DISTRIBUTED FILE SYSTEMS

Topics

- Introduction
- File Service Architecture
- DFS: Case Studies
  - Case Study: Sun NFS
  - Case Study: The Andrew File System

Introduction

- File system were originally developed for centralized computer systems and desktop computers.
- File system was as an operating system facility providing a convenient programming interface to disk storage.

Introduction

- Distributed file systems support the sharing of information in the form of files and hardware resources.
- With the advent of distributed object systems (CORBA, Java) and the web, the picture has become more complex.
- Figure 1 provides an overview of types of storage system.

Introduction

	Sharing	*Persis-tence*	*Distributed cache/replicas*	*Consistency maintenance*	*Example*
Main memory	×	×	×	1	RAM
File system	×	✓	×	1	UNIX file system
Distributed file system	✓	✓	✓	✓	Sun NFS
Web	✓	✓	✓	×	Web server
Distributed shared memory	✓	×	✓	✓	Ivy (Ch. 18)
Remote objects (RMI/ORB)	✓	×	×	1	CORBA
Persistent object store	✓	✓	×	1	CORBA Persistent Object Service
Peer-to-peer storage system	✓	✓	✓	✓	OceanStore(Ch. 10)

Figure 1. Storage systems and their properties

Types of consistency between copies: 1 - strict one-copy consistency
√ - approximate consistency
X - no automatic consistency

Introduction

- Figure 2 shows a typical layered module structure for the implementation of a non-distributed file system in a conventional operating system.

Introduction

Directory module:	relates file names to file IDs
File module:	relates file IDs to particular files
Access control module:	checks permission for operation requested
File access module:	reads or writes file data or attributes
Block module:	accesses and allocates disk blocks
Device module:	disk I/O and buffering

Figure 2. File system modules

Introduction

- File systems are responsible for the organization, storage, retrieval, naming, sharing and protection of files.
- Files contain both data and attributes.
- A typical attribute record structure is illustrated in Figure 3.

Introduction

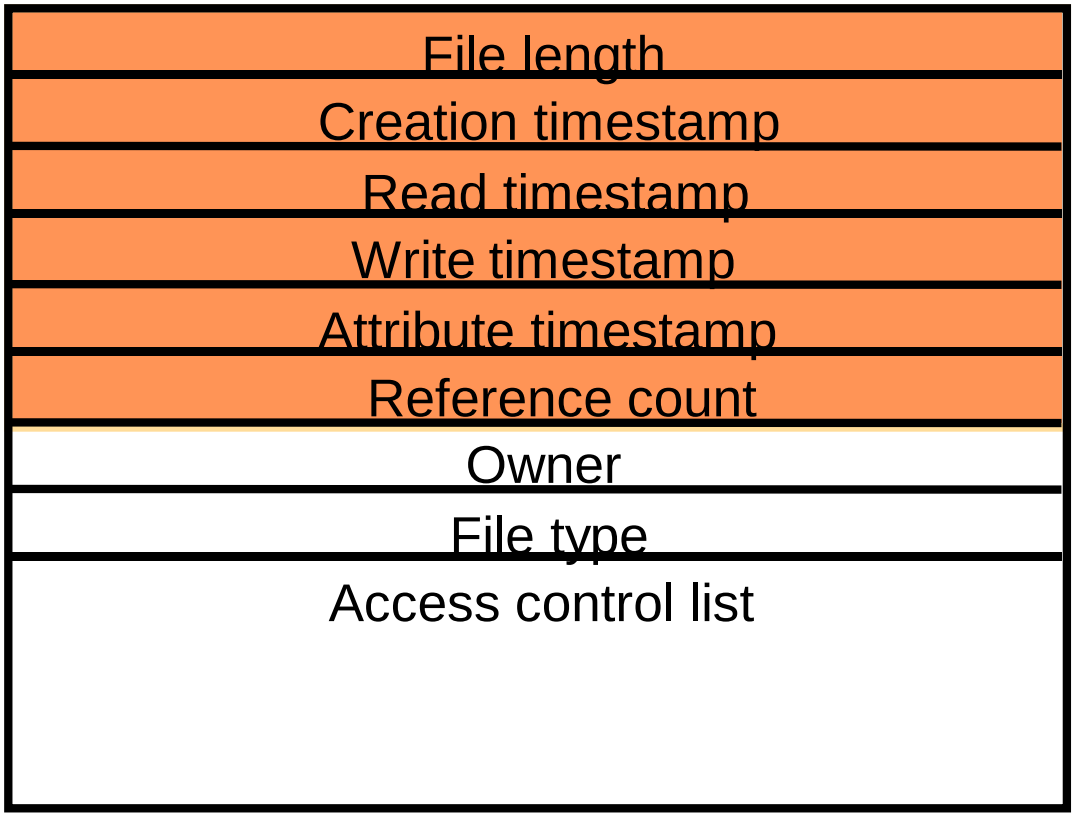


Figure 3. File attribute record structure

Introduction

- Figure 4 summarizes the main operations on files that are available to applications in UNIX systems.

Introduction

Figure 4. UNIX file system operations

filedes = open(name, mode) *filedes = creat(name, mode)*	Opens an existing file with the given *name*. Creates a new file with the given *name*. Both operations deliver a file descriptor referencing the open file. The *mode* is *read*, *write* or both.
status = close(filedes)	Closes the open file *filedes*.
count = read(filedes, buffer, n) *count = write(filedes, buffer, n)*	Transfers *n* bytes from the file referenced by *filedes* to *buffer*. Transfers *n* bytes to the file referenced by *filedes* from buffer. Both operations deliver the number of bytes actually transferred and advance the read-write pointer.
pos = lseek(filedes, offset, whence)	Moves the read-write pointer to offset (relative or absolute, depending on *whence*).
status = unlink(name)	Removes the file *name* from the directory structure. If the file has no other names, it is deleted.
status = link(name1, name2)	Adds a new name (*name2*) for a file (*name1*).
status = stat(name, buffer)	Gets the file attributes for file *name* into *buffer*.

Introduction

- Distributed File system requirements
  - Related requirements in distributed file systems are:
    - Transparency
    - Concurrency
    - Replication
    - Heterogeneity
    - Fault tolerance
    - Consistency
    - Security
    - Efficiency

File Service Architecture

- An architecture that offers a clear separation of the main concerns in providing access to files is obtained by structuring the file service as three components:
  - A flat file service
  - A directory service
  - A client module.
- The relevant modules and their relationship is shown in Figure 5.

File Service Architecture

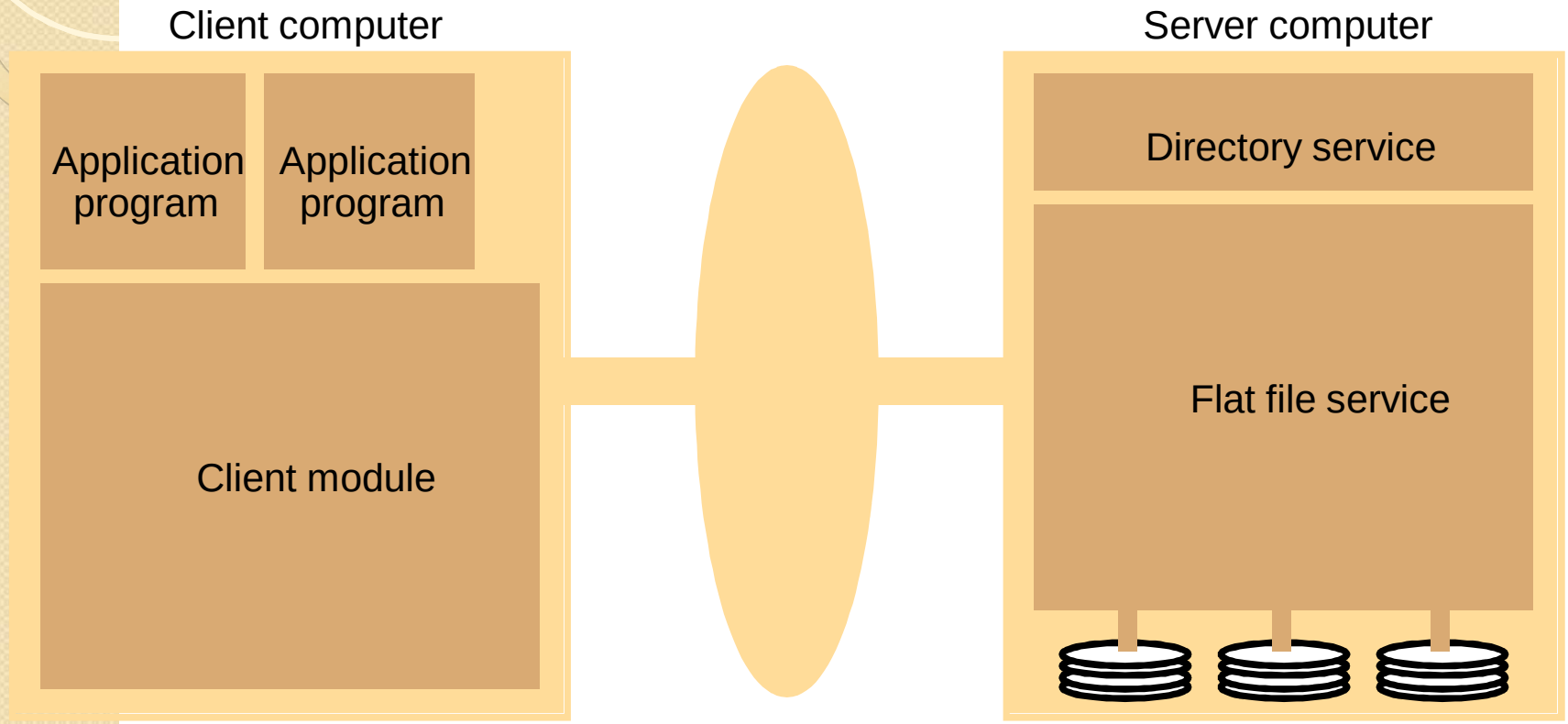


Figure 5. File service architecture

File Service Architecture

- The Client module implements exported interfaces by flat file and directory services on server side.
- Responsibilities of various modules can be defined as follows:
  - Flat file service:
    - Concerned with the implementation of operations on the contents of file. Unique File Identifiers (UFIDs) are used to refer to files in all requests for flat file service operations. UFIDs are long sequences of bits chosen so that each file has a unique among all of the files in a distributed system.

File Service Architecture

- Directory service:
  - Provides mapping between text names for the files and their UFIDs. Clients may obtain the UFID of a file by quoting its text name to directory service. Directory service supports functions needed generate directories, to add new files to directories.

File Service Architecture

- Client module:
  - It runs on each computer and provides integrated service (flat file and directory) as a single API to application programs. For example, in UNIX hosts, a client module emulates the full set of Unix file operations.
  - It holds information about the network locations of flat-file and directory server processes; and achieve better performance through implementation of a cache of recently used file blocks at the client.

File Service Architecture

- Flat file service interface:
  - Figure 6 contains a definition of the interface to a flat file service.

File Service Architecture

Read(FileId, i, n) -> Data -throws BadPosition	if *1≤i≤Length(File):* Reads a sequence of up to n items from a file starting at item *i* and returns it in *Data*.
Write(FileId, i, Data) -throws BadPosition	if *1≤i≤Length(File)+1*: Write a sequence of *Data* to a file, starting at item *i*, extending the file if necessary.
Create() -> FileId	Creates a new file of length0 and delivers a UFID for it.
Delete(FileId)	Removes the file from the file store.
GetAttributes(FileId) -> Attr	Returns the file attributes for the file.
SetAttributes(FileId, Attr)	Sets the file attributes (only those attributes that are not shaded in Figure 3.)

Figure 6. Flat file service operations

File Service Architecture

- Access control
  - In distributed implementations, access rights checks have to be performed at the server because the server RPC interface is an otherwise unprotected point of access to files.
- Directory service interface
  - Figure 7 contains a definition of the RPC interface to a directory service.

File Service Architecture

Lookup(Dir, Name) -> FileId -throws NotFound	Locates the text name in the directory and returns the relevant UFID. If *Name* is not in the directory, throws an exception.
AddName(Dir, Name, File) -throws NameDuplicate	If *Name* is not in the directory, adds(*Name*,*File*) to the directory and updates the file's attribute record. If *Name* is already in the directory: throws an exception.
UnName(Dir, Name)	If *Name* is in the directory, the entry containing *Name* is removed from the directory. If *Name* is not in the directory: throws an exception.
GetNames(Dir, Pattern) -> NameSeq	Returns all the text names in the directory that match the regular expression *Pattern*.

Figure 7. Directory service operations

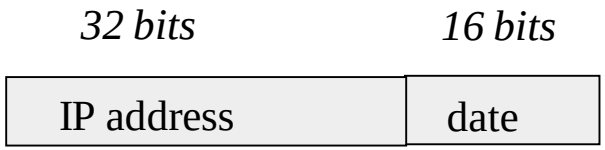
File Service Architecture

- Hierarchic file system
  - A hierarchic file system such as the one that UNIX provides consists of a number of directories arranged in a tree structure.
- File Group
  - A file group is a collection of files that can be located on any server or moved between servers while maintaining the same names.
    - A similar construct is used in a UNIX file system.
    - It helps with distributing the load of file serving between several servers.
    - File groups have identifiers which are unique throughout the system (and hence for an open system, they must be globally unique).

File Service Architecture

To construct a globally unique ID we use some unique attribute of the machine on which it is created, e.g. IP number, even though the file group may move subsequently.

File Group ID:



DFS: Case Studies

- NFS (Network File System)
  - Developed by Sun Microsystems (in 1985)
  - Most popular, open, and widely used.
  - NFS protocol standardized through IETF (RFC 1813)
- AFS (Andrew File System)
  - Developed by Carnegie Mellon University as part of Andrew distributed computing environments (in 1986)
  - A research project to create campus wide file system.
  - Public domain implementation is available on Linux (LinuxAFS)
  - It was adopted as a basis for the DCE/DFS file system in the Open Software Foundation (OSF, www.opengroup.org) DEC (Distributed Computing Environment

Case Study: Sun NFS

- Figure 8 shows the architecture of Sun NFS.

NFS architecture

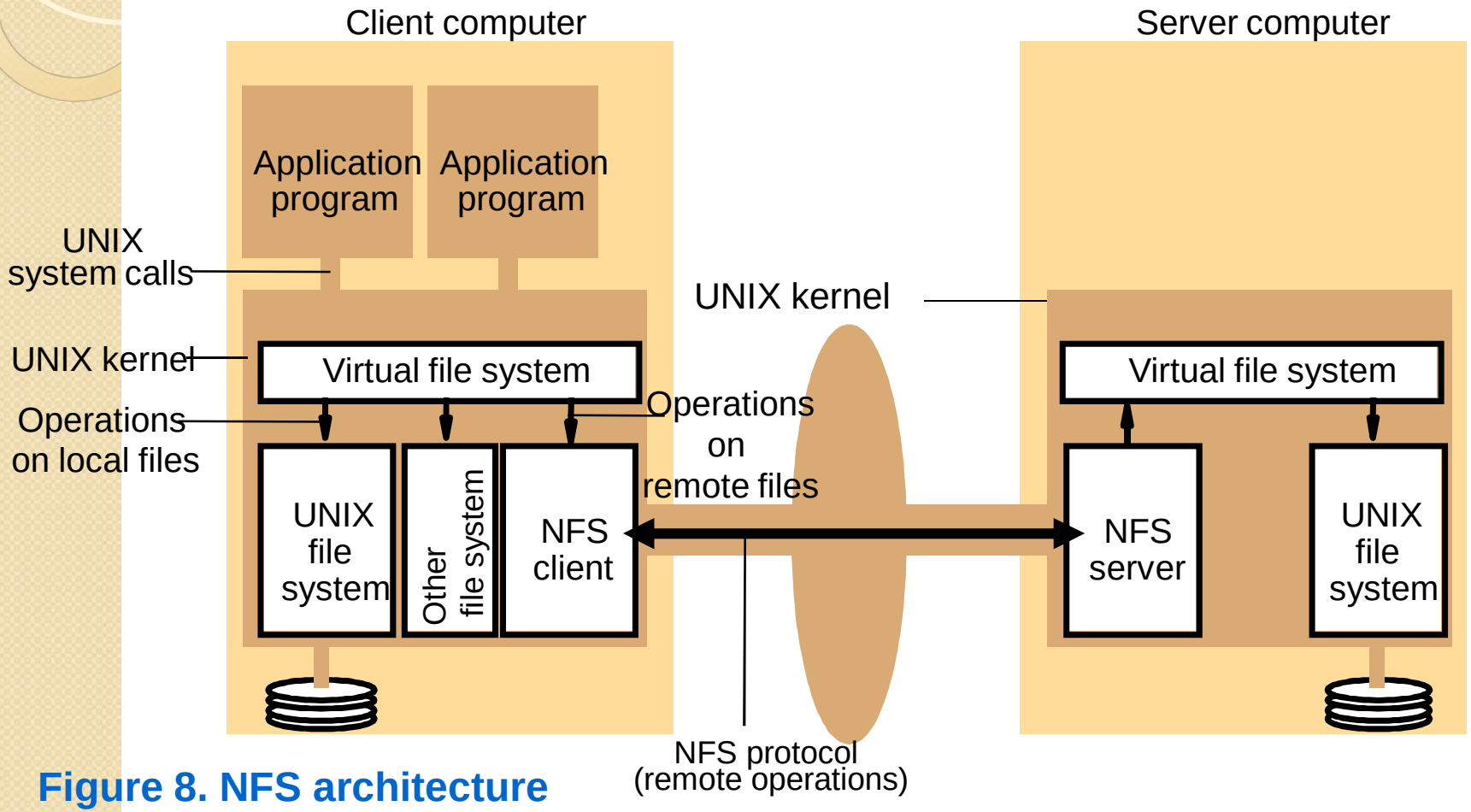


Figure 8. NFS architecture

Case Study: Sun NFS

- The file identifiers used in NFS are called file handles.

fh = file handle:

Filesystem identifier	i-node number	i-node generation

Case Study: Sun NFS

- A simplified representation of the RPC interface provided by NFS version 3 servers is shown in Figure 9.

Case Study: Sun NFS

- *read(fh, offset, count) -> attr, data*
- *write(fh, offset, count, data) -> attr*
- *create(dirfh, name, attr) -> newfh, attr*
- *remove(dirfh, name) status*
- *getattr(fh) -> attr*
- *setattr(fh, attr) -> attr*
- *lookup(dirfh, name) -> fh, attr*
- *rename(dirfh, name, todirfh, toname)*
- *link(newdirfh, newname, dirfh, name)*
- *readdir(dirfh, cookie, count) -> entries*
- *symlink(newdirfh, newname, string) -> status*
- *readlink(fh) -> string*
- *mkdir(dirfh, name, attr) -> newfh, attr*
- *rmdir(dirfh, name) -> status*
- *statfs(fh) -> fsstats*

Figure 9. NFS server operations (NFS Version 3 protocol, simplified)

Case Study: Sun NFS

- NFS access control and authentication
  - The NFS server is stateless server, so the user's identity and access rights must be checked by the server on each request.
    - In the local file system they are checked only on the file's access permission attribute.
  - Every client request is accompanied by the userID and groupID
    - It is not shown in the Figure 8.9 because they are inserted by the RPC system.
  - Kerberos has been integrated with NFS to provide a stronger and more comprehensive security solution.

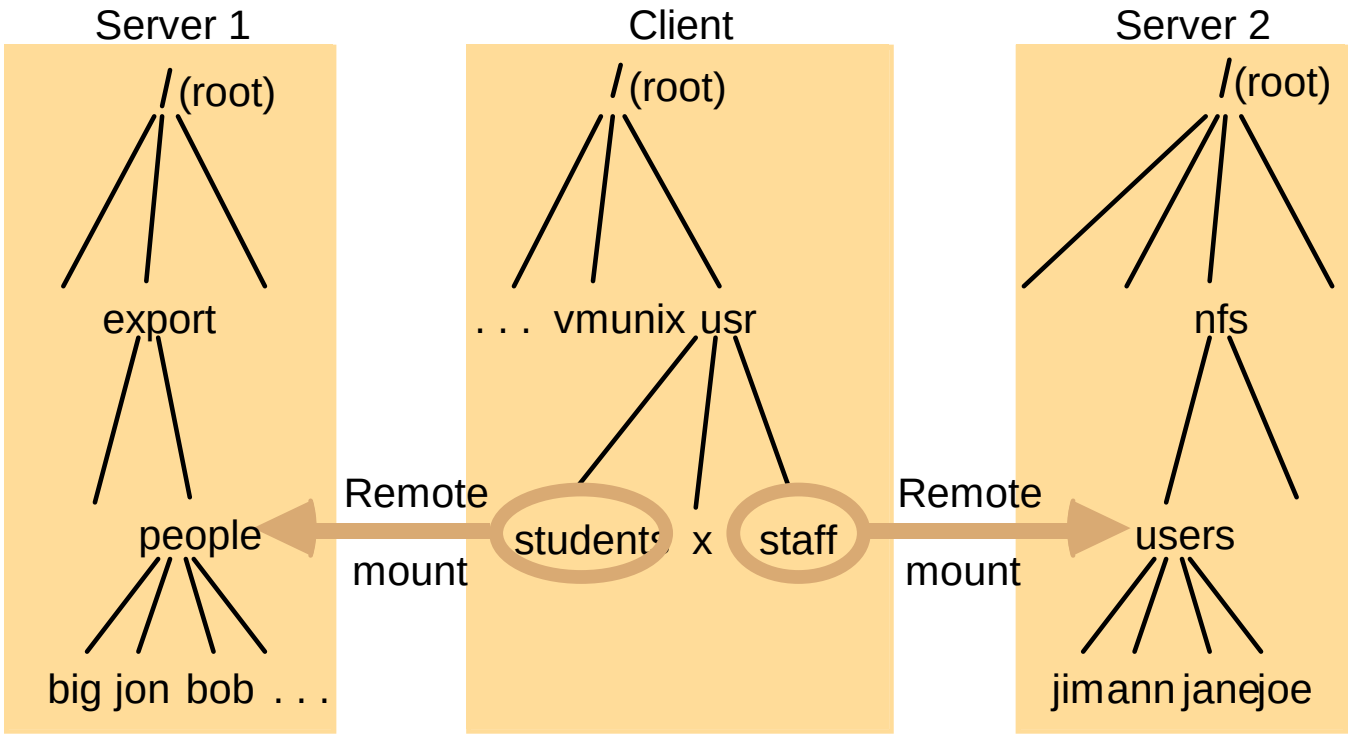
Case Study: Sun NFS

- Mount service
  - Mount operation:

    mount(remotehost, remotedirectory, localdirectory)
  - Server maintains a table of clients who have mounted filesystems at that server.
  - Each client maintains a table of mounted file systems holding:

    < IP address, port number, file handle>
  - Remote file systems may be hard-mounted or soft-mounted in a client computer.
  - Figure 10 illustrates a Client with two remotely mounted file stores.

Case Study: Sun NFS



Note: The file system mounted at */usr/students* in the client is actually the sub-tree located at */export/people* in Server 1; the file system mounted at */usr/staff* in the client is actually the sub-tree located at */nfs/users* in Server 2.

Figure 10. Local and remote file systems accessible on an NFS client

Case Study: Sun NFS

- Automounter
  - The automounter was added to the UNIX implementation of NFS in order to mount a remote directory dynamically whenever an ‘empty’ mount point is referenced by a client.
    - Automounter has a table of mount points with a reference to one or more NFS servers listed against each.
    - it sends a probe message to each candidate server and then uses the mount service to mount the filesystem at the first server to respond.
  - Automounter keeps the mount table small.

Case Study: Sun NFS

- Automounter Provides a simple form of replication for read-only filesystems.
  - E.g. if there are several servers with identical copies of /usr/lib then each server will have a chance of being mounted at some clients.

Case Study: Sun NFS

- Server caching
  - Similar to UNIX file caching for local files:
    - pages (blocks) from disk are held in a main memory buffer cache until the space is required for newer pages. Read-ahead and delayed-write optimizations.
    - For local files, writes are deferred to next sync event (30 second intervals).
    - Works well in local context, where files are always accessed through the local cache, but in the remote case it doesn't offer necessary synchronization guarantees to clients.

Case Study: Sun NFS

- NFS v3 servers offers two strategies for updating the disk:
  - Write-through - altered pages are written to disk as soon as they are received at the server. When a write() RPC returns, the NFS client knows that the page is on the disk.
  - Delayed commit - pages are held only in the cache until a commit() call is received for the relevant file. This is the default mode used by NFS v3 clients. A commit() is issued by the client whenever a file is closed.

Case Study: Sun NFS

- Client caching
  - Server caching does nothing to reduce RPC traffic between client and server
    - further optimization is essential to reduce server load in large networks.
    - NFS client module caches the results of read, write, getattr, lookup and readdir operations
    - synchronization of file contents (one-copy semantics) is not guaranteed when two or more clients are sharing the same file.

Case Study: Sun NFS

- Timestamp-based validity check
  - It reduces inconsistency, but doesn't eliminate it.
  - It is used for validity condition for cache entries at the client:

(T - Tc < t) v (Tmclient = Tmserver)

t	freshness guarantee
Tc	time when cache entry was last validated
Tm	time when block was last updated at server
T	current time

Case Study: Sun NFS

- t is configurable (per file) but is typically set to 3 seconds for files and 30 secs. for directories.
- it remains difficult to write distributed applications that share files with NFS.

Case Study: Sun NFS

- Other NFS optimizations
  - Sun RPC runs over UDP by default (can use TCP if required).
  - Uses UNIX BSD Fast File System with 8-kbyte blocks.
  - reads() and writes() can be of any size (negotiated between client and server).
  - The guaranteed freshness interval t is set adaptively for individual files to reduce getattr() calls needed to update Tm.
  - File attribute information (including Tm) is piggybacked in replies to all file requests.

Case Study: Sun NFS

- NFS performance
  - Early measurements (1987) established that:
    - Write() operations are responsible for only 5% of server calls in typical UNIX environments.
      - hence write-through at server is acceptable.
    - Lookup() accounts for 50% of operations -due to step-by-step pathname resolution necessitated by the naming and mounting semantics.
  - More recent measurements (1993) show high performance.
    - see www.spec.org for more recent measurements.

Case Study: Sun NFS

- NFS summary
  - NFS is an excellent example of a simple, robust, high-performance distributed service.
  - Achievement of transparencies are other goals of NFS:
    - Access transparency:
      - The API is the UNIX system call interface for both local and remote files.

Case Study: Sun NFS

- Location transparency:
  - Naming of filesystems is controlled by client mount operations, but transparency can be ensured by an appropriate system configuration.
- Mobility transparency:
  - Hardly achieved; relocation of files is not possible, relocation of filesystems is possible, but requires updates to client configurations.
- Scalability transparency:
  - File systems (file groups) may be subdivided and allocated to separate servers.

    Ultimately, the performance limit is determined by the load on the server holding the most heavily-used filesystem (file group).

Case Study: Sun NFS

- Replication transparency:
  - Limited to read-only file systems; for writable files, the SUN Network Information Service (NIS) runs over NFS and is used to replicate essential system files.
- Hardware and software operating system heterogeneity:
  - NFS has been implemented for almost every known operating system and hardware platform and is supported by a variety of filling systems.
- Fault tolerance:
  - Limited but effective; service is suspended if a server fails. Recovery from failures is aided by the simple stateless design.

Case Study: Sun NFS

- Consistency:
  - It provides a close approximation to one-copy semantics and meets the needs of the vast majority of applications.
  - But the use of file sharing via NFS for communication or close coordination between processes on different computers cannot be recommended.
- Security:
  - Recent developments include the option to use a secure RPC implementation for authentication and the privacy and security of the data transmitted with read and write operations.

Case Study: Sun NFS

- Efficiency:
  - –NFS protocols can be implemented for use in situations that generate very heavy loads.

Case Study: The Andrew File System (AFS)

- Like NFS, AFS provides transparent access to remote shared files for UNIX programs running on workstations.
- AFS is implemented as two software components that exist at UNIX processes called Vice and Venus.

(Figure 11)

Case Study: The Andrew File System (AFS)

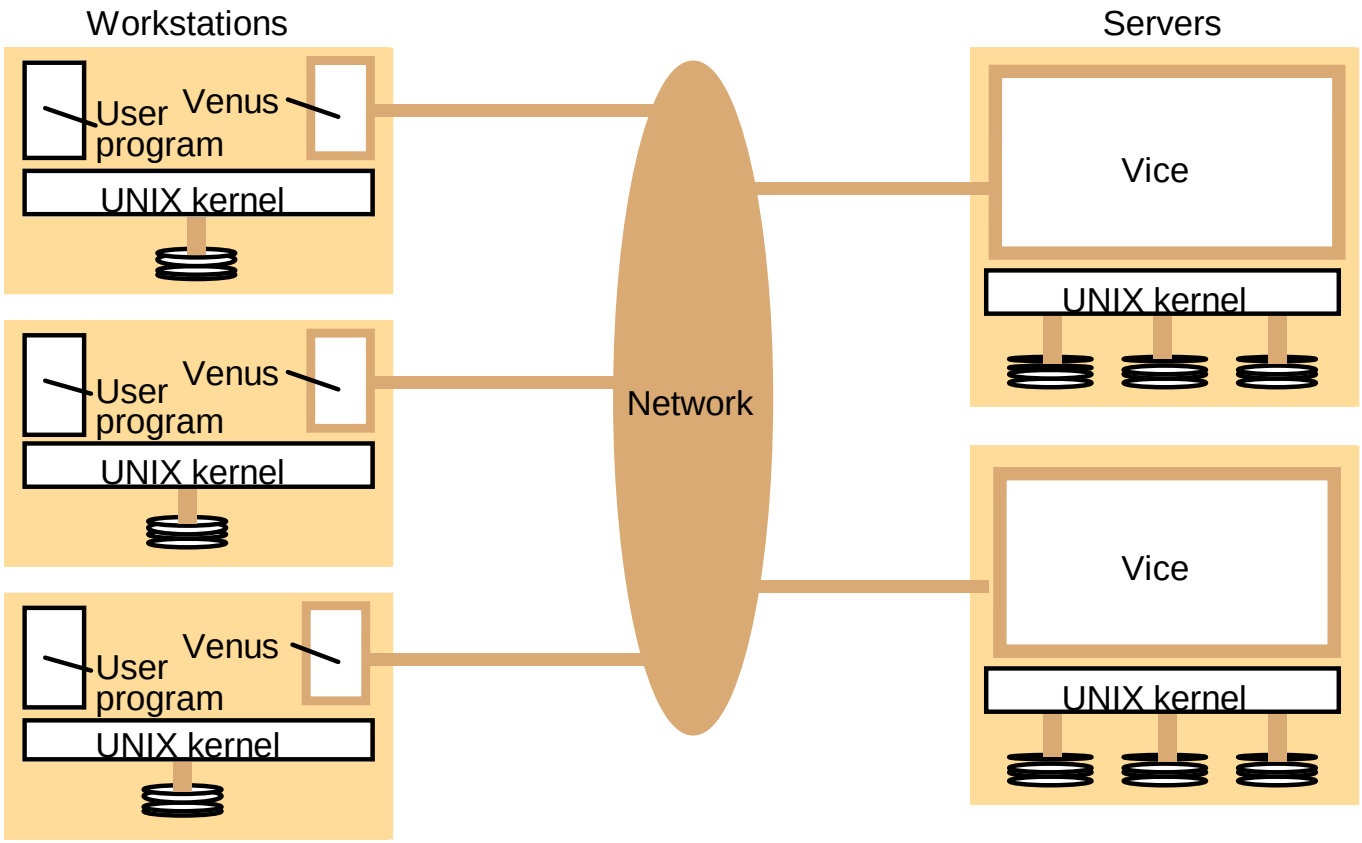


Figure 11. Distribution of processes in the Andrew File System

Case Study: The Andrew File System (AFS)

- The files available to user processes running on workstations are either local or shared.
- Local files are handled as normal UNIX files.
- They are stored on the workstation's disk and are available only to local user processes.
- Shared files are stored on servers, and copies of them are cached on the local disks of workstations.
- The name space seen by user processes is illustrated in Figure 12.

Case Study: The Andrew File System (AFS)

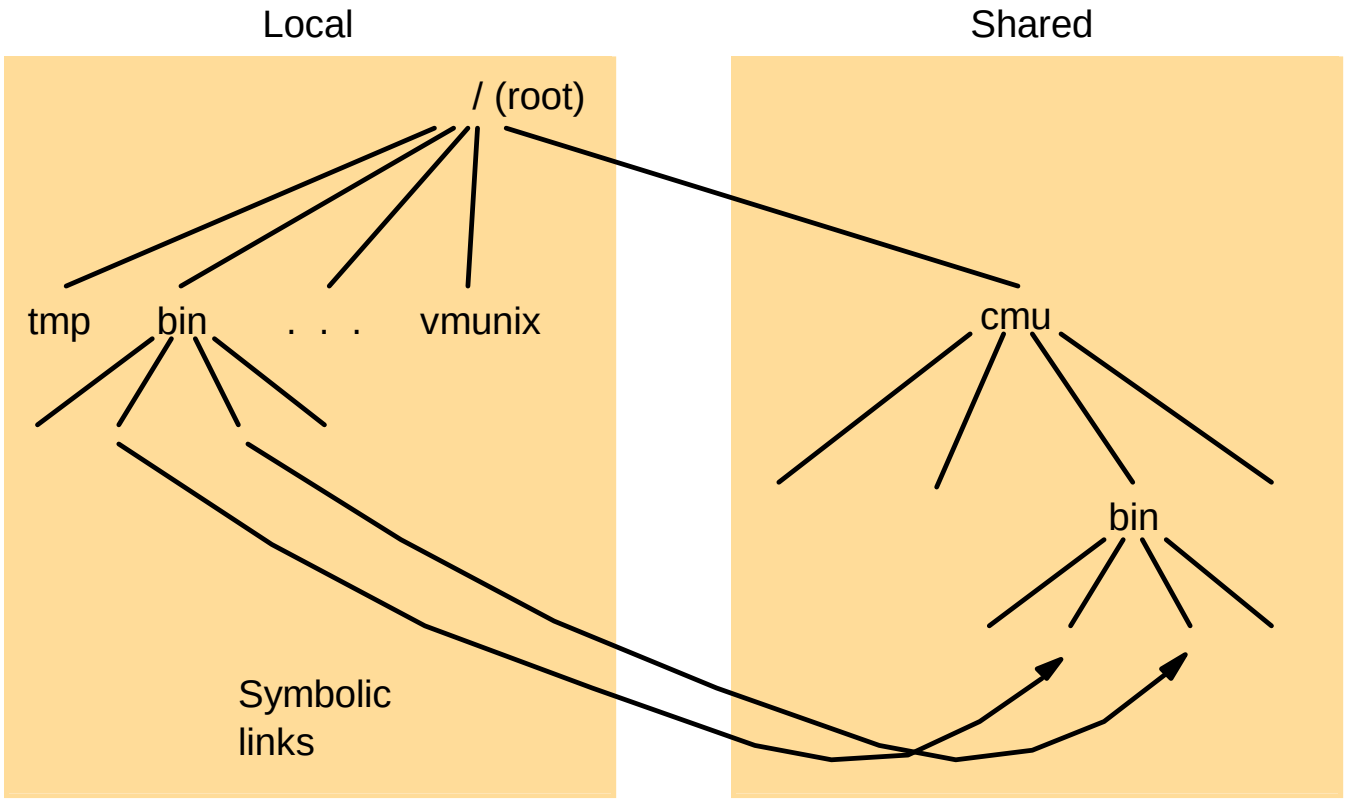


Figure 12. File name space seen by clients of AFS

Case Study: The Andrew File System (AFS)

- The UNIX kernel in each workstation and server is a modified version of BSD UNIX.
- The modifications are designed to intercept open, close and some other file system calls when they refer to files in the shared name space and pass them to the Venus process in the client computer.

(Figure 13)

Case Study: The Andrew File System (AFS)

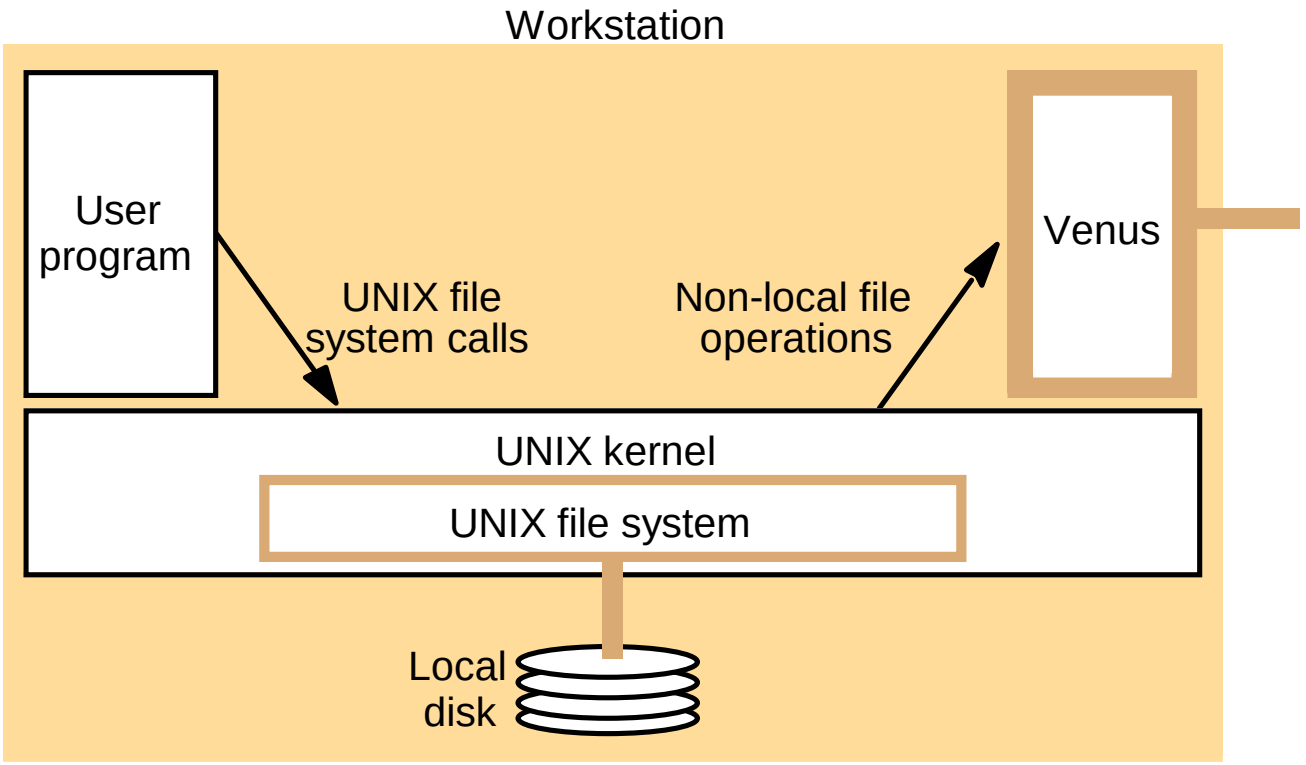


Figure 13. System call interception in AFS

Case Study: The Andrew File System (AFS)

- Figure 14 describes the actions taken by Vice, Venus and the UNIX kernel when a user process issues system calls.

Case Study: The Andrew File System (AFS)

User process	*UNIX kernel*	*Venus*	*Net*	*Vice*
open(FileName, mode)	If *FileName* refers to a file in shared file space, pass the request to Venus.	Check list of files in local cache. If not present or there is no valid *callback promise*, send a request for the file to the Vice server that is custodian of the volume containing the file.	→	Transfer a copy of the file and a *callback promise* to the workstation. Log the callback promise.
	Open the local file and return the file descriptor to the application.	Place the copy of the file in the local file system, enter its local name in the local cache list and return the local name to UNIX.	←	
read(FileDescriptor, Buffer, length)	Perform a normal UNIX read operation on the local copy.			
write(FileDescriptor, Buffer, length)	Perform a normal UNIX write operation on the local copy.			
close(FileDescriptor)	Close the local copy and notify Venus that the file has been closed.	If the local copy has been changed, send a copy to the Vice server that is the custodian of the file.	→	Replace the file contents and send a *callback* to all other clients holding *callback promises* on the file.

Figure 14. implementation of file system calls in AFS

Case Study: The Andrew File System (AFS)

- Figure 15 shows the RPC calls provided by AFS servers for operations on files.

Case Study: The Andrew File System (AFS)

Fetch(fid) -> attr, data	Returns the attributes (status) and, optionally, the contents of file identified by the *fid* and records a callback promise on it.
Store(fid, attr, data)	Updates the attributes and (optionally) the contents of a specified file.
Create() -> fid	Creates a new file and records a callback promise on it.
Remove(fid)	Deletes the specified file.
SetLock(fid, mode)	Sets a lock on the specified file or directory. The mode of the lock may be shared or exclusive. Locks that are not removed expire after 30 minutes.
ReleaseLock(fid)	Unlocks the specified file or directory.
RemoveCallback(fid)	Informs server that a Venus process has flushed a file from its cache.
BreakCallback(fid)	This call is made by a Vice server to a Venus process. It cancels the callback promise on the relevant file.

Figure 15. The main components of the Vice service interface

Application

Distributed file systems can be advantageous because they make it easier to distribute documents to multiple clients and they provide a centralized storage system so that client machines are not using their resources to store files. NFS from Sun Microsystems and Dfs from Microsoft are examples of distributed file systems.

Scope of Research

1. Research on Implement Snapshot of pNFS Distributed File System
2. Scale and Performance in a Distributed File System
3. A Scalable Distributed File System for Cloud Computing

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