# Last Class: Canonical Problems

- Election algorithms
  - Bully algorithm
  - Ring algorithm
- Distributed synchronization and mutual exclusion



# Today: More on Transactions

- Distributed transactions
- Implementation issues
  - Workspaces
  - Writeahead logs
- Concurrency control
  - Two phase locks
  - Time stamps

# 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

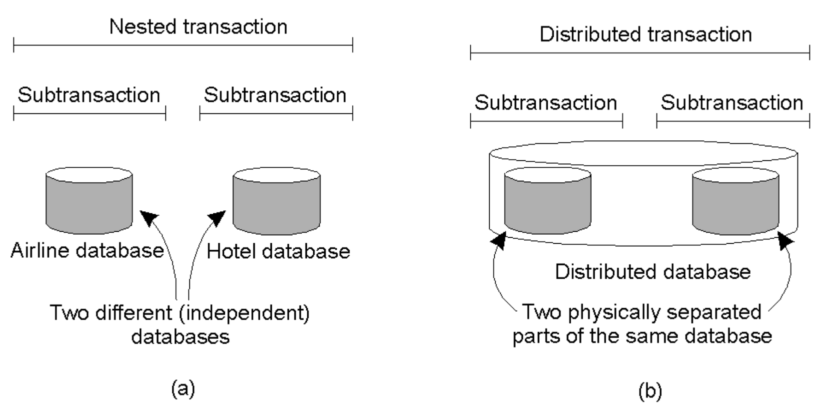
| Primitive | Description |
|---|---|
| BEGIN_TRANSACTION | Make the start of a transaction |
| END_TRANSACTION | Terminate the transaction and try to commit |
| ABORT_TRANSACTION | Kill the transaction and restore the old values |
| READ | Read data from a file, a table, or otherwise |
| WRITE | Write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

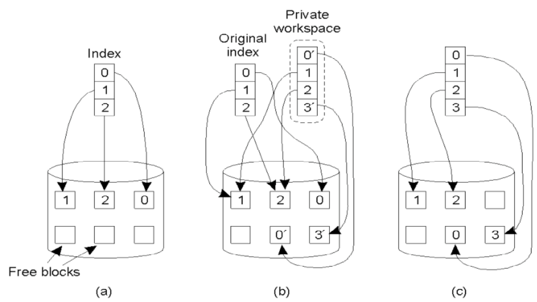


# Distributed Transactions



# 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) |

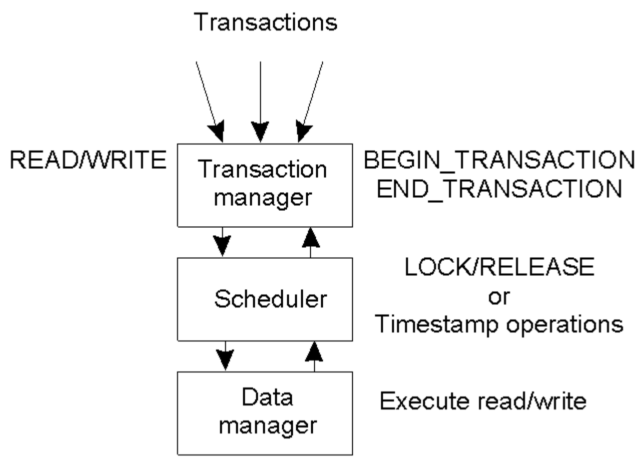
- a) A transaction
- b) – d) The log before each statement is executed



# 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

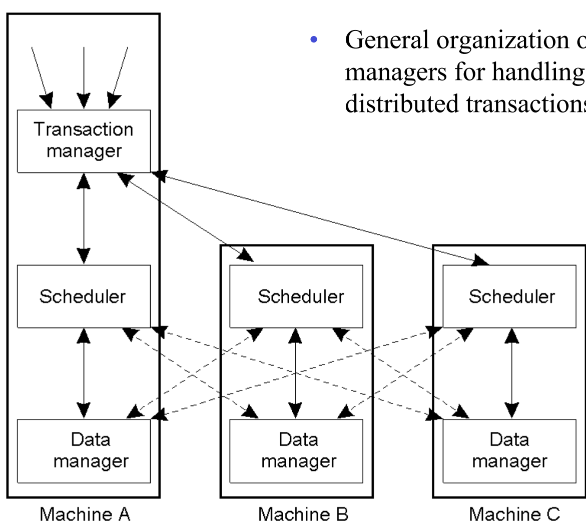



- General organization of managers for handling transactions.



# Distributed Concurrency Control

- General organization of managers for handling distributed transactions.



# Serializability

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

(a)

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

(b)

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

(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

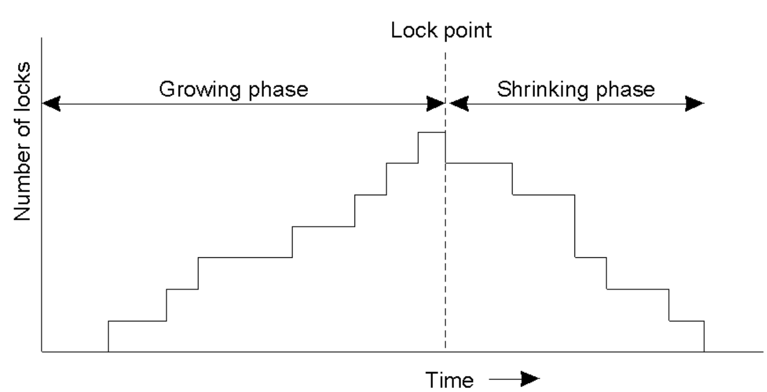
- Transaction does what it wants and *validates* changes prior to commit
  - Check if files/objects have been changed by committed transactions since they were opened
  - Insight: conflicts are rare, so works well most of the time
- Works well with private workspaces
- Advantage:
  - Deadlock free
  - 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

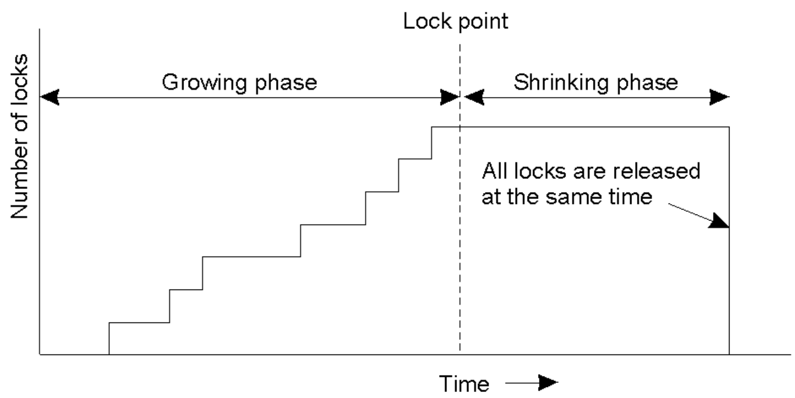


# Two-Phase Locking




- 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