Today: Distributed File Systems

- Overview of stand-alone (UNIX) file systems
- Issues in distributed file systems
- Next two classes: case studies of distributed file systems
  - NFS
  - Code
  - xFS
  - Log-structured file systems (time permitting)

File System Basics

- File: named collection of logically related data
  - Unix file: an uninterpreted sequence of bytes
- File system:
  - Provides a logical view of data and storage functions
  - User-friendly interface
  - Provides facility to create, modify, organize, and delete files
  - Provides sharing among users in a controlled manner
  - Provides protection

Unix File System Review

- User file: linear array of bytes. No records, no file types
- Directory: special file not directly writable by user
- File structure: directed acyclic graph [directories may not be shared, files may be shared *(why?)*]
- Directory entry for each file
  - File name
  - inode number
  - Major device number
  - Minor device number
- All inodes are stored at a special location on disk [super block]
  - Inodes store file attributes and a multi-level index that has a list of disk block locations for the file

Inode Structure

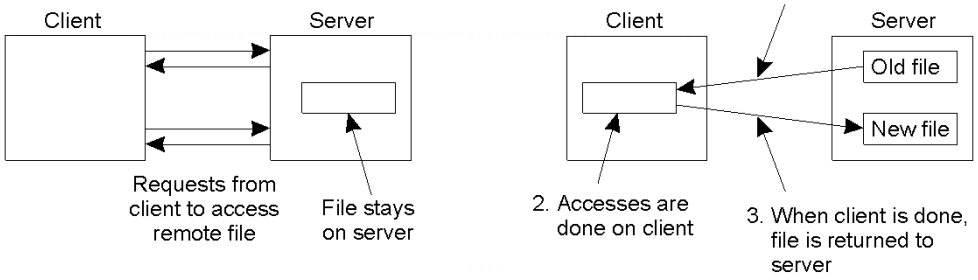
- Fields
  - Mode
  - Owner_ID, group_id
  - Dir_file
  - Protection bits
  - Last access time, last write time, last inode time
  - Size, no of blocks
  - Ref_cnt
  - Address[0], … address[14]
    - Multi-level index: 12 direct blocks, one single, double, and triple indirect blocks

Distributed File Systems

- *File service:* specification of what the file system offers
  - Client primitives, application programming interface (API)
- *File server:* process that implements file service
  - Can have several servers on one machine (UNIX, DOS,…)

- Components of interest
  - File service
  - Directory service

File Service



- Remote access model
  - Work done at the server
- Stateful server (e.g., databases)
- Consistent sharing (+)
- Server may be a bottleneck (-)
- Need for communication (-)

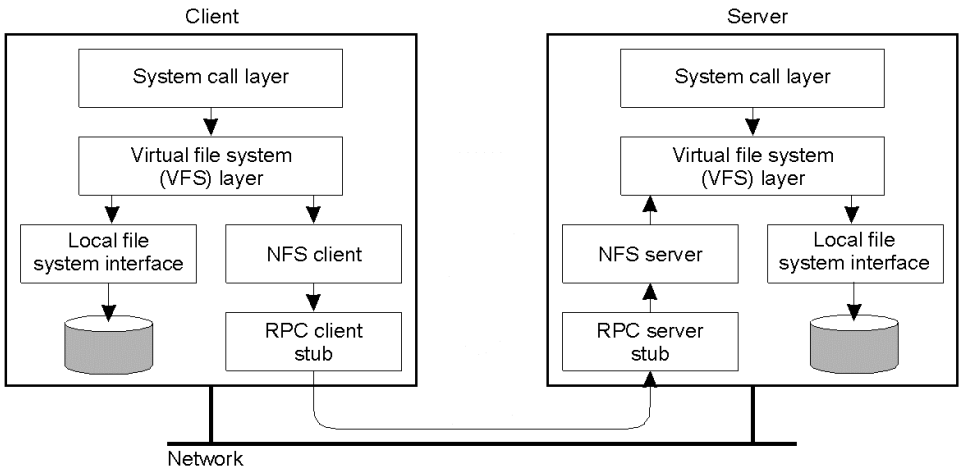
- Upload/download mode
  - Work done at the client
- Stateless server
- Simple functionality (+)
- Moves files/blocks, need storage (-)

System Structure: Server Type

- Stateless server
  - No information is kept at server between client requests
  - All information needed to service a requests must be provided by the client with each request *(what info?)*
  - More tolerant to server crashes
- Stateful server
  - Server maintains information about client accesses
  - Shorted request messages
  - Better performance
  - Idempotency easier
  - Consistency is easier to achieve

NFS Architecture

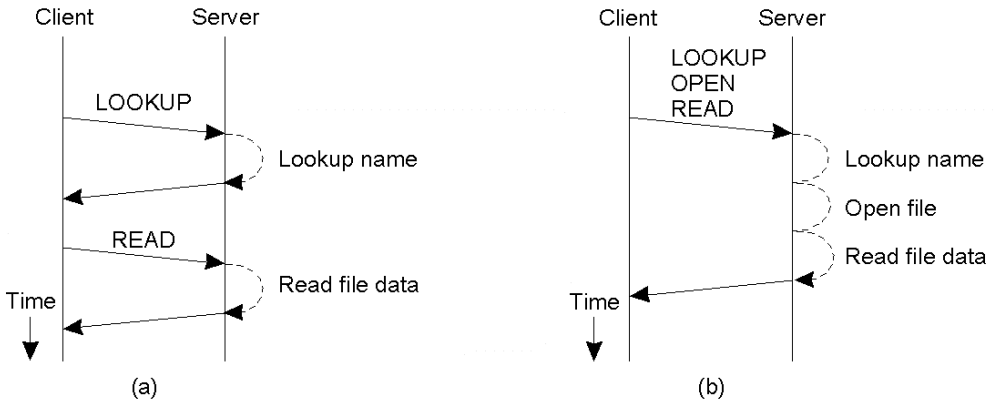
- Sun's Network File System (NFS) – widely used distributed file system
- Uses the virtual file system layer to handle local and remote files



NFS Operations

Operation	v3	v4	Description
Create	Yes	No	Create a regular file
Create	No	Yes	Create a nonregular file
Link	Yes	Yes	Create a hard link to a file
Symlink	Yes	No	Create a symbolic link to a file
Mkdir	Yes	No	Create a subdirectory in a given directory
Mknod	Yes	No	Create a special file
Rename	Yes	Yes	Change the name of a file
Rmdir	Yes	No	Remove an empty subdirectory from a directory
Open	No	Yes	Open a file
Close	No	Yes	Close a file
Lookup	Yes	Yes	Look up a file by means of a file name
Readdir	Yes	Yes	Read the entries in a directory
Readlink	Yes	Yes	Read the path name stored in a symbolic link
Getattr	Yes	Yes	Read the attribute values for a file
Setattr	Yes	Yes	Set one or more attribute values for a file
Read	Yes	Yes	Read the data contained in a file
Write	Yes	Yes	Write data to a file

Communication



a) Reading data from a file in NFS version 3.

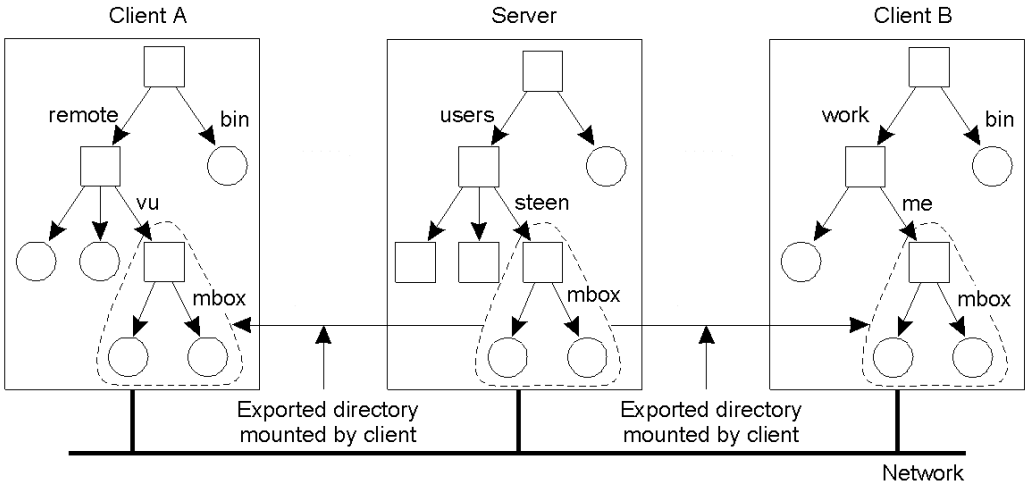
b) Reading data using a compound procedure in version 4.

Both versions use Open Network Computing (ONC) RPCs

- One RPC per operation (NFS v3); multiple operations supported in v4.

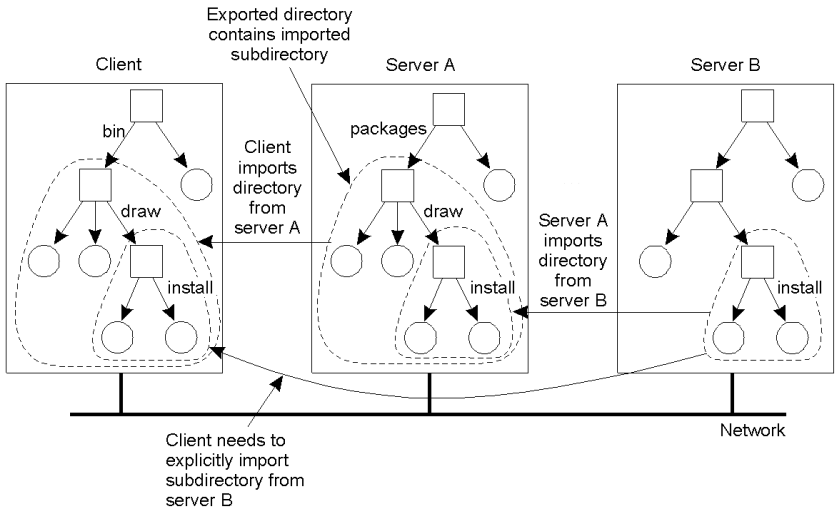
Naming: Mount Protocol

- NFS uses the mount protocol to access remote files
  - Mount protocol establishes a local name for remote files
  - Users access remote files using local names; OS takes care of the mapping

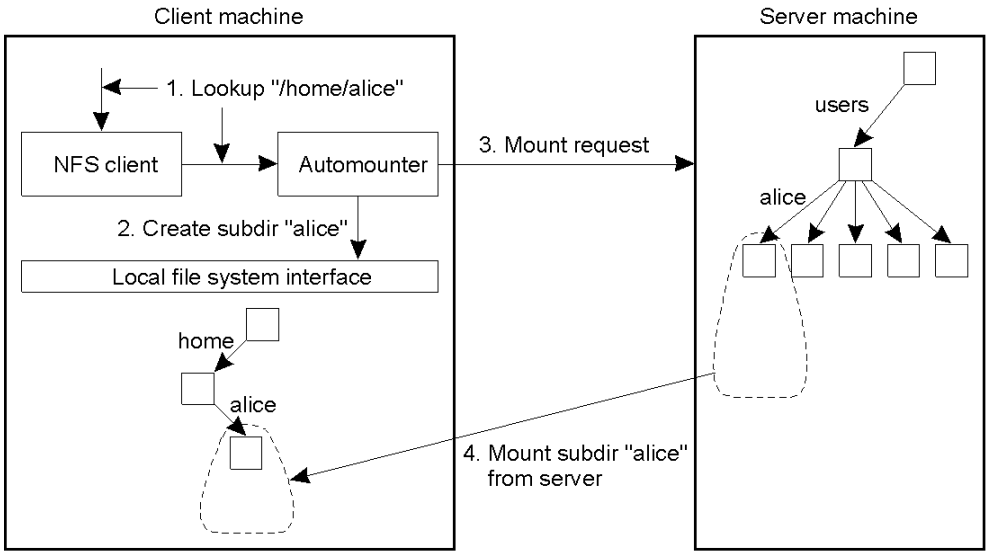


Naming: Crossing Mount Points

- Mounting nested directories from multiple servers
- NFS v3 does not support transitive exports (for security reasons)
  - NFS v4 allows clients to detects crossing of mount points, supports recursive lookups



Automounting



- Automounting: mount on demand

File Attributes (1)

Attribute	Description
TYPE	The type of the file (regular, directory, symbolic link)
SIZE	The length of the file in bytes
CHANGE	Indicator for a client to see if and/or when the file has changed
FSID	Server-unique identifier of the file's file system

- Some general mandatory file attributes in NFS.
  - NFS modeled based on Unix-like file systems
    - Implementing NFS on other file systems (Windows) difficult
  - NFS v4 enhances compatibility by using mandatory and recommended attributes

File Attributes (2)

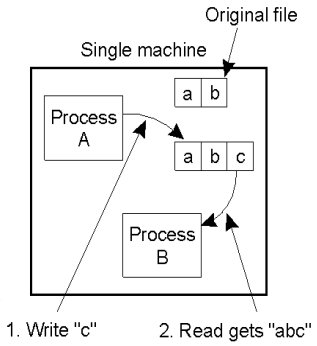
Attribute	Description
ACL	an access control list associated with the file
FILEHANDLE	The server-provided file handle of this file
FILEID	A file-system unique identifier for this file
FS_LOCATIONS	Locations in the network where this file system may be found
OWNER	The character-string name of the file's owner
TIME_ACCESS	Time when the file data were last accessed
TIME_MODIFY	Time when the file data were last modified
TIME_CREATE	Time when the file was created

- Some general recommended file attributes.

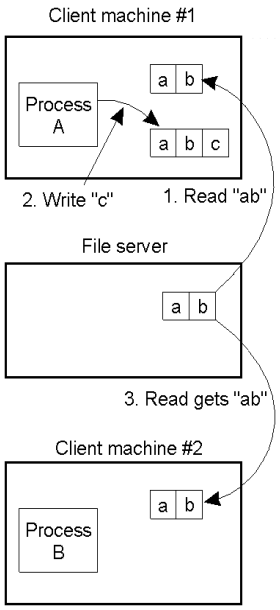
Semantics of File Sharing

a) On a single processor, when a *read* follows a *write*, the value returned by the *read* is the value just written.

b) In a distributed system with caching, obsolete values may be returned.



(a)



(b)

Semantics of File Sharing

Method	Comment
UNIX semantics	Every operation on a file is instantly visible to all processes
Session semantics	No changes are visible to other processes until the file is closed
Immutable files	No updates are possible; simplifies sharing and replication
Transaction	All changes occur atomically

- Four ways of dealing with the shared files in a distributed system.
  - NFS implements session semantics
    - Can use remote/access model for providing UNIX semantics (expensive)
    - Most implementations use local caches for performance and provide session semantics

File Locking in NFS

Operation	Description
Lock	Creates a lock for a range of bytes (non-blocking_
Lockt	Test whether a conflicting lock has been granted
Locku	Remove a lock from a range of bytes
Renew	Renew the lease on a specified lock

- NFS supports file locking
  - Applications can use locks to ensure consistency
  - Locking was not part of NFS until version 3
  - NFS v4 supports locking as part of the protocol (see above table)

File Locking: Share Reservations

Current file denial state

Request access	NONE	READ	WRITE	BOTH
READ	Succeed	Fail	Succeed	Fail
WRITE	Succeed	Succeed	Fail	Fail
BOTH	Succeed	Fail	Fail	Fail

(a)

Requested file denial state

Current access state	NONE	READ	WRITE	BOTH
READ	Succeed	Fail	Succeed	Fail
WRITE	Succeed	Succeed	Fail	Fail
BOTH	Succeed	Fail	Fail	Fail

(b)

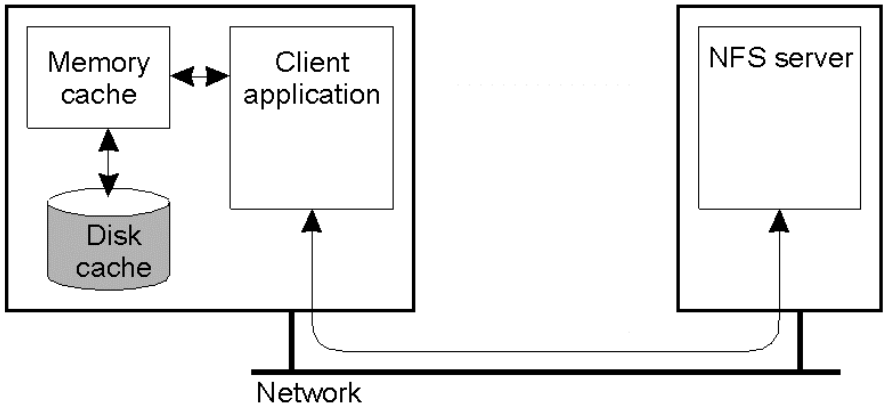
- The result of an *open* operation with share reservations in NFS.

a) When the client requests shared access given the current denial state.

b) When the client requests a denial state given the current file access state.

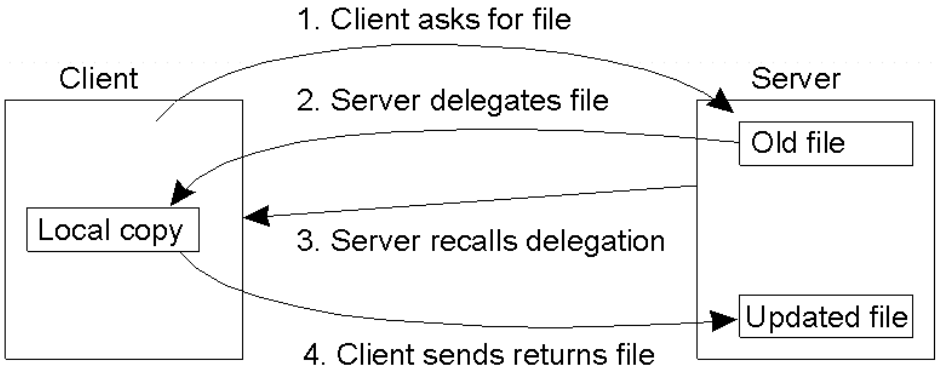
Client Caching

- Client-side caching is left to the implementation (NFS does not prohibit it)
  - Different implementation use different caching policies
    - Sun: allow cache data to be stale for up to 30 seconds

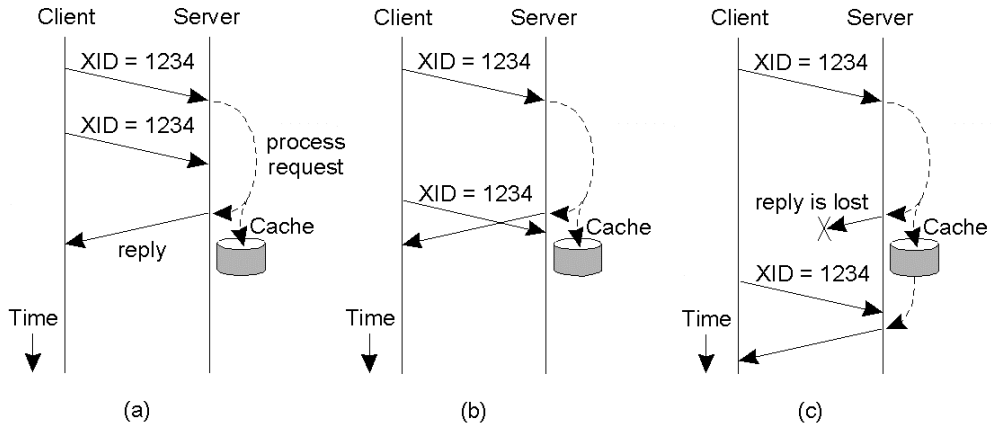


Client Caching: Delegation

- NFS V4 supports open delegation
  - Server delegates local open and close requests to the NFS client
  - Uses a callback mechanism to recall file delegation.



RPC Failures



- Three situations for handling retransmissions: use a duplicate request cache

a) The request is still in progress

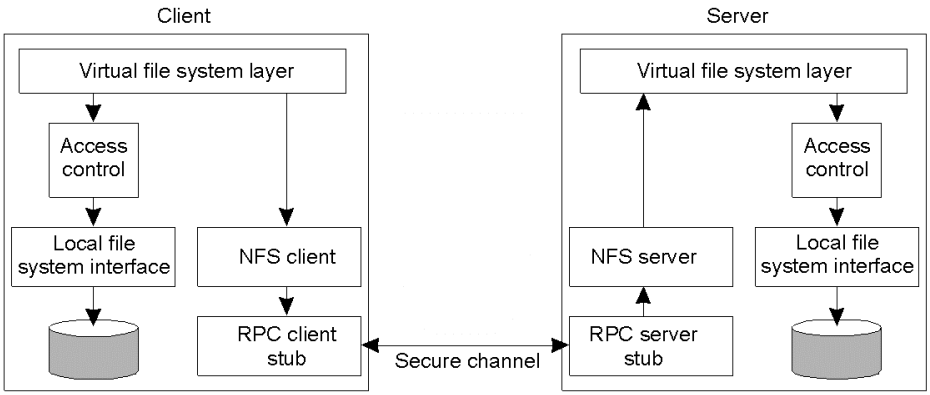
b) The reply has just been returned

c) The reply has been some time ago, but was lost.

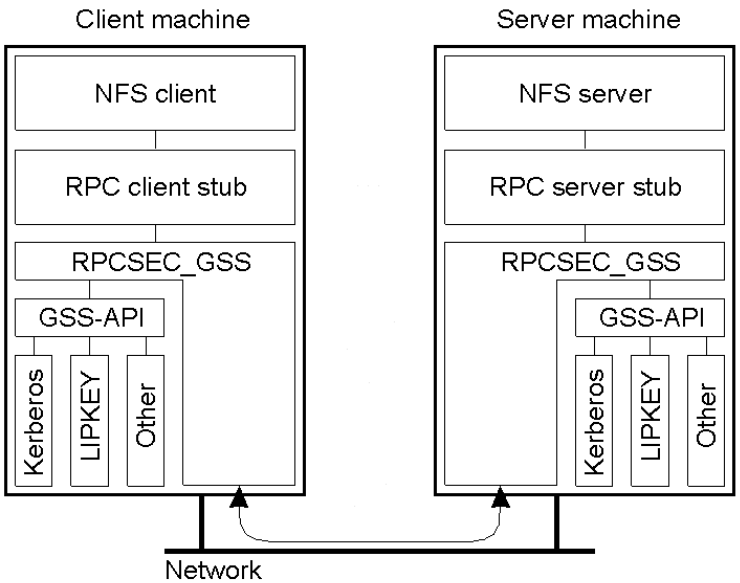
Use a duplicate-request cache: transaction Ids on RPCs, results cached

Security

- The NFS security architecture.
  - Simplest case: user ID, group ID authentication only



Secure RPCs



- Secure RPC in NFS version 4.

Replica Servers

- NFS ver 4 supports replications
- Entire file systems must be replicated
- FS_LOCATION attribute for each file
- Replicated servers: implementation specific