416 Distributed Systems

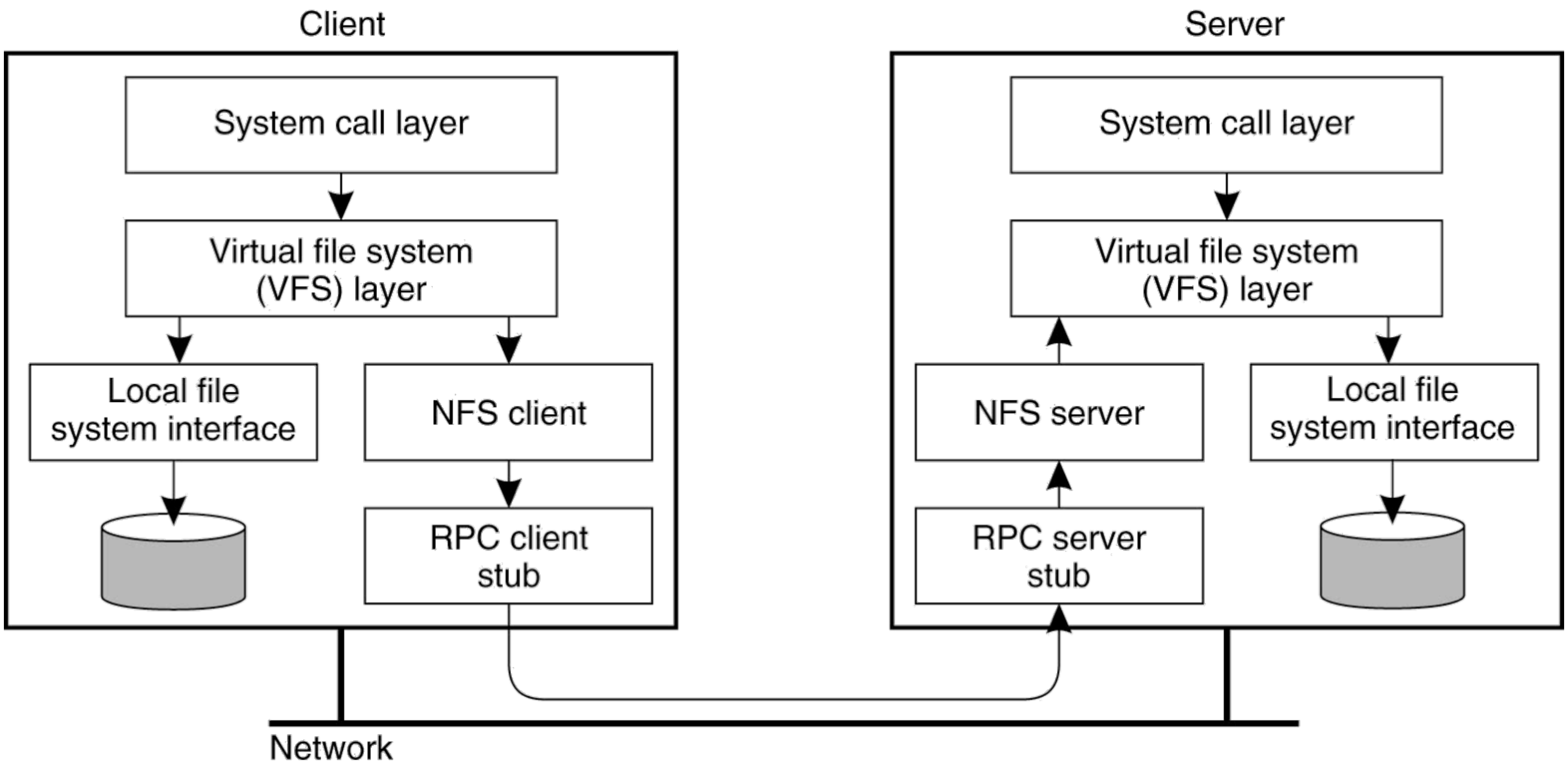
Distributed File Systems 2

Jan 20, 2016

Outline

- Why Distributed File Systems?
- Basic mechanisms for building DFSs
  - Using NFS and AFS as examples
    - NFS: network file system
    - AFS: andrew file system
- Design choices and their implications
  - Caching
  - Consistency
  - Naming
  - Authentication and Access Control

VFS Interception



A Simple Approach

- Use RPC to forward every filesystem operation to the server
  - Server serializes all accesses, performs them, and sends back result.
- Great: Same behavior as if both programs were running on the same local filesystem!
- Bad: Performance can stink. Latency of access to remote server often much higher than to local memory.
- For AFS context: bad bad bad: server would get hammered!

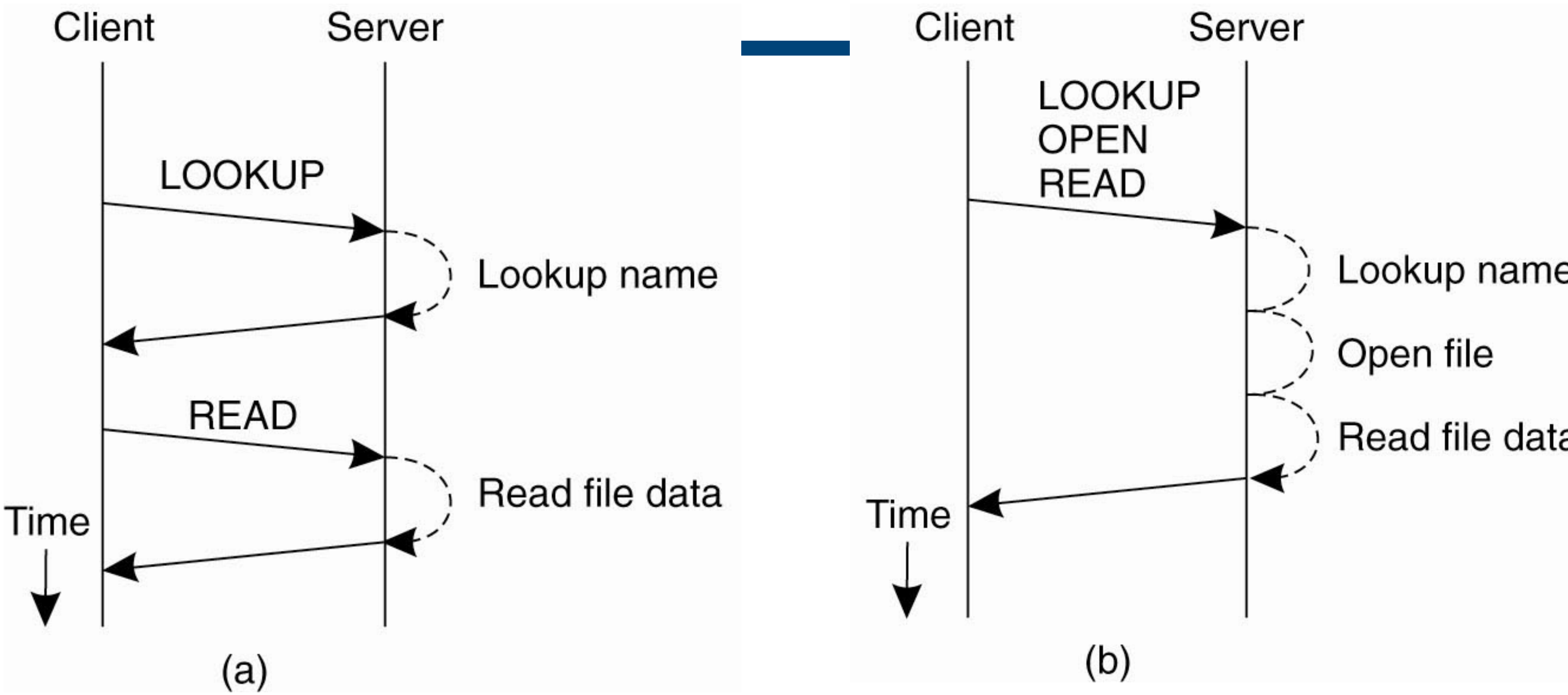
Lesson 1: Needing to hit the server for every detail impairs performance and scalability.

Question 1: How can we avoid going to the server for everything? *What* can we avoid this for? What do we lose in the process?

NFS V2 Design

- “Dumb”, “Stateless” servers w/ smart clients
- Portable across different OSes
- Low implementation cost
- Small number of clients
- Single administrative domain

Remote Procedure Calls in NFS



- (a) Reading data from a file in NFS version 3
- (b) Reading data using a compound procedure in version 4.

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Topic 1: Client-Side Caching

- Many systems (not just distributed!) rely on two solutions to every problem:
  1. Cache it!
  2. “All problems in computer science can be solved by adding another level of indirection. But that will usually create another problem.” -- David Wheeler

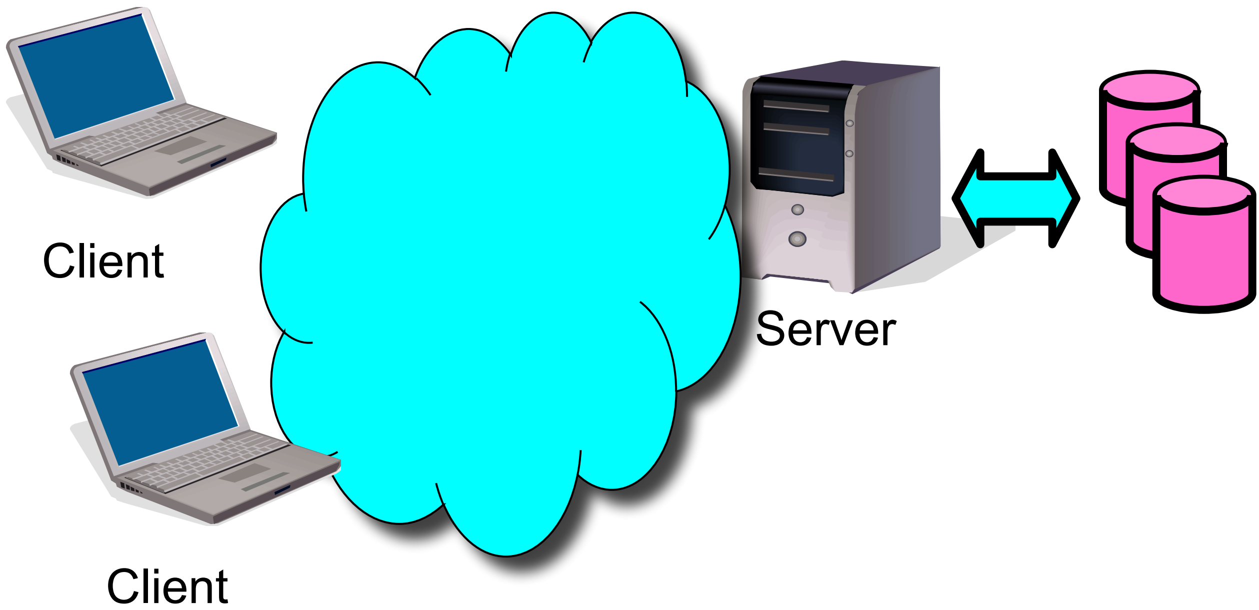
Client-Side Caching

- So, uh, what do we cache?
  - Read-only file data and directory data → easy
  - Data written by the client machine → when is data written to the server? What happens if the client machine goes down?
  - Data that is written by other machines → how to know that the data has changed? How to ensure data consistency?
  - Is there any pre-fetching?
- And if we cache... doesn’t that risk making things inconsistent?

Failures

- Server crashes
  - Data in memory but not disk lost
  - So... what if client does
    - seek() ; /* SERVER CRASH */; read()
    - If server maintains file position, this will fail (Why?). Ditto for open(), read()
- Lost messages: what if we lose acknowledgement for delete("foo")
  - And in the meantime, another client created foo anew?
- Client crashes
  - Might lose data in client cache

Use of caching to reduce network load



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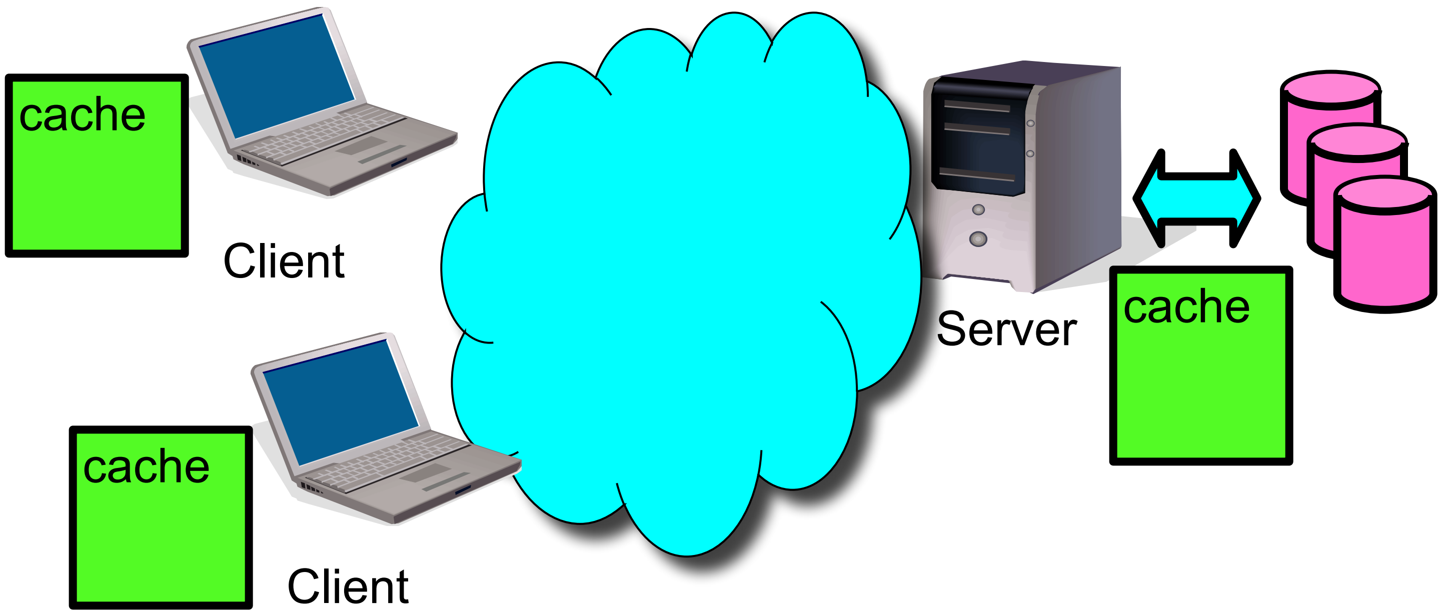
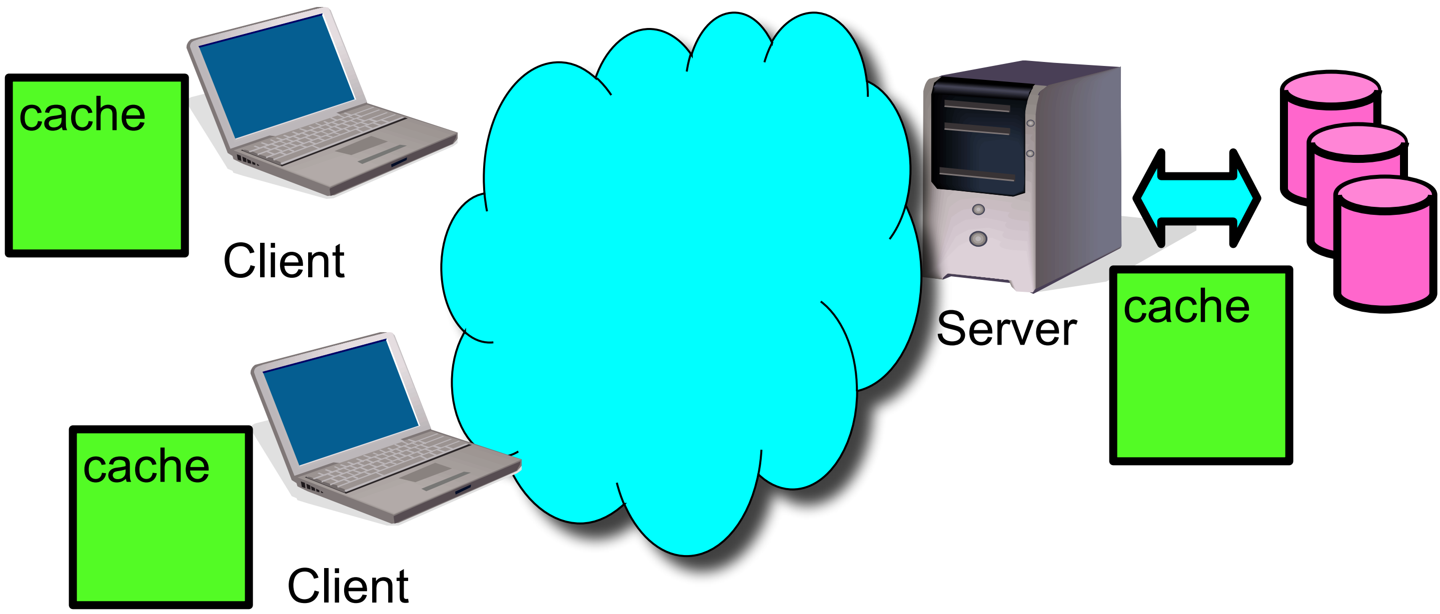


Use of caching to reduce network load

read(f1)



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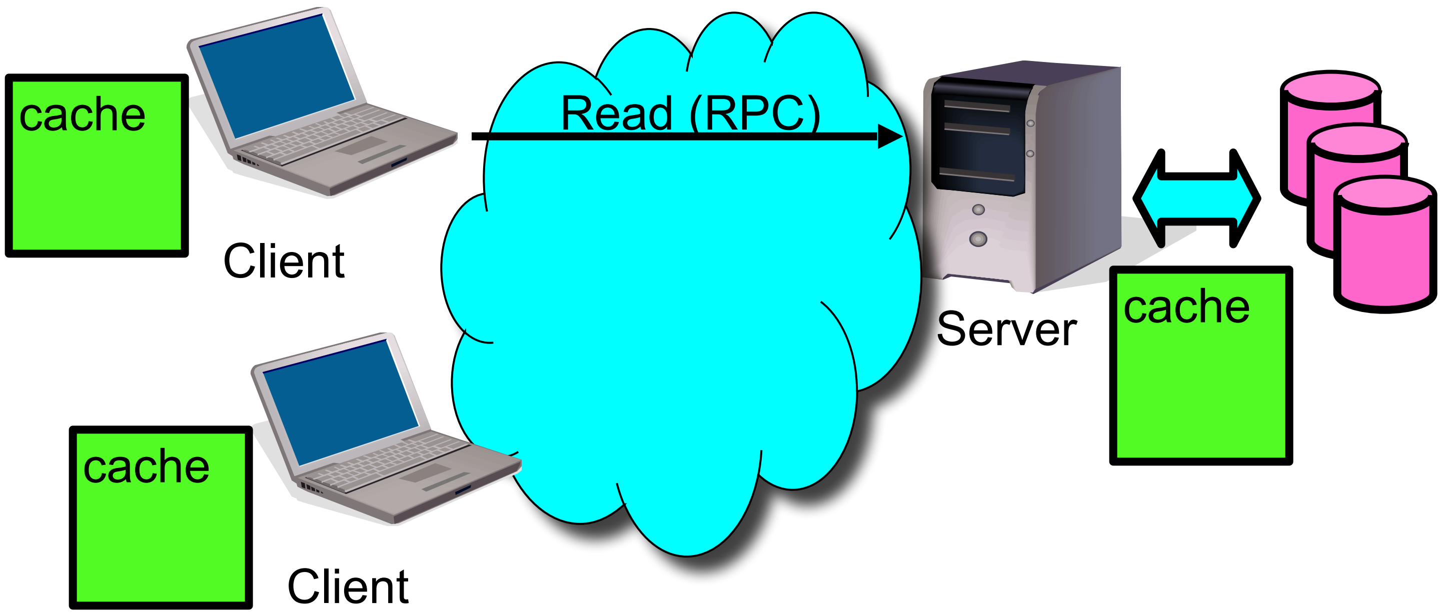

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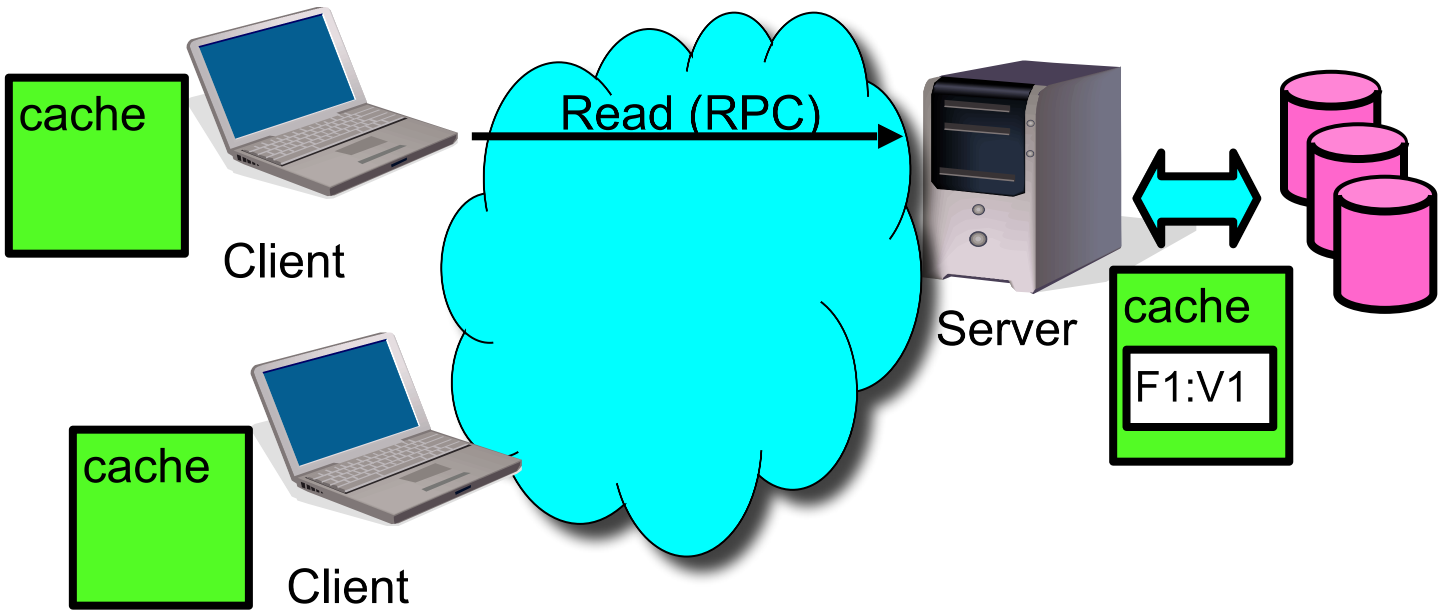

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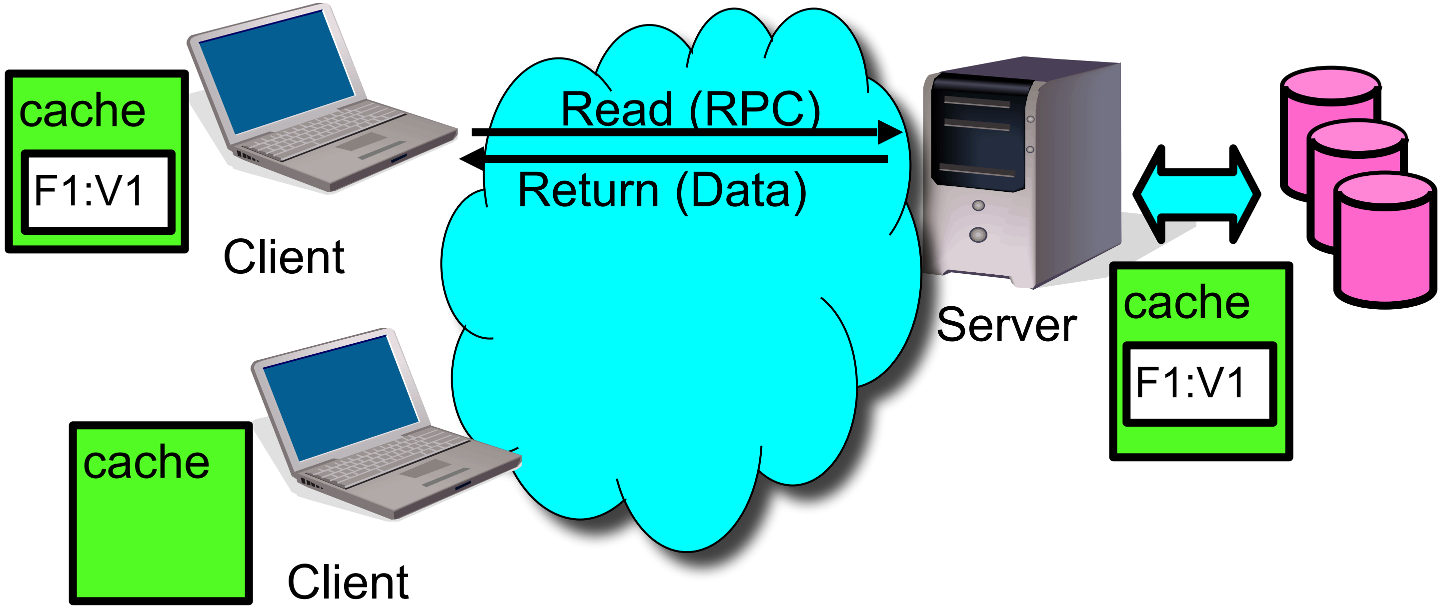
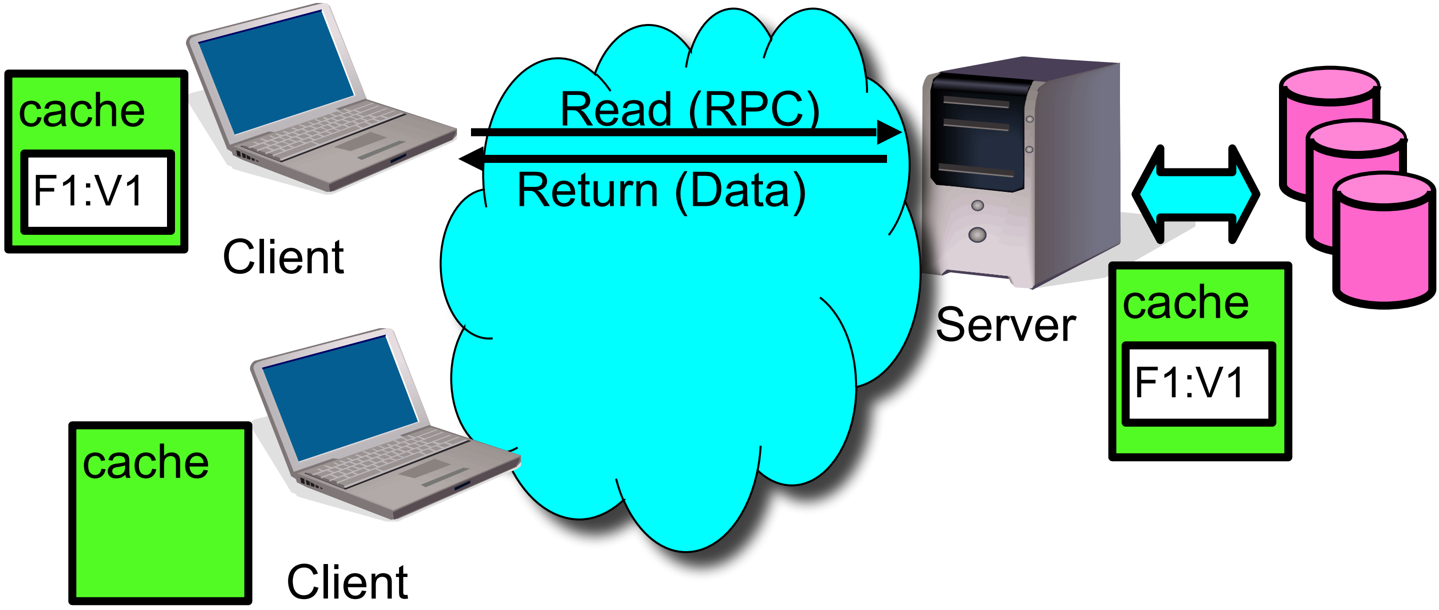


Use of caching to reduce network load

read(f1)→V1



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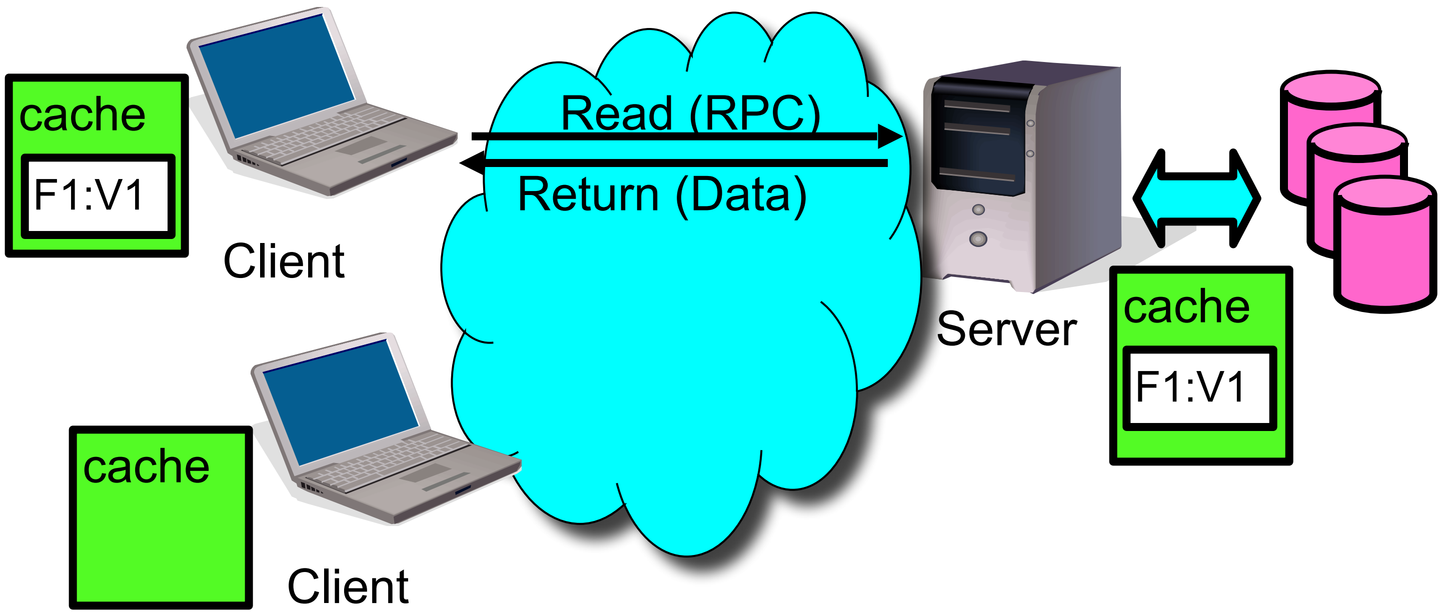

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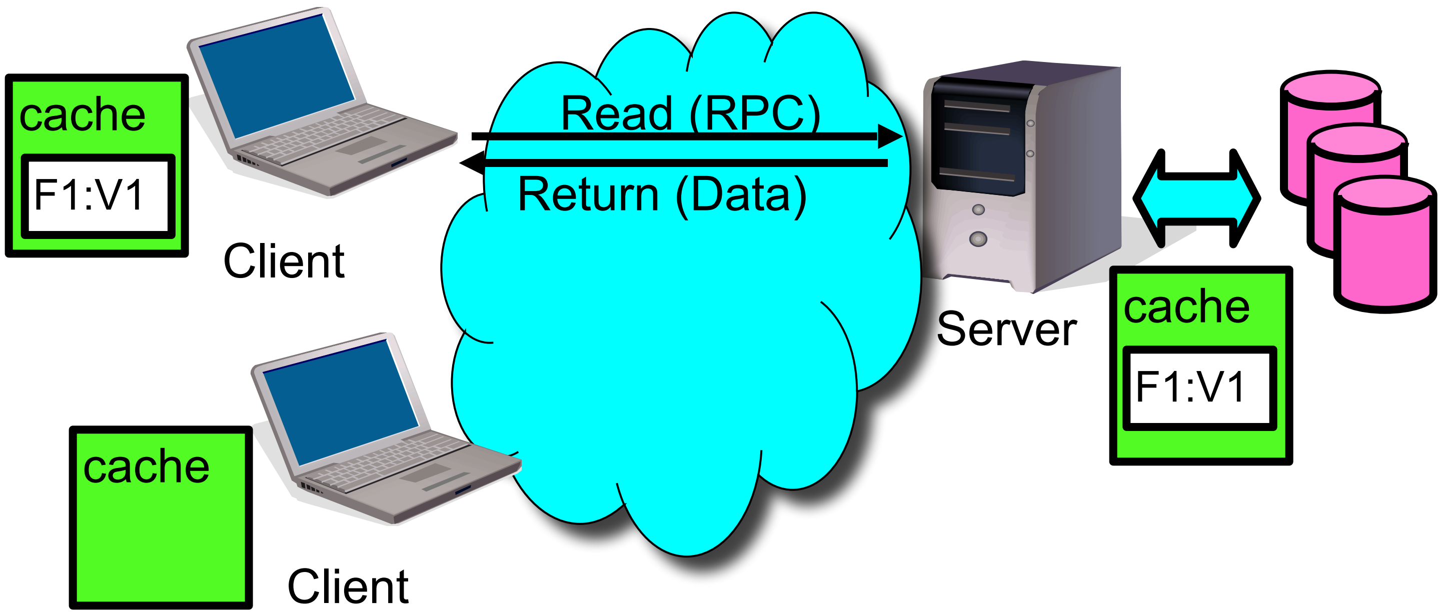

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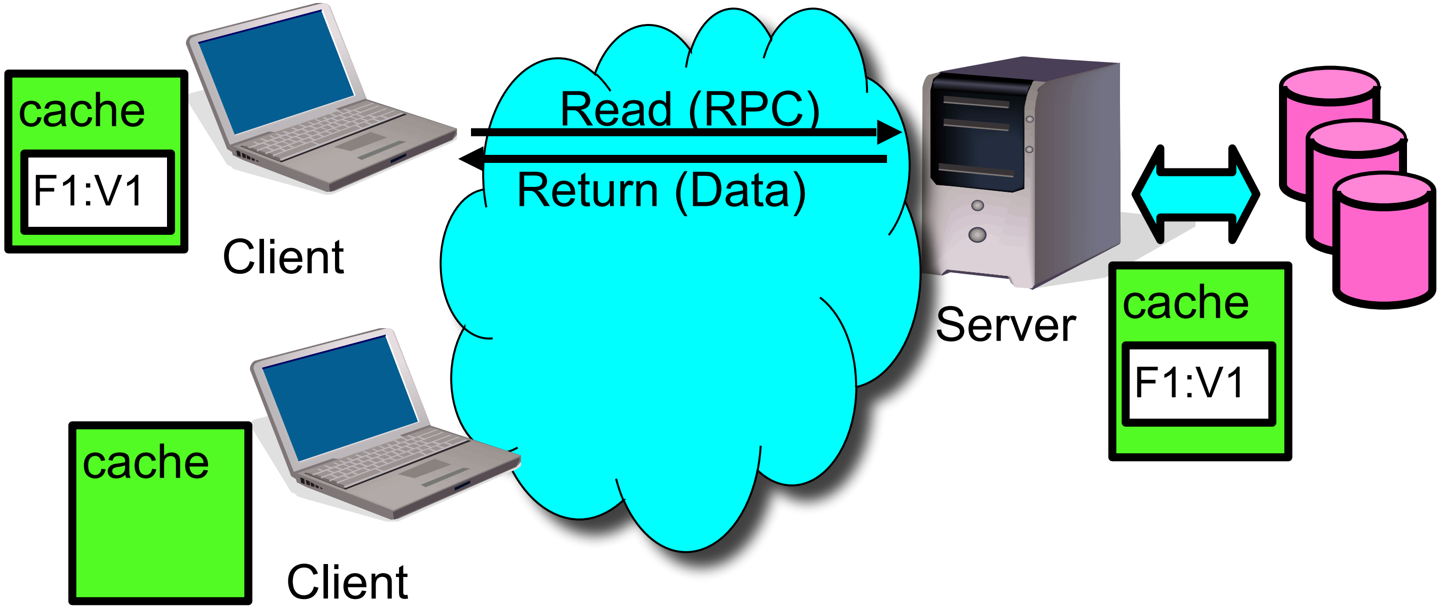
write(f1)



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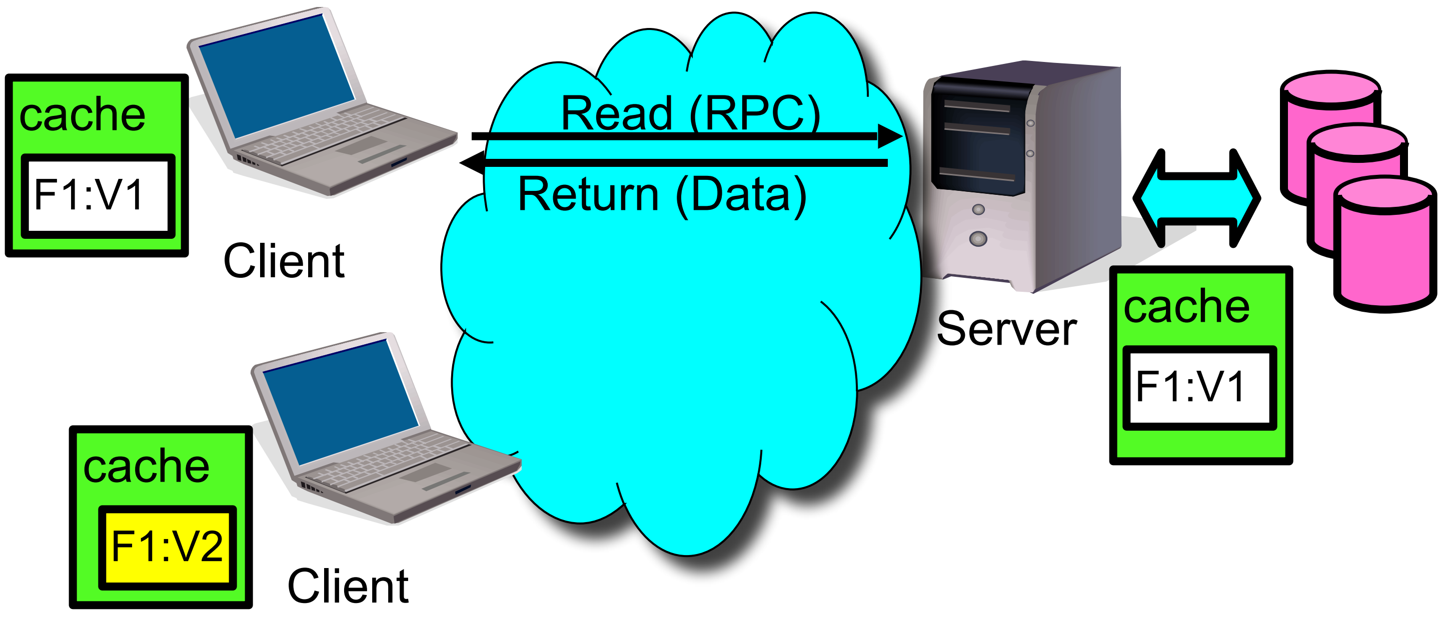

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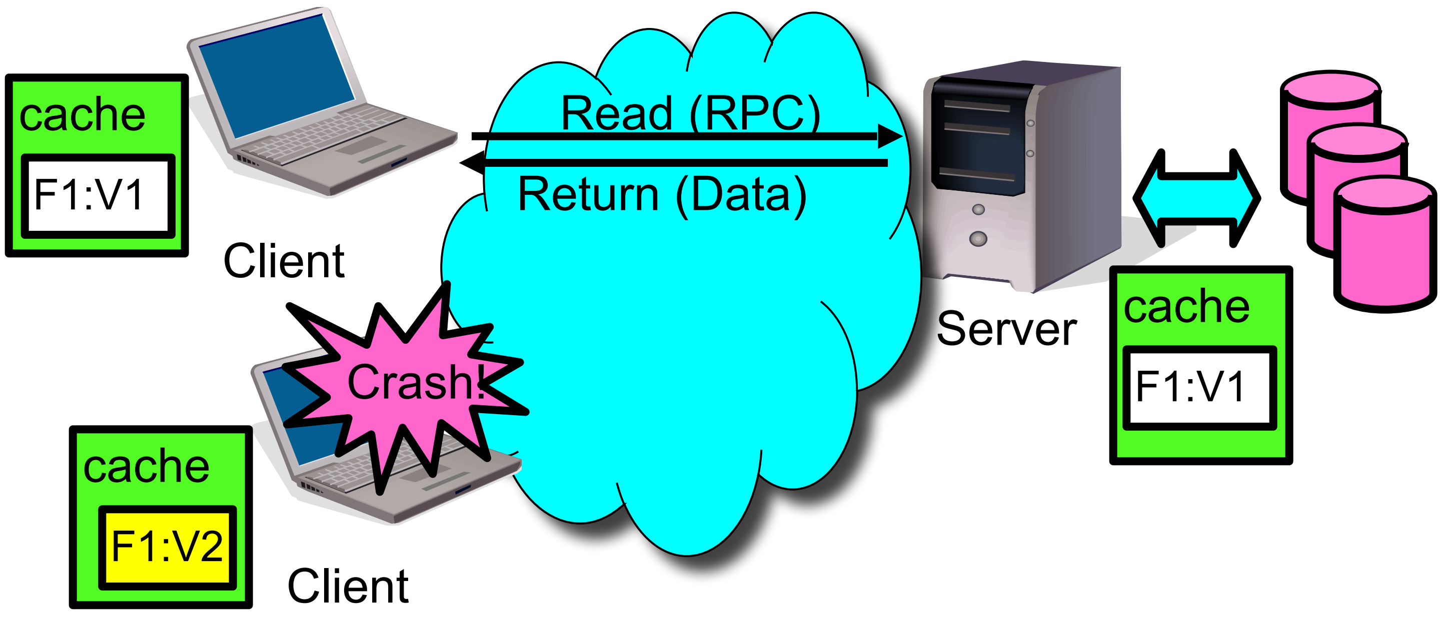

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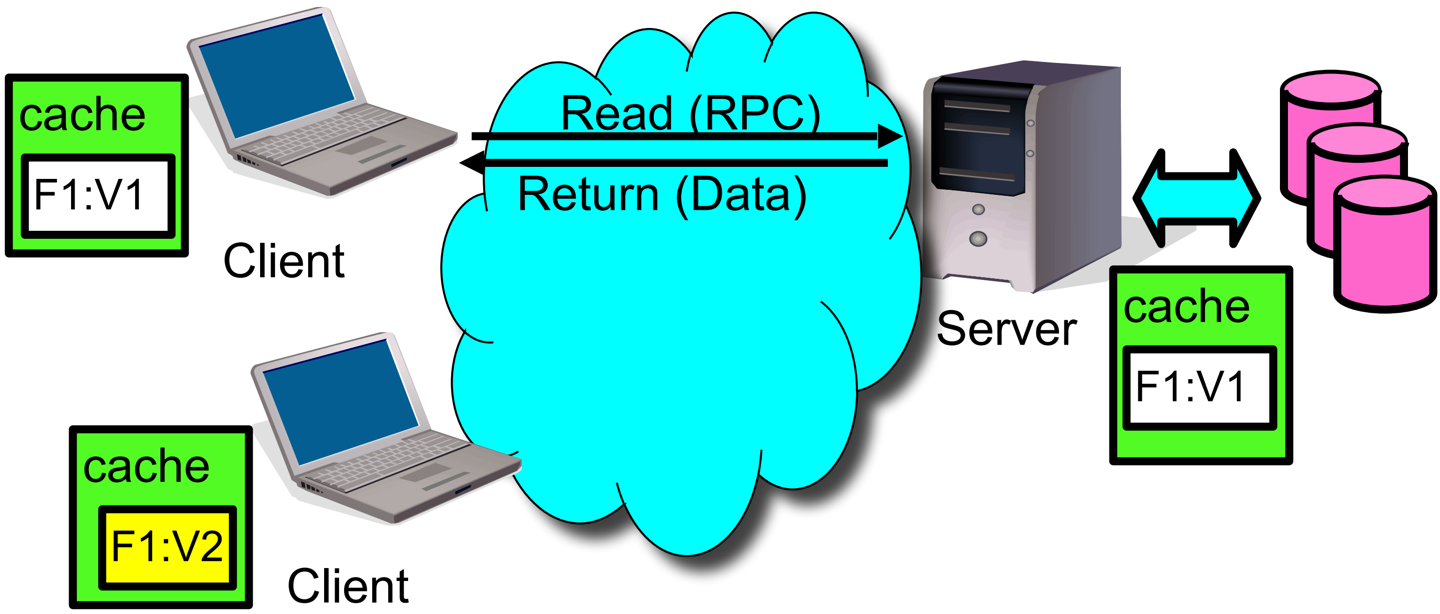

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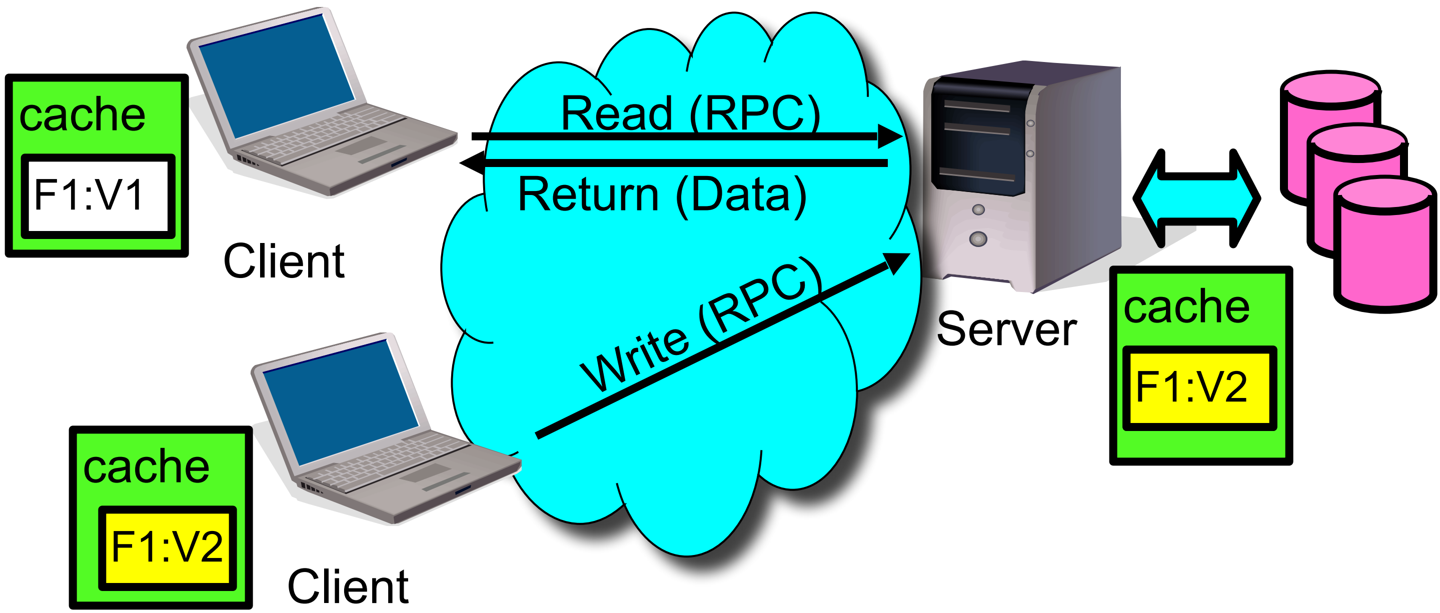

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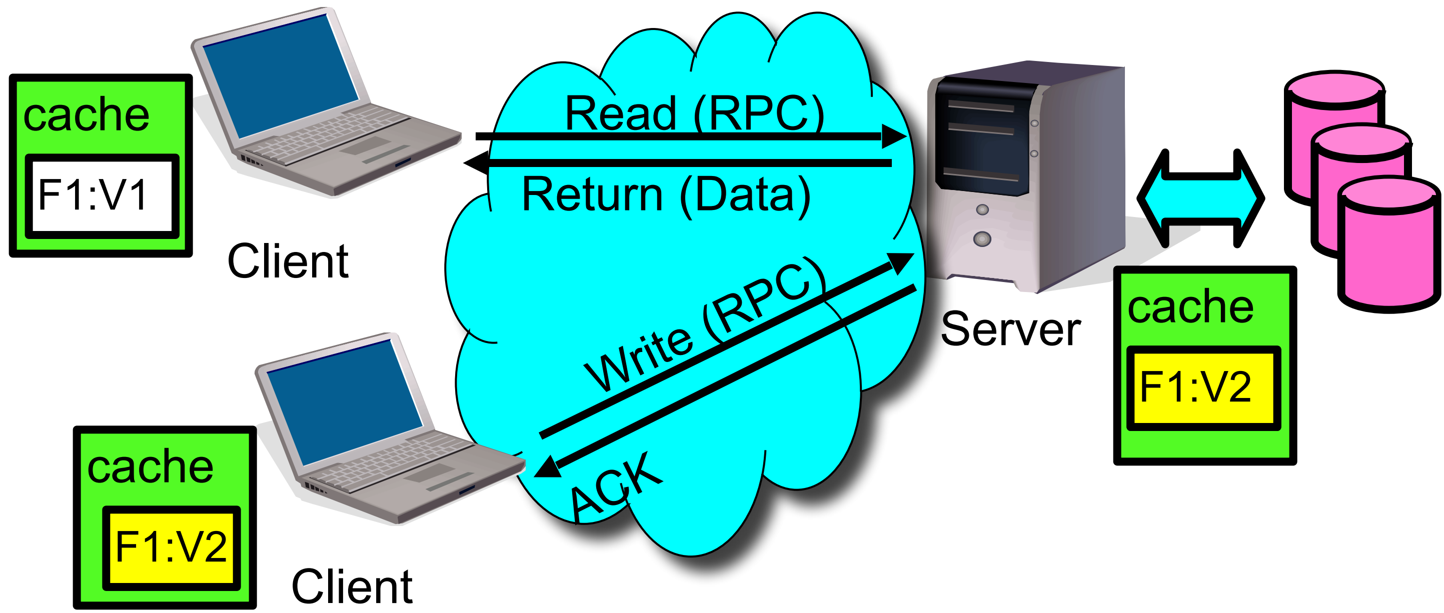
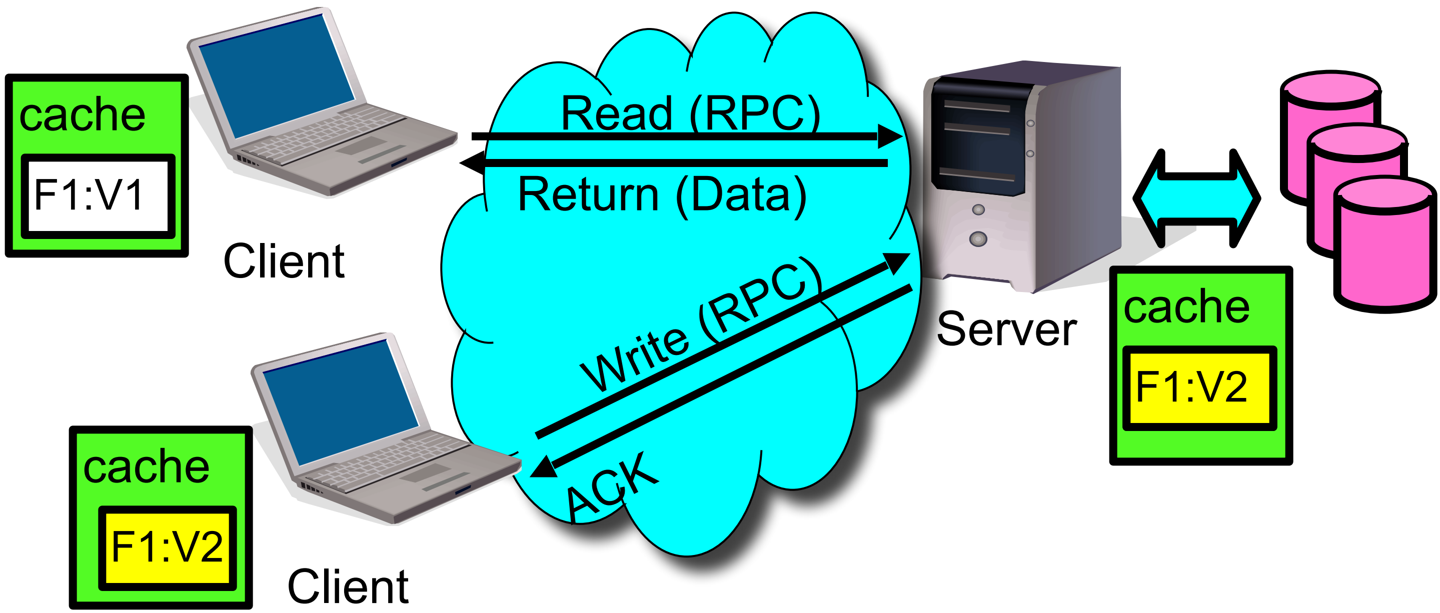


Use of caching to reduce network load

read(f1)→V1
read(f1)→V1
read(f1)→V1

write(f1)→OK



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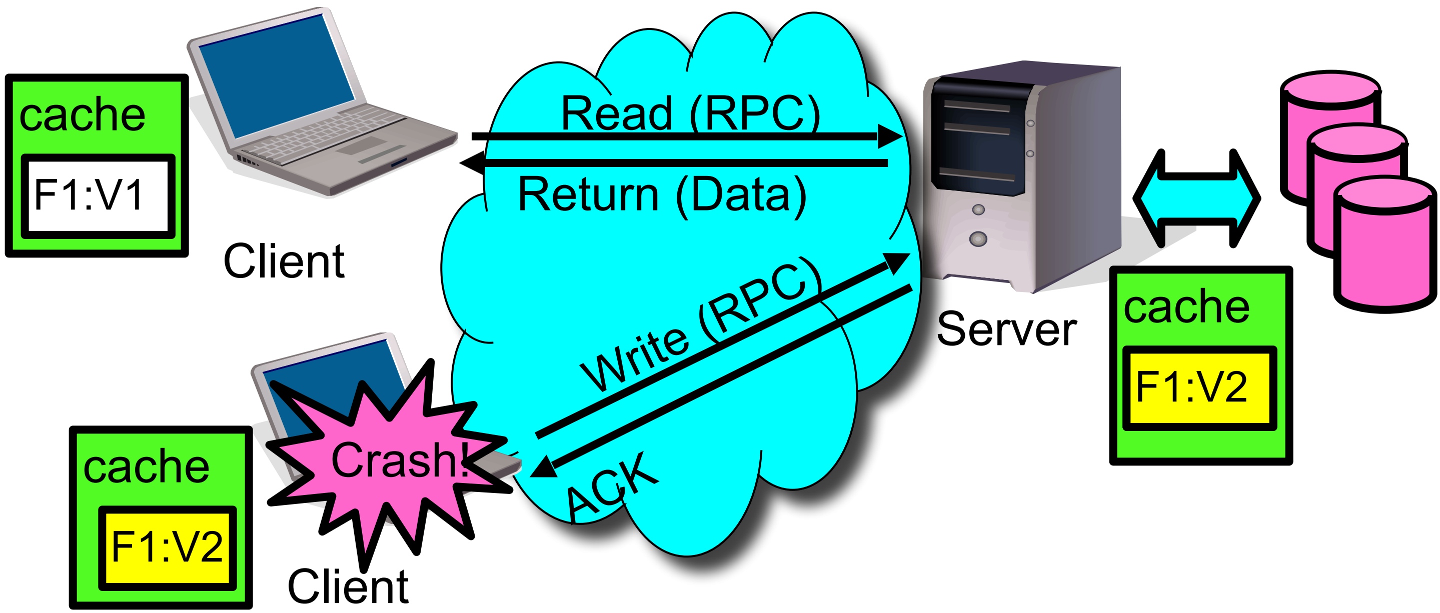

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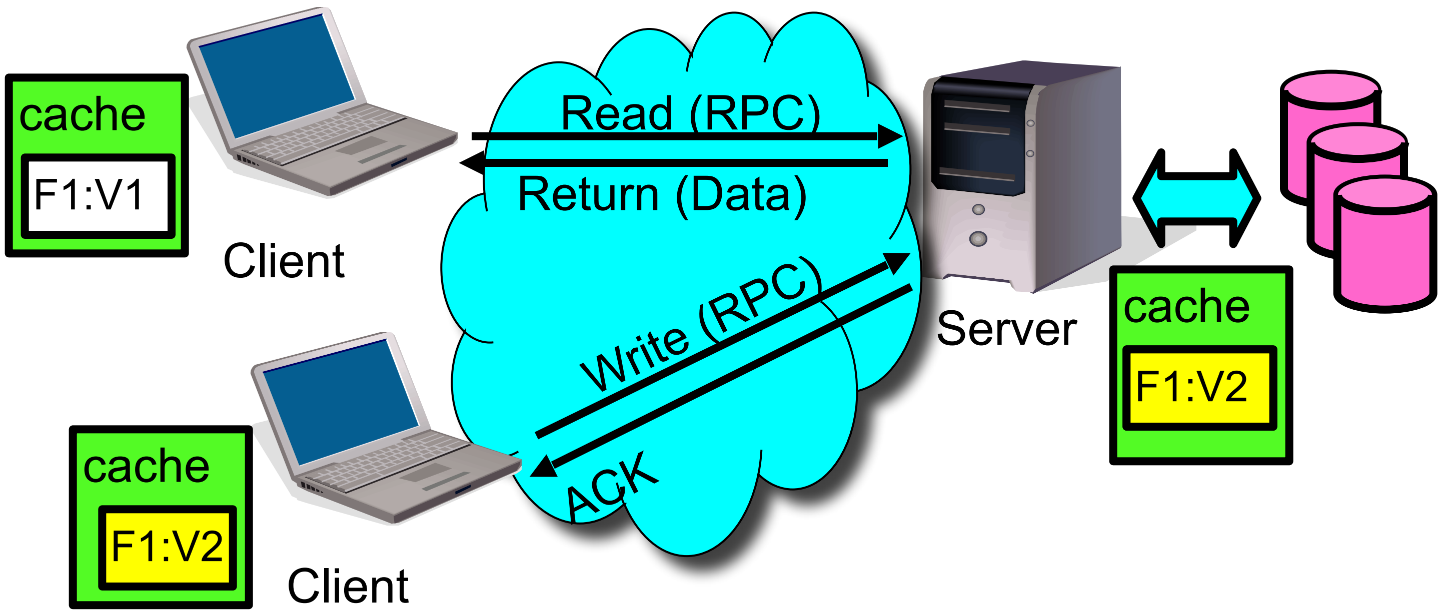

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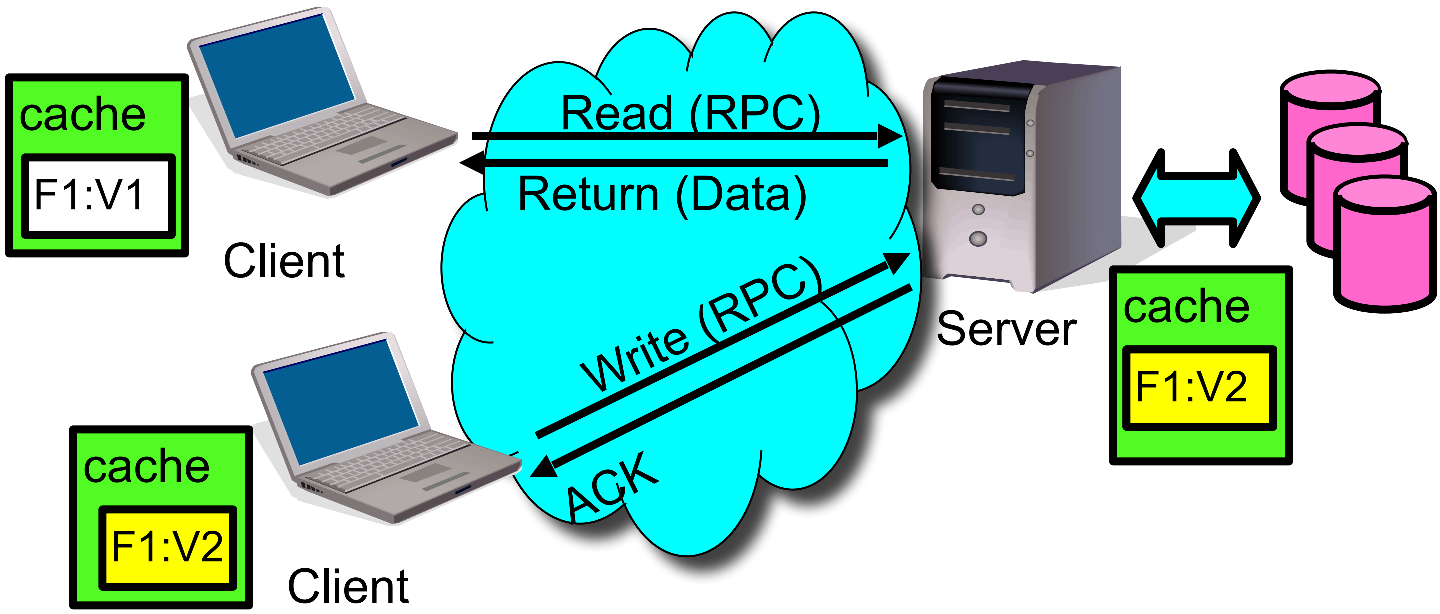
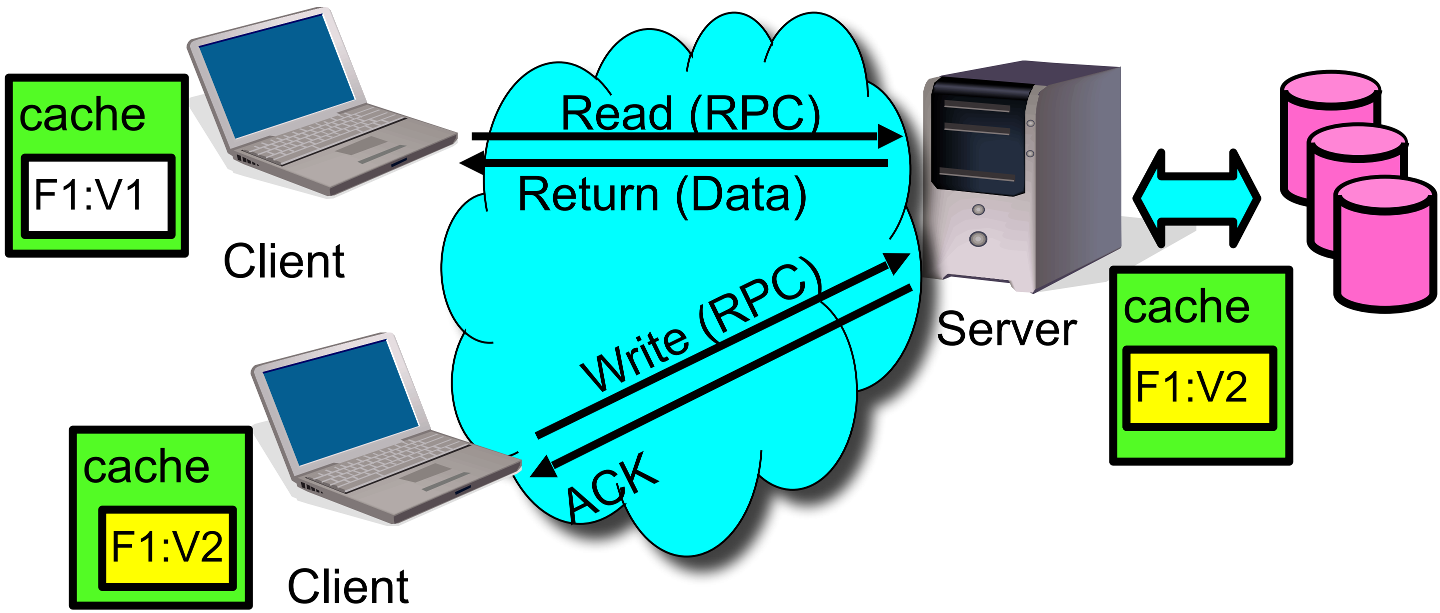


Use of caching to reduce network load

read(f1)→V1
read(f1)→V1
read(f1)→V1
read(f1)→V1

write(f1)→OK
read(f1)→V2



Client Caching in NFS v2

- Cache both clean and dirty file data and file attributes
  - Memory (e.g., DRAM) cache
- File attributes in the client cache expire after 60 seconds (file data doesn't expire)
- File data is checked against the modified-time in file attributes (which could be a cached copy)
  - Changes made on one machine can take up to 60 seconds to be reflected on another machine
- Dirty data are buffered on the client machine until file close or up to 30 seconds (Why 30s?)
  - If the machine crashes before then, the changes are lost

Implication of NFS v2 Client Caching

- Advantage: No network traffic if open/read/write/close can be done locally.
- But…. Data consistency guarantee is very poor
  - Simply unacceptable for some distributed applications
  - Productivity apps tend to tolerate such loose consistency
- Generally clients do not cache data on local disks

NFS’s Failure Handling – Stateless Server

- Files are state, but...
- Server exports files without creating extra state
  - No list of “who has this file open” (permission check on each operation on open file!)
  - No “pending transactions” across crash
- Crash recovery is “fast”
  - Reboot, let clients figure out what happened
- State stashed elsewhere
  - Separate MOUNT protocol
  - Separate NLM locking protocol
- Stateless protocol: requests specify exact state. read() → read([position]). no seek on server.

NFS’s Failure Handling

- Operations are idempotent
  - How can we ensure this?

NFS's Failure Handling

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  - How can we ensure this? Unique IDs on files/directories. It's not delete("foo"), it's delete(1337f00f), where that ID won't be reused (e.g., by same/other clients)

NFS’s Failure Handling

- Operations are idempotent
  - How can we ensure this? Unique IDs on files/directories. It’s not delete(“foo”), it’s delete(1337f00f), where that ID won’t be reused.
- Write-through caching: When file is closed, all modified blocks sent to server. close() does not return until bytes safely stored.
  - Close failures?
    - retry until things get through to the server
    - return failure to client
  - Most client apps can’t handle failure of close() call.
  - Usual option: hang for a long time trying to contact server

NFS Results

- NFS provides transparent, remote file access
- Simple, portable, *really popular*
  - (it’s gotten a little more complex over time, but...)
- Weak consistency semantics
- Requires hefty server resources to scale (write-through, server queried for lots of operations)

- Design take-away: smart server; dumb clients

AFS Goals

- Global distributed file system
  - “One AFS”, like “one Internet”
    - Why would you want more than one?
- **LARGE** numbers of clients, servers
  - 1000 machines could cache a single file,
  - Most local, some (very) remote
- Goal: O(0) work per client operation
  - O(1) may just be too expensive!

AFS Assumptions

- Client machines are un-trusted
  - Must **prove** they act for a specific user
    - Secure RPC layer
  - Anonymous “system:anyuser”
- Client machines have disks(!!)
  - Can cache whole files over long periods
- Write/write and write/read sharing are rare
  - Most files updated by one user, on one machine

Let’s look back at AFS

- NFS gets us partway there, but
  - Probably doesn’t handle scale (* - you can buy huge NFS appliances today that will, but they’re $$$-y).
  - Is very sensitive to network latency
- How can we improve this?
  - More aggressive caching (AFS caches on disk in addition to just in memory)
  - Prefetching (on open, AFS gets entire file from server, making later ops local & fast).
    - Remember: with traditional hard drives, large sequential reads are much faster than small random writes. So easier to support (client a: read whole file; client B: read whole file) than having them alternate. Improves scalability, particularly if client is going to read whole file anyway eventually.

Client Caching in AFS

- Callbacks! Clients register with server that they have a copy of file;
  - Server tells them: "Invalidate" if the file changed (but only does so on file close!)
  - This trades state for improved consistency
- What if server crashes? Lose all callback state!
  - Reconstruct callback information from clients
    - ask everyone "who has which files cached?"

AFS v2 RPC Procedures

- Procedures that are not in NFS
  - Fetch: return status and optionally data of a file or directory, and place a callback on it
  - RemoveCallBack: specify a file that the client has flushed from the local machine
  - BreakCallBack: from server to client, revoke the callback on a file or directory
    - What should the client do if a callback is revoked?
  - Store: store the status and optionally data of a file
- Rest are similar to NFS calls

Topic 2: File Access Consistency

- In UNIX local file system, concurrent file reads and writes have “sequential” consistency semantics
  - Each file read/write from user-level app is an atomic operation
    - The kernel locks the file vnode
  - Each file write is immediately visible to all file readers
- Neither NFS nor AFS provides such concurrency control
  - NFS: “sometime within 30 seconds”
  - AFS: session semantics for consistency (next slide)

Session Semantics in AFS v2

- What it means:
  - A file write is visible to processes on the same box immediately, but not visible to processes on other machines until the file is closed
  - When a file is closed, changes are visible to new opens, but are not visible to “old” opens
  - All other file operations are visible everywhere immediately
- Implementation
  - Dirty data are buffered at the client machine until file close, then flushed back to server, which leads the server to send “break callback” to other clients

AFS Write Policy

- Writeback cache
  - Opposite of NFS "every write is sacred"
  - Store chunk back to server
    - When cache overflows
    - On last user close()
  - ...or don't (if client machine crashes)
- Is writeback crazy?
  - Write conflicts "assumed rare"
  - Who wants to see a half-written file?

Results for AFS

- Lower server load than NFS
  - More files cached on clients
  - Callbacks: server not busy if files are read-only (common case)
- But maybe slower: Access from local disk is much slower than from another machine's memory over LAN
- For both:
  - Central server is bottleneck: all reads and writes hit it at least once;
  - is a single point of failure.
  - is costly to make them fast, beefy, and reliable servers.

Topic 3: Name-Space Construction and Organization

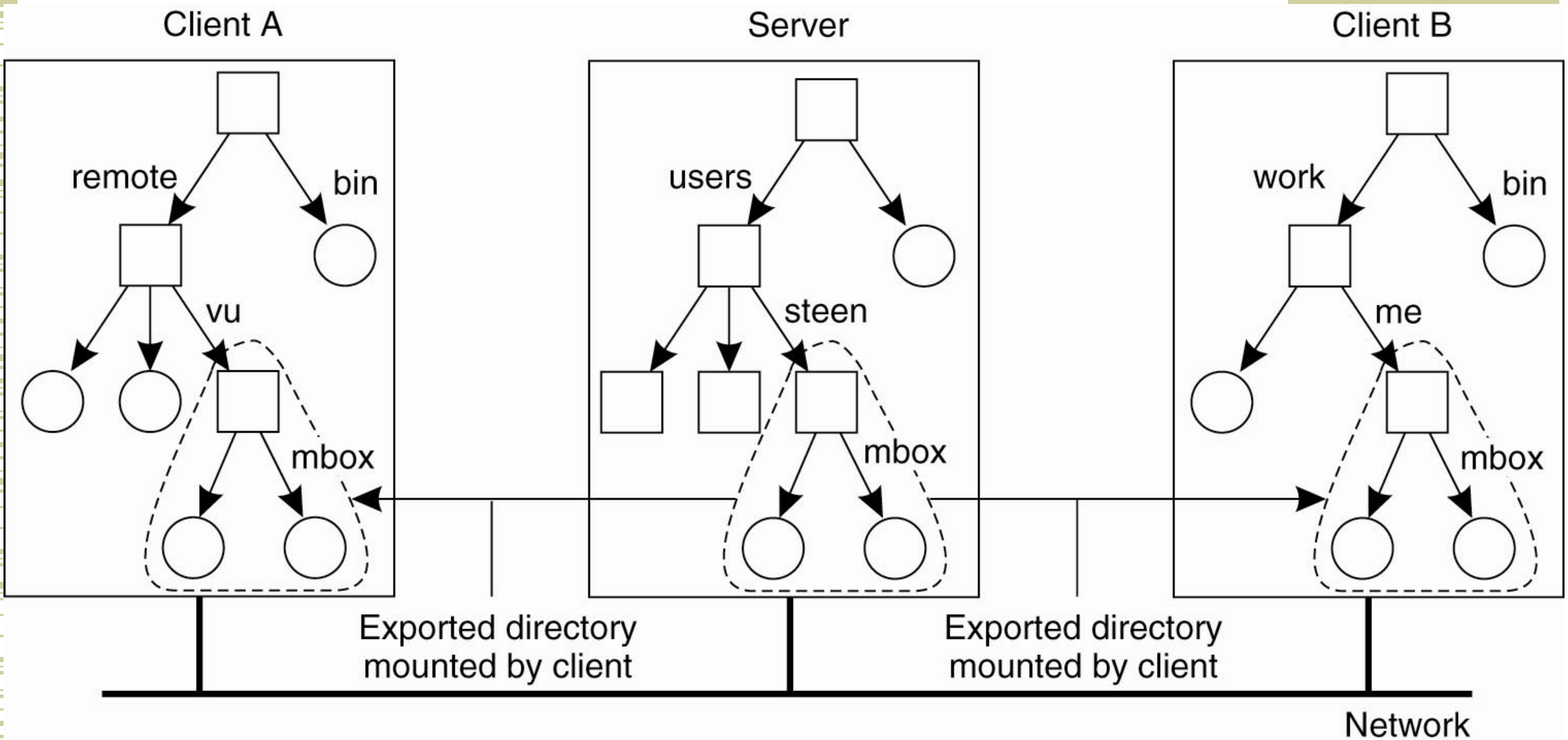
- NFS: per-client linkage
  - Server: export /root/fs1/
  - Client: mount server:/root/fs1 /fs1
- AFS: global name space
  - Name space is organized into Volumes
    - Global directory /afs;
    - /afs/cs.wisc.edu/vol1/…; /afs/cs.stanford.edu/vol1/…
  - Each file is identified as fid = <vol_id, vnode #, unique identifier>
  - All AFS servers keep a copy of “volume location database”, which is a table of vol_id→ server_ip mappings

Implications on Location Transparency

- NFS: no transparency
  - If a directory is moved from one server to another, client must remount

- AFS: transparency
  - If a volume is moved from one server to another, only the volume location database on the servers needs to be updated

Naming in NFS (1)



Naming in NFS (2)