NFS

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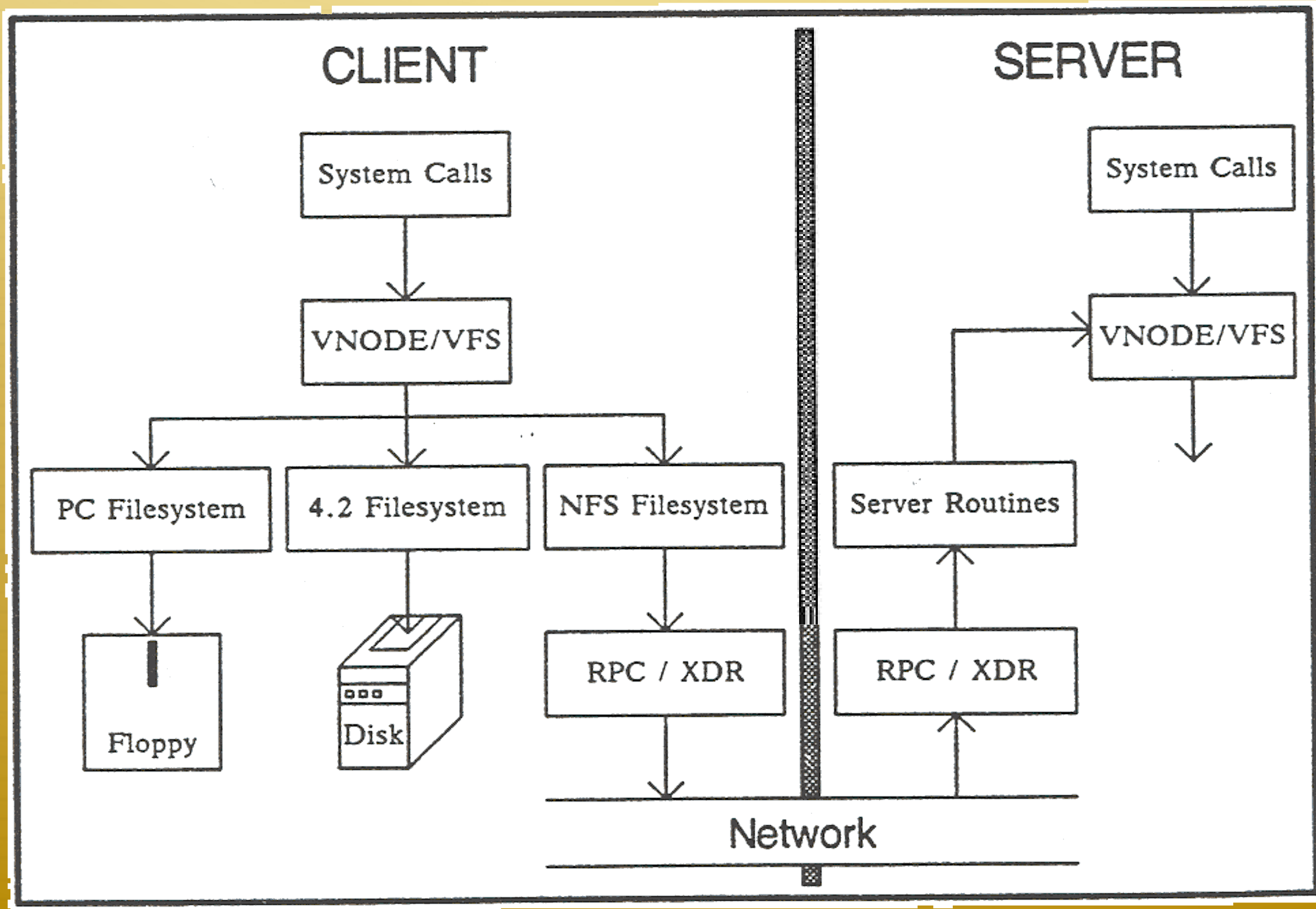
CSE 506

Big picture
(from Sandberg et al.)



Intuition

- Instead of translating VFS requests into hard drive accesses, translate them into remote procedure calls to a server
- Simple, right? I mean, what could possibly go wrong?

Challenges

- Server can crash or be disconnected
- Client can crash or be disconnected
- How to coordinate multiple clients accessing same file?
- Security
- New failure modes for applications
  - Goal: Invent VFS to avoid changing applications; use network file system transparently

Disconnection

- Just as a machine can crash between writes to the hard drive, a client can crash between writes to the server
- The server needs to think about how to recover if a client fails between requests
  - Ex: Imagine a protocol that just sends low-level disk requests to a distributed virtual disk.
  - What happens if the client goes away after marking a block in use, but before doing anything with it?
  - When is it safe to reclaim the block?
  - What if, 3 months later, the client tries to use the block?

Stateful protocols

- A stateful protocol has server state that persists across requests (aka connections)
  - Like the example on previous slide
- Server Challenges:
  - Knowing when a connection has failed (timeout)
  - Tracking state that needs to be cleaned up on a failure
- Client Challenges:
  - If the server thinks we failed (timeout), recreating server state to make progress

Stateless protocol

- The (potentially) simpler alternative:
  - All necessary state is sent with a single request
  - Server implementation much simpler!
- Downside:
  - May introduce more complicated messages
  - And more messages in general
- Intuition: A stateless protocol is more like polling, whereas a stateful protocol is more like interrupts
  - How do you know when something changes on the server?

NFS is stateless

- Every request sends all needed info
  - User credentials (for security checking)
  - File identifier and offset
- Each protocol-level request needs to match VFS-level operation for reliability
  - E.g., write, delete, stat

Challenge 1: Lost request?

- What if I send a request to the NFS server, and nothing happens for a long time?
  - Did the message get lost in the network (UDP)?
  - Did the server die?
  - Don’t want to do things twice, like write data at the end of a file twice
- Idea: make all requests *idempotent* or having the same effect when executed multiple times
  - Ex: write() has an explicit offset, same effect if done 2x

Challenge 2: Inode reuse

- Suppose I open file ‘foo’ and it maps to inode 30
- Suppose another process unlinks file ‘foo’
  - On a local file system, the file handle holds a reference to the inode, preventing reuse
  - NFS is stateless, so the server doesn’t know I have an open handle
    - The file can be deleted and the inode reused
    - My request for inode 30 goes to the wrong file! Uh-oh!

Generation numbers

- Each time an inode in NFS is recycled, its generation number is incremented
- Client requests include an inode + generation number
  - Detect attempts to access an old inode

Security

- Local uid/gid passed as part of the call
  - Uids must match across systems
  - Yellow pages (yp) service; evolved to NIS
  - Replaced with LDAP or Active Directory
- Root squashing: if you access a file as root, you get mapped to a bogus user (nobody)
  - Is this effective security to prevent someone with root on another machine from getting access to my files?

File locking

- I want to be able to change a file without interference from another client.
  - I could get a server-side lock
  - But what happens if the client dies?
  - Lots of options (timeouts, etc), but very fraught
  - Punted to a separate, optional locking service

Removal of open files

- Unix allows you to delete an open file, and keep using the file handle; a hassle for NFS
- On the client, check if a file is open before removing it
- If so, rename it instead of deleting it
  - .nfs* files in modern NFS
- When file is closed, then delete the file
- If client crashes, there is a garbage file left which must be manually deleted

Changing Permissions

- On Unix/Linux, once you have a file open, a permission change generally won't revoke access
  - Permissions cached on file handle, not checked on inode
  - Not necessarily true anymore in Linux
  - NFS checks permissions on every read/write---introduces new failure modes
- Similarly, you can have issues with an open file being deleted by a second client
  - More new failure modes for applications

Time synchronization

- Each CPU's clock ticks at slightly different rates
- These clocks can drift over time
- Tools like 'make' use modification timestamps to tell what changed since the last compile
  - In the event of too much drift between a client and server, make can misbehave (tries not to)
- In practice, most systems sharing an NFS server also run network time protocol (NTP) to same time server

Cached writes

- A local file system sees performance benefits from buffering writes in memory
  - Rather than immediately sending all writes to disk
  - E.g., grouping sequential writes into one request
- Similarly, NFS sees performance benefits from caching writes at the client machine
  - E.g., grouping writes into fewer synchronous requests

Caches and consistency

- Suppose clients A and B have a file in their cache
- A writes to the file
  - Data stays in A's cache
  - Eventually flushed to the server
- B reads the file
- Does B read the old contents or the new file contents?

Consistency

- Trade-off between performance and consistency
- Performance: buffer everything, write back when convenient
  - Other clients can see old data, or make conflicting updates
- Consistency: Write everything immediately; immediately detect if another client is trying to write same data
  - Much more network traffic, lower performance
  - Common case: accessing an unshared file

Close-to-open consistency

- NFS Model: Flush all writes on a close
- When you open, you get the latest version on the server
  - Copy entire file from server into local cache
- Can definitely have weirdness when two clients touch the same file
- Reasonable compromise between performance and consistency

Other optimizations

- Caching inode (stat) data and directory entries on the client ended up being a big performance win
- So did read-ahead on the server
- And demand paging on the client

NFS Evolution

- You read about what is basically version 2
- Version 3 (1995):
  - 64-bit file sizes and offsets (large file support)
  - Bundle file attributes with other requests to eliminate more stats
  - Other optimizations
  - Still widely used today

NFS V4 (2000)

- Attempts to address many of the problems of V3
  - Security (eliminate homogeneous uid assumptions)
  - Performance
- Becomes a stateful prototocol
- pNFS – proposed extensions for parallel, distributed file accesses
- Slow adoption

Summary

- NFS is still widely used, in part because it is simple and well-understood
  - Even if not as robust as its competitors
- You should understand architecture and key trade-offs
- Basics of NFS protocol from paper