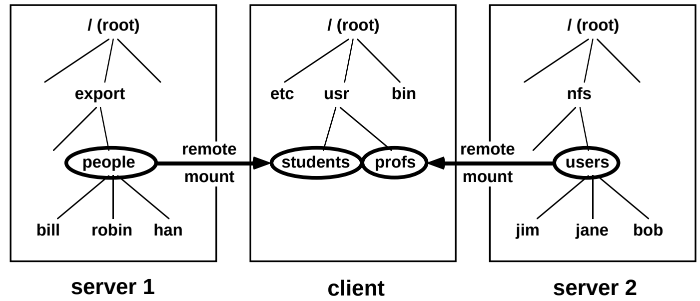
Sun's Network File System

- Designed by Sun Microsystems
  - First distributed file service designed as a project, introduced in 1985
  - To encourage its adoption as a standard
    - Definitions of the key interfaces were placed in the public domain in 1989
    - Source code for a reference implementation was made available to other computer vendors under license
    - Currently the *de facto* standard for LANs
- Provides transparent access to remote files on a LAN, for clients running on UNIX and other operating systems
  - A UNIX computer typically has a NFS client and server module in its OS kernel
    - Available for almost any UNIX and MACH
  - Client modules are available for Macintosh and PCs

Mounting Remote File Systems



- NFS supports mounting of remote file systems by client machines
  - Name space seen by each client may be different
  - Same file on server may have different path names on different clients
  - NFS does not enforce a single network-wide name space, but a uniform name space (and location transparency) can be established if desired

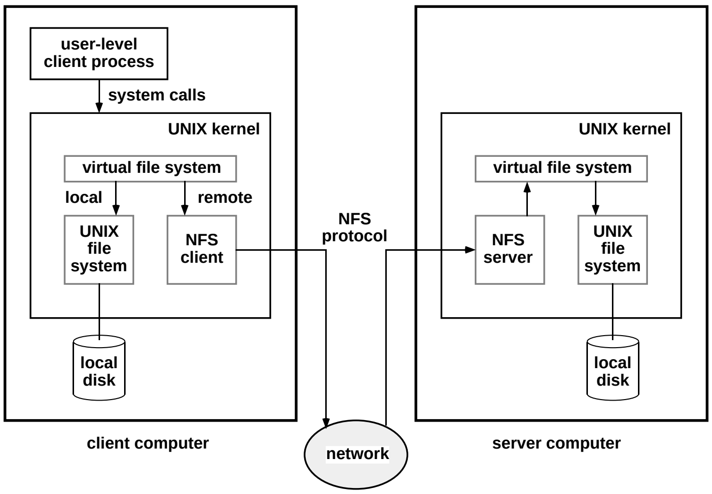
Mounting Remote File Systems (cont.)

- On each server
  - There is a file (usually /etc/exports) containing the names of local file systems that are available for remote mounting
  - An access list is associated with each name, and indicates which hosts are permitted to mount that file system
- On each client
  - A modified version of the UNIX *mount* command mounts a remote file system
    - Based on RPC — specifies remote host name, pathname of a directory in the remote file system, and local name where it is to be mounted
    - Mount requests are usually performed when the system is initialized (booted)
      - Usually specified in /etc/fstab
    - User may also be able to mount other remote file systems

Mounting Remote File Systems (cont.)

- Remote file systems may be
  - *Hard mounted* — when a user-level process accesses a file, it is suspended until the request can be completed
    - If a server crashes, the user-level process will be suspended until recovers
  - *Soft mounted* — after a small number of retries, the NFS client returns a failure code to the user process
    - Most UNIX utilities don't check this code…
- Automounting
  - The *automounter* dynamically mounts a file system whenever an "empty" mount point is referenced by a client
    - Further accesses do not result in further requests to the automounter…
    - Unless there are no references to the remote file system for several minutes, in which case the automounter unmounts it

NFS Software Architecture



- Virtual file system:
  - Separates generic file-system operations from their implementation (can have different types of local file systems)
  - Based on a file descriptor called a vnode that is unique networkwide (UNIX inodes are only unique on a single file system)

Distributed Naming Structures (Review)

- Mount remote directories onto local directories (possibly on demand)
  - Client-maintained mount information:
    - Used by UNIX and NFS — Sun's Network File System
    - Client maintains:
      - A set of local names for remote locations
      - A *mount table* (/etc/fstab) that specifies a:
        - » < remote machine name : pathname >
        - » and < local pathname >
    - At boot time, the local name is bound to the remote name
      - Afterwards, users refer to local pathname as if it were local, and the distributed OS takes care of the mapping
      - Location transparent and independent after the mount operation, but not before
  - Server-maintained mount information:
    - If files are moved to a different server, mount information need only be updated at servers

NFS Protocol

- NFS protocol provides a set of RPCs for remote file operations
  - Looking up a file within a directory
  - Manipulating links and directories
  - Creating, renaming, and removing files
  - Getting and setting file attributes
  - Reading and writing files
- NFS is stateless
  - Servers do not maintain information about their clients from one access to the next
    - There are no open-file tables on the server
  - There are no open and close operations
    - Each request must provide a unique file identifier, and an offset within the file
  - Easy to recover from a crash, but file operations must be idempotent

NFS Protocol (cont.)

- Because NFS is stateless, all modified data must be written to the server's disk before results are returned to the client
  - Server crash and recovery should be invisible to client —data should be intact
  - ✘ Lose benefits of caching
    - Solution — RAM disks with battery backup (un-interruptable power supply), written to disk periodically
- A single NFS write is guaranteed to be atomic, and not intermixed with other writes to the same file
  - However, NFS does not provide concurrency control
    - A write system call may be decomposed into several NFS writes, which may be interleaved
    - Since NFS is stateless, this is not considered to be an NFS problem

Caching in NFS

- Traditional UNIX
  - Caches file blocks, directories, and file attributes
  - Uses read-ahead (prefetching), and delayed-write (flushes every 30 seconds)
- NFS servers
  - Same as in UNIX, except server's write operations perform write-through
    - Otherwise, failure of server might result in undetected loss of data by clients
- NFS clients
  - Caches results of read, write, getattr, lookup, and readdir operations
  - Possible inconsistency problems
    - Writes by one client do not cause an immediate update of other clients' caches

Caching in NFS (cont.)

- NFS clients (cont.)
  - File reads
    - When a client caches one or more blocks from a file, it also caches a timestamp indicating the time when the file was last modified on the server
    - Whenever a file is opened, and the server is contacted to fetch a new block from the file, a validation check is performed
      - Client requests last modification time from server, and compares that time to its cached timestamp
      - If modification time is more recent, all cached blocks from that file are invalidated
      - Blocks are assumed to valid for next 3 seconds (30 seconds for directories)
  - File writes
    - When a cached page is modified, it is marked as dirty, and is flushed when the file is closed, or at the next periodic flush
  - Now two sources of inconsistency: delay after validation, delay until flush

Distributed Naming Structures (Review)

- Single name space for remote and local directories
  - Names of form: /.../*machine*/*fs*/*pathname*
  - Used by:
    - CMU's Andrew, now in OSF's Distributed Computing Environment (DCE)
    - Berkeley's Sprite
  - File names are always the same, whether file is remote or local
  - As clients access a file, the server sends a copy to the client's workstation, and the workstation caches the file
    - In Andrew, local disks are used
    - In Sprite, large memories are used, and workstations are diskless
    - More details on these two next time…
  - Location independent, not location transparent

CMU's Andrew File System

- Designed by Carnegie Mellon University
  - Developed during mid-1980s as part of the Andrew distributed computing environment
  - Designed to support a WAN of more than 5000 workstations
  - Much of the core technology is now part of the Open Software Foundation (OSF) Distributed Computing Environment (DCE), available for most UNIX and some other operating systems
- Provides transparent access to remote files on a WAN, for clients running on UNIX and other operating systems
  - Access to all files is via the usual UNIX file primitives
  - Compatible with NFS — servers can mount NFS file systems

Caching in Andrew

- When a remote file is accessed, the server sends the entire file to the client
  - The entire file is then stored in a disk cache on the client computer
    - Cache is big enough to store several hundred files
- Implements session semantics
  - Files are cached when opened
  - Modified files are flushed to the server when they are closed
  - Writes may not be immediately visible to other processes
- When client caches a file, server records that fact — it has a *callback* on the file
  - When a client modifies and closes a file, other clients lose their callback, and are notified by server that their copy is invalid

How Can Andrew Perform Well?

- Most file accesses are to files that are infrequently updated, or are accessed by only a single user, so the cached copy will remain valid for a long time
- Local cache can be big — maybe 100 MB — which is probably sufficient for one user's working set of files
- Typical UNIX workloads:
  - Files are small, most are less than 10kB
  - Read operations are 6 times more common than write operations
  - Sequential access is common, while random access is rare
  - Most files are read and written by only one user; if a file shared, usually only one user modifies it
  - Files are referenced in bursts