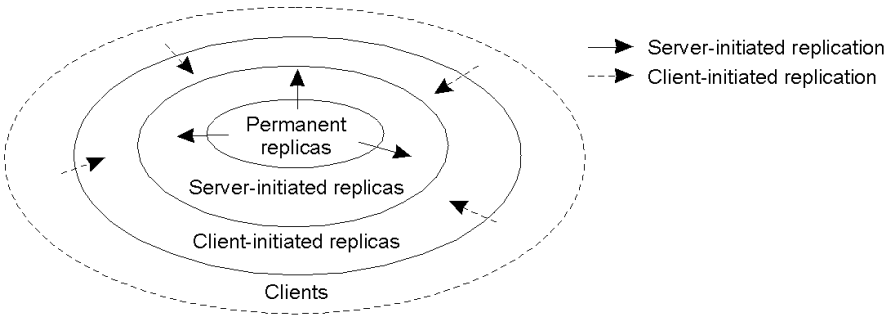
# Replica Placement

**Model:** We consider objects (and don't worry whether they contain just data or code, or both)

**Distinguish different processes:** A process is capable of hosting a replica of an object or data:

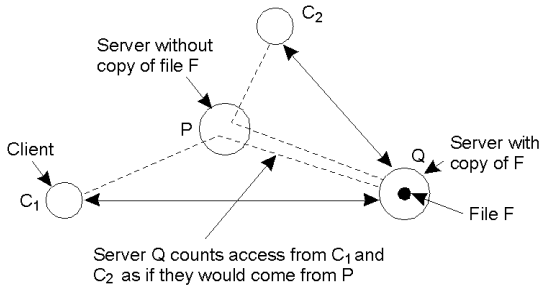
- **Permanent replicas:** Process/machine always having a replica
- **Server-initiated replica:** Process that can dynamically host a replica on request of another server in the data store
- **Client-initiated replica:** Process that can dynamically host a replica on request of a client (client cache)

# Replica Placement




- The logical organization of different kinds of copies of a data store into three concentric rings.
- Examples: web servers file servers multicast trees

# Server-Initiated Replicas




- Keep track of access counts per file, aggregated by considering server closest to requesting clients
- Number of accesses drops below threshold *D* =>drop file
- Number of accesses exceeds threshold *R* =>replicate file
- Number of access between *D* and *R* =>migrate file

# Client-Initiated Replicas

- More like a client cache
  - Keep it on disk?
  - Keep it in memory?
  - How much space to use?
  - How long to keep copy/replica?
  - How to detect data is stale?
- Read-only files work best
- Sharing data among client processes may be good. Sharing space is essential

# Update Propagation (1/3)

- Propagate only notification/invalidation of update (often used for caches)
- Transfer data from one copy to another (distributed databases)
- Propagate the update *operation* to other copies (also called active replication)

**Observation:** No single approach is the best, but depends highly on available bandwidth and read-to-write ratio at replicas.

# Update Propagation (2/3)

- Pushing updates: server-initiated approach, in which update is propagated regardless whether target asked for it.
- Pulling updates: client-initiated approach, in which client requests to be updated.

| Issue | Push-based | Pull-based |
|---|---|---|
| 1: | List of client caches | None |
| 2: | Update (and possibly fetch update) | Poll and update |
| 3: | Immediate (or fetch-update time) | Fetch-update time |

*1: State at server*
*2: Messages to be exchanged*
*3: Response time at the client*

# Update Propagation (3/3)

**Observation:** We can dynamically switch between pulling and pushing using **leases**: A contract in which the server promises to push updates to the client until the lease expires.

**Issue:** Make lease expiration time dependent on system's behavior (adaptive leases):

- Age-based leases: An object that hasn't changed for a long time, will not change in the near future, so provide a long-lasting lease
- Renewal-frequency based leases: The more often a client requests a specific object, the longer the expiration time for that client (for that object) will be
- State-based leases: The more loaded a server is, the shorter the expiration times become

**Question:** Why are we doing all this?

# Epidemic Algorithms

**Basic idea:** Assume there are no write–write conflicts:

- Update operations are initially performed at one or only a few replicas
- A replica passes its updated state to a limited number of neighbors
- Update propagation is lazy, i.e., not immediate
- Eventually, each update should reach every replica

**Anti-entropy:** Each replica regularly chooses another replica at random, and exchanges state differences, leading to identical states at both afterwards

**Gossiping:** A replica which has just been updated (i.e., has been **contaminated**), tells a number of other replicas about its update (contaminating them as well).

# System Model

- We consider a collection servers, each storing a number of objects
- Each object *O* has a *primary* server at which updates for *O* are always initiated (avoiding write-write conflicts)
- An update of object *O* at server *S* is always time-stamped; the value of *O* at *S* is denoted *VAL*(*O*,*S*)
- T(*O*,*S*) denotes the timestamp of the value of object *O* at server *S*

# Anti-Entropy

- **Basic issue:** When a server *S* contacts another server *S** to exchange state information, three different strategies can be followed:
- **Push**: *S* only forwards all its updates to *S*:*
  if *T(O,S*) < T(O,S)*
  then *VAL(O,S*) <= VAL(O,S)*
- **Pull**: *S* only fetched updates from *S*:*
  if *T(O,S*) > T(O,S)*
  then *VAL(O,S*) <= VAL(O,S)*
- **Push-Pull**: *S* and *S** exchange their updates by pushing and pulling values.
- **Observation:** if each server periodically randomly chooses another server for exchanging updates, an update is propagated in *O(log(N))* time units.

**Question**: why is pushing alone not efficient when many servers have already been updated?

# Gossiping

**Basic model:** A server *S* having an update to report, contacts other servers. If a server is contacted to which the update has already propagated, *S* stops contacting other servers with probability 1/*k*.

If *s* is the fraction of ignorant servers (i.e., which are unaware of the update), it can be shown that with many servers:

$$s = e^{-(k+1)(1-s)}$$

| *k* | *s* |
|---|---|
| 1 | 0.2000 |
| 2 | 0.0600 |
| 3 | 0.0200 |
| 4 | 0.0070 |
| 5 | 0.0025 |

Observation: If we really have to ensure that all servers are eventually updated, gossiping alone is not enough

# Deleting Values

**Fundamental problem:** We cannot remove an old value from a server and expect the removal to propagate. Instead, mere removal will be undone in due time using epidemic algorithms

**Solution:** Removal has to be registered as a special update by inserting a *death certificate*

**Next problem:** When to remove a death certificate (it is not allowed to stay forever):

- Run a global algorithm to detect whether the removal is known everywhere, and then collect the death certificates (looks like garbage collection)
- Assume death certificates propagate in finite time, and associate a maximum lifetime for a certificate (can be done at risk of not reaching all servers)

**Note:** it is necessary that a removal actually reaches all servers.

**Question:** What's the scalability problem here?

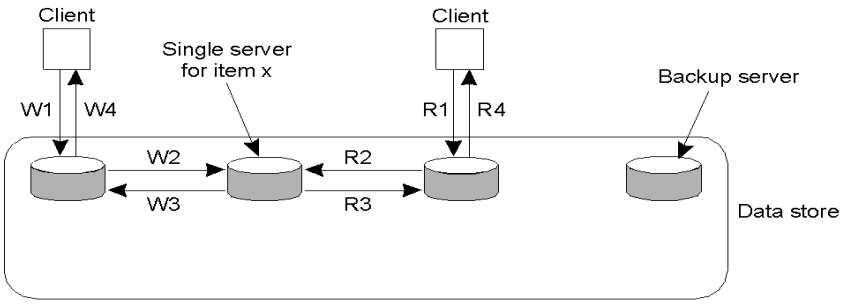
# Consistency Protocols

**Consistency protocol:** describes the implementation of a specific consistency model. We will concentrate only on sequential consistency.

- Primary-based protocols
- Replicated-write protocols
- Cache-coherence protocols

# Primary-Based Protocols (1/4)

- All read and write operations go to server
- Example: used in traditional client-server systems that do not support replication.

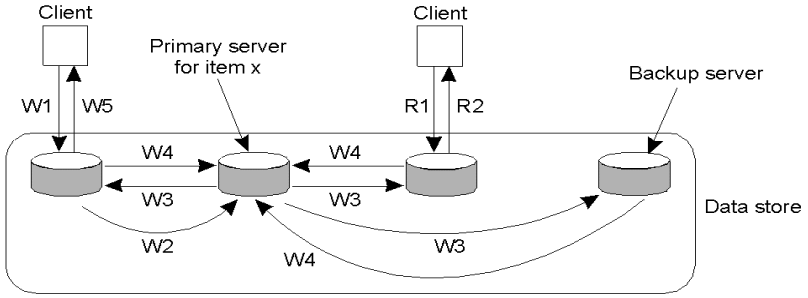



W1. Write request
W2. Forward request to server for x
W3. Acknowledge write completed
W4. Acknowledge write completed

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

# Primary-Based Protocols (2/4)

**Primary-backup protocol**: writes are typically forwarded to server



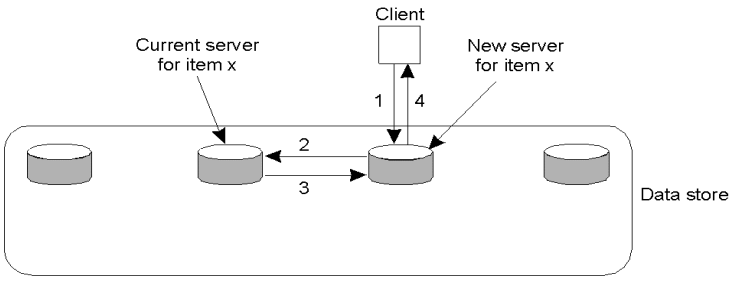

W1. Write request
W2. Forward request to primary
W3. Tell backups to update
W4. Acknowledge update
W5. Acknowledge write completed

R1. Read request
R2. Response to read

**Example**: Traditionally applied in distributed databases and file systems that require a high degree of fault tolerance. Replicas are often placed on same LAN.

# Primary-Based Protocols (3/4)

**Primary-based, local-write protocol**: migrate the data, do not replace it.

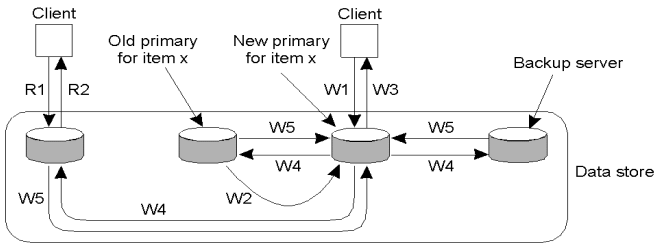



1. Read or write request
2. Forward request to current server for x
3. Move item x to client's server
4. Return result of operation on client's server

**Example**: Establishes only a fully distributed, non-replicated data store. Useful when writes are expected to come in series from the same client (e.g., mobile computing without replication.

# Primary-Based Protocols (4/4)

**Primary-backup protocol with local writes**: replicate data only for reading



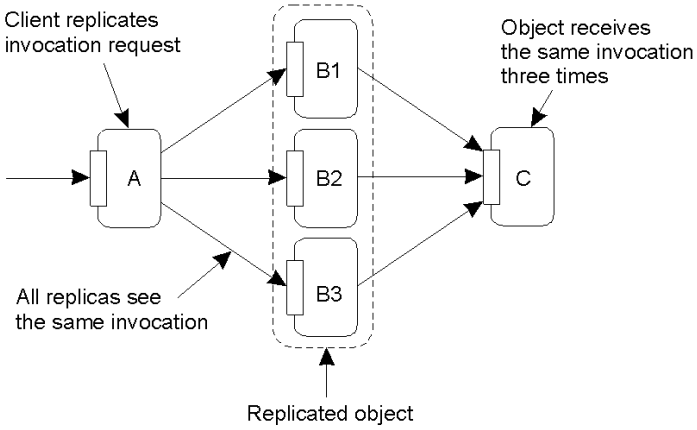

W1. Write request
W2. Move item x to new primary
W3. Acknowledge write completed
W4. Tell backups to update
W5. Acknowledge update

R1. Read request
R2. Response to read

**Example:** Distributed shared memory systems, but also mobile computing in *disconnected mode* (ship all relevant files to user before disconnecting, and update later on).

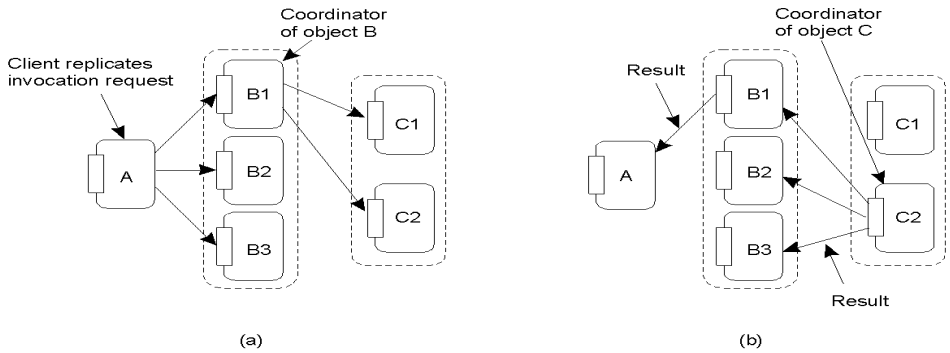
# Replicated-Write Protocols(1/2)

- **Active replication:** Updates are forwarded to multiple replicas, where they are carried out.
- One problem to deal with: replicated invocations:



# Replicated-Write Protocols (2/2)

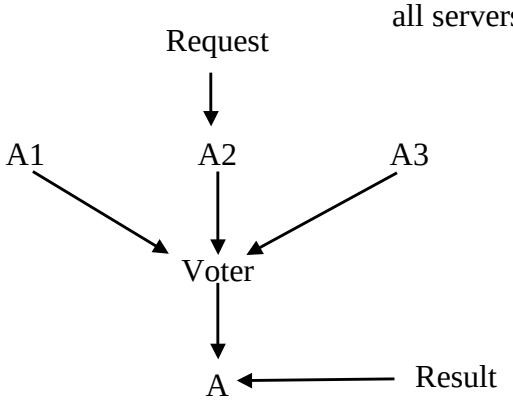
**Replicated invocations:** "Centralized" Solution Assign a coordinator on each side (client and server), which ensures that only one invocation (a), and one reply is send (b).




# Triple Modular Redundancy

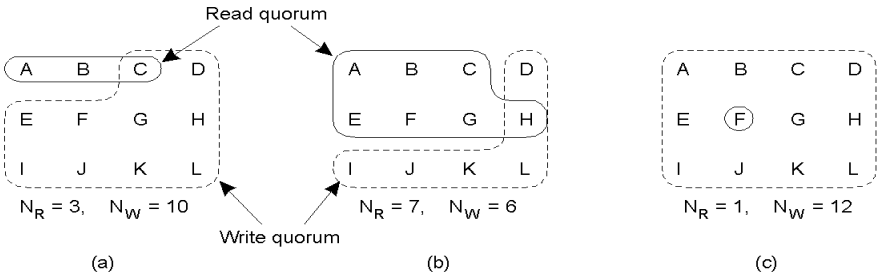
- Simple to implement
- Vote on all three results
- Majority (50% + 1) wins

Request is replicated to all servers.



# Quorum-Based Protocols

**Quorum-based protocols:** Ensure that each operation is carried out in such a way that a majority vote is established: distinguish **read quorum** and **write quorum**:




# Example: Lazy Replication

- Basic model: number of replica servers jointly implement a causal-consistent data store.
- Clients normally talk to **front ends** which maintain data to ensure causal consistency.