Network File System (NFS)

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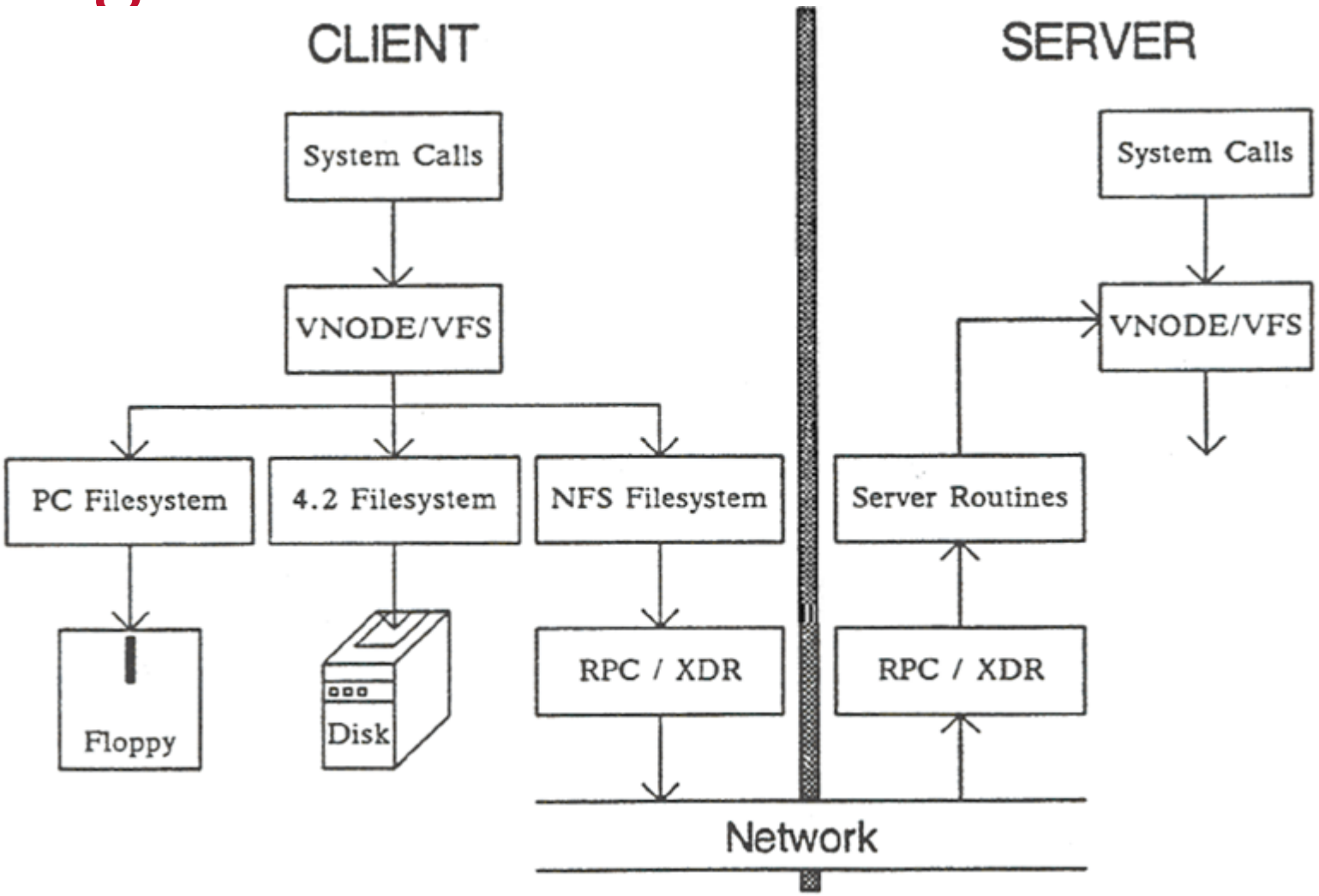
(Based on slides by Don Porter and Mike Ferdman)

Big Picture



From *Sandberg et al., 1985*

Intuition and Challenges

Intuition:

- Translate VFS requests into remote procedure calls to server
  - Instead of translating them into disk accesses

Challenges:

- Server can crash or be disconnected
- Client can crash or be disconnected
- How to coordinate multiple clients on same file?
- Security
- …

Stateful vs. Stateless Protocols

- ***Stateful protocol***: server keeps track of past requests
  - I.e., state persist across requests on the server
- ***Stateless protocol***: server does not keep track of past requests
  - Client should send all necessary state with a single request

- Challenge of stateful: Recovery from crash/disconnect
- Server side challenges:
  - Knowing when a connection has failed (timeout)
  - Tracking state that needs to be cleaned up on a failure
- Client side challenges:
  - If server thinks we failed (timeout), must recreate server state

Stateful vs. Stateless Protocols

- Drawbacks of stateless:
  - May introduce more complicated messages
  - And more messages in general

NFS is Stateless

- Every request sends all needed info
  - User credentials (for security checking)
  - File handle and offset
- Each request matches a VFS operation
  - e.g., *lookup, read, write, unlink, stat*
  - there is no *open* or *close* among NFS operations
- Default NFS transport protocol (up to NFSv3) was UDP.

Challenge: Lost Request?

- Request sent to NFS server, no response received
  - Did the message get lost in the network (UDP)?
  - Did the server die?
  - Is the server slow?
    - Don't want to do things twice
      - Bad idea: write data at the end of a file twice
- Idea: Make all requests ***idempotent***
  - Requests have same effect when executed multiple times
    - Ex: write() has an explicit offset, same effect if done twice
  - Some requests not easy to make idempotent
    - E.g., deleting a file
    - Server keeps a cache of recent requests and ignores requests found in the cache

Challenge: inode Reuse

- Process A opens file 'foo'
  - Maps to inode 30
- Process B unlinks file 'foo'
  - On local system, OS holds reference to the inode alive
  - NFS is stateless, server doesn't know about open handle
    - The file can be deleted and the inode reused
    - Next request for inode 30 will go to the wrong file
- Idea: ***Generation Numbers***
  - If inode in NFS is recycled, generation number is incremented
  - Client requests include an inode + generation number
    - Enables detecting attempts to access an old inode

Challenge: 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
- Problem with "root": root on one machine becomes root everywhere
- Solution: root squashing – root (UID 0) mapped to "nobody"
  - Ineffective security
    - Can send any UID in the NFS packet
    - With root access on NFS client, "su" to another user to get UID

Challenge: File Locking

- Must have way to change file without interference
  - Get a server-side lock
    - What happens if the client dies?
    - Lots of options (timeouts, etc), mostly bad
  - Punted to a separate, optional locking service
    - Such as Network Lock Manager (NLM)
    - With ugly hacks and timeouts

Challenge: Removal of Open Files

- Recall: Unix allows accessing deleted files if still open
  - Reference in in-memory inode prevents cleanup
    - Applications expect this behavior; how to deal with it in NFS?
- On client, check if file is open before removing it
  - If yes, rename file instead of deleting it
    - `.nfs*` files in modern NFS
  - When file is closed, delete temp file
    - If client crashes, garbage file is left over ☹
  - Only works if the same client opens and then removes file

Challenge: Time Synchronization

- Each CPU's clock ticks at slightly different rates
  - These clocks can drift over time
- Tools like 'make' use timestamps
  - Clock drift can cause programs to misbehave

```
make[2]: warning: Clock skew detected.
Your build may be incomplete.
```

- Systems using NFS must have clocks synchronized
  - Using external protocol like Network Time Protocol (NTP)
    - Synchronization depends on unknown communication delay
    - Very complex protocol but works pretty well in practice

Challenge: Caches and Consistency

- Clients A and B have file in their cache
- Client A writes to the file
  - Data stays in A's cache
  - Eventually flushed to the server
- Client B reads the file
  - Does B see the old contents or the new file contents?
    - Who tells B that the cache is stale?
    - Server can tell, but only after A actually wrote/flushed the data

Consistency/Performance Tradeoff

- Performance: cache always, write when convenient
  - Other clients can see old data, or make conflicting updates
- Consistency: write everything immediately
  - And tell everyone who may have it cached
    - Requires server to know the clients which cache the file (stateful ???)
  - Much more network traffic, lower performance
  - Not good for the common case: accessing an unshared file

Close-to-Open Consistency

- NFS Model: Flush all writes on a close
- On open, check the cached version's time stamp
  - If stale, invalidate the cache
  - Makes sure you get the latest version on the server when opening a file

NFS Evolution

- The simple protocol was version 2
- Version 3 (1995):
  - 64-bit file sizes and offsets (large file support)
  - Bundle attributes with other requests to eliminate stat()
  - Other optimizations
  - Still widely used today

NFSv4 (2000)

- Attempts to address many of the problems of v3
  - Security (eliminate homogeneous UID assumptions)
  - Performance
- Provides a stateful protocol
- pNFS – extensions for parallel distributed accesses
- Too advanced for its own good
  - Much more complicated then v3
    - Slow adoption
  - Barely being phased in now
    - With hacks that lose some of the features (looks more like v3)