$300
	Write C:\$297
Read B: \$200	
	Read B: \$200
	Write B:\$203
Write B:\$204	

ACID Properties

- *Atomic:* all or nothing
- *Consistent*: transaction takes system from one consistent state to another
- *Isolated*: Immediate effects are not visible to other (serializable)
- *Durable:* Changes are permanent once transaction completes (commits)

Client 1	Client 2
Read A: $100	
Write A: $96	
Read B: $200	
Write B:$204	
	Read C: $300
	Write C:$297
	Read B: $204
	Write B:$207

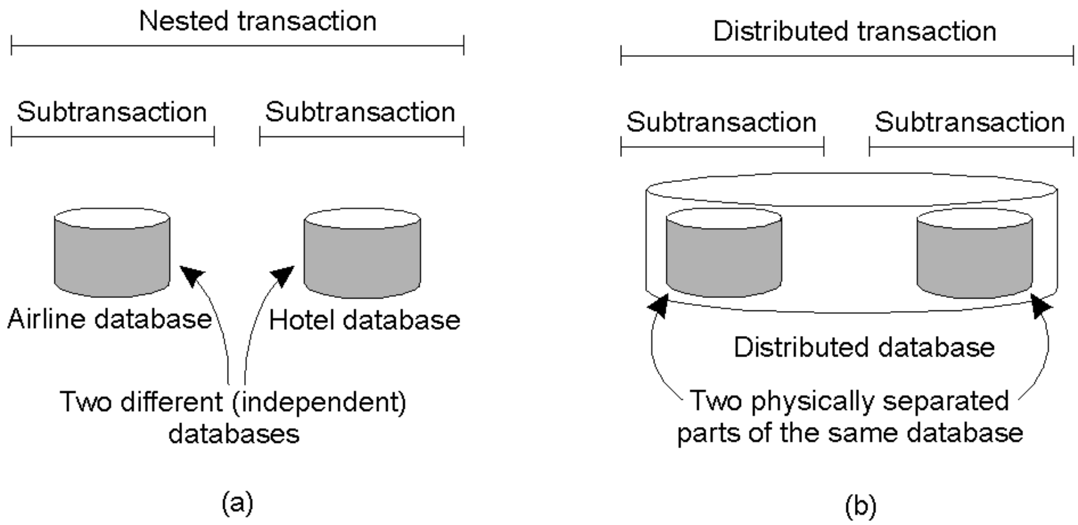
Transaction Primitives

Primitive	Description
BEGIN_TRANSACTION	Make the start of a transaction
END_TRANSACTION	Terminate the transaction and try to commit
ABORT_TRANSACTION	Kill the transaction and restore the old values
READ	Read data from a file, a table, or otherwise
WRITE	Write data to a file, a table, or otherwise

Example: airline reservation

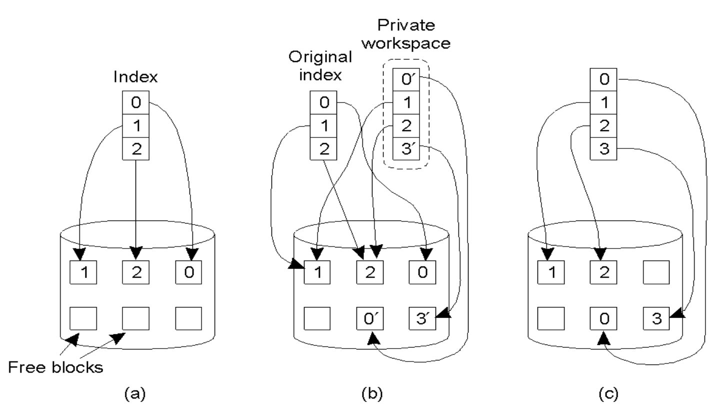
```
Begin_transaction
    if(reserve(NY,Paris)==full) Abort_transaction
    if(reserve(Paris,Athens)==full)Abort_transaction
    if(reserve(Athens,Delhi)==full) Abort_transaction
End_transaction
```

Distributed Transactions



Implementation: Private Workspace

- Each transaction get copies of all files, objects
- Can optimize for reads by not making copies
- Can optimize for writes by copying only what is required
- Commit requires making local workspace global



Option 2: Write-ahead Logs

- *In-place updates*: transaction makes changes *directly* to all files/objects
- *Write-ahead log:* prior to making change, transaction writes to log on *stable storage*
  - Transaction ID, block number, original value, new value
- Force logs on commit
- If abort, read log records and undo changes [*rollback*]
- Log can be used to rerun transaction after failure

- Both workspaces and logs work for distributed transactions
- Commit needs to be *atomic* [will return to this issue in Ch. 7]

Writeahead Log Example

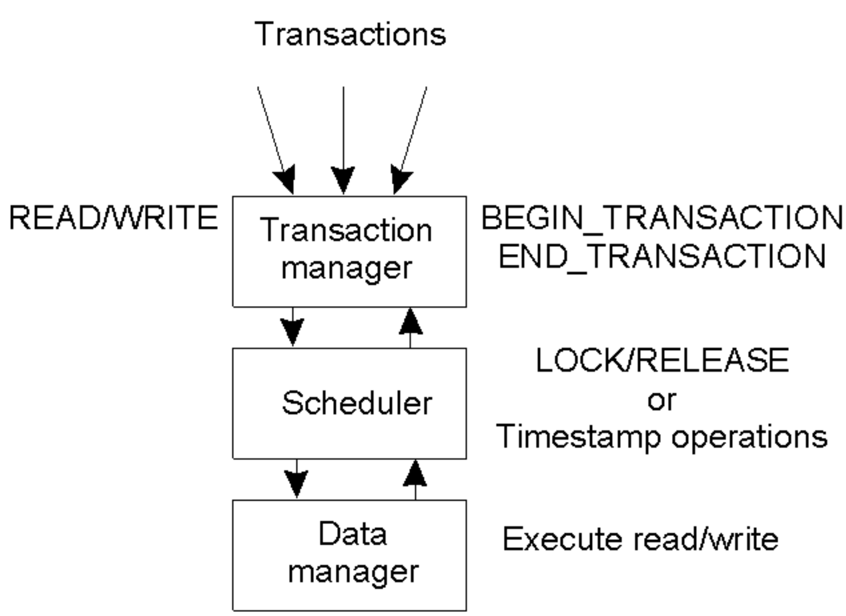
	Log	Log	Log
x = 0;			
y = 0;			
BEGIN_TRANSACTION;			
x = x + 1;	[x = 0 / 1]	[x = 0 / 1]	[x = 0 / 1]
y = y + 2		[y = 0/2]	[y = 0/2]
x = y * y;			[x = 1/4]
END_TRANSACTION;			
(a)	(b)	(c)	(d)

- a) A transaction
- b) – d) The log before each statement is executed

Concurrency Control

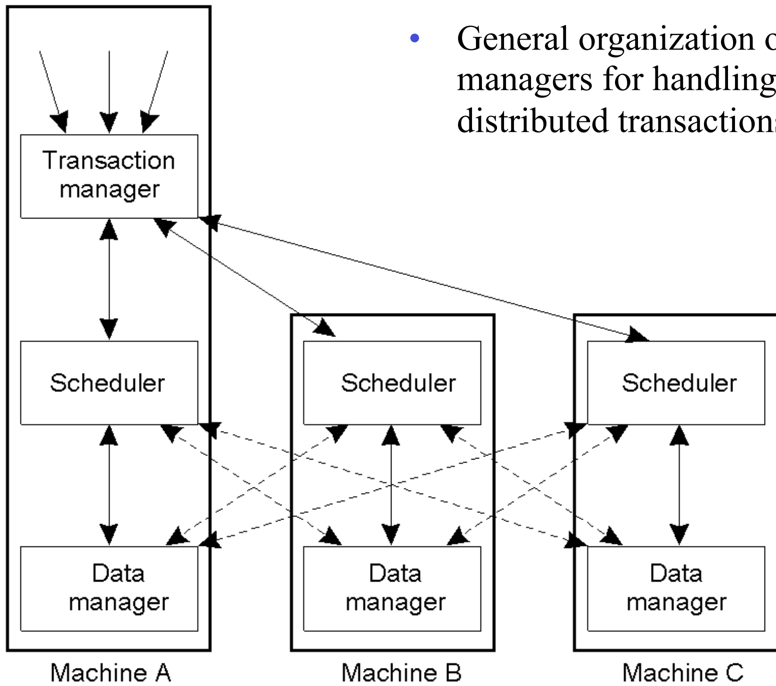
- Goal: Allow several transactions to be executing simultaneously such that
  - Collection of manipulated data item is left in a consistent state
- Achieve consistency by ensuring data items are accessed in an specific order
  - Final result should be same as if each transaction ran sequentially
- Concurrency control can implemented in a *layered* fashion

Concurrency Control Implementation



- General organization of managers for handling transactions.

Distributed Concurrency Control



- General organization of managers for handling distributed transactions.

Serializability

BEGIN_TRANSACTION
x = 0;
x = x + 1;
END_TRANSACTION
	BEGIN_TRANSACTION
	x = 0;
	x = x + 2;
	END_TRANSACTION
		BEGIN_TRANSACTION
		x = 0;
		x = x + 3;
		END_TRANSACTION

(a)	(b)	(c)

Schedule 1	x = 0; x = x + 1; x = 0; x = x + 2; x = 0; x = x + 3	Legal
Schedule 2	x = 0; x = 0; x = x + 1; x = x + 2; x = 0; x = x + 3;	Legal
Schedule 3	x = 0; x = 0; x = x + 1; x = 0; x = x + 2; x = x + 3;	Illegal

- Key idea: properly schedule conflicting operations
- Conflict possible if at least one operation is write
  - Read-write conflict
  - Write-write conflict

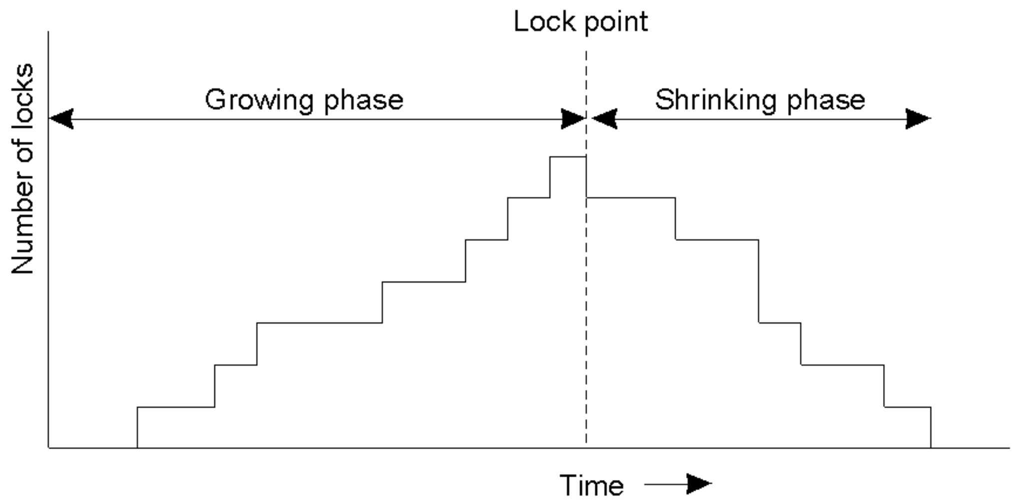
Optimistic Concurrency Control

- Transaction does what it wants and *validates* changes prior to commit
  - Check if files/objects have been changed by committed transactions since they were opened
  - Insight: conflicts are rare, so works well most of the time
- Works well with private workspaces
- Advantage:
  - Deadlock free
  - Maximum parallelism
- Disadvantage:
  - Rerun transaction if aborts
  - Probability of conflict rises substantially at high loads
- Not used widely

Two-phase Locking

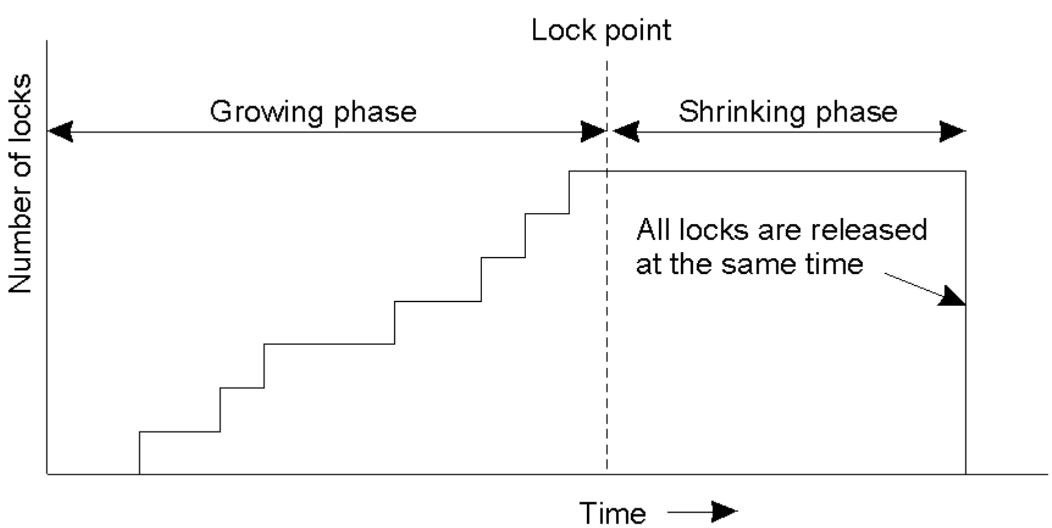
- Widely used concurrency control technique
- Scheduler acquires all necessary locks in growing phase, releases locks in shrinking phase
  - Check if operation on *data item x* conflicts with existing locks
    - If so, delay transaction. If not, grant a lock on *x*
  - Never release a lock until data manager finishes operation on *x*
  - One a lock is released, no further locks can be granted
- Problem: deadlock possible
  - Example: acquiring two locks in different order
- Distributed 2PL versus centralized 2PL

Two-Phase Locking



- Two-phase locking.

Strict Two-Phase Locking



- Strict two-phase locking.

Timestamp-based Concurrency Control

- Each transaction Ti is given timestamp ts(Ti)
- If Ti wants to do an operation that conflicts with Tj
  - Abort Ti if *ts(Ti)* < *ts(Tj)*
- When a transaction aborts, it must restart with a new (larger) time stamp
- Two values for each data item *x*
  - *Max-rts(x):* max time stamp of a transaction that read *x*
  - *Max-wts(x):* max time stamp of a transaction that wrote *x*

Reads and Writes using Timestamps

- $Read_i(x)$
  - If $ts(T_i) < max\text{-}wts(x)$ then Abort T_i
  - Else
    - Perform $R_i(x)$
    - $Max\text{-}rts(x) = \max(max\text{-}rts(x), ts(T_i))$
- $Write_i(x)$
  - If $ts(T_i)<max\text{-}rts(x)$ or $ts(T_i)<max\text{-}wts(x)$ then Abort T_i
  - Else
    - Perform $W_i(x)$
    - $Max\text{-}wts(x) = ts(T_i)$

Pessimistic Timestamp Ordering