

NFS & AFS

“Good judgment comes from experience...
Experience comes from bad judgment.”
- attributed to many

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Synchronization

- Who runs shell? Passes test suite?
- Who will be around November 17th at midnight?
- Today
 - NFS, AFS
 - Partially covered by textbook: 11.9, 17.6
 - Chapter 17 is short, why not just read it?

Synchronization

- Upcoming lectures
 - Wednesday OS Structure (Matt)
 - Friday Virtualization (Glenn)
 - Monday Lock-free Programming (Wes)

Outline

- Why remote file systems?
- VFS interception
- NFS vs. AFS
 - Architectural assumptions & goals
 - Namespace
 - Authentication, access control
 - I/O flow
 - Rough edges

Why?

- Why remote file systems?
- Lots of “access data everywhere” technologies
 - Laptop
 - Multi-gigabyte flash-memory keychain USB devices
 - 4G Hitachi MicroDrive fits in a CompactFlash slot
 - iPod
- Are remote file systems dinosaurs?

Remote File System Benefits

- Reliability
 - Not many people carry multiple copies of data
 - Multiple copies *with you* aren't much protection
 - Backups are nice
 - Machine rooms are nice
 - Temperature-controlled, humidity-controlled
 - Fire-suppressed
 - Time travel is nice too
- Sharing
 - Allows multiple users to access data
 - May provide authentication mechanism

Remote File System Benefits

- Scalability
 - Large disks are cheaper
- Locality of reference
 - You don't use every file every day...
 - Why carry *everything* in expensive portable storage?
- Auditability
 - Easier to know who said what when with central storage...

What *is* A Remote File System?

- OS-centric view
 - Something that supports file-system system calls “for us”
- Other possible views
 - RFS/DFS architect, for example
 - Mostly out of scope for this class
- Compared today
 - Sun Microsystems NFS
 - CMU/IBM/Transarc/IBM/open-source AFS

VFS interception

- VFS provides “pluggable” file systems
- Standard flow of remote access
 - User process calls read()
 - Kernel dispatches to VOP_READ() in some VFS
 - nfs_read()
 - check local cache
 - send RPC to remote NFS server
 - put process to sleep

VFS interception

- Standard flow of remote access (continued)
 - client kernel process manages call to server
 - retransmit if necessary
 - convert RPC response to file system buffer
 - store in local cache
 - wake up user process
 - back to `nfs_read()`
 - copy bytes to user memory

NFS Assumptions, goals

- Workgroup file system
 - Small number of clients
 - Very small number of servers
- Single administrative domain
 - All machines agree on “set of users”
 - ...which users are in which groups
 - Client machines run mostly-trusted OS
 - “User #37 says read(...)”

NFS Assumptions, goals

- “Stateless” file server
 - Of course files are “state”, but...
 - Server *exports* files without creating extra state
 - No list of “who has this file open”
 - No “pending transactions” across crash
 - Result: crash recovery “fast”, protocol “simple”

NFS Assumptions, goals

- “Stateless” file server
 - Of course files are “state”, but...
 - Server **exports** files without creating extra state
 - No list of “who has this file open”
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 - Result: crash recovery “fast”, protocol “simple”
- Some inherently “stateful” operations
 - File locking
 - Handled by “separate service” “outside of NFS”
 - Slick trick, eh?

AFS Assumptions, goals

- Global distributed file system
 - *Uncountable* clients, servers
 - “One AFS”, like “one Internet”
 - Why would you want more than one?
- Multiple administrative domains
 - username@*cellname*
 - de0u@andrew.cmu.edu
 - davide@cs.cmu.edu

AFS Assumptions, goals

- 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
 - Most users on one machine at a time

AFS Assumptions, goals

- Support *many* clients
 - 1000 machines could cache a single file
 - Some local, some (very) remote

NFS Namespace

- Constructed by client-side file system mounts
 - mount server1:/usr/local /usr/local
- Group of clients *can achieve* common namespace
 - Every machine can execute same mount sequence at boot
 - If system administrators are diligent

NFS Namespace

- “Auto-mount” process based on “maps”
 - /home/dae means server1:/home/dae
 - /home/owens means server2:/home/owens

NFS Security

- Client machine presents credentials
 - user #, list of group #s –from Unix process
- Server accepts or rejects credentials
 - “root squashing”
 - map uid 0 to uid -1 unless client on special machine list
- Kernel process on server “adopts” credentials
 - Sets user #, group vector based on RPC
 - Makes system call (e.g., read()) with those credentials

AFS Namespace

- Assumed-global list of AFS cells
- Everybody sees same files in each cell
 - Multiple servers inside cell invisible to user
- Group of clients *can achieve* private namespace
 - Use custom cell database

AFS Security

- Client machine presents Kerberos ticket
 - Allows arbitrary binding of (machine,user) to (realm,principal)
 - davide on a cs.cmu.edu machine can be de0u@andrew.cmu.edu
 - iff the password is known!
- Server checks against *access control list*

AFS ACLs

- Apply to directory, not to individual files
- ACL format
 - de0u rldwka
 - davide@cs.cmu.edu rl
 - de0u:friends rl
- Negative rights
 - Disallow “joe rl” even though joe is in de0u:friends

AFS ACLs

- AFS ACL semantics are not Unix semantics
 - Some parts obeyed in a vague way
 - Cache manager checks for files being executable, writable
 - Many differences
 - Inherent/good: can name people in different administrative domains
 - “Just different”
 - ACLs are per-directory, not per-file
 - Different privileges: create, remove, lock
 - Not exactly Unix / not tied to Unix

NFS protocol architecture

- root@client executes mount-filesystem RPC
 - returns “file handle” for root of remote file system
- client RPC for each pathname component
 - /usr/local/lib/emacs/foo.el in /usr/local file system
 - h = lookup(root-handle, “lib”)
 - h = lookup(h, “emacs”)
 - h = lookup(h, “foo.el”)
 - Allows disagreement over pathname syntax
 - Look, Ma, no “/”!

NFS protocol architecture

- I/O RPCs are *idempotent*
 - multiple repetitions have same effect as one
 - lookup(h, “emacs”) generally returns same result
 - read(file-handle, offset, length) ⇒ bytes
 - write(file-handle, offset, buffer, bytes)
- RPCs do not create server-memory state
 - no RPC calls for open()/close()
 - write() succeeds (to disk) or fails before RPC completes

NFS file handles

- Goals
 - Reasonable size
 - Quickly map to file on server
 - “Capability”
 - Hard to forge, so possession serves as “proof”
- Implementation (inode #, inode generation #)
 - inode # - small, fast for server to map onto data
 - “inode generation #” - must match value stored in inode
 - “unguessably random” number chosen in create()

NFS Directory Operations

- Primary goal
 - Insulate clients from server directory format
- Approach
 - readdir(dir-handle, cookie, nbytes) returns list
 - name, inode # (for display by ls -l), cookie

AFS protocol architecture

- **Volume** = miniature file system
 - One user's files, project source tree, ...
 - Unit of disk quota administration, backup
 - **Mount points** are pointers to other volumes
- Client machine has Cell-Server Database
 - /afs/andrew.cmu.edu is a **cell**
 - **protection server** handles authentication
 - **volume location server** maps volumes to **file servers**

AFS protocol architecture

- Volume location is *dynamic*
 - Moved between servers transparently to user
- Volumes may have multiple *replicas*
 - Increase throughput, reliability
 - Restricted to “read-only” volumes
 - /usr/local/bin
 - /afs/andrew.cmu.edu/usr

AFS Callbacks

- Observations
 - Client disks can cache files indefinitely
 - Even across reboots
 - Many files nearly read-only
 - Contacting server on each open() is wasteful
- Server issues *callback promise*
 - If this file changes in 15 minutes, I will tell you
 - *callback break* message
 - 15 minutes of free open(), read() for that client
 - More importantly, 15 minutes of peace for server

AFS file identifiers

- Volume number
 - Each file lives *in a volume*
 - Unlike NFS “server1's /usr0”
- File number
 - inode # (as NFS)
- “Uniquifier”
 - allows inodes to be re-used
 - Similar to NFS file handle inode generation #s

AFS Directory Operations

- Primary goal
 - Don't overload servers!
- Approach
 - Server stores directory as hash table on disk
 - Client fetches whole directory as if a file
 - **Client** parses hash table
 - Directory maps name to fid
 - Client caches directory (indefinitely, across reboots)
 - Server load reduced

AFS access pattern

`open( "/afs/cs.cmu.edu/service/systypes" )`

- VFS layer hands off “/afs” to AFS client module
- Client maps cs.cmu.edu to pt & vlDB servers
- Client authenticates to pt server
- Client volume-locates root.cell volume
- Client fetches “/” directory
- Client fetches “service” directory
- Client fetches “systypes” file

AFS access pattern

open(“/afs/cs.cmu.edu/service/newCSDB”)

- VFS layer hands off “/afs” to AFS client module
- Client fetches “newCSDB” file

open(“/afs/cs.cmu.edu/service/systypes”)

- Assume
 - File is in cache
 - Server hasn't broken callback
 - Callback hasn't expired
- Client can read file with *no server interaction*

AFS access pattern

- Data transfer is by *chunks*
 - Minimally 64 KB
 - May be whole-file
- Write*back* cache
 - Opposite of NFS “every write is sacred”
 - Store chunk back to server
 - When cache overflows
 - On last user close()

AFS access pattern

- Is writeback crazy?
 - Write conflicts “assumed rare”
 - Who needs to see a half-written file?

NFS “rough edges”

- Locking
 - Inherently stateful
 - lock must *persist across client calls*
 - lock(), read(), write(), unlock()
 - “Separate service”
 - Handled by same server
 - Horrible things happen on server crash
 - Horrible things happen on client crash

NFS “rough edges”

- Some operations not really idempotent
 - unlink(file) returns “ok” *once*, then “no such file”
 - server caches “a few” client requests
- Caching
 - No real consistency guarantees
 - Clients typically cache attributes, data “for a while”
 - No way to know when they're wrong

NFS “rough edges”

- Large NFS installations are brittle
 - Everybody must agree on *many* mount points
 - Hard to load-balance files among servers
 - No volumes
 - No atomic moves
- Cross-realm NFS access basically nonexistent
 - No good way to map uid#47 from an unknown host

AFS “rough edges”

- Locking
 - Server refuses to keep a waiting-client list
 - Client cache manager refuses to poll server
 - User program must invent polling strategy
- Chunk-based I/O
 - No real consistency guarantees
 - close() failures surprising

AFS “rough edges”

- ACLs apply to *directories*
 - “Makes sense” if files will inherit from directories
 - Not always true
 - Confuses users
- Directories inherit ACLs
 - Easy to expose a whole tree accidentally
 - What else to do?
 - No good solution known
 - DFS horror

AFS “rough edges”

- Small AFS installations are punitive
 - Step 1: Install Kerberos
 - 2-3 servers
 - Inside locked boxes!
 - Step 2: Install ~4 AFS servers (2 data, 2 pt/vldb)
 - Step 3: Explain Kerberos to your users
 - Ticket expiration!
 - Step 4: Explain ACLs to your users

Summary - NFS

- Workgroup network file service
- Any Unix machine can be a server (easily)
- Machines can be both client & server
 - My files on my disk, your files on your disk
 - Everybody in group can access all files
- *Serious* trust, scaling problems
- “Stateless file server” model only partial success

Summary –AFS

- Worldwide file system
- Good security, scaling
- Global namespace
- “Professional” server infrastructure per cell
 - Don't try this at home
 - Only ~190 AFS cells (2005-11, also 2003-02)
 - 8 are cmu.edu, ~15 are in Pittsburgh
- “No write conflict” model only partial success

Further Reading

- NFS
 - RFC 1094 for v2 (3/1989)
 - RFC 1813 for v3 (6/1995)
 - RFC 3530 for v4 (4/2003)

Further Reading

- AFS
 - “The ITC Distributed File System: Principles and Design”, Proceedings of the 10th ACM Symposium on Operating System Principles, Dec. 1985, pp. 35-50.
 - “Scale and Performance in a Distributed File System”, ACM Transactions on Computer Systems, Vol. 6, No. 1, Feb. 1988, pp. 51-81.
 - IBM AFS User Guide, version 36
 - <http://www.cs.cmu.edu/~help/afs/index.html>