Epidemic Protocols

- Used in Bayou system from Xerox PARC
- Bayou: weakly connected replicas
  - Useful in mobile computing (mobile laptops)
  - Useful in wide area distributed databases (weak connectivity)
- Based on theory of epidemics *(spreading infectious diseases)*
  - Upon an update, try to "infect" other replicas as quickly as possible
  - Pair-wise exchange of updates (*like pair-wise spreading of a disease)*
  - Terminology:
    - Infective store: store with an update it is willing to spread
    - Susceptible store: store that is not yet updated
- Many algorithms possible to spread updates

Spreading an Epidemic

- Anti-entropy
  - Server *P* picks a server *Q* at random and exchanges updates
  - Three possibilities: only push, only pull, both push and pull
  - Claim: A pure push-based approach does not help spread updates quickly (Why?)
    - Pull or initial push with pull work better
- Rumor mongering (aka *gossiping*)
  - Upon receiving an update, *P* tries to push to *Q*
  - If *Q* already received the update, stop spreading with prob *1/k*
  - Analogous to "hot" gossip items => stop spreading if "cold"
  - Does not guarantee that all replicas receive updates
    - Chances of staying susceptible: $s = e^{-(k+1)(1-s)}$

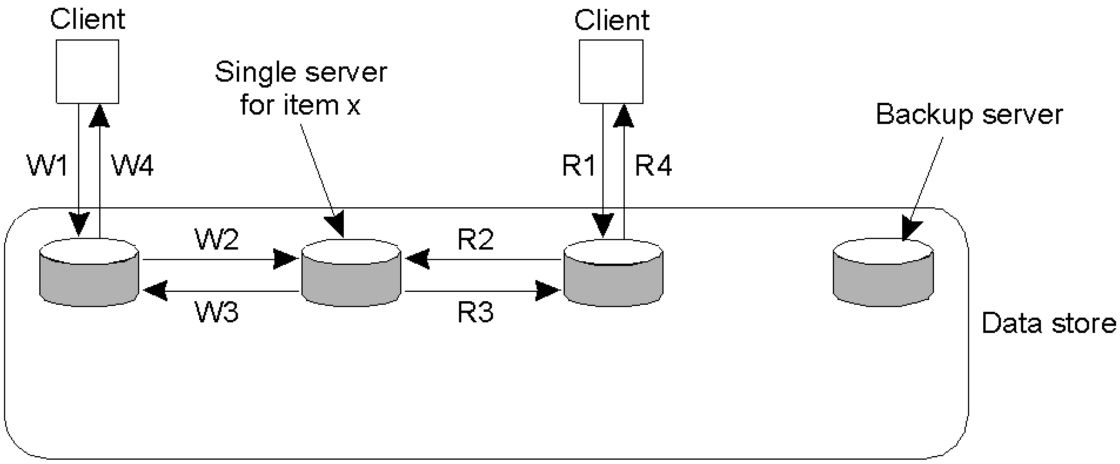
Removing Data

- Deletion of data items is hard in epidemic protocols
- Example: server deletes data item *x*
  - No state information is preserved
    - Can't distinguish between a deleted copy and no copy!
- Solution: death certificates
  - Treat deletes as updates and spread a death certificate
    - Mark copy as deleted but don't delete
    - Need an eventual clean up
      - Clean up dormant death certificates

Implementation Issues

- Two techniques to implement consistency models
  - Primary-based protocols
    - Assume a primary replica for each data item
    - Primary responsible for coordinating all writes
  - Replicated write protocols
    - No primary is assumed for a data item
    - Writes can take place at any replica

Remote-Write Protocols

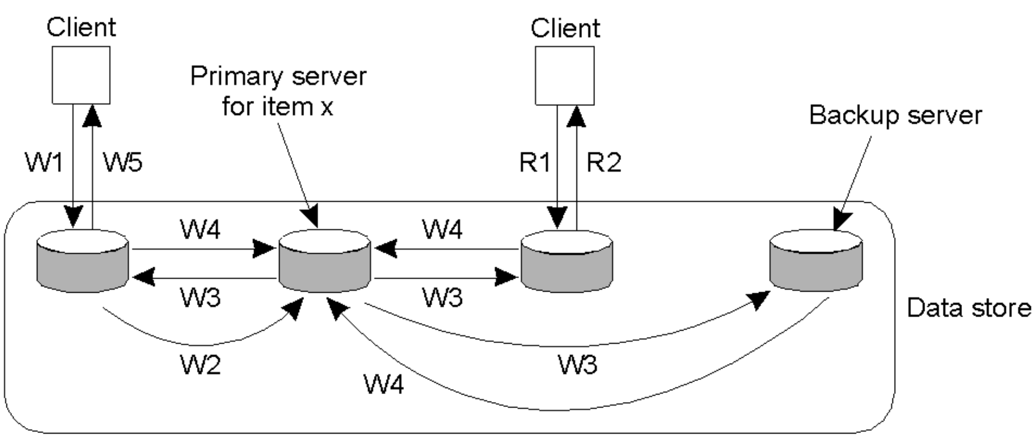


W1. Write request
W2. Forward request to server for x
W3. Acknowledge write completed
W4. Acknowledge write completed

R1. Read request
R2. Forward request to server for x
R3. Return response
R4. Return response

- **Traditionally used in client-server systems (no replication)**

Remote-Write Protocols (2)

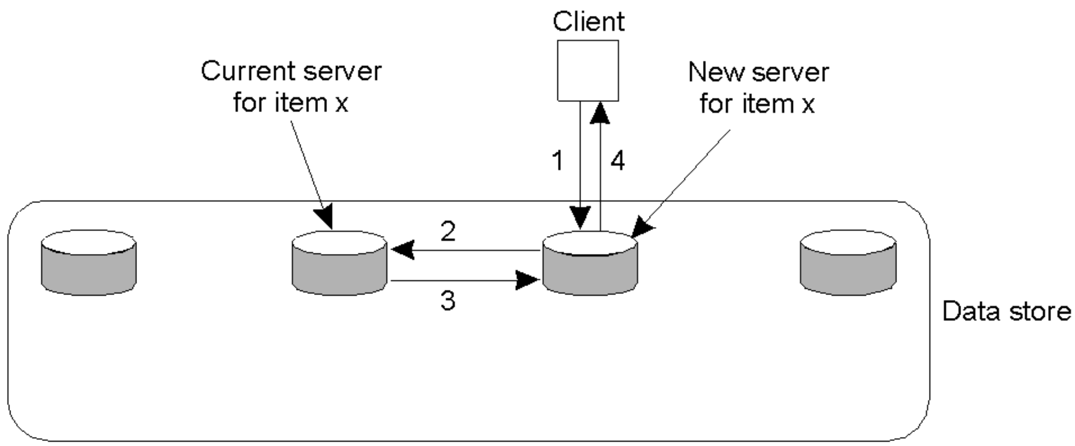


W1. Write request
W2. Forward request to primary
W3. Tell backups to update
W4. Acknowledge update
W5. Acknowledge write completed

R1. Read request
R2. Response to read

- Primary-backup protocol
  - Allow local reads, sent writes to primary
  - Block on write until all replicas are notified
  - Implements sequential consistency

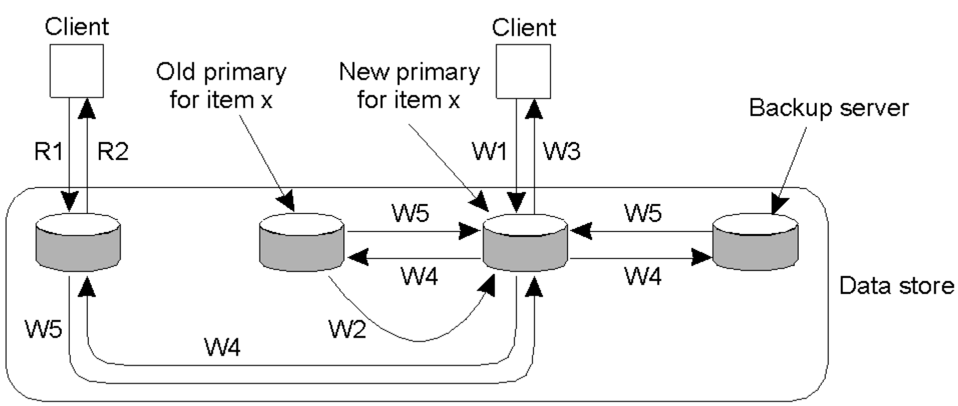
Local-Write Protocols (1)



1. Read or write request
2. Forward request to current server for x
3. Move item x to client's server
4. Return result of operation on client's server

- Primary-based local-write protocol in which a single copy is migrated between processes.
  - Limitation: need to track the primary for each data item

Local-Write Protocols (2)



W1. Write request
W2. Move item x to new primary
W3. Acknowledge write completed
W4. Tell backups to update
W5. Acknowledge update

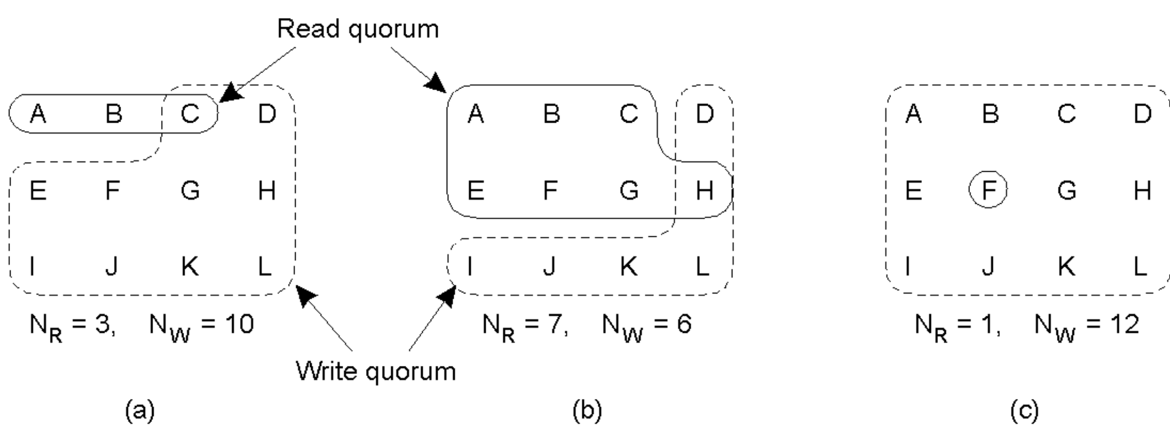
R1. Read request
R2. Response to read

- Primary-backup protocol in which the primary migrates to the process wanting to perform an update

Replicated-write Protocols

- Relax the assumption of one primary
  - No primary, any replica is allowed to update
  - Consistency is more complex to achieve
- Quorum-based protocols
  - Use voting to request/acquire permissions from replicas
  - Consider a file replicated on *N* servers
    - $N_R + N_W > N$ $N_W > N/2$
  - Update: contact N_W servers and get them to agree to do update (associate version number with file)
  - Read: contact N_R and obtain version number
    - If all servers agree on a version number, read

Gifford's Quorum-Based Protocol



- Three examples of the voting algorithm:

a) A correct choice of read and write set

b) A choice that may lead to write-write conflicts

c) A correct choice, known as ROWA (read one, write all)

Replica Management

- Replica server placement
  - Web: geophically skewed request patterns
  - Where to place a proxy?
    - K-clusters algorithm
- Permanent replicas versus temporary
  - Mirroring: all replicas mirror the same content
  - Proxy server: on demand replication
- Server-initiated versus client-initiated

Content Distribution

- Will come back to this in Chap 12
- CDN: network of proxy servers
- Caching:
  - update versus invalidate
  - Push versus pull-based approaches
  - Stateful versus stateless
- Web caching: what semantics to provide?

Final Thoughts

- Replication and caching improve performance in distributed systems
- Consistency of replicated data is crucial
- Many consistency semantics (models) possible
  - Need to pick appropriate model depending on the application
  - Example: web caching: weak consistency is OK since humans are tolerant to stale information (can reload browser)
  - Implementation overheads and complexity grows if stronger guarantees are desired

Fault Tolerance

- Single machine systems
  - Failures are all or nothing
    - OS crash, disk failures
- Distributed systems: multiple independent nodes
  - Partial failures are also possible (some nodes fail)
- *Question:* Can we automatically recover from partial failures?
  - Important issue since probability of failure grows with number of independent components (nodes) in the systems
  - Prob(failure) = Prob(Any one component fails)=1-P(no failure)

A Perspective

- Computing systems are not very reliable
  - OS crashes frequently (Windows), buggy software, unreliable hardware, software/hardware incompatibilities
  - Until recently: computer users were "tech savvy"
    - Could depend on users to reboot, troubleshoot problems
  - Growing popularity of Internet/World Wide Web
    - "Novice" users
    - Need to build more reliable/dependable systems
  - Example: what is your TV (or car) broke down every day?
    - Users don't want to "restart" TV or fix it (by opening it up)
- Need to make computing systems more reliable
  - Important for online banking, e-commerce, online trading, webmail…

Basic Concepts

- Need to build *dependable* systems
- Requirements for dependable systems
  - Availability: system should be available for use at any given time
    - 99.999 % availability (five 9s) => very small down times
  - Reliability: system should run continuously without failure
  - Safety: temporary failures should not result in a catastrophic
    - Example: computing systems controlling an airplane, nuclear reactor
  - Maintainability: a failed system should be easy to repair

Basic Concepts (contd)

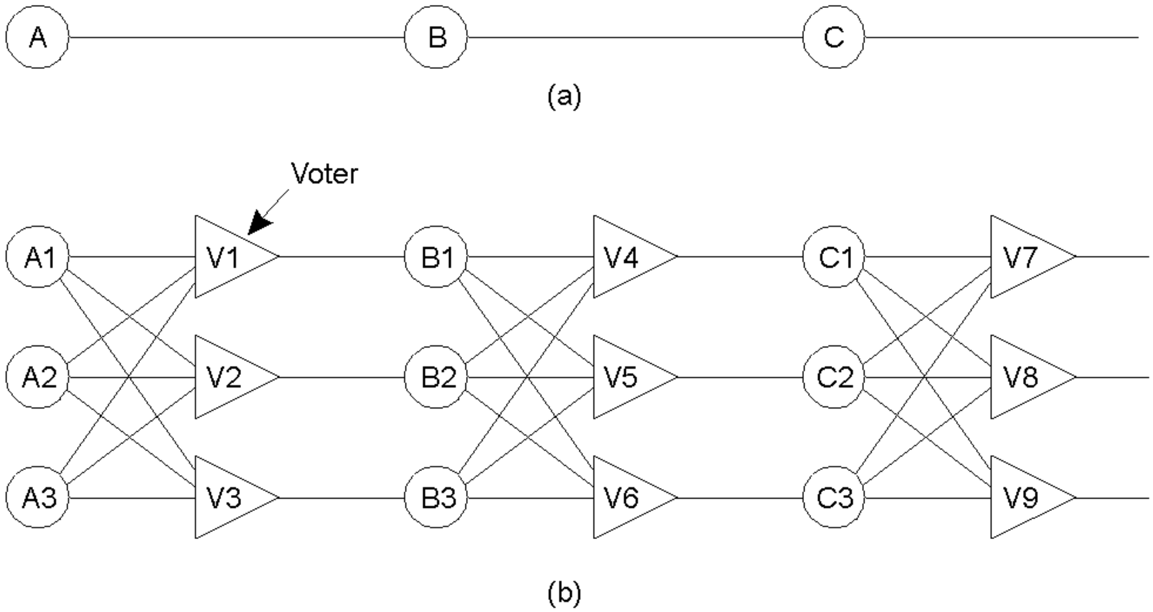
- Fault tolerance: system should provide services despite faults
  - Transient faults
  - Intermittent faults
  - Permanent faults

Failure Models

Type of failure	Description
Crash failure	A server halts, but is working correctly until it halts
Omission failure *Receive omission* *Send omission*	A server fails to respond to incoming requests A server fails to receive incoming messages A server fails to send messages
Timing failure	A server's response lies outside the specified time interval
Response failure *Value failure* *State transition failure*	The server's response is incorrect The value of the response is wrong The server deviates from the correct flow of control
Arbitrary failure	A server may produce arbitrary responses at arbitrary times

- Different types of failures.

Failure Masking by Redundancy



- Triple modular redundancy.