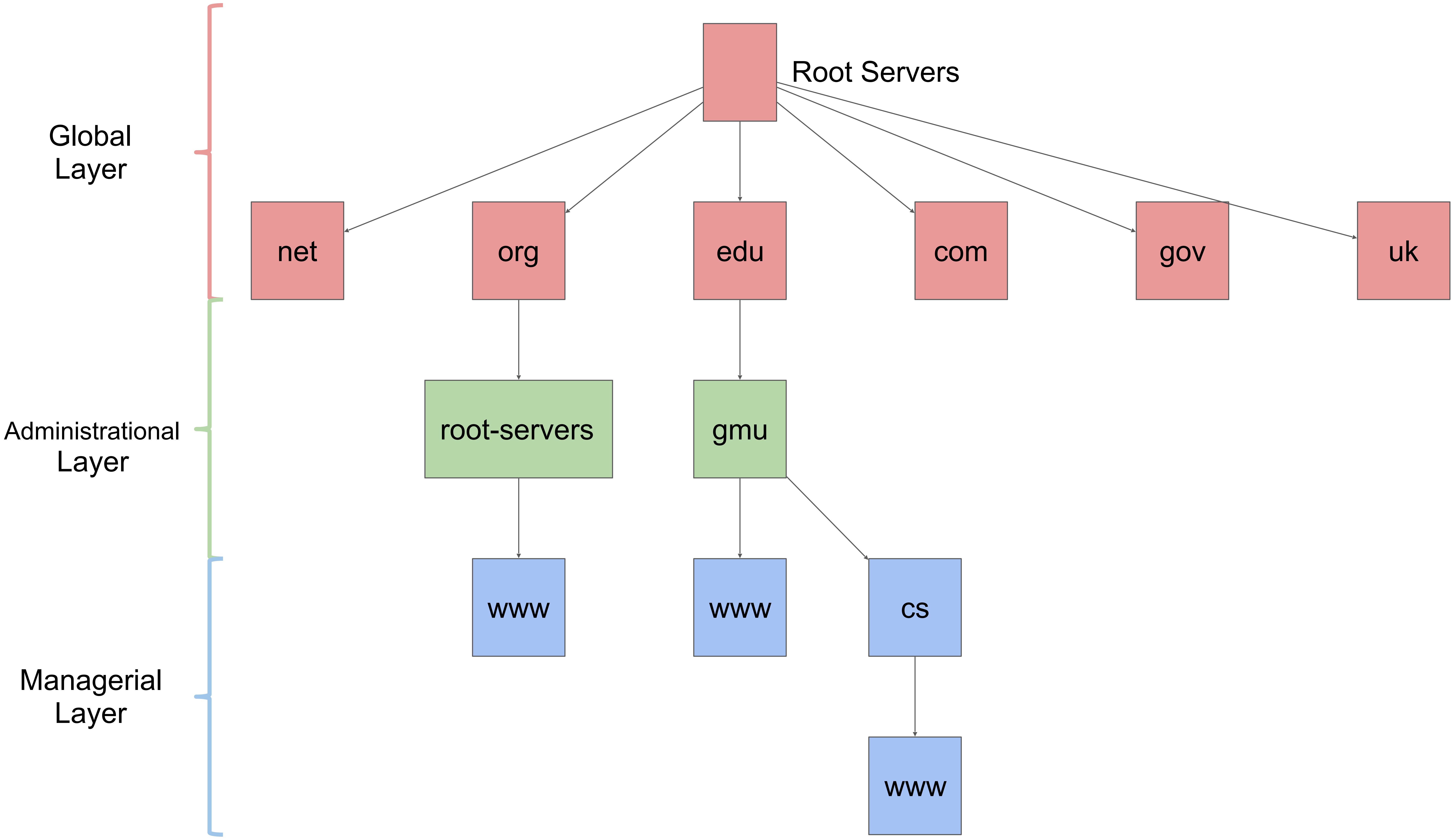
Distributed Filesystems - NFS

CS 475, Spring 2019
Concurrent & Distributed Systems

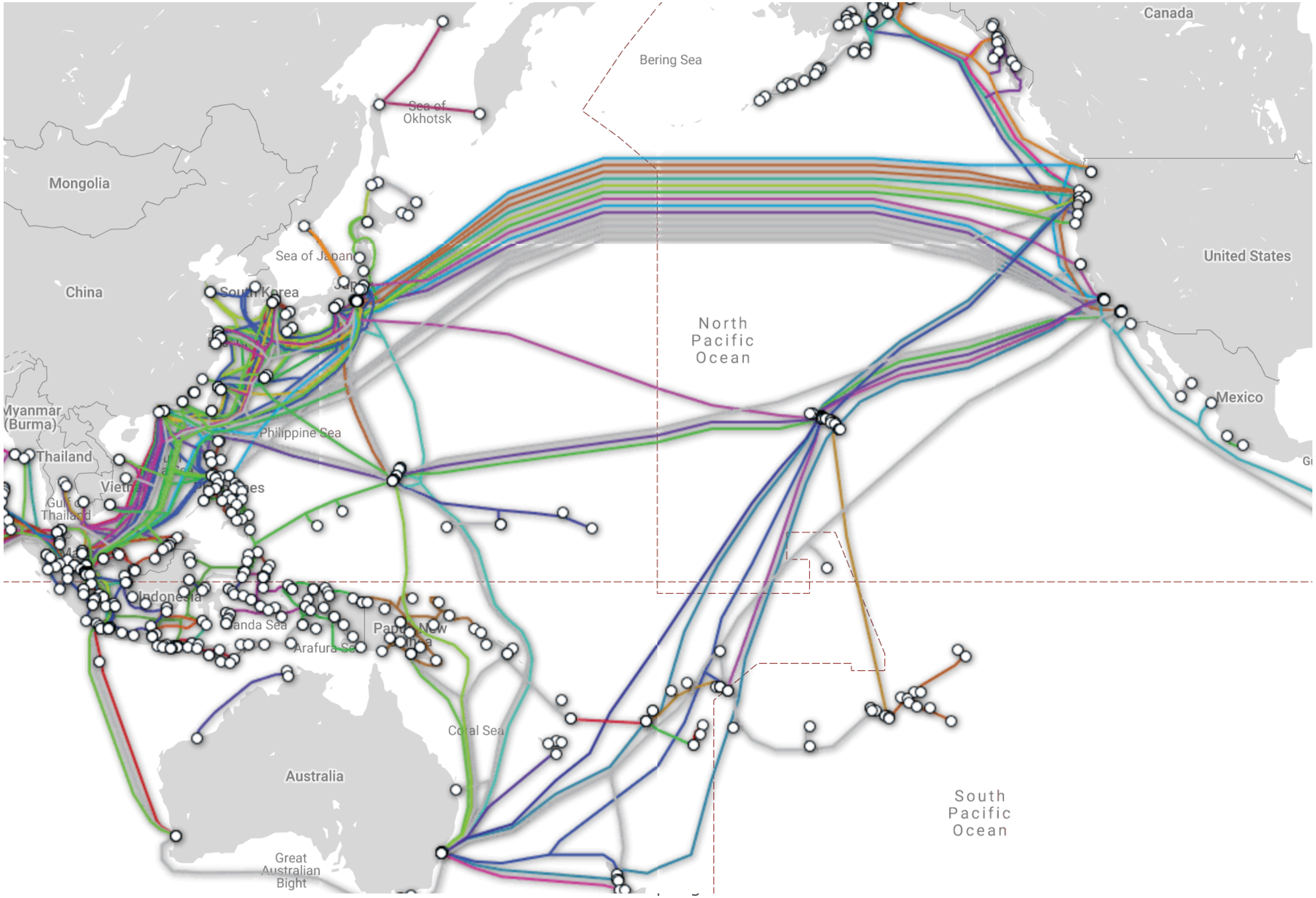
Review: Domain Name System



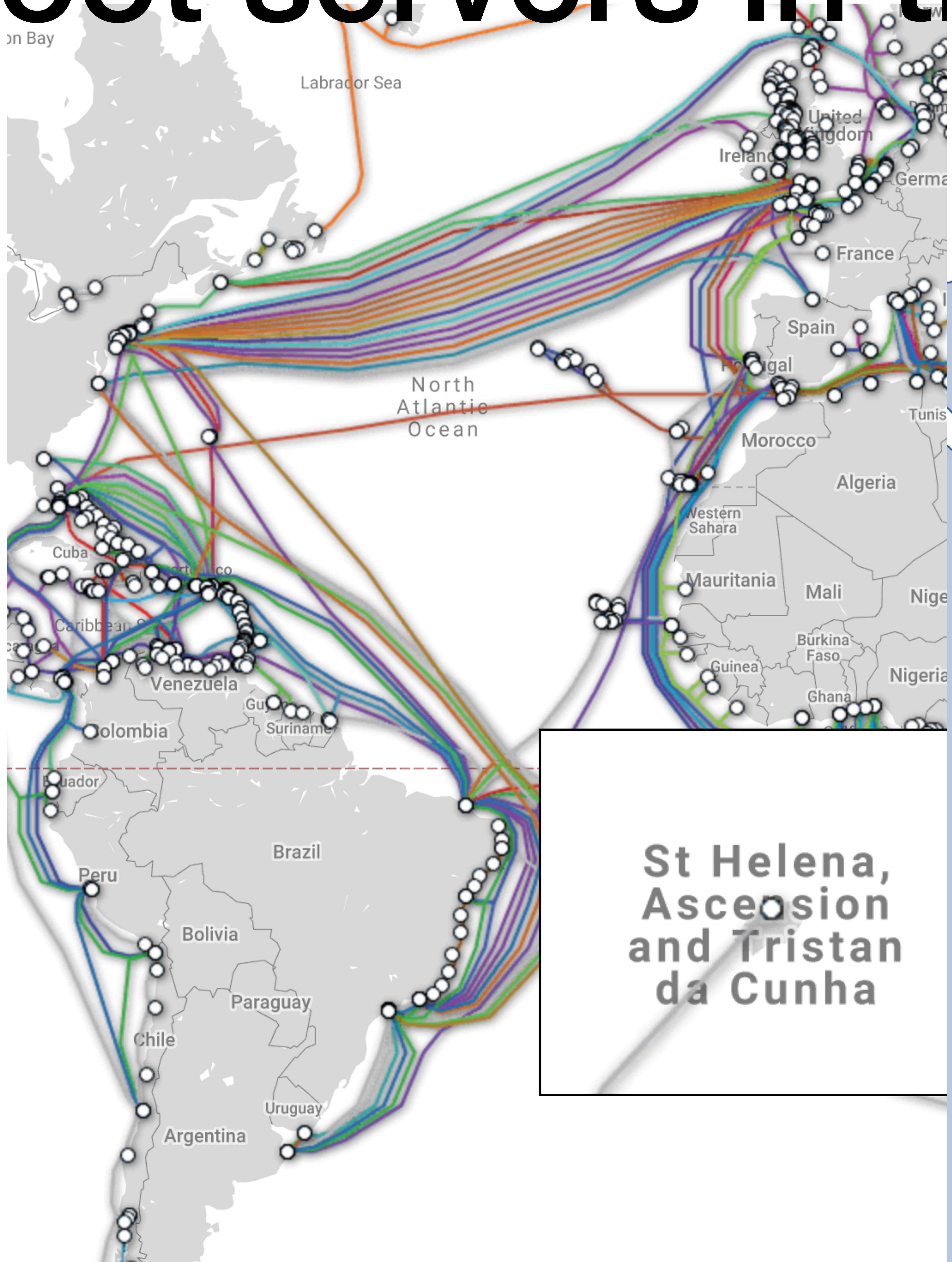
Review: Domain Name System - Root servers

www.root-servers.net

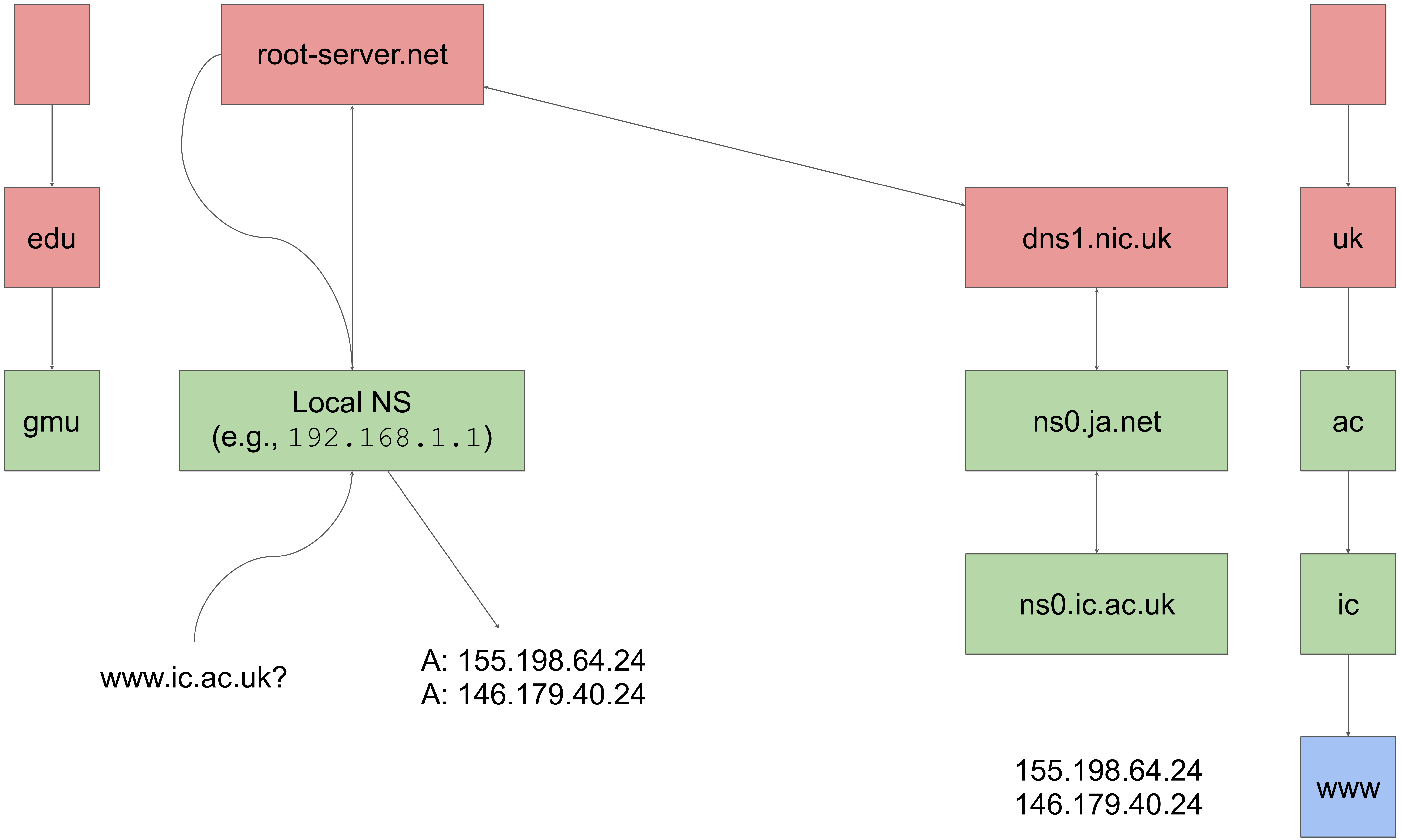
Why root servers in the Pacific?



Why no root servers in t



Review: Domain Name System - Resolution



Review: DNS-SD in practice - Zeroconf

- Modern Operating Systems all have a zeroconf daemon
  - Apple: *Bonjour* protocol
    - mDNSResponder released as open source, used by Android
  - Microsoft:
    - *Netbios* (not mDNS)
      - Until Windows XP (at least?)
    - *Link-Local Multicast Name Resolution* (LLMNR)
      - From Windows Vista
  - GNU/Linux
    - *Avahi* service
- Building block of modern IOT devices

Review: Filesystem consistency

- What consistency guarantees do a filesystem provide?
- read, write, sync, close
- On sync, guarantee writes are persisted to disk
- Readers see most recent
- What does a network file system do?

Review: Network Filesystem Consistency

- How do you maintain these same semantics?
- (Cheat answer): Very, very expensive
  - EVERY write needs to propagate out
  - EVERY read needs to make sure it sees the most recent write
  - Oof. Just like Ivy.
  - Can't get availability
  - What should we do? <—— today's lecture

Today

- This week - case studies in replication
- Today: NFS - a very widely used distributed file system
- Reminder:
  - HW4 is due 4/15!

Files

- File:
  - Name
  - Size (bytes)
  - Create/Access/Modification Time
  - Contents (binary)
- Directory:
  - Maintains a list of the files (and their metadata) in that directory

File Operations

- Create
- Write – at write pointer location
- Read – at read pointer location
- Reposition within file - seek
- Delete
- Truncate
- Open(F_i) – search the directory structure on disk for entry F_i, and move the content of entry to memory
- Close (F_i) – move the content of entry F_i in memory to directory structure on disk

Directory Operations

- Search for a file
- Create a file
- Delete a file
- List a directory
- Rename a file
- Traverse the file system

Open file locking

- Provided by some operating systems and file systems
  - Similar to reader-writer locks
  - Shared lock similar to reader lock – several processes can acquire concurrently
  - Exclusive lock similar to writer lock
- Mediates access to a file
- Mandatory or advisory:
  - Mandatory – access is denied depending on locks held and requested
  - Advisory – processes can find status of locks and decide what to do

Directory Structure

- Directories contain information about the files in them
- Directories can be nested
- Operations on directories:
  - Create file
  - List files
  - Delete file
  - Rename file

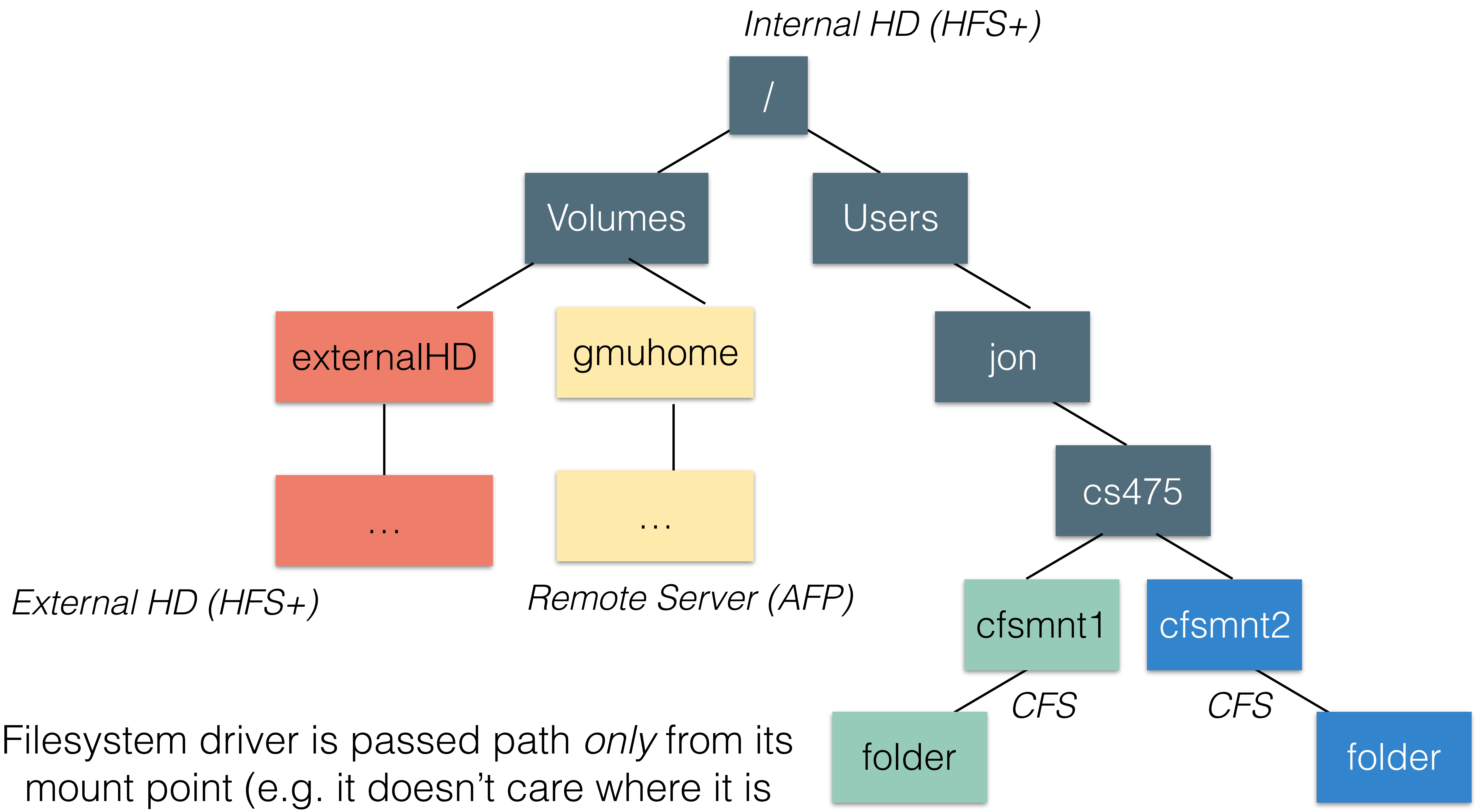
Filesystems

- Define how files and directory structure is maintained
- Exposes this information to the OS via a standard interface (driver)
- OS can provide user with access to that filesystem when it is **mounted**
  - (Example: NFS, AFP, SMB)

Filesystem Functionality

- Directory management (maps entries in a hierarchy of names to files-on-disk)
- File management (manages adding, reading, changing, appending, deleting) individual files
- Space management: where on disk to store these things?
- Metadata management

Mounting Filesystems



Filesystem driver is passed path *only* from its mount point (e.g. it doesn't care where it is mounted)

Distributed File Systems

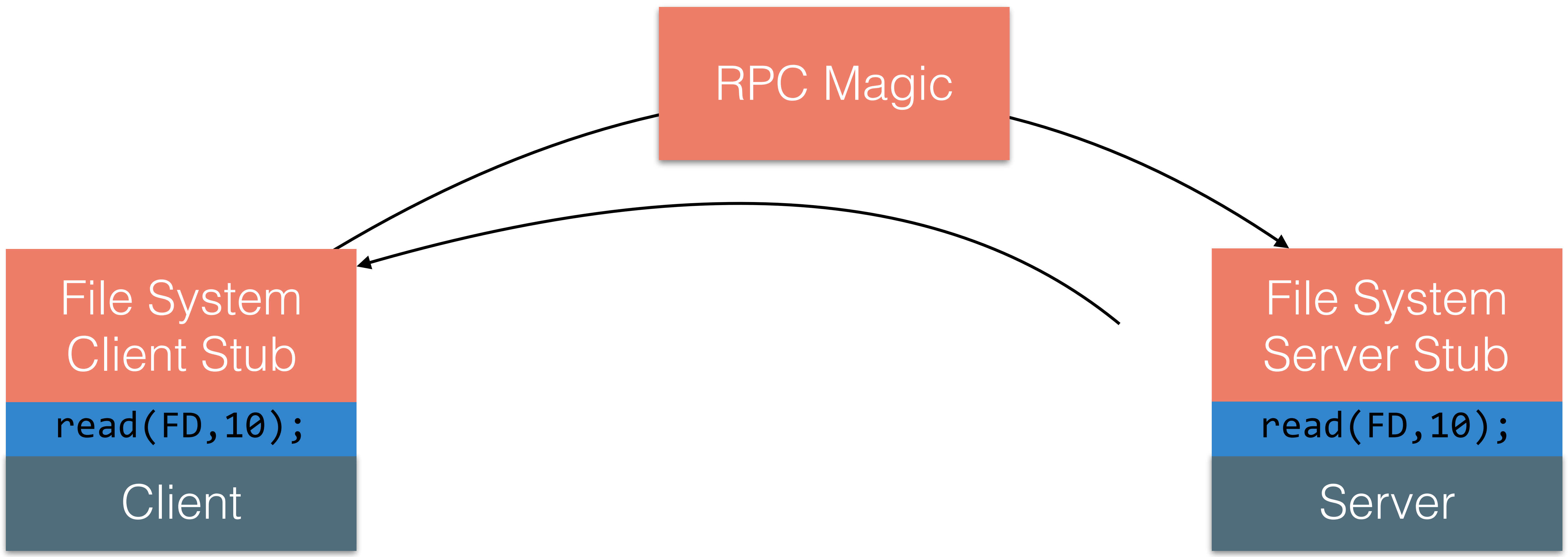
- Goals
  - Shared filesystem that will look the same as a local filesystem
  - Scale to many TB's of data/many users
  - Fault tolerance
  - Performance

Distributed File Systems

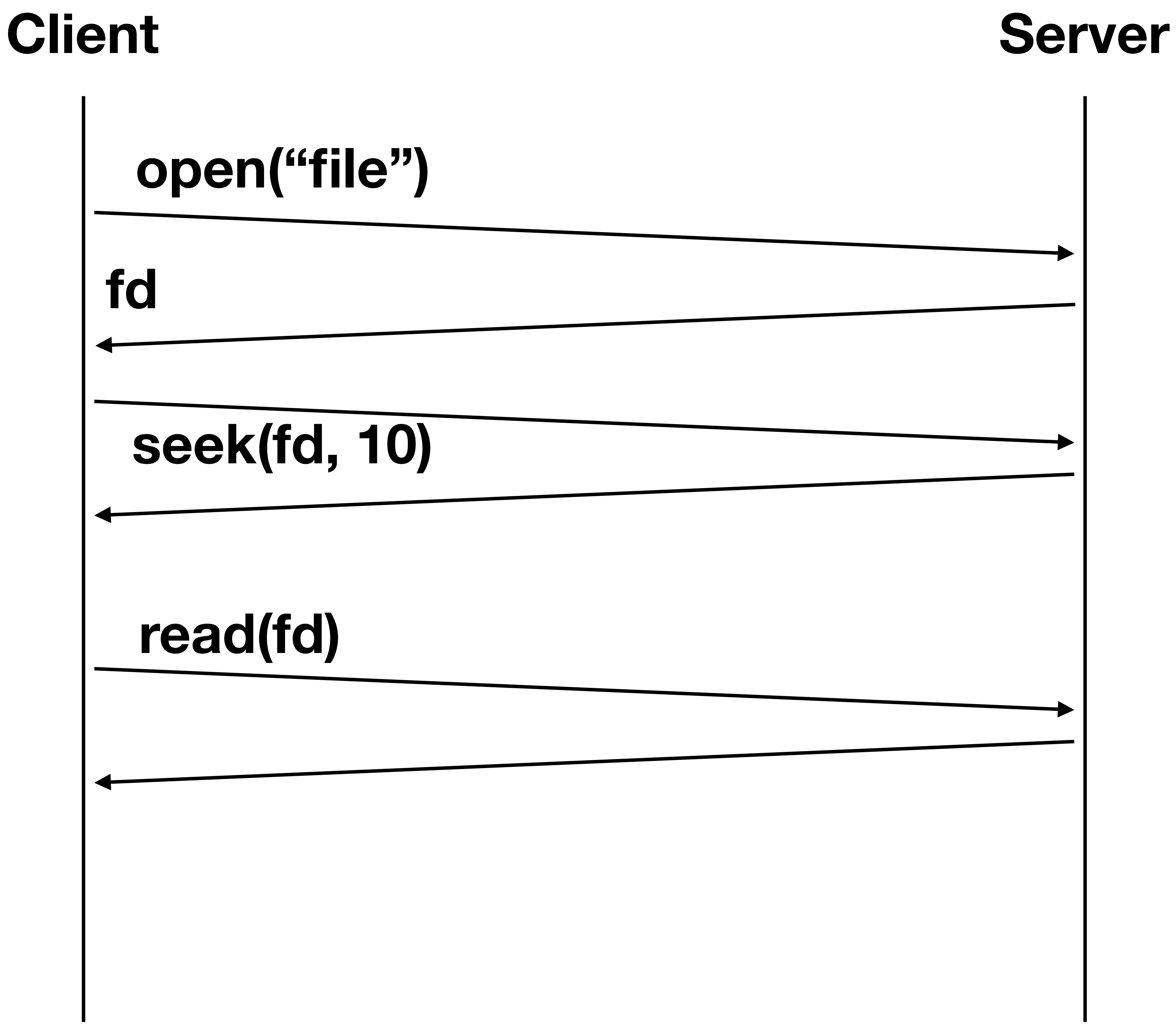
- Challenges:
  - Heterogeneity (different kinds of computers with different kinds of network links)
  - Scale (maybe lots of users)
  - Security (access control)
  - Failures
  - Concurrency

Strawman Approach

- Use RPC to forward every filesystem operation to the server
- Server serializes all accesses, performs them, and sends back result.



Strawman Approach



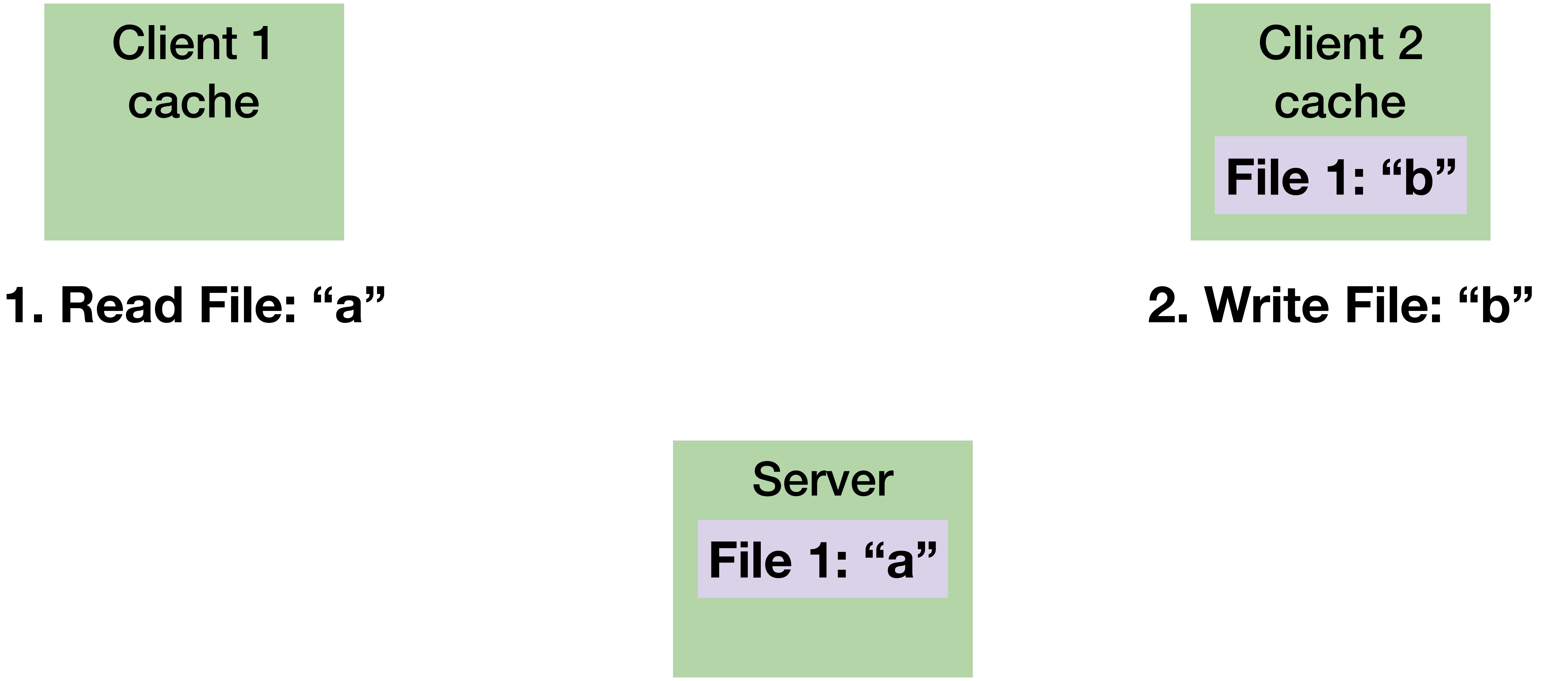
Strawman Approach

- 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

NFS

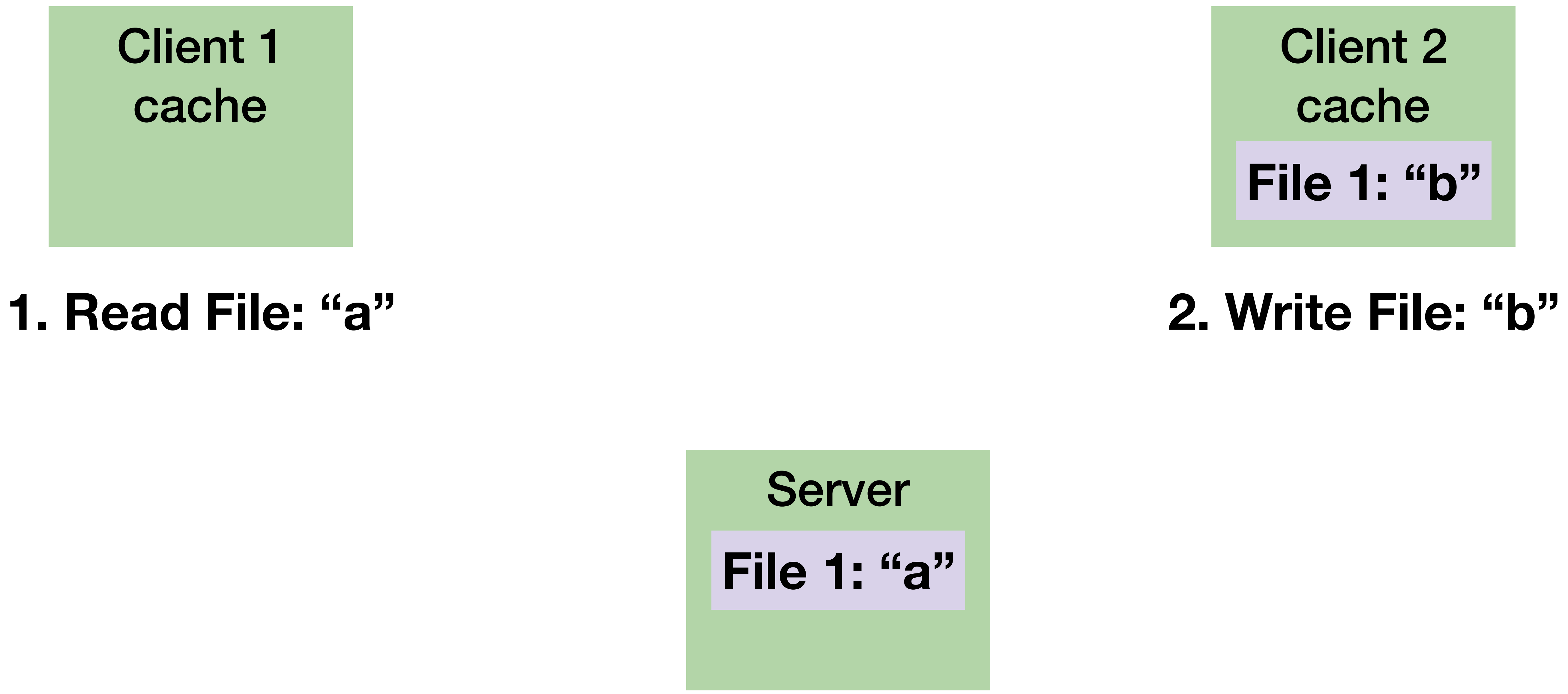
- Cache file blocks, file headers, etc., at both clients and servers.
- Advantage: No network traffic if open/read/write/close can be done locally.
- But: failures and cache consistency.
- NFS trades some consistency for increased performance... what does caching get us?

Cache Consistency: Update Visibility



Update Visibility: When do Client 2’s writes become apparent to the server?

Cache Consistency: Stale reads



Stale reads: Once the server gets updated, how does client 1 know that File 1 has been updated?

Cache Consistency Strawman

- Before any read(), ask server if file has changed
  - If not, use cached version
  - If so, get fresh data from server
- Bad news: floods the server with requests
- Anyway: this alone is not enough to make sure each read() sees the latest write()
  - How do we know when the write() gets committed? Would need to have locking.

NFS Caching - Close-to-open

- Implemented by most NFS clients
- Contract:
  - if client A write()s a file, then close()s it,
  - then client B open()s the file, and read()s it,
  - client B's reads will reflect client A's writes
- Benefit: clients need only contact server during open() and close()—not on every read() and write()

NFS Caching - Close-to-open

Client 1 cache

1. Open File
2. Read File: “a”

Client 2 cache

File 1: “b”

3. Open File
4. Write File: “b”
7. Close File

Server

File 1: “b”

Client 3 cache

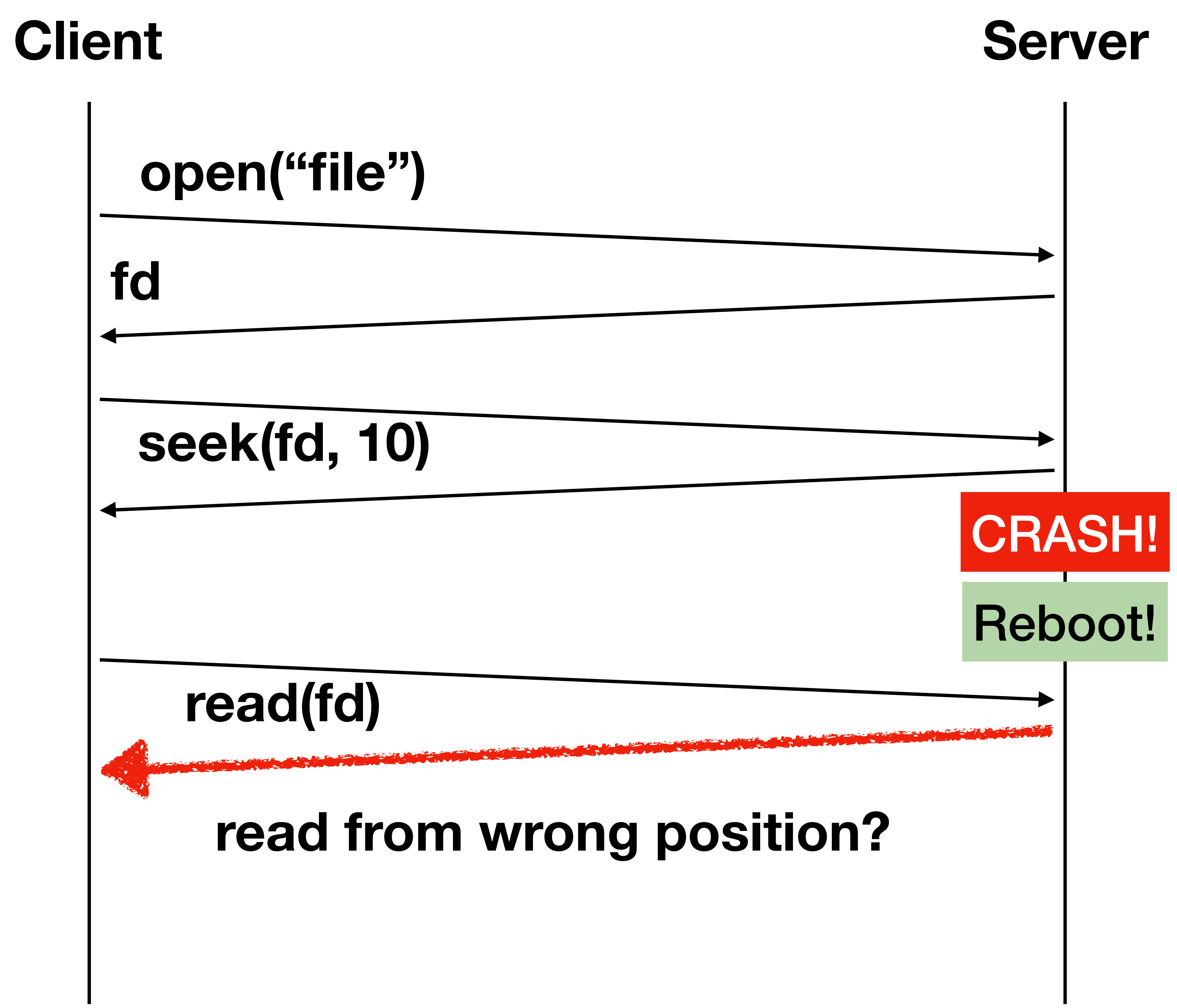
8. Open File
9. Read File: “b”

Client 4 cache

5. Open File
6. Read File: “a”

Note: in practice, client caches periodically check server to see if still valid

NFS + Failures



Problem: read() depends on server remembering that client did seek()!

How to solve?

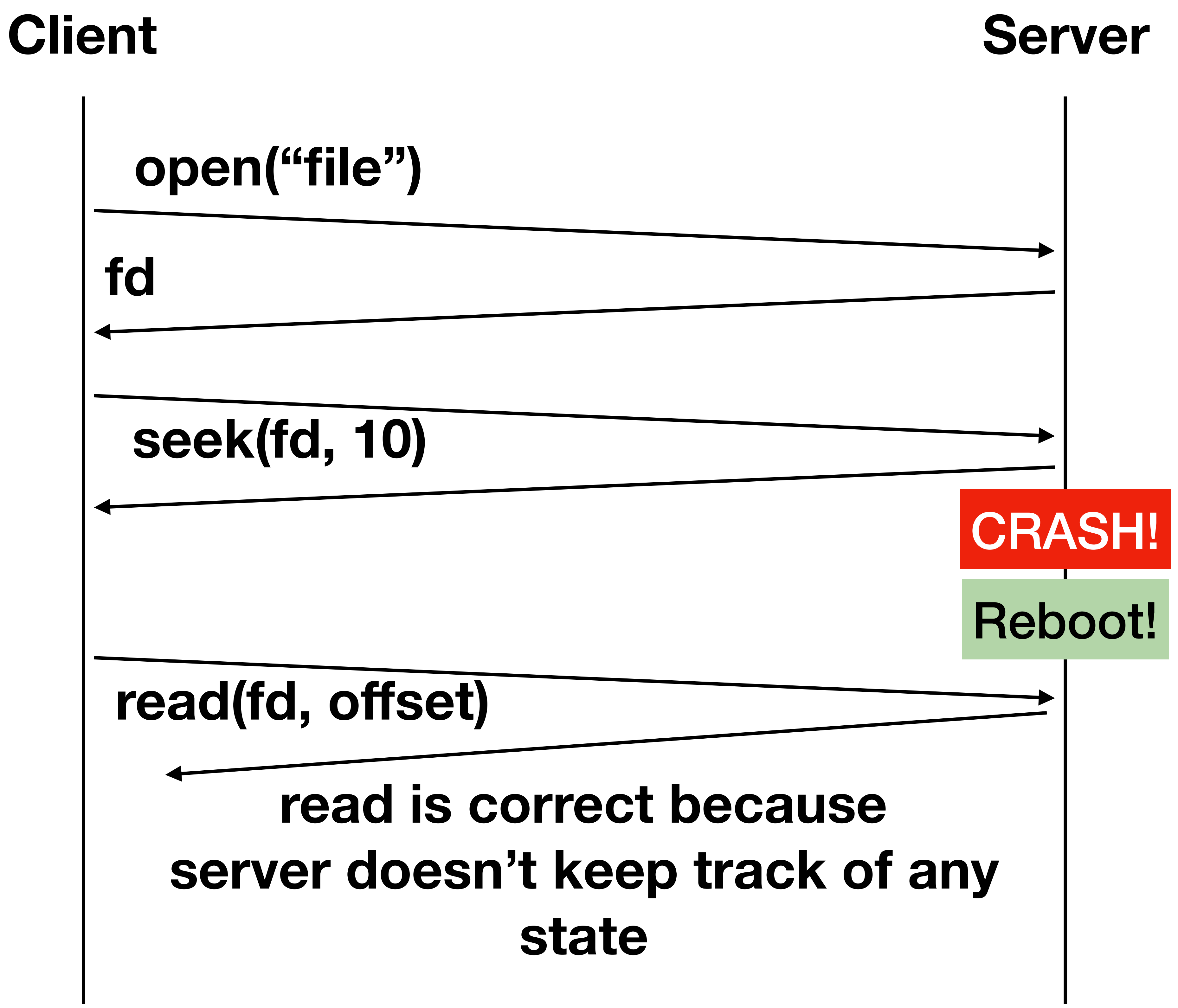
NFS is Weakly Consistent

- NFS checks for updates periodically while a file is open
- Multiple clients calling read at the same moment could see different values
- If there are multiple writers at once, there are **no guarantees** for ordering
  - Reader might see writes from **both** writers
- NFS is an “AP” system

NFS + Server crash?

- Data in memory but not disk lost
- So... what if client does seek() ; /* SERVER CRASH */; read()
  - If server maintains file position, this will fail. Ditto for open(), read()
- Stateless protocol: requests specify exact state. read() -> read([position]). no seek on server.

NFS + Server Crash



NFS + Lost Messages?

- Lost messages: what if we lose acknowledgement for delete(“foo”)
- And in the meantime, another client created foo a new file called foo?
- Solution: 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.

NFS + Client Crashes

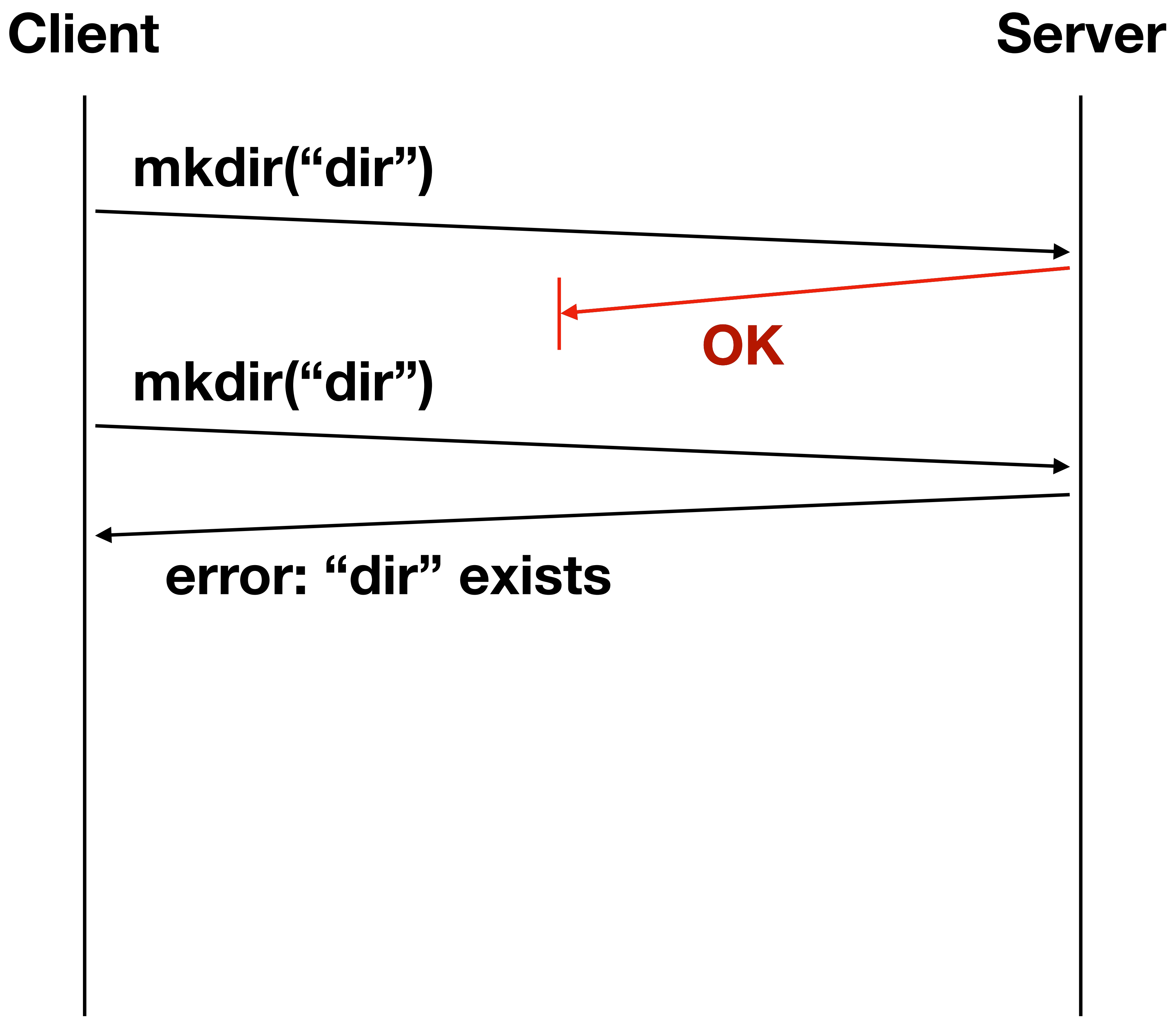
- Might lose data in client cache
- Doesn’t matter:
  - If lose other people’s data, can always retrieve it again
- Local writes go to cache until close() is called and returns (which flushes to server)
- If lose your own writes sooner, SOL

NFS Failure Handling

- You can choose -
  - retry until things get through to the server
  - return failure to client
- Most client apps can't handle failure of close() call. NFS tries to be a transparent distributed filesystem -- so how can a write to local disk fail? And what do we do, anyway?
- Usual option: hang for a long time trying to contact server

NFS Failure Handling

- Not everything is idempotent! Some stuff leaks through!



NFS + Locking

- Does NFS support locks?
- Nope! How could it support locks and still be stateless?
- Fault-tolerant lock servers are **really hard** to implement (distributed agreement strikes again!)

NFS Security

- What prevents unauthorized users from issuing RPCs to an NFS server?
- What prevents unauthorized users from forging NFS replies to an NFS client?
- **Nothing: IP-address based security only. Client A can access mount M. That's it!**

NFS Limitations

- Security: what if untrusted users can be root on client machines?
- Scalability: how many clients can share one server?
  - Writes always go through to server
  - Some writes are to "private," unshared files that are deleted soon after creation
- Can you run NFS on a large, complex network?
  - Effects of latency? Packet loss? Bottlenecks?
- Important question: whose fault are these limitations? Are they intractable (because of the very problem we are trying to solve)? Or are we just not thinking hard enough?

Other Approaches

- What about handling hundreds of thousands of concurrent clients and exabytes of data?
- We will discuss GFS, the Google File System next Weds in lecture 23 - it does exactly this!

HW4 Discussion