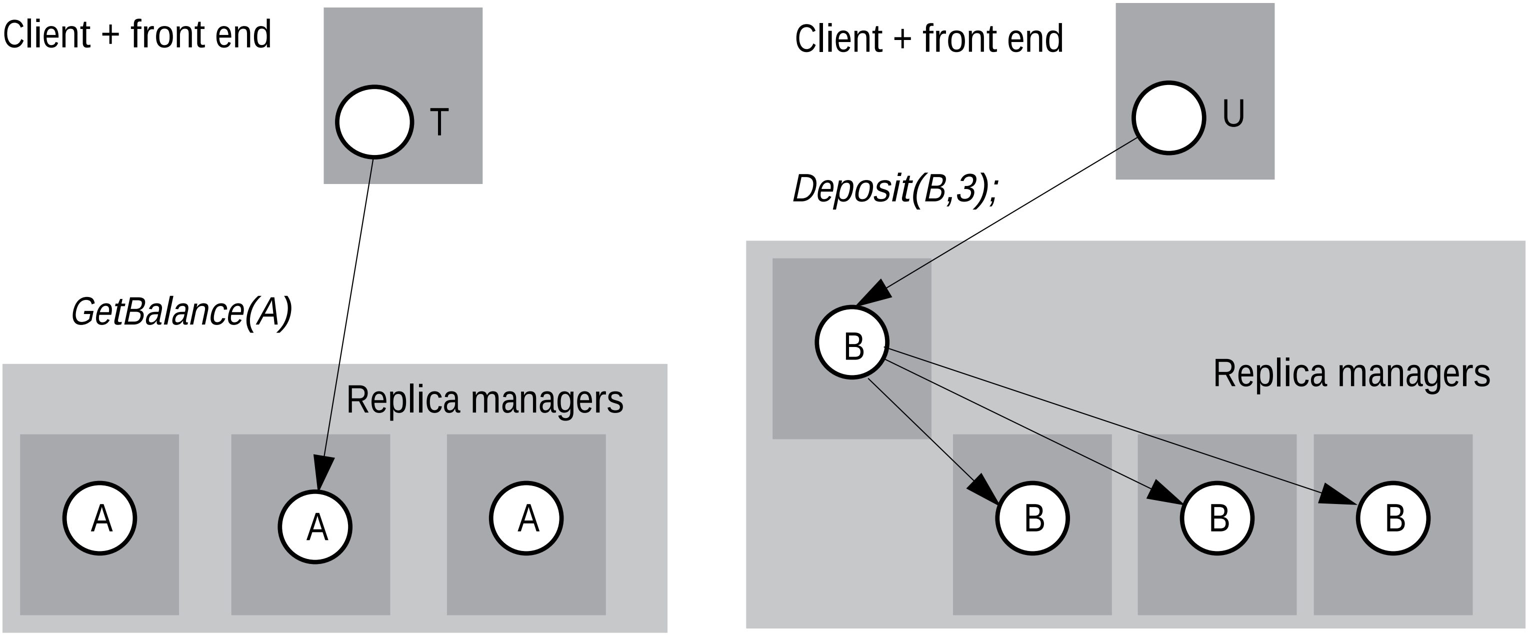
Transactions with Replicated Data

Distributed Software Systems

One copy serializability

- Replicated transactional service
  - Each replica manager provides concurrency control and recovery of its own data items in the same way as it would for non-replicated data
- Effects of transactions performed by various clients on replicated data items are the same as if they had been performed one at a time on a single data item
- Additional complications: failures, network partitions
  - Failures should be serialized wrt transactions, i.e. any failure observed by a transaction must appear to have happened before a transaction started

Figure 14.18 Replicated transactional service.



Replication Schemes

- Read one – Write All
  - Cannot handle network partitions
- Schemes that can handle network partitions
  - Available copies with validation
  - Quorum consensus
  - Virtual Partition

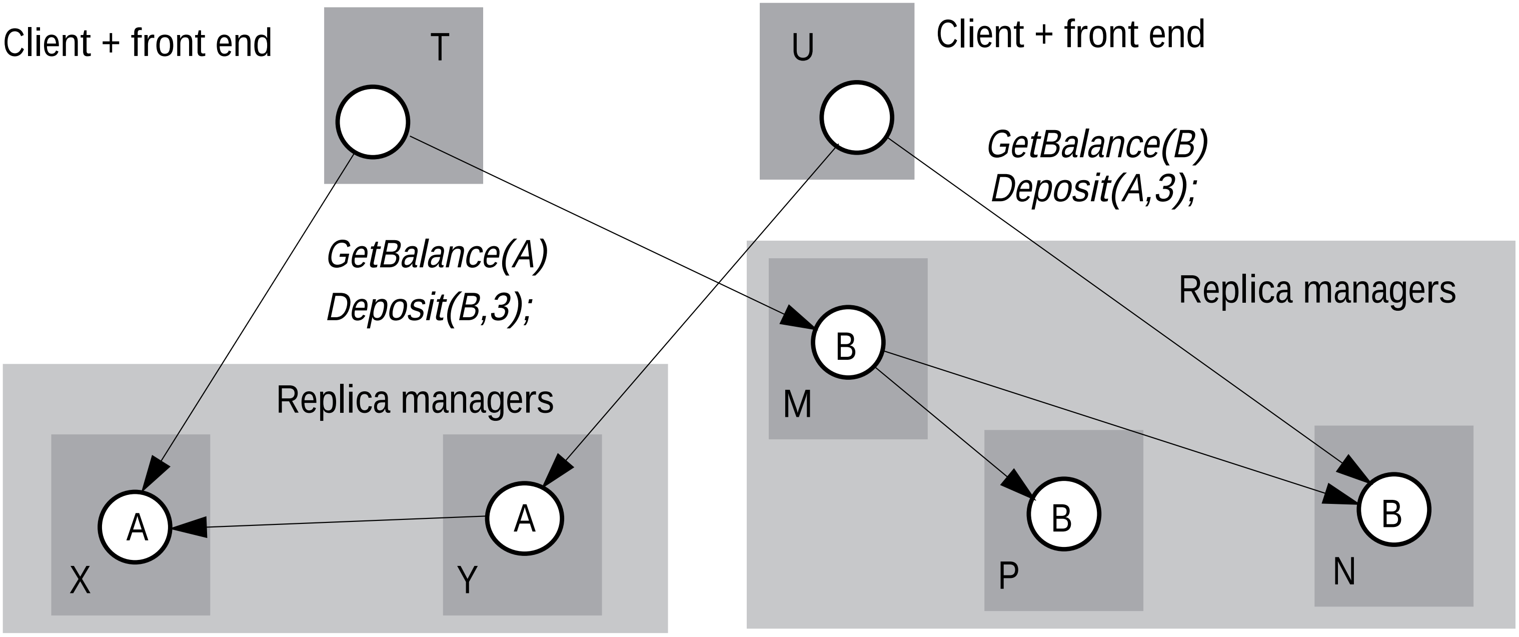
Read one/Write All

- One copy serializability
  - Each write operation sets a write lock at each replica manager
  - Each read sets a read lock at one replica manager
- Two phase commit
  - Two-level nested transaction
    - Coordinator -> Workers
    - If either coordinator or worker is a replica manager, it has to communicate with replica managers
- Primary copy replication
  - ALL client requests are directed to a single primary server
    - Different from scheme discussed earlier

Available copies replication

- Can handle some replica managers are unavailable because they have failed or communication failure
- Reads can be performed by any available replica manager but writes must be performed by all available replica managers
- Normal case is like read one/write all
  - *As long as the set of available replica managers does not change during a transaction*

Figure 14.19 Available copies.



Available copies replication

- Failure case
  - One copy serializabilty requires that failures and recovery be serialized wrt transactions
  - This is not achieved when different transactions make conflicting failure observations
  - Example shows local concurrency control not enough
  - Additional concurrency control procedure (called *local validation*) has to be performed to ensure correctness
- Available copies with local validation assumes no network partition - i.e. functioning replica managers can communicate with one another

Local validation - example

- Assume X fails just after T has performed GetBalance and N fails just after U has performed GetBalance
- Assume X and N fail before T & U have performed their Deposit operations
  - T’s Deposit will be performed at M & P while U’s Deposit will be performed at Y
  - Concurrency control on A at X does not prevent U from updating A at Y; similarly concurrency control on B at N does not prevent Y from updating B at M & P
  - Local concurrency control not enough!

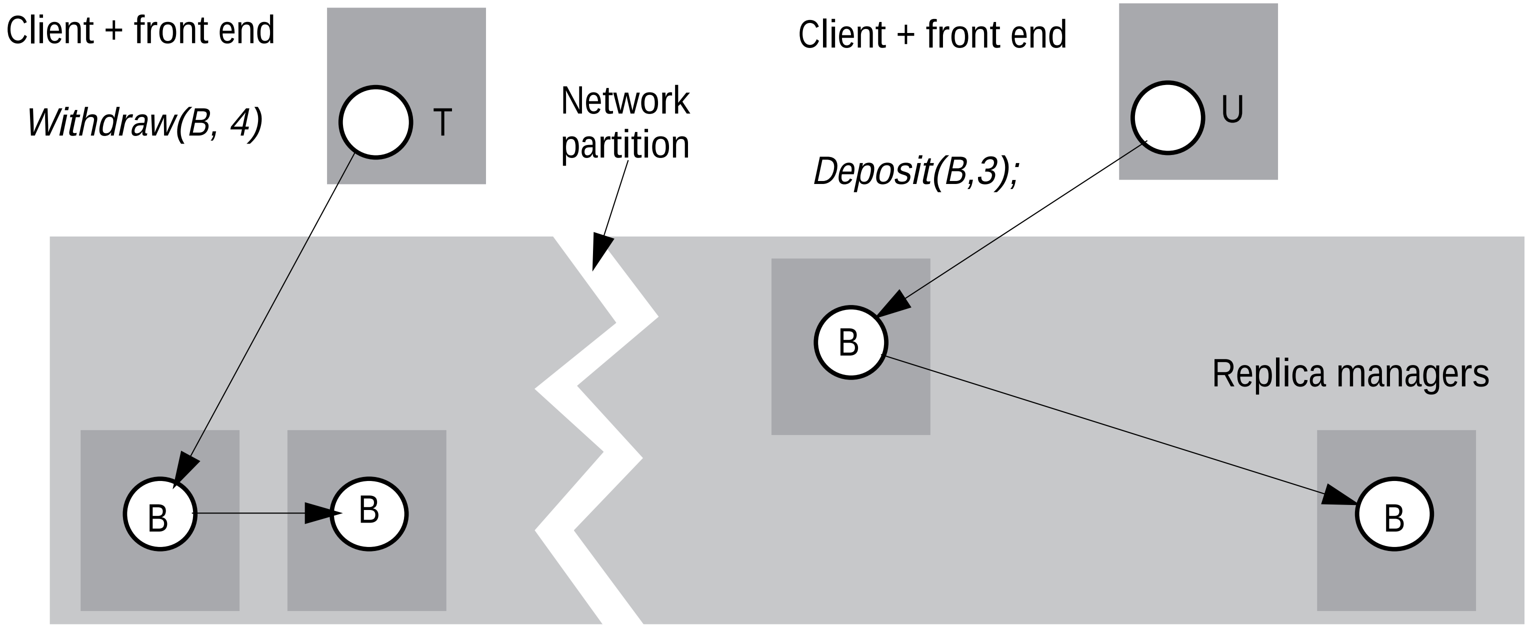
Local validation cont’d

- T has read from an item at X, so X’s failure must be *after* T.
- T observes the failure of N, so N’s failure must be *before* T
  - N fails -> T reads A at X; T writes B at M & P -> T commits -> X fails
  - Similarly, we can argue:
    X fails -> U reads B at N; U writes A at Y -> U commits -> N fails

Local validation cont’d

- Local validation ensures such incompatible sequences cannot both occur
- Before a transaction commits it checks for failures (and recoveries) of replica managers of data items it has accessed
- In example, if T validates before U, T would check that N is still unavailable and X,M, P are available. If so, it can commit
- U’s validation would fail because N has already failed.

Figure 14.20 Network partition.



Handling Network Partitions

- Network partitions separate replica managers into two or more subgroups, in such a way that the members of a subgroup can communicate with one another but members of different subgroups cannot communicate
- Optimistic approaches
  - Available copies with validation
- Pessimistic approaches
  - Quorum consensus

Available Copies With Validation

- Available copies algorithm applied within each partition
  - Maintains availability for Read operations
- When partition is repaired, possibly conflicting transactions in separate partitions are validated
  - The effects of a committed transaction that is now aborted on validation will have to be undone
    - Only feasible for applications where such compensating actions can be taken

Available copies with validation cont'd

- Validation
  - Version vectors (Write-Write conflicts)
  - Precedence graphs (each partition maintains a log of data items affected by the Read and Write operations of transactions
  - Log used to construct precedence graph whose nodes are transactions and whose edges represent conflicts between Read and Write operations
    - No cycles in graph corresponding to each partition
  - If there are cycles in graph, validation fails

Quorum consensus

- A quorum is a subgroup of replica managers whose size gives it the right to carry out operations
- Majority voting one instance of a quorum consensus scheme
  - R + W > total number of votes in group
  - W > half the total votes
  - Ensures that each read quorum intersects a write quorum, and two write quora will intersect
- Each replica has a version number that is used to detect if the replica is up to date.

Virtual Partitions scheme

- Combines available copies and quorum consensus
- Virtual partition = set of replica managers that have a read and write quorum
- If a virtual partition can be formed, available copies is used
  - Improves performance of Reads
- If a failure occurs, and virtual partition changes during a transaction, it is aborted
- Have to ensure virtual partitions do not overlap

Figure 14.21 Two network partitions.

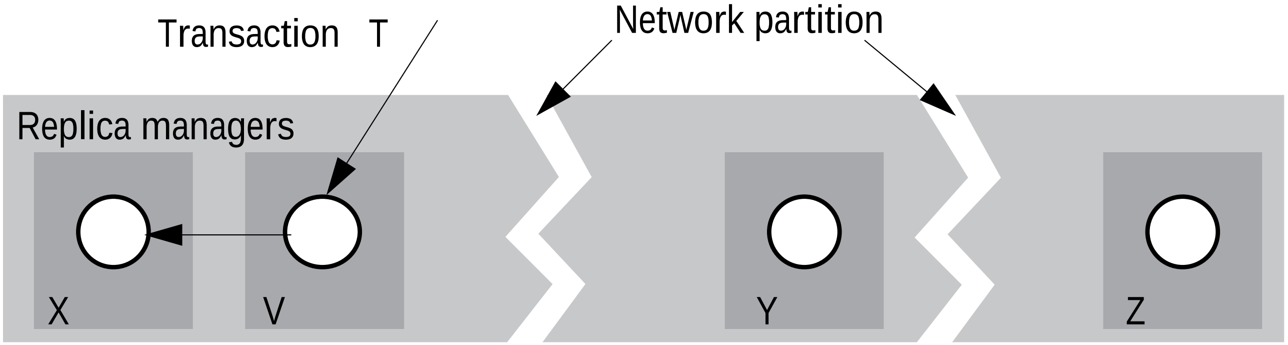


Figure 14.22 Virtual partition.

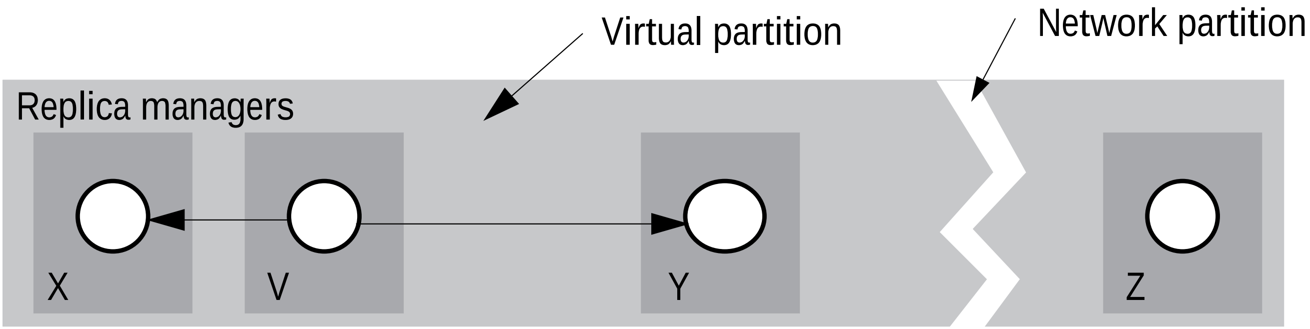


Figure 14.23 Two overlapping virtual partitions.

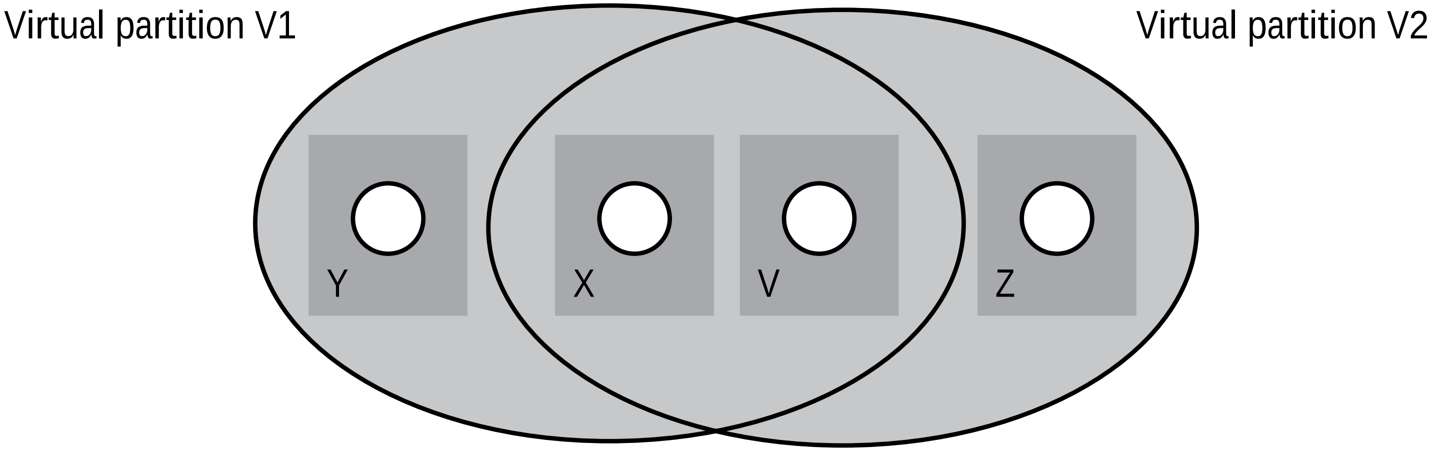


Figure 14.24 Creating a virtual partition.

Phase 1:

- The initiator sends a *Join* request to each potential member. The argument of *Join* is a proposed logical timestamp for the new virtual partition;
- When a replica manager receives a *Join* request it compares the proposed logical timestamp with that of its current virtual partition;
  - If the proposed logical timestamp is greater it agrees to join and replies *Yes;*
  - If it is less, it refuses to join and replies *No;*

Phase 2:

- If the initiator has received sufficient *Yes* replies to have *Read* and *Write* quora, it may complete the creation of the new virtual partition by sending a *Confirmation* message to the sites that agreed to join. The creation timestamp and list of actual members are sent as arguments;
- Replica managers receiving the *Confirmation* message join the new virtual partition and record its creation timestamp and list of actual members.